ASSESSMENT OF THE INFLUENCE OF TERMITES ON GEOTECHNICAL PROPERTIES OF SOME LATERITIC SOILS IN ADO-EKITI, SOUTHWESTERN NIGERIA.

BY

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CERTIFICATION

This is to certify that this work was carried out and submitted by ABE, OMOLOYE ELIJAH (CVE/04/4240) to the department of Civil Engineering and is accepted as meeting the requirement for the award of Masters of Engineering in Civil Engineering (Transportation Engineering Option) of the Federal University of Technology, Akure, Nigeria.

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ABSTRACT

The determination of the influence of activities of termites on the engineering properties of Termite reworked soils and non-reworked surrounding soils from Ado-Ekiti, Southwestern Nigeria was carried out. Two termite hills from two locations were chosen. Twenty bulk representative soil samples depicting twelve Termite reworked soils and eight non-reworked surrounding lateritic soil samples were collected. Some geotechnical and geochemical parameters such as grain size distribution, consistency limits, linear shrinkage, compaction characteristics, California Bearing Ratio (CBR), triaxial compression characteristics, compressive strength from moulded bricks, permeability characteristics, X-ray and Differential Thermal Analysis (DTA) of the soils were determined. The results of these tests showed that the specific gravity of grains and the CBR of the termite reworked soils are higher than those of the surrounding soils. However, the plasticity indices and linear shrinkage of the termite reworked soils were significantly lower than those of the surrounding soils while the triaxial test showed that the angles of internal friction and cohesion of termite reworked soils are higher than those of the surrounding soils. Also, compaction characteristics showed that there is an increase in the value of Maximum Dry Density (MDD) with a reduction in the Optimum Moisture Content (OMC) of termite reworked soils. The permeability test showed that termite reworked soils are more permeable than the surrounding soils. Also, termite reworked soils have higher strengths as revealed by compressive strength tests carried out on moulded bricks made from them than those made from non reworked soils. The chemical analysis of the soils showed that termite activities increase iron, manganese, magnesium, calcium, potassium, zinc and phosphorus levels of the soil. Aluminum was also detected only in the soil around the queen of the termites. X-ray analysis and DTA of the soils showed that, Kaolinite, the major clay mineral, increases with the activities of termite. All the geotechnical tests carried out favoured termite reworked soils as a better engineering soil than the surrounding lateritic soils. Findings from this work indicate that reworking by termites has improved the engineering properties of the studied termite reworked soils.

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CHAPTER ONE

1.0 INTRODUCTION

The increasing need of engineering infrastructure today has led to more research work on the material used for construction works in most cases lateritic soils. The name "laterite" is a latin word "later" meaning brick. The name is regarded to be appropriate because soils under this classification are regarded as forming hard, inpenetrable and often irreversible pans when dried. These soils are known as "engineering soils" based on the fact that they are extensively used by Civil Engineers to construct engineering structures such as road and buildings.

Lateritic soils abound in virtually all parts of the tropical world. They find wide applications not only as foundations for structures but more importantly as construction materials. Although, lateritic soils possess geotechnical, mineralogical and physical characteristics that make them fair to good engineering soils, their properties may need to be improved upon. In some cases, soil stabilization, as the process of improvement is called, has over the years gained wide popularity among users of soils.

Quite unknown to many people, however, some social insects and burrowing animals do modify the structure and hence some geotechnical and geochemical properties of soils. Earthworm, for instance, rework alluvial deposits and makes them at times more porous and permeable while termites (social insects) rework soils and make them appear stronger. Termitaria, which are edifices built by tropical termites abound in virtually all parts of the tropics.

Construction of termite moulds involves excavation of the soil and mass shifting of the excavated soils to the surface. The soils (mostly of clay and silt size fraction) are then mixed with saliva and faecal materials from the termites and at times some other debris are added to form a tough material referred to as 'carton' with variable compositions. A termitarium, which, may be up to 7m high, may weigh up to two and a half tons (Atkins 1980). The termitaria which are huge mounds built by these termites allow them to have a great degree of control over the temperature and humidity of the environment in which they live.

Generally, several soils in the tropics in particular are being reworked by the activities of these termites. The determination of the effect of reworking by termites on the engineering properties of the soil is a major objective of this research work.

1.1 AIMS

This research aims at the following:

- determination of termite additives to laterite soils to make them better construction materials.

- determination of geotechnical properties and behaviours of termite remoulded lateritic soils.

1.2 OBJECTIVES

The objectives of this research are to:-

* determine the chemical composition and geotechnical properties of lateritic soil reworked by termites and,
* evaluate the geotechnical properties of soil reworked by termites in comparison with the surrounding soils that have not been reworked,

1.3 EXPECTED CONTRIBUTION TO KNOWLEDGE

Termites, widespread and abundant in drier areas in the tropics are not only pests, but can also play an important beneficial role in recovering degraded ecosystems.

They are a resource that can be used and managed, together with locally available organic resources, to counteract land degradation through their soil burrowing and feeding activities.

Findings obtained from these investigations would be invaluable not only to contractors but also to government establishments who are interested in the utility of soils reworked by termites.

1.4 SCOPE OF WORK

Samples of termite reworked soils from two different locations in the study area and samples of non-reworked soils collected from points adjacent to the termite soil corresponding to the four cardinal points at each of the locations were subjected to the following laboratory tests:-

* Specific gravity test
* Consistency limit test
* Grain size distribution test
* Strength tests such as:
    - Compaction test
    - CBR test
    - Triaxial test
* Strength characteristics of the soils from moulded bricks.
* Linear shrinkage test

The following were also determined:-

* Chemical analysis of the soils
* X-Ray analysis of the soils
* Differential thermal analysis (DTA) of the soils.
* Permeability of the soils.

1.5 LOCATION OF THE STUDY AREA

The study area is located in Ado-Ekiti, the capital city of Ekiti State, South Western Nigeria. Ado-Ekiti is located between latitudes $07^0\ 31^1$ and $07^0\ 49^1$ north of the equator and longitudes $05^0\ 07^1$ and $05^0\ 27^1$ east of the Greenwich Meridian (Ebisemiju, 1993). The area is readily accessible by a network of roads which also link the area with nearby towns. Fig 1.1 shows the map of the study location.

Soil samples were taken from two locations within the city i.e one location beside the male hostel designated as Abuja hostel of the Federal Polytechnic and the other location beside the health centre along Igirigiri road in Odo-Ado quarters within the city. A total of twenty samples were taken with ten samples taken from each location.

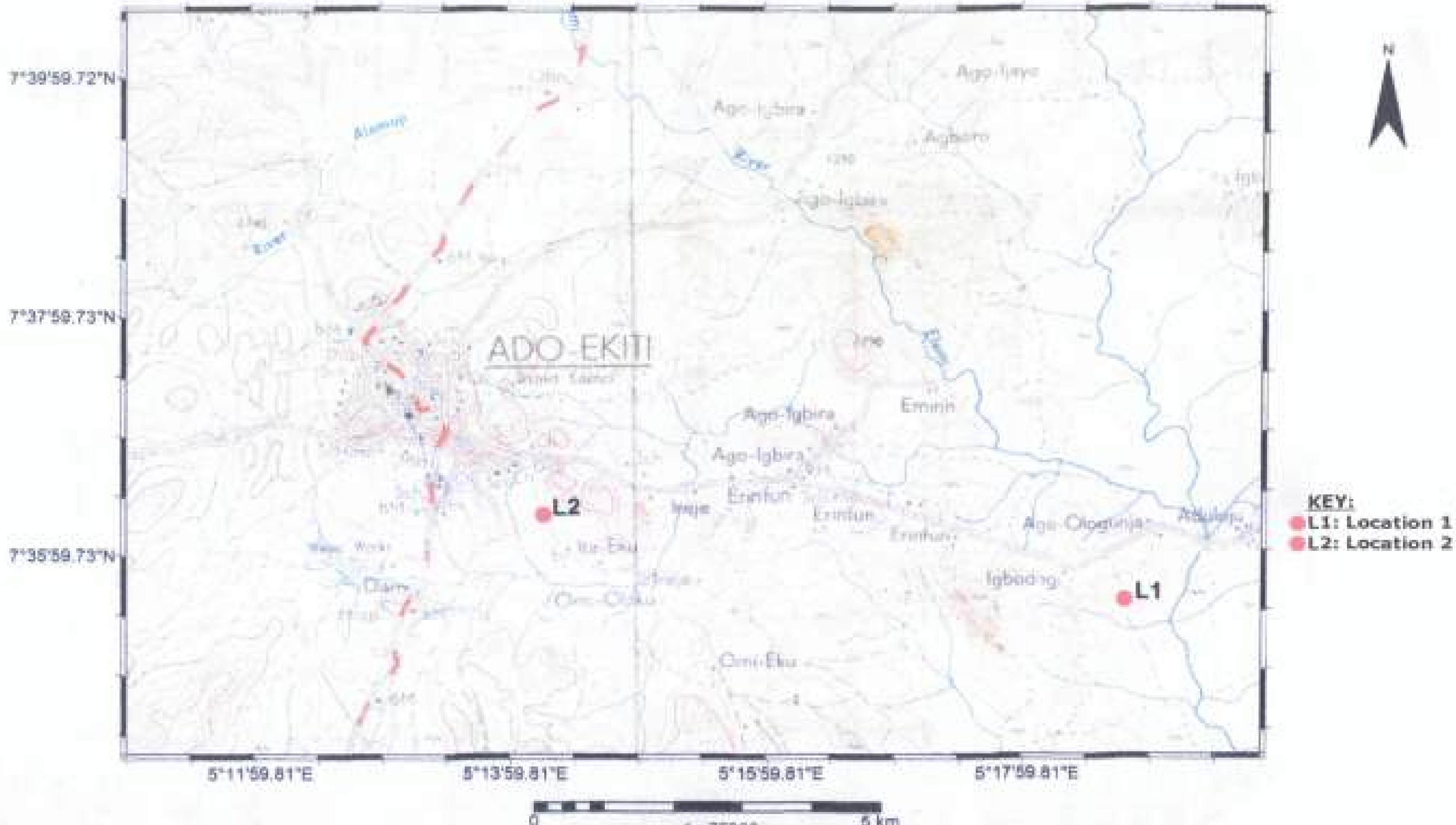


Fig1.1: Topographical map showing where samples were taken (Adapted, Federal Surveys)

CHAPTER TWO

2.0 GEOMORPHOLOGY AND GEOLOGY OF THE STUDY AREA

2.1 CLIMATE AND VEGETATION

The climatic condition is tropical with two distinct seasons occurring in the area. These include the rainy season and dry season. The rainy season commences in March and ends in October with a peak in July/August while the dry season is between November and February.

During the rainy season, up to 1500mm of rainfall may be experienced. The temperature varies from $21^{0}C - 35^{0}C$ throughout the year with an average value of $28^{0}C$.

The vegetation pattern varies in accordance with the climate and rainfall. The overall vegetation in the area is tropical rainforest. During the rainy season, the soil of the area is well covered by varieties of green plants and during the dry season, the plants are dried up, leaving only few shrubs and trees surviving the dry season.

2.2 TOPOGRAPHY AND DRAINAGE

The land in Ado-Ekiti rises northwards and westerwards from 335 metres in southeast and attains a maximum elevation of about 730 metres in the south west (Ebisemiju, 1993).

The relative relief, that is, the difference between the highest and lowest points in the region, therefore, is 395m.

Very steep slopes exceeding 45^0 are associated with the surfaces of rocky ridges and hills (inselberges) and scarps while moderately steep gradients (15^0 – 30^0) are characteristics of the residual regolithmentled hills in and around Ado-Ekiti. (Ebisemiju 1993) also stated that the inselberg slopes are smoothly rounded in forms with occasional vertical faces. Moerate slope gradient (5^0 – 15^0) are characteristics of the region of moderate relief, the low relief in the central and eastern parts has gentle slopes with characteristic angle of 3^0.

The low relief and gentle gradients characteristic of much of Ado-Ekiti region, which favour agricultural and construction activities, also make much of the region susceptible to flooding and flood hazards during the rainy season.

2.3 REGIONAL GEOLOGY

The geology of Ado-Ekiti is dominated by crystalline rocks of the basement complex of southwestern, Nigeria (Fig. 2.1). The rock sequence in the area is as follows:- pegmatites and aplites series, gneisses and migmatites. The rock generally trend north-south in direction. The granitic rocks are found in the western and Northern parts of the area while the charnokitic rocks are located within a narrow belt of intrusive within the granitic rocks. The migmatites are found in the eastern part. The quartzite rock type are located in the western and central area as elongated bodies within the granitic and charnokitic rocks.

The lateritic soils found within Ado-Ekiti are abundant and are the bi-product of rocks mentioned above. The nature and type of laterite soils found in the area depends greatly on the parent rock from which they have been derived. They vary from highly clayey lateritic soils for charnokite-derived from gneissic silty soils for those derived from gneissic and migmatitic rocks. The gravelly lateritic soils are those derived from the elongated bodies of quartzite. The gravelly texture is a product of partial weathering resulting from the relatively resistant quartzite bodies.

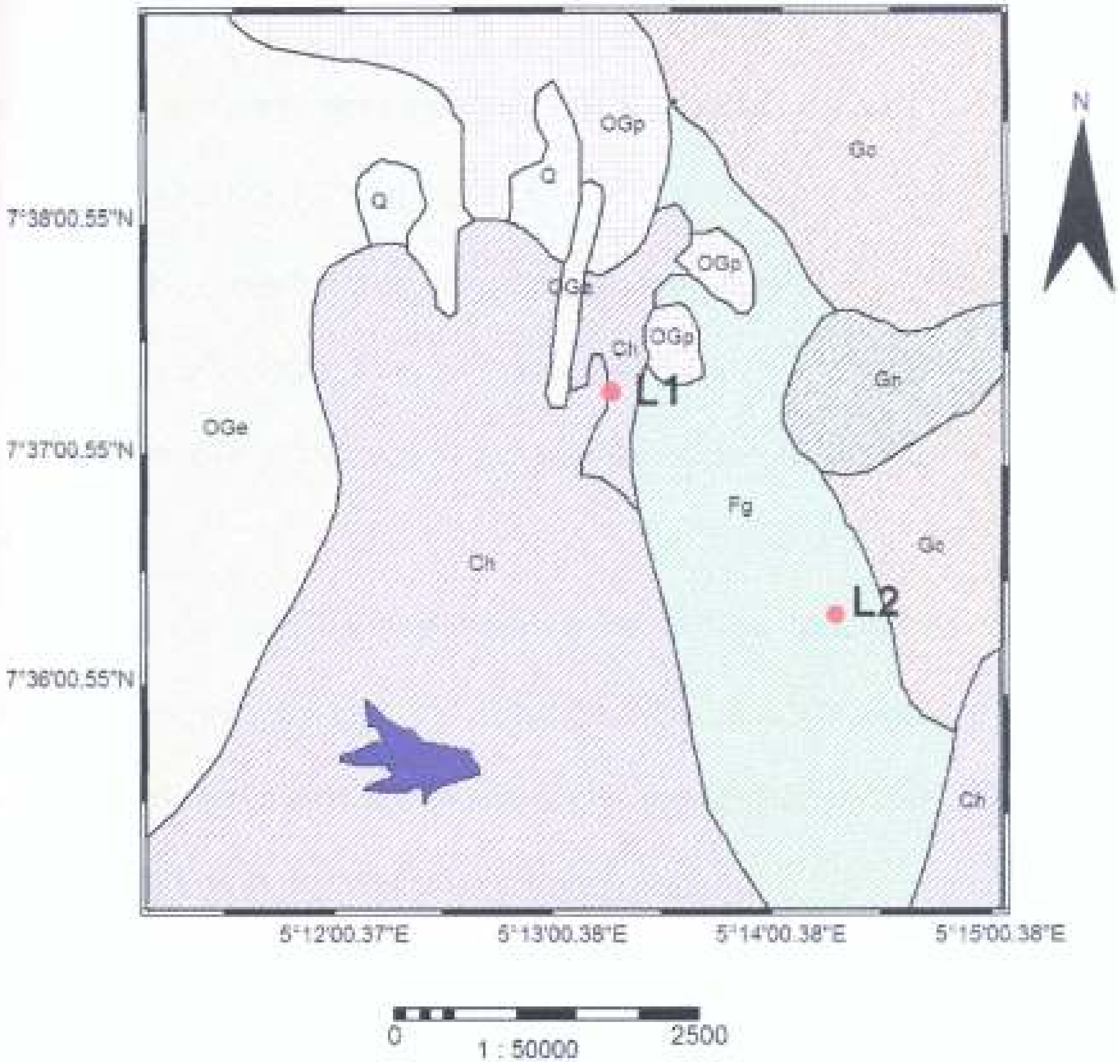


Fig. 2.1: Geological Map of the Study Area (Modified after Geology of Nigeria Akure Sheet 61)

Ch: Chanockite (coarse grained)

OGp: Coarse porphyritic biotite & biotite-hornblende

Fg: Fine Grained Chanokite

OGf: Fine to medium grained biotite and biotite-muscovite

Gc: Gneissic Chanokite

Gn: Granite gneiss

OGe: Medium grained biotite-granite

Q: Quazites

Dam: Ureje Dam

KEY:

L1 - LOCATION 1

L2 - LOCATION 2

CHAPTER THREE

LITERATURE REVIEW

3.0 LATERITES FORMATION AND STABILIZATION

3.1 DEFINITION OF LATERITE

The term "laterite" was first used by Buchanan (1807) who described it as a reddish iron, rich material and used in a compositional sense as a weathering product composed principally of oxides, hydroxides of aluminium and manganese.

There has been definitions given by various researchers. A chemical approach was given by Ola (1983) on the basis of silica aluminium ratio. He said, generally, ratios of silica to sequioxide represented by $Si0_2$ / (Fe_2O_3 + Al_2 O_3) which are less than 1.33 are indicative of laterites.

Alexander and Cady (1962) defined laterite as a highly weathered material that is rich in secondary oxides of Fe, Al or both, nearly devoid of bases and primary silicates, but may largely contain quartz and kaolinite. It is either hard or capable of hardening on exposure to alternate wetting and drying.

Du Preez (1956), defined laterites as a vesicular concretional, vermicular, pisolite or concrete like mass consisting chiefly of ferric oxide with or without mechanical entangled quartz or minor quantities of alumina and manganese.

For engineering purposes, it may be more convenient to look at definitions that define properties of soils. Therefore, to the engineer, laterite is all unconsolidated material above bedrock (O'flaherty, 1974).

Gidigasu (1972) defined laterite as being of reddish brown or dark brown colour with or without modules or concretions and generally (but not exclusively) found below hardened ferruginous crusts or hard pan. Laterite is usually the end product of weathering.

3.2 FORMATION OF LATERITE

Considerable work has been carried out on lateritic soils in many different countries over the years and detailed reviews of available literature have already been presented by Maignien (1966), Little (1969), Lyon Associates (1971) and Gidigasu (1972).

Maignien (1966) and Gidigasu (1972) have identified three major stages in the process of laterization. The first stage (decomposition) is characterized by physico-chemical breakdown of primary minerals and the release of constituent elements. The second stage involves leaching, under appropriate drainage conditions, of combined silica and bases and the relative accumulation or enrichment from outside sources (absolute accumulation) of oxides and hydroxides of sesquioxides (mainly Al_2O_3, and Fe_2 O_3, the most resistant components to leaching).

The level of which the second stage is carried depends on the nature and the extent of the chemical weathering of the primary minerals. Under the conditions of intense and prolonged physico-chemical weathering, even clay minerals are destroyed and silica is leached. The third stage (dehydration or desiccation) involves partial or complete dehydration (sometimes involving hardening) of the sesquoxide – rich materials and secondary minerals.

Laterite formation factors include climate (precipitation, leaching, capillary rise and temperature), topography (drainage), vegetation, parent rock (iron rich rocks) and time. Of these primary factors, climate is considered the most important.

Little (1969) suggested that most of the factors listed above for laterite formation also apply to many temperate sites and yet laterization does not take place. He tentatively suggested that it may be that only in the high temperatures of the tropics is bacterial metabolism sufficiently stimulated to produce laterization effects.

3.3 STABILIZATION OF LATERITE

Stabilization in a broad sense, incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance. The highway engineer is continually faced with the problem of increasing the strength and stability of the natural soil in order to improve its bearing properties.

Winterkorn (1955) opined that the chief objectives of stabilization are to improve soil strength, bearing capacity and durability under cyclical conditions such as varying moisture content or repeated application of stress. The growth of soil stabilization has economic roots. Its economic importance varies from the possibility of improving soils at the site of construction for use as foundation or materials for construction.

In the developing countries like India, soil stabilization methods with locally available materials have considerable scope in reducing the initial construction cost of highway pavement and for stage construction (Bindra 1981). According to him, Soil stabilization for highway purposes can be divided into the following main groups; Mechanical stabilization, Cement stabilization, Lime stabilization and Bituminous stabilization. Other methods of stabilization may include chemical stabilization, thermal stabilization, and electrical stabilization.

3.4 TERMITES AND THEIR EFFECTS ON SOILS

3.4.1 TERMITES

A termite (also known as a white ant) is any member of the order Isoptera, a group of social insects that eat wood and other cellulose-rich vegetable matter (Mueller and Gerardo, 1986). Most termite species are tropical or subtropical, but a few live in temperate regions. They are of great biological and economic interest. They live in colonies that number from several hundred to several million individuals at maturity. A typical colony contains workers, soldiers and reproductive individuals of both sexes, often containing several egg-laying queens.

Termites are known to be destructive and they build large mounds or hills otherwise known as "Termitaria" by using reworked soils in their surrounding. A termitarium may be up to 8m high or above and it allows the termite to have a great degree of control over temperature and humidity of their environment.

Termitarium is built either from soil excavated in course of digging underground tunnels or from soil and sand collected on the surface. The soils, mostly of clay and silt size fraction, are mixed with saliva and sticky solution produced or spit by the nasute and nasutoid soldiers (having long frontal rostrum or gland), and faecal materials from the termites.

3.4.2.1 TYPES OF TERMITES

More than 2,230 species of termites are known, divided into two groups, the drywood and the subterranean types. A third group, dampwood termites, are normally not mentioned as they are principally only found in the northwestern USA, (Mansikkamaki, Paavo and Vihavainen, 1980). Subterranean termites are most common and cause 95% of all termite damages to buildings. The preventive control of drywood termites is more difficult than that of subterranean termites. Termites are related to cockroaches, and they are not related to ants who are their worst enemies. Some ants feed almost solely on termites.

Factors that limit the distribution of termites are temperature, air and ground moisture and availability of food. The risk of subterranean termites can normally be assessed by studying the vegetation and rainfall of an area and then comparing it with a similar area in the same or a neighbouring country where termites have been found (Michael and Williams 1975). The drywood hazard is more difficult to predict, but wherever drywood termites occur, subterranean termites are almost always present (Thakur 1988).

Drywood Termites

Drywood termites are restricted to coastal areas as they rely on high air humidity. They meet their moisture needs from the atmosphere and by digesting wood. They can survive in wood with as low as 6% moisture content (Lund 1967). They eat the inside of the wood and leave a thin shell for protection, which can make detection difficult. They attack both conifers and non-conifers. They can be detected by inspecting timbers and looking for small holes, normally 1.5mm in diameter, which are used for expulsion of excreta (Harris

1971). Drywood termite attack can also be recognized by finding the pile of faecal pellets, which look life fine sand, ejected from their workings. Protection of a house from attack by dry wood termites is difficult, as they do not need ground contact and enter houses through the roof.

Subterranean Termites

Subterranean termites are more widespread than dry wood termites and of greater economic consequence. They rely principally on the soil for moisture, and they can dig down 70 meters to get to the ground water table (Lee and Wood 1974). They build shelter tubes or covered runways to protect against enemies (mainly ants) and the sun, as they are easily dried out when exposed. The tunnels can be as long as 50 meters. Many termites grow fungi in their nest, which help to keep the nest at a high humidity level (90% relative humidity) and help to break down the cellulose they consume. The fungi are also believed to serve as a source of vitamins. Subterranean termites eat all of the wood and often cover the wood with soil for protection.

3.4.2.2 FEEDING HABITS OF TERMITE

The main diet for termites is the cellulose found in woody materials; they are the only insect that can digest cellulose. Lignin, the other main part of wood, is also consumed, but it cannot be digested. This gluey material can be found as part of the soil in the nest, and is the likely reason why termite mound soils are hard. It increases compressive strength but does not increase the soils resistance to erosion.

The drywood species generally digest the cellulose with the aid of protozoa in the intestine. Some subterranean termites chew up the cellulose and then allow it to be partially decomposed by fungi before it is consumed. The digestive system capability differs between species, which makes termite extermination difficult. Most species prefer dead wood already attacked by fungus. Tests have shown that some termites will consume twice as much Ponderosa pine if it is decayed than if it is sound (Edwards and Mill 1986).

Termite live on vegetable matter almost exclusively, but they also consume leather, cloth, rubber, live trees and various crops like wheat, date palms, potato and yams. They do extensive damage to other materials in their quest for food. Telecommunication and electrical cables are often attacked, and their penetration of lead sheathed electrical cable is well documented (Harris 1971, Edwards and Mill 1986, French 1983). During drought or near drought conditions termite attacks appear most acute, and they even attack impregnated wood, causing mass deaths among themselves, to reach non-poisonous wood essential for the survival of the colony (Hickin, 1971).

3.4.3 EFFECTS OF TERMITES ON SOIL

Termites, traditionally viewed as pests in many occasions, can also be human friends. Termite activities repair the damage caused by soil degradation (crusting) through excavation across crusted surfaces, and the production of large voids that improve soil porosity and water infiltration into soil. Termites also enhance the decomposition of surface-applied organic materials stimulating nutrient release, which can then be used by growing plants (Mando 1997). These results confirm that termites are not only pests, but can also be highly beneficial biological agents whose bioturbating and decomposing activities can be managed indirectly (with organic matter) to enhance primary production. Farmers in Burkina Faso and in other areas of West Africa are extensively making use of termite-mediated processes to enhance soil restoration and agricultural production in their farming systems (e.g the zai/tassa system, where organic material is put into small holes in which termites enhance decomposition and increase water infiltration; (Roose et al., 1992 and Mando et al., 2000).

These results also show that soil structure degradation is the result of eradicating native soil fauna (termites in this case) that were responsible for constructing and opening voids near the soil surface (top 10cm), and counteracting the degrading processes destroying these voids. In order to avoid future land degradation, and to recover currently degraded lands, mando suggested that organic resources should be applied in a continued manner, to feed termites and maintain and promote their populations and their soil and plant regenerative activities.

The humus eating termites attain an alkaline pH of 11 to 12.5 in the mid gut (Brune and Kuhl 1996). It is said that this is the highest pH in the biological world.

Mando (1997) observed that most of the soils in Sahel are characterized by very low infiltration capacity, nutrient imbalance, reduced biodiversity and low to nil primary productivity. This situation has led to increasingly miserable social condition such as decrease in per capita availability of arable land, decrease in per capita food production, decline of human welfare and social crises due to ever increasing land shortage.

He also observed that soil rehabilitation efforts have been undertaken by governments of several Sahelian countries which had failed but an alternative practice for rehabilitating crusted soils is through the application of various mulches to the soil surface that attract termites and/or increase their activity which create conditions that permit root penetration into the soil, recovery of a diverse vegetative cover and restoration of primary productivity.

Mando summarized the result of his experiment thus: "Soil rehabilitation, restoration of vegetative diversity, primary productivity and agricultural potential is stimulated through termite activities". The transport of material to the soil surface by termite loosened the soil enabling water to infiltrate more rapidly. Both termites and mulch reduced runoff and increased soil water content (storage).

Termite activity was also found to increase soil porosity, soil saturated hydraulic conductivity, improve soil water status and reduce soil density and soil resistance to cone penetration.

Bruyn LAL De and A. J. Conacher (2006) viewed that termites contribute actively to soil turnover. Termites seem to either increase infiltration by improving soil structure and porosity or to decrease infiltration by producing compact surfaces which assist runoff and erosion. Other effects involve the chemical alteration of the soil profile by termites collecting and transporting live and dead animal and plant materials to their nest structures, and by the additions of secretions and excreta in nest construction. The majority of termites probably increase carbon and nutrient levels, especially nitrogen, phosphorus and potassium, as well as exchangeable magnesium and calcium, the result of the research said. The extent of the increases depends greatly on the type of mound construction and the degree to which organic material is incorporated.

Adeyemi and Salami (2004) while investigating some geotechnical properties of two termite reworked lateritic soils in Ago-Iwoye, Southwestern Nigeria noticed the following:-

(i) That termite-reworked samples have significantly higher specific gravity than the neighbouring soils.

(ii) That, on grains size distribution, the amount of fines is higher in the termite-reworked samples from one location whereas it is lower in the termite reworked sample from another location and thus concluded that the influence, of reworking by termites on grain size distribution parameters is not clear-cut.

(iii) The plasticity of termite-reworked soil is significantly lower than that of the surrounding soil.

(iv) That linear shrinkage of termite-reworked soils are lower than those samples from neighbouring soil.

(v) That there is no clear-cut influence of reworking by termites on the compaction parameters of the studied soils.

(vi) That both the uncured and cured unconfined compressure strengths of the termite-reworked soils compacted at the optimum moisture content are significantly higher than those of the surrounding soils.

(vii) That termite-reworked soils have higher CBR than the surrounding soils.

CHAPTER FOUR

4.0 MATERIALS AND METHODS

This project work involved sample collection (field work), sample preparation and detailed laboratory analyses on the geotechnical properties of the collected samples. All the field equipment and the methods used for the preparation of the samples are discussed here.

4.1 FIELD EQUIPMENT

The equipment used for the collection of samples for the purpose of this project are cutlass, digger, shovel, sample bag/sack, measuring tape.

The cutlass was used for slashing the cover vegetation, the digger was used to break the termite hill, and also to dig and remove the surrounding soils that have not been reworked by the termites. The soil samples were collected using shovel and kept in sample bags. The measuring tape was used to measure the height of the termite hill likewise to measure the depth where the termite queen was located inside the hill.

4.2 SAMPLING

Bulk samples of termite reworked soils and non-reworked soils were obtained. Twenty samples were taken altogether from two different locations that is, ten samples from each location. In each location, two samples were taken from the upper part of the termitarium after the outer surface has been scraped off with cutlass, then another two samples were taken from where the queen of the termites was found after the termitarium has been broken and two samples were taken from the bottom of the termitarium. Four different samples were taken from the surrounding of the termitarium and this was done by measuring 4m (four meters) away from the 4-cardinal points of the termitarium (i.e. 4m away from the East, West, North and South of the termitarium). The same process was repeated in the second location.

The samples were labelled as follows:

1. Location 1: Abuja Hostel, Federal Polytechnic, Ado-Ekiti.

(i) NRS 1 – 4: Non-reworked soils

(ii) TTRS 1 – 2: Termite reworked soils from top of termitarium.

(iii) QTRS 1 – 2: Termite reworked soils from the Queen of termite surrounding

(iv) BTRS 1 – 2: Termite reworked soils from bottom of termitarium.

2. Location 2: Health Centre, Odo-Ado, Ado-Ekiti.

(i) NRS 1 – 4: Non-reworked soils

(ii) TTRS 1 – 2: Termite reworked soils from top of termitarium.

(iii) QTRS 1 – 2: Termite reworked soils from the Queen of termite surrounding

(iv) BTRS 1 – 2: Termite reworked soils from bottom of termitarium.

Location 1, NRS 1 – 4 (non-reworked soils) were taken at depth of 0.5m corresponding to where the queen of the termites of the first termitarium was found while location 2, NRS 1-4 were taken at depth of 0.61m corresponding to where the queen of the termite of the second termitarium was found.

4.3 SAMPLE PREPARATION

The samples of soil collected were air dried for several weeks before tested in accordance with BS 1377 standards and AASHTO specification.

4.4 LABORATORY ANALYSIS

The laboratory tests that were carried out on these soils samples include both the index and mechanical properties of soils. Some of the properties of the soils were carried out in the following laboratories.

* Geotechnical laboratory, Civil Engineering Department of the Federal University of Technology, Akure.
* Chemical laboratory, Dept of Soil and Crop Science, Federal University of Technology, Akure.
* X-Ray Unit, Rolab Research and Diagnostic Laboratory, Ibadan Oyo State.
* International Institute for Tropical Agriculture (IITA), Ibadan, Oyo State.

4.4.1 SPECIFIC GRAVITY

This is expressed as the ratio of the weight of a given volume of the soil in air at a specific temperature to the weight in air of equal volume of water at the same temperature. It is also known as a measure of the density of the soil to that of water at a given temperature. Standard specific gravities are at specified temperatures.

Lohne and Damirel (1973), suggested that the specific gravity of a soil particle is a very good index property to characterize lateritic soil because it reflects their sesquioxide content and hence the extent of laterisation.

Bowles (1985), gave the following classification for soils with various specific gravity values.

Type of Soil	**Specific Gravity (G_s)**
Sand	2.65 – 2.67
Silty sand	2.67 – 2.70
Inorganic clay	2.70 – 2.80
Soils with micas or iron	2.75 – 3.00
Organic soils	Variable, but may be under 2.00

4.4.2 CONSISTENCY LIMITS TESTS

Consistency limits tests provide an excellent basis for the classification and identification of fine grained soils. This is due to the fact that it is possible for the soils that have closely similar grading curves to exhibit widely different engineering properties based on the differences in the characteristics of clay size particles. Consistency limits give the plasticity characteristics of a cohesive soil. This test includes liquid limit, plastic limit and shrinkage limit or linear shrinkage. The difference between the liquid and plastic limit gives the plasticity index which is the range of moisture content within which the soil remain plastic.

Consistency limit values are indicative of the clay mineral in a soil, expressed as percentage of moisture content reckoned on the dry soil. The change from one limit to the other is accompanied by important change in physical and chemical properties of a soil. A Swedish soil scientist called Atterberg (1911), first highlighted the significance of consistency limits hence the test is alternatively known as Atterberg limit test.

Liquid Limit (w_L) – This is defined as the minimum moisture content at which the soil will flow under the application of a very small shearing force. The apparatus used is a flat glass plate, weighing balance, two plastic knives, a grooving tool, wash bottles, Casagrande dish and well labeled cans.

This limit is sometimes used to estimate settlement C_C in consolidation problems, where $C_C = 0.009\ (W_L\text{-}10)$.

Plastic Limit (w_p) – This is the water content below which a soil is non plastic or ceases to behave as a plastic material and become brittle. It is the water content at which it is no longer possible to roll the clay into an unbroken thread of about 3mm diameter.

Plasticity Index (w_I) – This is the difference between liquid limit and plastic limit representing the quantity of water required to change soil from its plastic limit to liquid limit.

Plasticity Index, I_P = Liquid limit – Plastic limit

The lower the plasticity index of a soil, the better the soil for construction purposes. Ola (1980) listed some factors that affect plasticity and these are parent material, degree of laterisation, clay size content, type of clay mineral and topographic conditions.

LINEAR SHRINKAGE (LS)

Shrinkage limit is the moisture content at which further removal or loss of water from the soil sample does not cause any further decrease in the volume of the soil under the same temperature and pressure. The linear shrinkage is always used instead of the shrinkage limit due to the hazards involved with the use of mercury for the test and likewise, mercury is very expensive and it cannot be determined directly in the soil classification.

4.4.3 GRAIN SIZE DISTRIBUTION

This analysis was carried out in an attempt to determine the relative proportion of different grain sizes which make up a given soil mass. It is expressed as a percentage of the total dry weight and gives the percentage content of the various fractions i.e boulders, cobbles, gravels, sands, silts, clays and colloidal size particles.

There are three stages in the grain size analysis of laterites and these are:

- Wet sieving
- Mechanical or sieve analysis
- Hydrometer analysis

Wet sieving – The aim was to separate coarse fraction of the soil from the fine ones. The apparatus used are weighing balance, sieves, drying pan, sieves brushes and paper tape.

Procedure – (i) About 500g of the air dried sample was soaked in water for 24 hours. (ii) The soaked sample was sieved through 63μm sieve. (iii) The sample retained was oven-dried for another 24 hours.

This is aimed at separating the silt and clay fractions from the coarse fraction (sand and gravel). The fraction retained on the sieve was transferred to a container and oven-dried at temperature of 100-110^{0}C.

The two fractions were then subjected to further analysis.

Mechanical or sieve analysis – The separated coarse fraction were oven dried for 24 hours at temperature of 100^0C. This was then subjected to mechanical sieving by using set of sieves arranged in descending order of aperture size. The whole set was transferred to the sieve shaker. The sieve shaker was put on for 10 minutes. The time of sieving is very crucial and it has to be standardized in order to avoid mechanical instability (Malomo, 1977). Mechanical instability is peculiar to lateritic soils in the tropics and is the susceptibility of grains of soils to breakdown when its level of mechanical energy is increased. This is as a result of increase in time of sieving or during compaction test. The percentage retained on each sieve was then computed by dividing the weight retained on each sieve with the original soil weight. The percentage passing through the sieve was then computed and these were plotted on semi-logarithm chart to obtain the grading curve.

Hydrometer Analysis – This analysis is aimed at estimating the percentage of silt and clay size particles of the soils. It is based on stoke's law which states that the settling velocity of a spherical particle is directly proportional to particle size (D), the difference in densities of particle and the fluid through which the particle is falling and inversely proportional to viscosity of the fluid. This analysis has a limitation based on the fact that not all grains are spherical or rounded in shape.

4.4.4. STRENGTH TESTS

4.4.4.1 COMPACTION TEST

This is the most effective and commonest form of mechanical stabilization and it involves rearranging constituents of soil by the application of load. It is a means of modifying the physical characteristics of the given soil with a view to improving its engineering properties. Compaction test was carried out to obtain both Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) of the soil samples. Optimum moisture content is the moisture content at which the maximum dry density is attained.

It is generally believed that three phase systems are involved in soil mass in the compaction process and these are; soil, water and air phases. With increasing compaction and addition of water, more air (void) was displaced resulting in an increase in the dry density. Above OMC, the dry density start to fall because water is replacing soil and the effective stress is reduced. Many parameters determine the energy generated on the soil during compaction and these are:

1. Weight of Rammer
2. Height of fall of the Rammer
3. The number of layers of soil
4. The number of blows per layer

5. The volume of the compacting mould.

There are about three levels of laboratory compaction and each level is characterized by a given energy. They are:

1. Standard ASSHTO which generates the least energy.
2. Modified AASHTO which impacts the highest energy.
3. West African level which is the most recent and its energy is a compromise between the standard AASHTO and the modified AASHTO.

This research work involves compaction at modified AASHTO.

4.4.4.2 CALIFORNIA BEARING RATIO (CBR)

This type of test is a means of classifying the suitability of a soil for use either as a sub-grade or sub-base course material in highway construction. It was developed by California division of highways in 1929 and it was not based on any known soil mechanics principle but it has been proved over the years to be a good estimate of strength characteristics of soils. The principal aim of this test is to measure the penetration of a certain load on a soil relative to California Bearing ratio. That is, it gives information concerning expected soil expansion beneath the pavement when the soil becomes saturated and it also gives an indication of strength loss from field saturation.

Generally, two moulds of soil are often compacted for immediate penetration testing and the other testing after soaking for several hours (i.e soaked and unsoaked CBR) with a surcharge approximately equal to, the pavement weight used in the field usually in "kg". A surcharge of the same magnitude as for the swell test is placed on the soil sample in both penetration tests for CBR values.

4.4.4.3 TRIAXIAL COMPRESSION TEST

This is the strength test commonly used in laboratory today. The soil specimen, cylindrical in shape, was subjected to direct stresses acting in three mutually perpendicular directions under the unconsolidated undrained (UU) condition at a strain rate of 0.7%/min. In the common solid cylindrical specimen test, the major principal stress (σ_1) was applied in the vertical direction and the other two principal stresses (σ_2 and σ_3) were applied in the horizontal direction by the third pressure round the specimen. This test covered the determination of the compressive strength of a specimen of saturated cohesive soil in the Triaxial compression apparatus under conditions in which the cell pressure was maintained constant and there was no change in the total water content of the specimen.

4.4.5 CHEMICAL ANALYSIS OF THE SOIL SAMPLES

DETERMINATION OF METALS IN THE SAMPLE

a). SAMPLING

The samples were taken and kept in polythene bags upon transportation to the laboratory. The soil samples were air-dried and sieved with 2mm mesh (Carter, 1992). The sieved samples were used for the various mineral analysis.

b). TREATMENT OF SAMPLES FOR METAL ANALYSIS

Two grammes of each of the samples was weighed into a boiling tube and digested using a digestion mixture containing concentrated hydrochloric acid and trioxonitrate V acid prepared as described by Rowel, (1993).

Fifteen mil of the digestion acid was added to the soil and heated with a funnel placed on the mouth of the tube. After heating at 120^0c for 2hrs, it was cooled, diluted to 50ml with 8.8% HNO_3, which was then filtered.

The filtrate was used for the various metal analysis.

c). DETERMINATION OF THE CONCENTRATION OF THE METALS

The metals were determined by using Atomic Absorption Spectrophotometer (AAS). Series of standard of each of the metals were prepared and run together with each sample at various wavelength using a hollow cathode lamp of each metal (Ademoroti, 1996).

The concentration of the metals was calculated as follows:-

$$\text{mg/kg metal} = \frac{\text{mg metal from machine}}{\text{Weight of sample}} \times v$$

Where V = final volume for dilution

DETERMINATION OF TOTAL PHOSPHORUS

A. EXTRACTION OF THE TOTAL PHOSPHORUS FROM SOIL

The phosphorus was extracted by method described by Tell (1984) and IITA (1979). Five grammes of the sieved soil was weighed into a conical flask and 30ml of perchloric acid was added. The mixture was heated on a hot plate inside a fume cupboard at 130^0C until the solution was clear and when white fumes of perchloric acid appeared and soil residue became white.

The mixture was then cooled, diluted with distilled water, filtered into 100ml standard flask and diluted to the mark with distilled water. The phosphorus was determined colorimetrically using the blue molybdate method (Murphey et al, 1962). Series of standard phosphorus were prepared (Ademoroti 1996) and the absorption of the sample and standard were read at 660mm.

The total phosphorus was calculated from the following:-

$$\text{ppm of phosphorus in soil} = \text{ppm from standard} \times \frac{V_1}{V_2} \times D$$

Where

V_1 = total volume of extract

V_2 = volume of extract used that was diluted

D = dilution factor

4.4.6 COMPRESSIVE STRENGTH TESTS ON MOULDED BRICKS

Three bricks were moulded from each sample of the soil and the average compressive strength was determined from the maximum load the bricks could withstand and the area of the bricks. This was determined after a curing period of seven, fourteen, twenty one and twenty eight days (Taylor, 1991).

4.4.7 X-RAY ANALYSIS

The powdered specimen was mounted on a small pedestal connected with a continuously rotating base. The X-rays were permitted to hit the specimen and be diffracted upon a film. Each line of the pattern represents a reflection from different atomic planes within the mineral (Krynine & Judd 1957).

The clay minerals can be identified further by the temperatures required to extract structural water from their lattices.

4.4.8 DIFFERENTIAL THERMAL ANALYSIS (DTA)

In differential thermal analysis, the temperature of the sample and a thermally inert reference material were measured as a function of temperature (usually sample temperature).

Any transition which the sample undergoes will result in liberation or absorption of energy by the sample with a corresponding deviation of its temperature from that of the reference (Krynine & Jude 1957). This differential temperature versus the programmed temperature at which the whole system is being changed tells the analyst the temperature at which the transition occurs and whether the transition is exothermic or endothermic.

The effect of high temperatures on clay minerals was studied by this differential thermal analysis. The amount of water released by a mineral when heated to a high temperature is measured by using a special thermal balance (Krynine & Jude 1957).

In this analysis, a sample of the soil materials and calcined alumina (heat-treated and thus reduced to powdered aluminium oxide) were placed in cavities of a nickel block and heated to 1100^0C at the rate of about 12^0/min (Krynine & Jude 1957). A curve of temperature difference between the material under test and calcined alumina was drawn on an automatic recording drum, and each material yielded a characteristic curve.

4.4.9 PERMEABILITY TEST

This test was carried out on the soil samples to determine the coefficient of permeability of the soil. The falling-head permeability method (Bowles 1986) was used in this study. Also, a total of three tests were conducted on each sample.

The coefficient of permeability, K, was calculated from

$$K = 2.3 \frac{al}{At} \log_{10} \frac{h_1}{h_2}$$

Where

h_1 = initial head in cm

h_2 = final head in cm

t = time interval in sec

L = length of sample in cm

a = area of stand pipe in cm^2

A = Cross-sectional area of soil sample in cm^2

CHAPTER FIVE

5.0 RESULT AND DISCUSSION

This chapter presents the results of various geotechnical, chemical, X-Ray and DTA tests carried out on all the samples. Tables and graphs were also plotted for each test. Properties such as grain size distribution, compaction and California Bearing Ratio of the soil samples (both Termite Reworked as well as the surrounding lateritic soil samples) were determined. The following symbols were used to designate soil samples:-

TTRS - Termite Reworked soil from top of termitarium.

QTRS - Termite Reworked soil from the Queen of termite surrounding.

BTRS - Termite Reworked soil from bottom of termitarium.

NRS - Non Reworked soil

5.1 SPECIFIC GRAVITY

This is an important index property of soil that is closely linked with mineralogy/chemical composition. It shows the sesquioxide content and hence the extent of laterisation (Lohnes and Demirel, 1973). The specific gravity values of the soils are shown in Table 5.1

The Table shows that specific gravity value ranges from 2.65-2.76 for the surrounding soils in location 1, while the value ranges between 2.74 and 3.02 in the termite reworked soils from the same location. From location 2, the value is between 2.79 and 3.00 for termite reworked soils while the value ranges from 2.72-2.79 in the surrounding soils. This result indicates that termite reworked soils from both locations have higher specific gravity than the surrounding soils, thus the termite reworked soils have a higher degree of laterization.

Table 5.1: Result of Specific Gravity Test

	Surrounding Soils		*Termite Reworked Soils*	
	Sample	***Specific Gravity***	***Sample***	***Specific gravity***
Location 1	NRS 1	2.65	TTRS 1	2.76
	NRS 2	2.71	TTRS 2	2.74
	NRS 3	2.76	QTRS 1	3.02
	NRS 4	2.70	QTRS 2	2.81
			BTRS 1	2.83
			BTRS 2	2.80
Location 2	NRS 1	2.75	TTRS 1	2.79
	NRS 2	2.72	TTRS 2	2.85
	NRS 3	2.79	QTRS 1	3.00
	NRS 4	2.76	QTRS 2	2.80
			BTRS 1	2.82
			BTRS 2	2.81

5.2 GRAIN SIZE DISTRIBUTION

The percentage grain size distribution of the studied soils are summarized in Table 5.2 while the grading curves of both termite reworked soils and the surrounding soils from both locations, the graphs of grain size and hydrometer analyses are shown in figures 5.1 and 5.2. The actual measurements from the laboratory sieve and hydrometer analyses are presented in Appendix A.

From Table 5.2, it can be observed that all the soil samples are fairly graded. From location 1, the percentage of sand in the termite-reworked soil is between 29% and 56% but in the surrounding soil from the same location, the percentage of sand is between 23% and 47%. From the same location, it is observed that the percentage fines is between 41% and 67% in the termite reworked soils while it is between 50% and 75% in the surrounding soils.

Soils from location 2 are of high percentage of fines as shown in the Table. Termite reworked soils contain 28%-66% of fines while the surrounding soils have 51%-75%. The percentage coarse of the termite reworked soils from this location is between 34% and 72% while that of the surrounding soil is between 25% and 49%. Generally, it can be inferred that soils from both locations have high percentage of clay (22%-49% in the termite reworked soil and 29%-61% for the surrounding soils). This may be as a result of their parent materials as it has been noted by Adeyemi, (1995) that parent material causes a remarkable effect on the grain size distribution characteristics of the derived soils.

Table 5.2: The result of grain size distribution of the studied soils in percentages.

	Surrounding Soil						*Termite Reworked Soils*					
ion	*Sample*	*% Gravel*	*% Sand*	*% Silt*	*% Clay*	*% Fines*	*Sample*	*% Gravel*	*% Sand*	*% Silt*	*% Clay*	*% Fines*
	NRS 1	1	24	46	29	75	TTRS 1	3	30	31	36	67
	NRS 2	4	23	25	48	73	TTRS 2	4	29	18	49	67
	NRS 3	2	45	2	51	53	QTRS 1	8	34	18	40	58
	NRS 4	3	47	19	31	50	QTRS 2	5	43	15	39	54
							BTRS 1	3	56	10	31	41
							BTRS 2	7	40	15	38	53
	NRS 1	5	20	14	61	75	TTRS 1	2	62	12	24	36
	NRS 2	4	23	21	52	73	TTRS 2	12	60	5	23	28
	NRS 3	2	47	10	41	51	QTRS 1	4	30	18	48	66
	NRS 4	3	46	5	46	51	QTRS 2	5	58	9	28	37
							BTRS 1	3	67	8	22	30
							BTRS 2	7	56	8	29	37

5.3 CONSISTENCY LIMITS

This is an important factor in the selection of laterite both as sub-grade and sub-base material. Excessively high plasticity often leads to a common type of road failure in the tropics. This is a failure which results from plastic flow of soil on the application of load. The summary of the consistency limits and plasticity index of the studied soils are presented in Table 5.3

From the Table, both the liquid limit and plastic limit of the soils from both locations are relatively high. The plasticity index (I_P), which is the difference between the liquid limit and plastic limit is seen to be lower for termite reworked soils (5.5 to 16.5) in location 1, while it is higher for the surrounding soils (17.0 – 23.6) in the same location. It is 3.0 to 11.5 for termite reworked soils in location 2 and 13.3 to 20.5 for surrounding soils in the same location.

Table 5.3: Mean values of consistency limits of the studied soils

Location	*Surrounding soils*				*Termite Reworked Soils*			
	Sample	*L.L (%)*	*P.L (%)*	*P.I*	*Sample*	*L.L. (%)*	*P.L. (%)*	*P.I.*
1	NRS 1	42.0	25.0	17.0	TTRS 1	32.5	24.5	8.0
	NRS 2	40.0	19.5	20.5	TTRS 2	30.0	24.5	5.5
	NRS 3	38.0	13.4	23.6	QTRS 1	35.0	31.0	7.0
	NRS 4	35.0	12.2	22.8	QTRS 2	40.0	30.0	10.0
					BTRS 1	34.5	21.2	13.3
					BTRS 2	37.0	19.5	16.5
2	NRS 1	38.0	17.5	20.5	TTRS 1	28.0	20.0	8.0
	NRS 2	34.5	18.1	16.4	TTRS 2	25.0	16.5	8.5
	NRS 3	34.0	20.7	13.3	QTRS 1	32.0	21.3	10.7
	NRS 4	30.0	16.5	13.5	QTRS 2	30.0	27.0	3.0
					BTRS 1	32.0	22.0	10.0
					BTRS 2	27.0	15.5	11.5

5.4 LINEAR SHRINKAGE

Linear Shrinkage is a parameter used in the evaluation of soils as highway sub-base material. Gidigasu (1973), suggested that any soil with linear shrinkage below 10% would not pose a field compaction problem. Madedor (1983), also suggested that a linear shrinkage below 8% ($\leq$ 8%) indicates a soil that is good as a sub-base material. Table 5.4 shows the summary of the linear shrinkage values of the studied soils.

The linear shrinkage is generally high for all the samples in both locations but those of the termite reworked soils are lower (8.5% - 11%) than those of the surrounding soils (8.6% - 15.0%). The termite reworked soils are better road construction material compared with the surrounding soils.

Table 5.4: Linear Shrinkage Values of the studied soils

Location	*Surrounding Soils*		*Termite Reworked Soils*	
	Sample	*Linear Shrinkage (%)*	*Sample*	*Linear Shrinkage (%)*
1	NRS 1	10.7	TTRS 1	8.8
	NRS 2	12.9	TTRS 2	7.8
	NRS 3	13.6	QTRS 1	8.6
	NRS 4	8.6	QTRS 2	8.5
			BTRS 1	10.1
			BTRS 2	9.5
2	NRS 1	15.0	TTRS 1	9.8
	NRS 2	10.0	TTRS 2	11.0
	NRS 3	10.7	QTRS 1	10.0
	NRS 4	11.4	QTRS 2	9.3
			BTRS 1	10.0
			BTRS 2	8.8

5.5 COMPACTION CHARACTERISTICS

Compaction is a means of rearranging the constituents of a soil by the application of load. It makes soil less susceptible to settlement under load (especially repeated loading). Compaction is carried out to determine the moisture content that will produce a soil with maximum dry density. The moisture content that causes the maximum dry density is known as the Optimum Moisture Content (OMC). When compacting a soil, the Maximum Dry Density is often raised while the Optimum Moisture Content is lowered. Table 5.5 shows the summary of the Maximum Dry Density and the corresponding Optimum Moisture Content of the studied soils compacted at Modified AASHTO level.

From the Table, it is observed that all the soils have high MDD values. The termite-reworked soils from both locations and one of the surrounding soils from location one (i.e NRS 2) are having higher values of MDD.

In location 1 values of MDD for termite reworked soils range from 1935kg/m^3 – 2350kg/m^3 while it is 1650kg/m^3 - 1800kg/m^3 for the surrounding soils from the same location. In location 2, the same trend was observed with termite-reworked soils having higher values of MDD (i.e 1750kg/m^3 – 1840kg/m^3) while that of the surrounding soils vary from 1600kg/m^3 to 1650kg/m^3.

The plots of dry density against moisture content of the soils are shown in figures 5.3 and 5.4.

Lohnes and Demirel (1973) stated that there exist a relationship between MDD and clay content of soils. The higher the clay content, the higher the MDD. It can therefore be said that Termite reworked soils in the two locations are biochemically stabilized as a result of termite activities.

Table 5.5: Result of compaction characteristics of the studied soils

	Surrounding soils			*Termite Reworked Soils*		
Location	*Sample*	*MDD (kg/m^3)*	*OMC (%)*	*Sample*	*MDD (kg/m^3)*	*OMC (%)*
1	NRS 1	1710	17.0	TTRS 1	2185	9.0
	NRS 2	1800	16.0	TTRS 2	2136	9.5
	NRS 3	1650	23.6	QTRS 1	2350	7.6
	NRS 4	1680	16.9	QTRS 2	2090	11.5
				BTRS 1	1935	8.4
				BTRS 2	1995	11.8
2	NRS 1	1630	22.2	TTRS 1	1760	18.5
	NRS 2	1650	22.5	TTRS 2	1780	20.0
	NRS 3	1600	21.0	QTRS 1	1780	14.8
	NRS 4	1600	22.5	QTRS 2	1840	16.0
				BTRS 1	1760	18.3
				BTRS 2	1750	19.0

MDD = Maximum Dry Density

OMC = Optimum Moisture Content

5.6 CALIFORNIA BEARING RATIO (CBR)

This test is used to estimate the bearing capacity of highway sub-grade and sub-base materials (Simon et al, 1973, Gidigasu, 1980). CBR values were determined for both the termite-reworked soils and surrounding soils. The result of this test is shown in Table 5.6 (See Appendix B for the chart of California Bearing Ratio).

From the Table, it can be deduced that for the non-reworked samples in location 1, the CBR varies from 32 to 37 while for the termite reworked samples, the CBR varies from 41 to 67.

On the other hand, for the non-reworked samples in location 2, the CBR varies from 8 to 12 while for the termite reworked samples, the CBR varies from 12 to 25. Since the CBR has linear relationship with the shear strength characteristics of a soil, the higher the CBR of a soil, the better is the soil for engineering purpose. Hence, termite reworked soils are better materials used in estimating the bearing capacity of highway sub-grade and sub-base materials.

Table 5.6: Result of California Bearing Ratio (CBR) of the studied soils.

	Surrounding soils			*Termite Reworked Soils*		
Location	***Sample***	***Penetration***	***CBR***	***Sample***	***Penetration***	***CBR***
1	NRS 1	2.5 5.0	29 32	TTRS 1	2.5 5.0	54 49
	NRS 2	2.5 5.0	34 32	TTRS 2	2.5 5.0	51 50
	NRS 3	2.5 5.0	32 37	QTRS 1	2.5 5.0	62 67
	NRS 4	2.5 5.0	34 37	QTRS 2	2.5 5.0	61 52
				BTRS 1	2.5 5.0	40 41
				BTRS 2	2.5 5.0	40 42
2	NRS 1	2.5 5.0	8.0 9.0	TTRS 1	2.5 5.0	13 14
	NRS 2	2.5 5.0	7.0 12.0	TTRS 2	2.5 5.0	11 16
	NRS 3	2.5 5.0	8.0 12.0	QTRS 1	2.5 5.0	17 17
	NRS 4	2.5 5.0	7.0 8.0	QTRS 2	2.5 5.0	25 24
				BTRS 1	2.5 5.0	10 12
				BTRS 2	2.5 5.0	10 13

5.7 TRIAXIAL TEST

This is the shear strength test that is commonly used in laboratory today for determining cohesion and angle of internal friction of soils. The shear strength of most soils is made up of a combination of friction and cohesion. Coarse-grained soils depend mainly on "friction" between the grains for their shear strength while in fine-grained soils, shear strength depends mainly on the "cohesion" between the grains, and does not vary with the compressive load. But in coarse grained soils, it varies with the compressive load at right angles to the shear plane. Therefore, shear strength or shearing resistance of a soil depends on a large number of factors, but is generally considered to be made up of the internal friction between the grains, and the cohesion of the grains. Table 5.7 shows the values of cohesion (c) and angle of internal friction (ϕ) of the studied soils obtained from the mohr curves drawn for the studied soils (see fig. 5.5a to fig. 5.6j) . From the Table, it is observed that termite reworked soils have higher values of cohesion and angle of internal friction than the surrounding soils. For non-reworked samples in location 1, the value of cohesion ranges from 42.5KN/m^2 to 65KN/m^2 while the value of angle of internal friction ranges from 17.5^0 to 22^0. On the other hand, for termite reworked samples in location 2, the value of cohesion ranges from 80KN/m^2 to 120KN/m^2 while the value of angle of internal friction ranges from 16^0 to 34^0. The same trend was also observed in location 2. It is believed that increase in cohesion increases the shear strength and the bearing capacity of soils. It is also observed that the results show that the soils are unsaturated. The percentage of saturation for all the samples are shown in table 5.8. For non-reworked soil in location 1, the value ranges from 0.7480 to 0.9440 and for termite reworked soils, it is from 0.7914 to 0.9554. On the other hand, for location 2, it varies from 0.7918 to 0.9415 for non-reworked soil samples while it ranges from 0.6435 to 0.9500 for termite reworked soils.

Since the shear strength of soils depends on the combination of cohesion and angle of internal friction, higher values of cohesion and friction increase the shear strength.

Table 5.7: Result of cohesion (c) and angle of internal friction (ϕ) of the studied soils with a rate of strain of 0.7%/min (unconsolidated undrained)

	surrounding Soil			*Termite Reworked Soils*		
Location	*Sample*	*Cohesion (c)kN/m²*	*Friction (ϕ)*	*Sample*	*Cohesion (c) kN/m²*	*Friction (ϕ)*
1	NRS 1	50.0	17.5	TTRS 1	80.0	19.0
	NRS 2	42.5	20.0	TTRS 2	90.0	23.0
	NRS 3	50.0	17.5	QTRS 1	90.0	16.0
	NRS 4	50.0	22.0	QTRS 2	120.0	26.0
				BTRS 1	80.0	34.0
				BTRS 2	95.0	22.5
2	NRS 1	40.0	20.0	TTRS 1	130.0	27.0
	NRS 2	30.0	26.0	TTRS 2	80.0	34.0
	NRS 3	20.0	30.0	QTRS 1	155.0	26.0
	NRS 4	20.0	30.0	QTRS 2	100.0	28.0
				BTRS 1	80.0	34.0
				BTRS 2	125.0	27.5

Table 5.8: Result of Percentage of saturation of the studied soils.

	surrounding Soil		*Termite Reworked Soils*	
Location	*Sample*	*% saturation*	*Sample*	*% Saturation*
1	NRS 1	0.8191	TTRS 1	0.9554
	NRS 2	0.8570	TTRS 2	0.9296
	NRS 3	0.9440	QTRS 1	0.7914
	NRS 4	0.7480	QTRS 2	0.9390
			BTRS 1	0.5170
			BTRS 2	0.8260
2	NRS 1	0.8848	TTRS 1	0.8748
	NRS 2	0.9415	TTRS 2	0.9500
	NRS 3	0.7918	QTRS 1	0.6435
	NRS 4	0.8507	QTRS 2	0.8615
			BTRS 1	0.8601
			BTRS 2	0.8752

5.8 COMPRESSIVE STRENGTH TEST ON MOULDED BRICKS

Compressive strength tests are mostly carried out on bricks for the assessment of their appropriate structural use in any part of the building (wall, roof, etc). The results of compressive strength tests on moulded bricks are shown in Appendix C and figs. 5.7 and 5.8 show the graphs of compressive strength against age of moulded bricks.

The results showed that value of compressive strength of bricks made from termite reworked soils are higher than those made from non-reworked soils. For the non-reworked samples in location 1, the compressive strength varies from 1.66N/mm^2 to 4.52 N/mm^2 while for the termite reworked samples, it varies from 1.42N/mm^2 to 5.47N/mm^2. On the other hand, for the non-reworked samples in location 2, the compressive strength varies from 1.47N/mm^2 to 4.76N/mm^2 while for termite reworked samples, it varies from 1.61N/mm^2 to 5.47N/mm^2.

5.9 X-RAY ANALYSIS OF THE STUDIED SOILS

Minerals in the clay fractions were identified from the oriented and random powder diffraction pattern following the procedures given by Brown and Brindley (1980). Identification of the minerals present in the soil samples was based on X-Ray Powder data for minerals (George Brown, 1961) as shown in table 5.9a.

From the results of X-ray diffraction analysis, the following conclusions were arrived at regarding the mineralogy of the soil samples. It can be noted that kaolinite is prominent in the termite reworked samples than the non-reworked samples with some quartz, chlorite, illite, halloysite minerals.

In location 1, (see figs. 5.9a and b), the presence of kaolinite was confirmed by the following characteristic peaks; 7.08A°, 4.24A°, 3.71A°, 3.43A°, 2.28A°, 1.825A°, 1.542A°, 1.36A°, 1.175A°, 1.006A°. The presence of quartz was likewise confirmed by the following reflections; 4.24A°, 3.43A°, 1.542A°, 1.379A°, 2.28A°, 1.67A°, 1.252A°, 1.175A° and 1.071A°. Furthermore, the presence of illite was confirmed by characteristic peaks

2.368A°, 1.542A°, 2.43A°, 1.67A°and Halloysite by 3.43A°, 1.67A° while chlorite and felspar were confirmed by 7.08A° and 0.914A° respectively.

TABLE 5.9a: X-RAY POWDER DATA FOR MINERALS (GEORGE BROWN, 1961)

rtz	Kaolinite		Kaolinite		Illite		Felspar		Chlorite		Halloysite	
I	d (A°)	I	d (A°)	I	d (A°)	I	d (A°)	I	d (A°)	I	d (A°)	I
35	7.16	10+	1.619	6	10.0	10	6.44	2	14.2	10	10.1	10
100	4.46	4	1.584	4	4.94	2	6.35	<1	7.08	4	4.46	8
12	4.36	5	1.542	5B	4.47	9	5.84	<1	4.71	6	3.40	5
12	4.18	5	1.489	8	3.68	2b	5.65	<1	3.534	6	2.56	5
6	4.13	3	1.467	2	3.32	9	4.04	9	2.829	9	2.37	3
9	3.845	4	1.452	4B	3.16	½	3.89	2	2.604	2	2.23	3
6	3.741	2	1.429	4	2.86	1	3.75	7	2.567	2	1.67	3
17	3.573	10+	1.403	2	2.60	6	3.64	4	2.458	3	1.48	5
<1	3.372	4	1.390	2	2.50	1	3.48	1	2.273	3	1.28	1
7	3.144	3	1.371	2	2.41	4	3.37	1	2.013	2	1.23	1
3	3.097	3	1.338	4	2.158	2	3.210	>15	1.886	2		
<1	2.753	3	1.305	6B	1.982	1	3.178	10	1.717	3		
15	2.558	6	1.292	2	1.689 1.639	3	3.021	3	1.567	3		
3	2.526	4	1.282	5	1.53	6	2.953 2.920	1	1.549	3		
<1	2.91	8	1.264	3			2.833 2.826	2	1.392	2		
7	2.370	6	1.246	3			0.982	1				
11	2.338	9	1.235	3			0.913	2				
9	2.288	8	1.217	1								
3	2.247	2	1.200	3								
4	2.186	3	1.190	3								
2	2.`	3	1.168	2								
5	2.061	2	1.124	1								
2	1.989	6	1.094	3								
4	1.939	4	1.082	2								
4	1.896	3	1.057	1								
2	1.869	2	1.049	2								
<1	1.839	4	1.039	2								
<1	1.809	2	1.021	2								
4	1.781	4	1.013	2								
1	1.707	2										
2	1.685	2										
2	1.662	7										
2												

In location 2 (see Figs. 5.10a and b), the presence of kaolinite was confirmed by the following characteristics peaks; 7.37A⁰, 7.08A⁰, 7.07A ⁰ 4.04A⁰, 1.93A⁰, 1.82A⁰, 1.59A⁰, 1.54A⁰, 1.50A⁰, 1.48A⁰, 1.36 A⁰, 1.25A⁰, 1.22A⁰ and 1.05A⁰.

The presence of quartz was also confirmed by the following reflections 3.3A^0, 2.31A^0, 1.82A^0, 159A^0, 1.54A^0, 1.27A^0, 1.175A^0, 1.22A^0 and 1.05A^0. The presence of illite was confirmed by the following: 3.3A^0, 3.24A^0, 1.59A^0, 154A^0, 1.48A^0, and 1.50A^0. Furthermore, halloysite was confirmed by the following reflections, 1.48A^0, and 1.27A^0 and chlorite by 7.08A^0 while felspar was confirmed by 4.04A^0 and 3.24A^0.

Table 5.9b shows that termite activities increased the quantities of minerals in the soil samples. For non reworked soils in location 1, the quantities of kaolinite, quartz, illite and chlorite are 17.47, 31.37, 2.05 and 2.92 respectively, while for termite reworked soils, the values are 44.76, 33.76, 2.61 and 6.95 respectively.

Also, for non reworked soils in location 2, quantities of kaolinite, quartz, illite and chlorite are 28.5, 18.5, 8.0, 0 respectively while for termite reworked soils, the values are 29.5, 27.0 14.5 and 2.0 respectively.

TABLE 5.9b: RELATIVE PERCENTAGES OF QUANTITIES OF MINERALS IN THE STUDIED SOILS

erals	Location 1				Location 2			
	NRS		TRS		NRS		TRS	
	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percen
lorite	2.92	4.68	6.95	7.81	-	-	2.0	2.63
dspar	7.16	11.47	-	-	13.0	18.3	3.0	3.95
loysite	1.46	2.34	0.95	1.07	3.0	4.23	-	-
e	2.05	3.28	2.61	2.93	8.0	11.27	14.5	19.08
olinite	17.47	27.98	44.76	50.28	28.5	40.14	29.5	38,82
artz	31.37	50.25	33.76	37.92	18.5	26.06	27.0	35.53

5.10 DIFFERENTIAL THERMAL ANALYSIS (DTA)

The clay minerals can be identified by the temperatures required to extract structural water from their lattices or transformation of one clay minerals into another. The amount of water released by a mineral when heated to a high temperature was measured by using thermal balance. The characteristic curves for the type of clay minerals identified in the soil samples are shown in figs. 5.11 and 5.12. The figures show that termite reworked soil samples L1, TRS (ie. from location 1) and L2, TRS (i.e. from location 2) give examples of such curves for some major types of clay minerals. In the case of kaolinite, the structural water starts to be released at temperatures of about 450^0C and 250^0C respectively which correspond to the breaking point of the endothermic curve.

On the other hand, for non reworked soil samples LI, NRS (i.e. from location 1) and L2, NRS (i.e from location 2), the structural water starts to be released at temperatures of about 320^{0}C and 520^{0}C respectively. Further heating causes recrystallization in the termite reworked soil which starts at the temperature of about 600^{0}C, 1100^{0}C (LI, TRS); 510^{0}C, 1120^{0}C (L2, TRS) and for the non-reworked soils 600^{0}C, 1150^{0}C (LI, NRS); 1050^{0}C, 1380^{0}C (L2, NRS) corresponding to the starting point of the exothermic curve. In the process of recrystallization, both alumina and silica were formed.

5.11 CHEMICAL ANALYSIS

Attempts have been made to identify and classify laterite soils on the basis of chemical characteristics. Femor (1911) was perhaps the first to propose a comprehensive system of nomenclature for laterite soils based on the content of the so called laterite constituents (Fe, Al, and Mn).

The results of the chemical analysis of the studied soils are presented in Table 5.10. From the table, the following observations can be made of soils in both locations:

- Aluminum was only detected in the queen of the termite surrounding with values ranging from 3.12 to 3.30mg/kg for soils in location one and 2.70 mg/kg to 2.98mg/kg for soils in location two.
- Iron content in the termite reworked soil was higher than the adjacent soils. Its value ranges from 1466 mg/kg to 1606.67 mg/kg in the termite reworked

soils and 1212.50 mg/kg to 1224.50 mg/kg in the non reworked soils. The same trend was also observed in the soils in location two.

- Magnesium content in the soils from location 2 increases from 817.18 mg/kg to 838.79 mg/kg in the termite reworked soils while that of non reworked soils is from 680.45 mg/kg to 682.50 mg/kg in the same location one. Location two also follows the same trend. This implies that the activities of the termite increases the magnesium content of the soils.
- Potassium values increases in the termite reworked soil than the non reworked soils in both locations. The value ranges from 256.88mg/kg-262.40mg/kg for the non-reworked samples and 275mg/kg- 569.40mg/kg for termite reworked samples in location 1. For location 2, it is 280.65mg/kg-291.28mg/kg for non reworked samples and 310.49mg/kg-440.28mg/kg for termite reworked samples. This is because potassium is the dominant cation in the gut fluid of termite,
- Sodium content decreases but the values of the sodium are higher than potassium in the matrices of the soils. The value of sodium content ranges from 1020.45mg/kg to 1025.35mg/kg for non-reworked soils and 548.25mg/kg to 943.38mg/kg for termite reworked soils in location 1. On the other hand for the non-reworked soils in location 2, the value varies

950.25mg/kg to 980.50mg/kg while for the termite reworked samples, the values varies from 620.60mg/kg to 710.80mg/kg.

- Values of manganese content are higher in the termite reworked soils than the non reworked soils from both locations. For location 1, the value ranges from 8.14mg/kg to 8.34mg/kg for non reworked samples and 8.20mg/kg to 8.75mg/kg for termite reworked samples. For location 2, the value ranges from 8.10mg/kg to 8.34mg/kg for non reworked samples whereas, it ranges from 8.42mg/kg to 8.67mg/kg for termite reworked samples.
- Values of zinc content are also higher for termite reworked soils than the non reworked soils from both locations. The results show that for non-reworked samples the value ranges from 26.80mg/kg to28.65mg/kg for location 1, while it is 43.5mg/kg to 56.92mg/kg for termite reworked samples for the same location. For location 2, the values ranges from 80.88mg/kg to 85.20mg/kg for non – reworked samples while it varies from 88.45mg/kg to 98.95mg/kg for termite reworked soil samples. Zinc is a component of cement and hence termite will improve the concrete properties of soil.
- Phosphorus content of the soil is higher in the termite reworked soils than the non reworked soils from both locations. The values ranges from 10.00mg/kg to10.37mg/kg for non – reworked samples and 11.00mg/kg to

11.80mg/kg for termite reworked samples in location1. For location 2, the values ranges from 7.50mg/kg to 8.00mg/kg for non –reworked soil while the values ranges from 18.12mg/kg to 26.61mg/kg for termite reworked samples. This type of soil will improve the phosphorus content of crops and it is noted that a diet deficient in phosphorus causes rickets (Bruyn LAL De, A.J. Conacher).

TABLE 5.10: RESULTS OF CHEMICAL ANALYSIS OF THE STUDIED SOILS

LOCATION	METALS	NON REWORKED SOILS				TERMITE REWORKED SOILS					
		NRS 1	NRS 2	NRS 3	NRS 4	TTRS 1	TTRS 2	QTRS 1	QTRS 2	BTRS 1	BTRS 2
1	Aluminum (mg/kg)	ND	ND	ND	ND	ND	ND	3.30	3.12	ND	ND
	Iron (mg/kg)	1223.25	1220.20	1212.50	1224.50	1606.67	1600.50	1466.02	1522.40	1555.40	1560.55
	Manganese(mg/kg)	8.34	8.28	8.14	8.26	8.67	8.52	8.20	8.40	8.50	8.75
	Magnesium(mg/kg)	681.84	680.45	682.50	681.40	817.18	820.20	838.79	830.30	825.20	822.55
	Calcium (mg/kg)	4.77	4.82	4.79	4.63	4.54	4.80	4.98	5.00	4.80	4.80
	Sodium (mg/kg)	1022.39	1020.45	1025.35	1022.75	555.01	548.25	940.62	943.38	750.20	765.45
	Potassium (mg/kg)	256.88	260.60	258.48	262.40	567.50	569.40	275.00	280.48	320.48	310.80
	Zinc (mg/kg)	27.69	28.65	26.80	27.50	56.92	55.98	44.62	43.50	48.50	50.22
	Phosphorus (ppm)	10.28	10.37	10.25	10.00	11.15	11.28	11.73	11.80	11.10	11.00

ND: Not Detected

LOCATION	METALS	NON REWORKED SOILS				TERMITE REWORKED SOILS					
		NRS 1	NRS 2	NRS 3	NRS 4	TTRS 1	TTRS 2	QTRS 1	QTRS 2	BTRS 1	BTRS 2
2	Aluminum (mg/kg)	ND	ND	ND	ND	ND	ND	2.70	2.98	ND	ND
	Iron (mg/kg)	1355.20	1420.75	1380.40	1461.05	1742.05	1750.20	1417.48	1420.88	1550.25	1565.42
	Manganese(mg/kg)	8.22	8.10	8.29	8.34	8.42	8.55	8.67	8.60	8.50	8.46
	Magnesium(mg/kg)	755.25	748.68	754.25	744.77	903.45	900.80	708.56	712.45	820.48	810.95
	Calcium (mg/kg)	3.05	3.04	3.06	3.08	3.04	3.08	4.80	4.62	3.50	4.25
	Sodium (mg/kg)	950.25	980.50	962.85	970.70	703.15	710.80	701.12	704.20	620.60	705.20
	Potassium (mg/kg)	280.65	291.28	289.12	288.75	315.28	310.49	438.75	440.28	350.25	394.41
	Zinc (mg/kg)	80.88	85.20	82.15	81.54	90.15	88.45	97.69	96.89	95.88	98.95
	Phosphorus (ppm)	7.50	7.67	7.62	8.00	18.12	18.60	26.61	24.15	24.20	20.60

ND: Not Detected

5.12 PERMEABILITY TEST

The coefficient of permeability depends primarily on the average size of the pores, which in turn is related to the distribution of particle sizes, particle shape and soil structure (Craig, 1979).

The results of permeability tests on both the termite reworked soils and non-reworked soils are shown in Table 5.11. Generally the effect of termite on the permeability characteristics of the soils could easily be seen from the results. From the table, it can be deduced that termite reworked soils from both locations have higher coefficients of permeability than the surrounding soils.

In location 1, the value ranges from 6.10cm/sec to 7.29cm/sec for termite reworked soils and 3.78cm/sec to 4.90cm/sec for non reworked soils. Also in location 2, it ranges from 4.90cm/sec to 6.95cm/sec for termite reworked soils and 4.15cm/sec to 4.60cm/sec for non reworked soils

Table 5.11: **RESULT OF PERMEABILITY TEST**

LOCATION	SAMPLE	TIME INTERVAL			$Kx10^{-2}$ (cm/Sec)
		T_1(s)	t_2(s)	$(t_2 - t_1)$(s)	
1	NRS 1	6.3	13.2	6.9	4.33
	NRS 2	5.6	11.7	6.1	4.90
	NRS 3	6.5	13.8	7.3	4.10
	NRS 4	6.7	14.6	7.9	3.78
	TTRS 1	3.8	8.0	4.2	7.12
	TTRS 2	4.2	8.6	4.4	6.80
	QTRS 1	4.0	8.1	4.1	7.29
	QTRS 2	4.5	9.0	4.5	6.64
	BTRS 1	3.2	8.1	4.9	6.10
	BTRS 2	4.6	9.2	4.6	6.50

LOCATION	SAMPLE	TIME INTERVAL			$Kx10^{-2}$ (cm/Sec)
		T_1(s)	t_2(s)	$(t_2 - t_1)$(s)	
2	NRS 1	5.7	12.3	6.6	4.53
	NRS 2	6.4	13.2	6.8	4.40
	NRS 3	6.6	13.8	7.2	4.15
	NRS 4	5.4	11.9	6.5	4.60
	TTRS 1	5.1	9.8	4.7	6.36
	TTRS 2	5.8	10.9	5.1	5.86
	QTRS 1	4.2	8.9	4.7	6.36
	QTRS 2	3.9	8.2	4.3	6.95
	BTRS 1	6.0	12.6	6.6	4.53
	BTRS 2	5.2	11.3	6.1	4.90

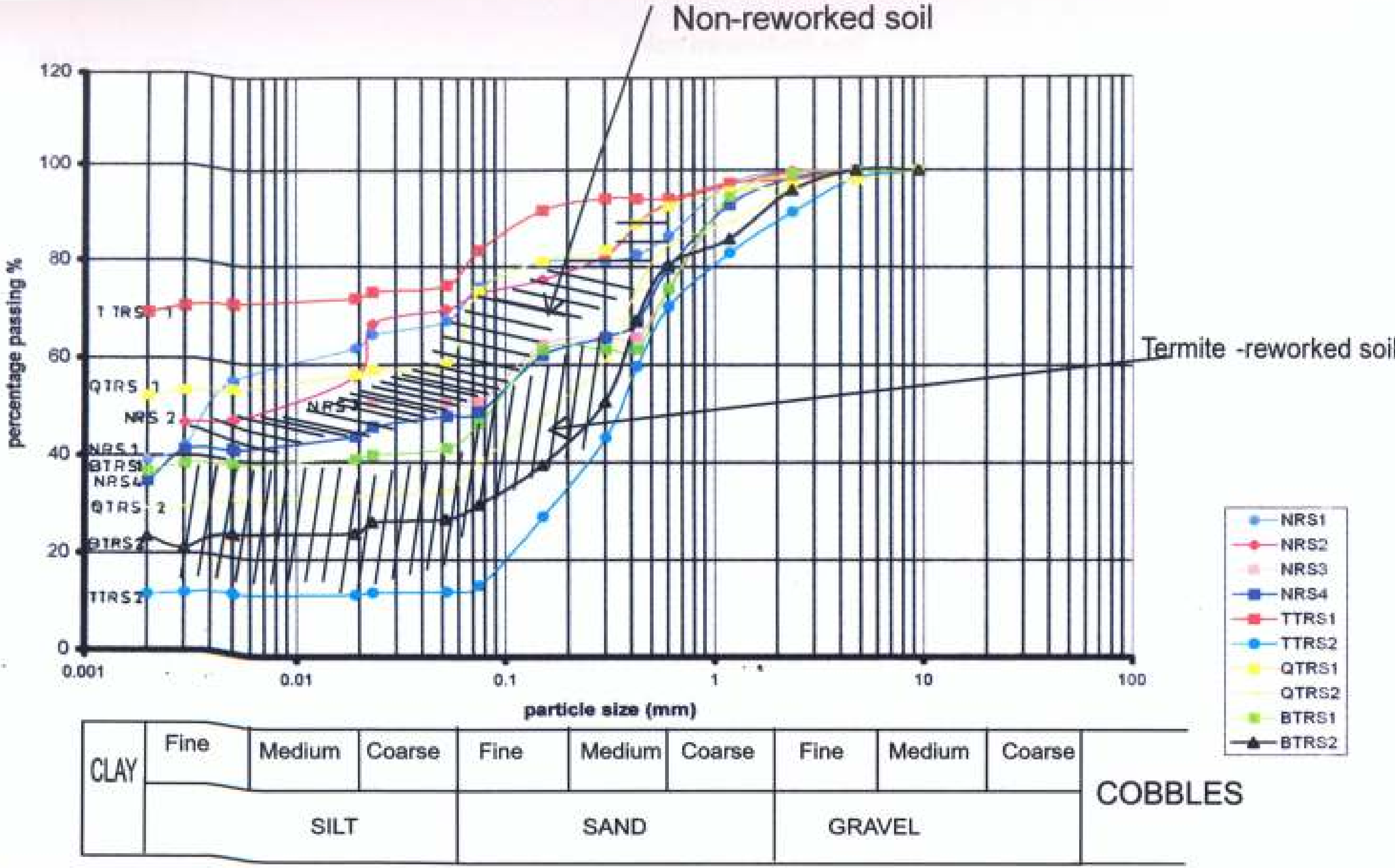


Fig. 5.1: Particle size distribution curve for all the samples from location 1

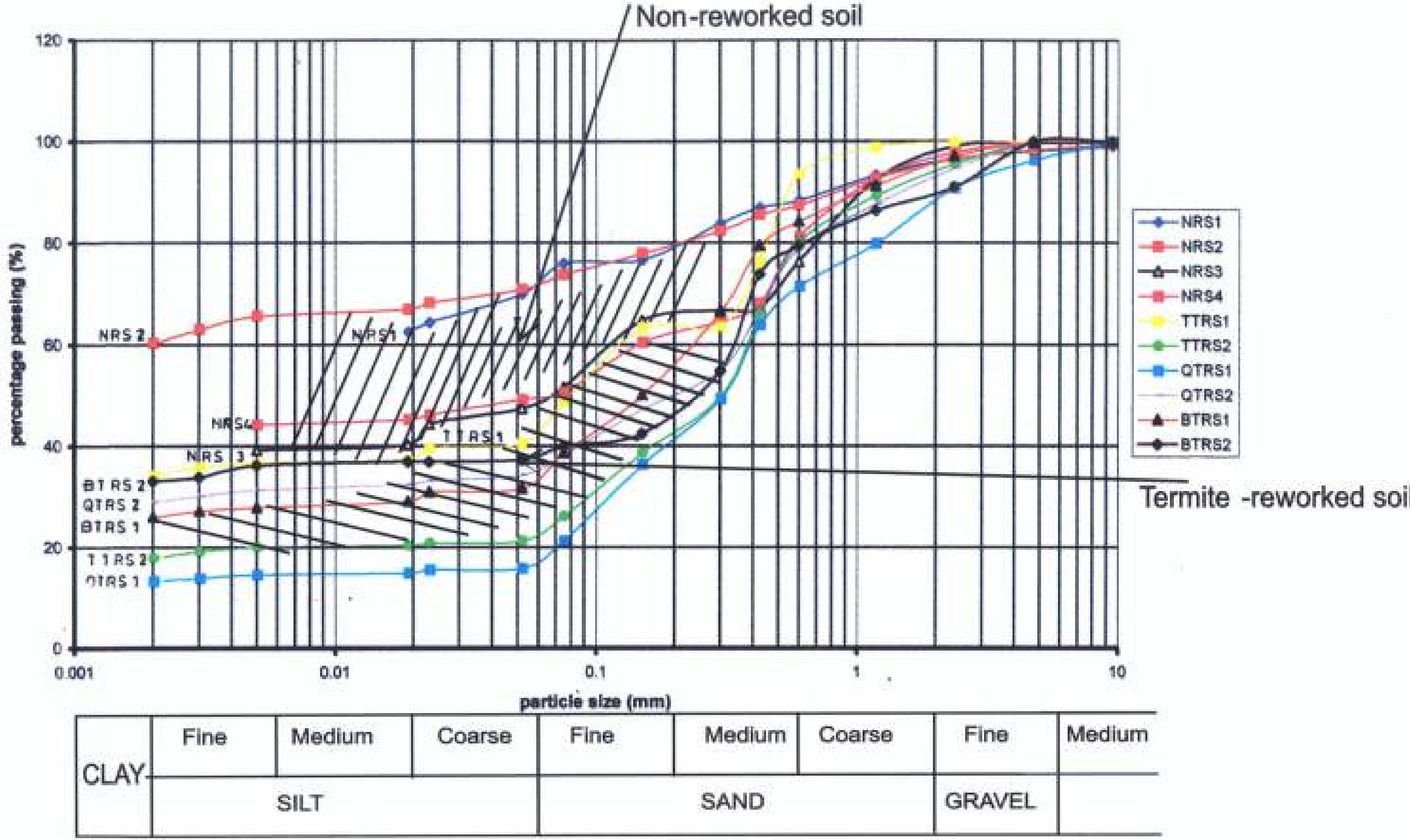


Fig. 5.2: Particle size distribution curve for all the samples from location 2

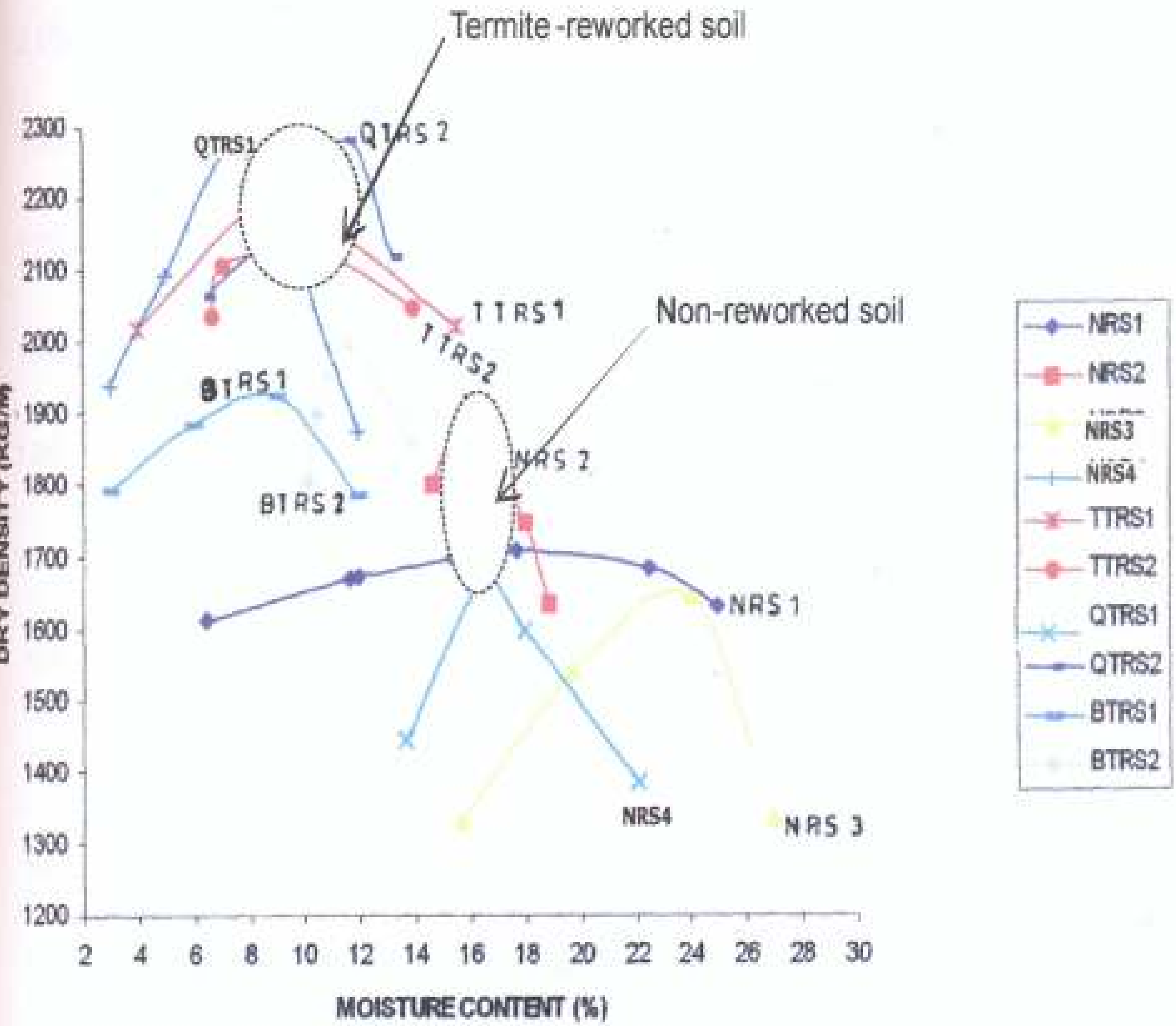


Fig. 5.3: Variation of dry density with percentage moisture content for all samples from Location 1

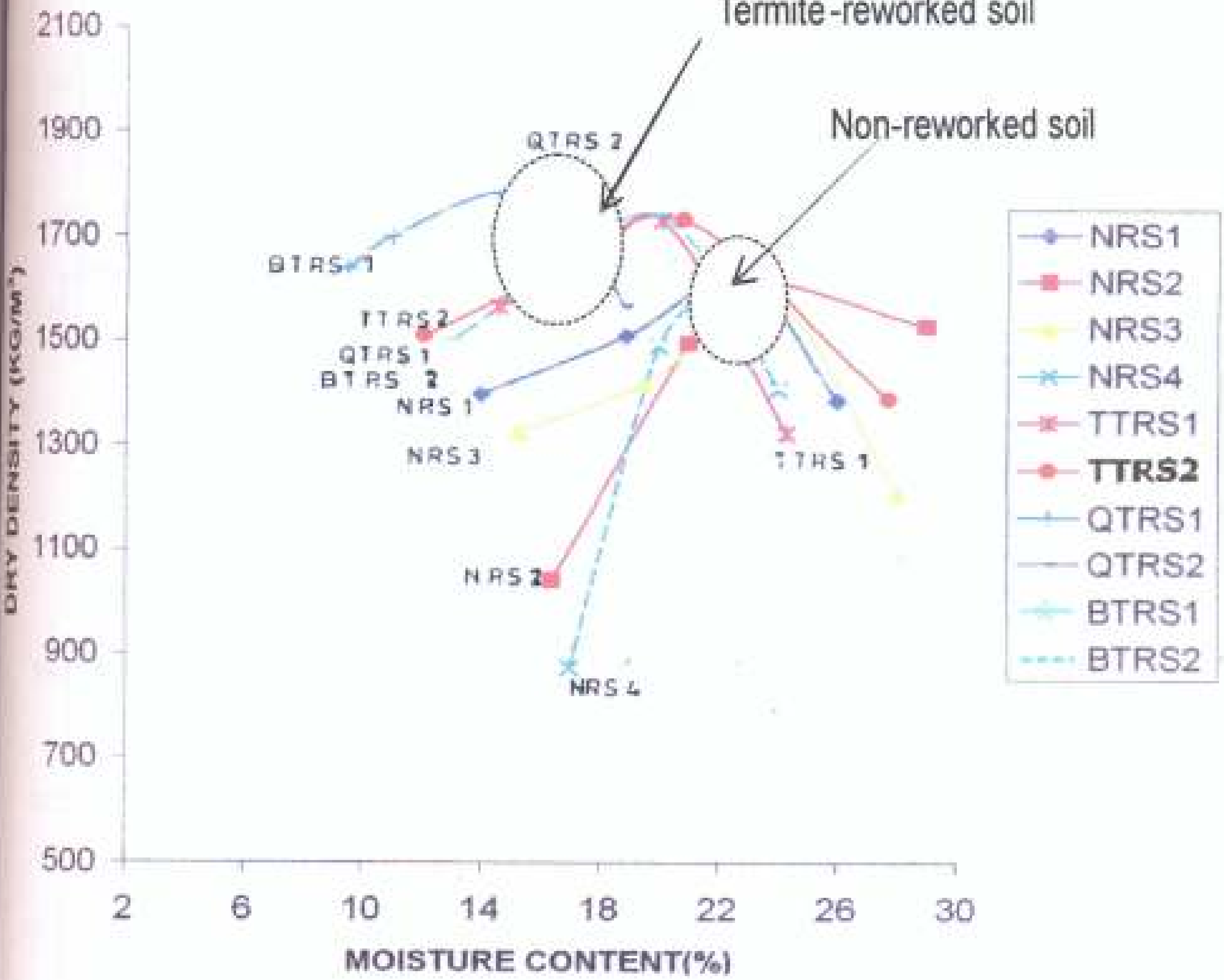


Fig. 5.4: Variation of dry density with percentage moisture content for all samples from Location 2

C^1=50 KN/m², $\varnothing^1$=17.5°, rate of strain = 0.7%/min, Unconsolidated Undrained Test

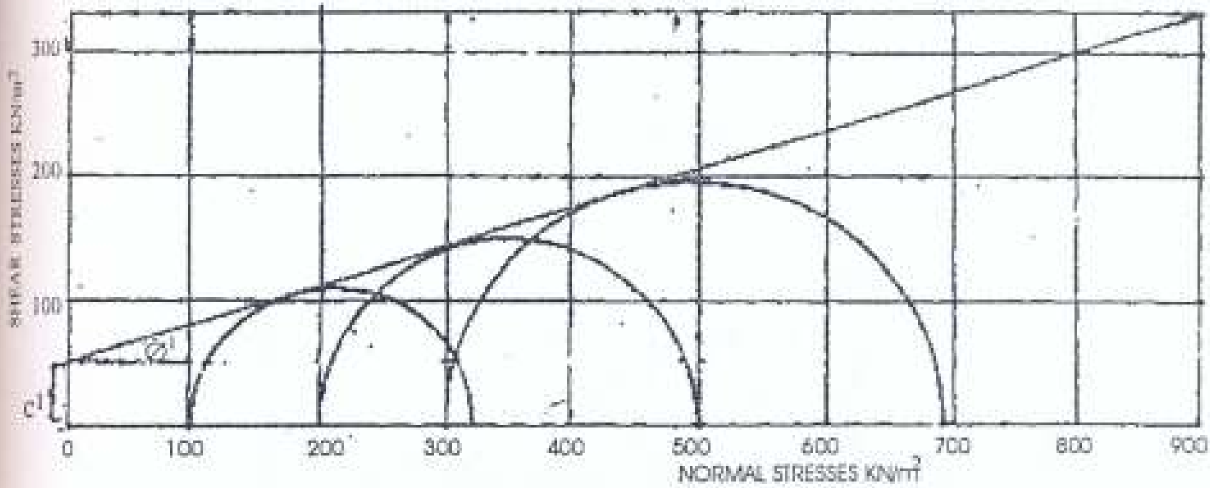


Fig. 5.5a: Showing Mohr Circles of Location 1, NRS 1

C^1=42 KN/m², $\varnothing^1$=20°, rate of strain = 0.7%/min, Unconsolidated Undrained Test

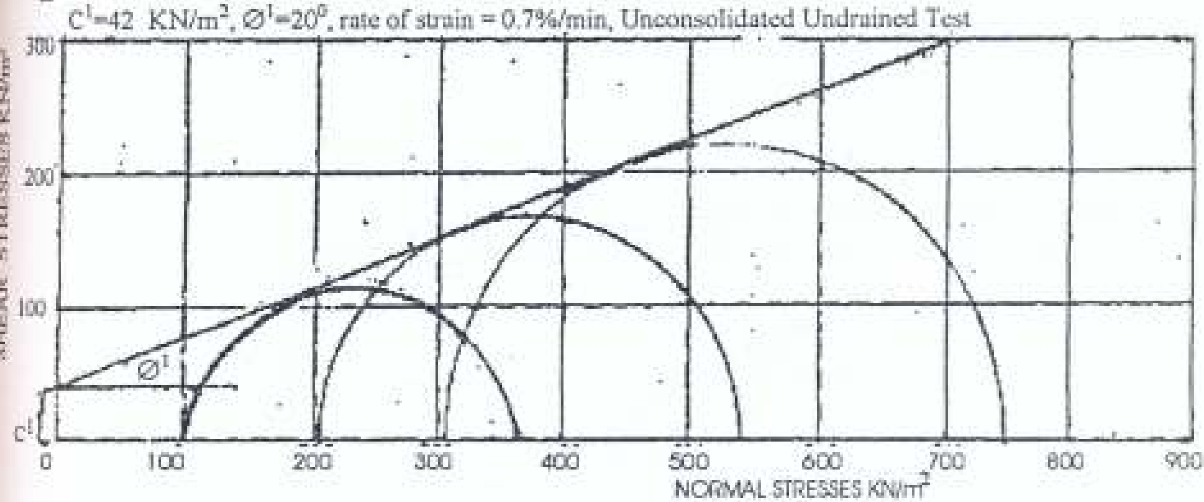


Fig. 5.5b: Showing Mohr Circles of Location 1, NRS 2

C^1=50 KN/m^2, $\varnothing^1$=17.5^0, rate of strain = 0.7%/min, Unconsolidated Undrained Test

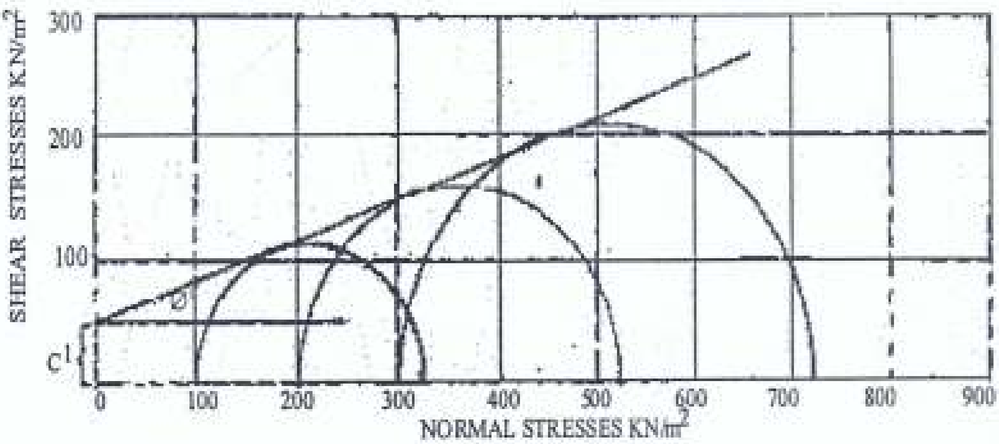


Fig. 5.5c: Showing Mohr Circles of location 1, NRS 3

C^1=65 KN/m^2, $\varnothing^1$=22^0, rate of strain = 0.7%/min, Unconsolidated Undrained Test

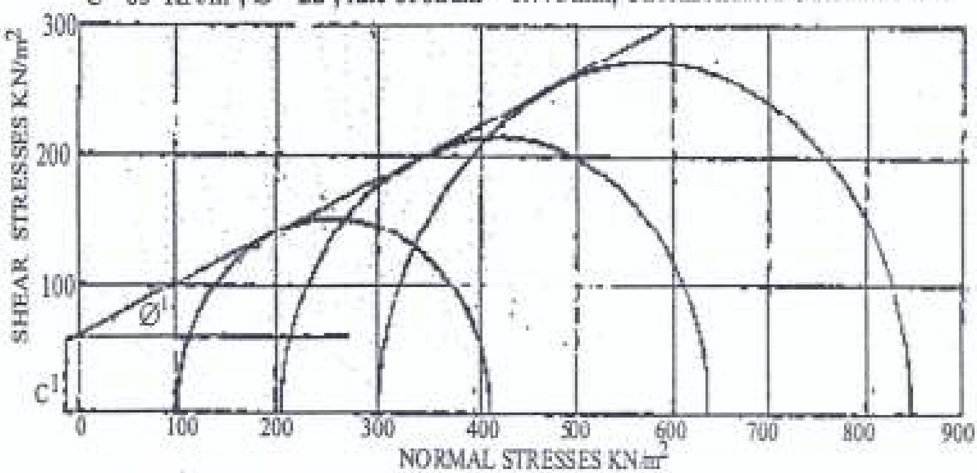


Fig. 5.5d: Showing Mohr Circles of location 1, NRS 4

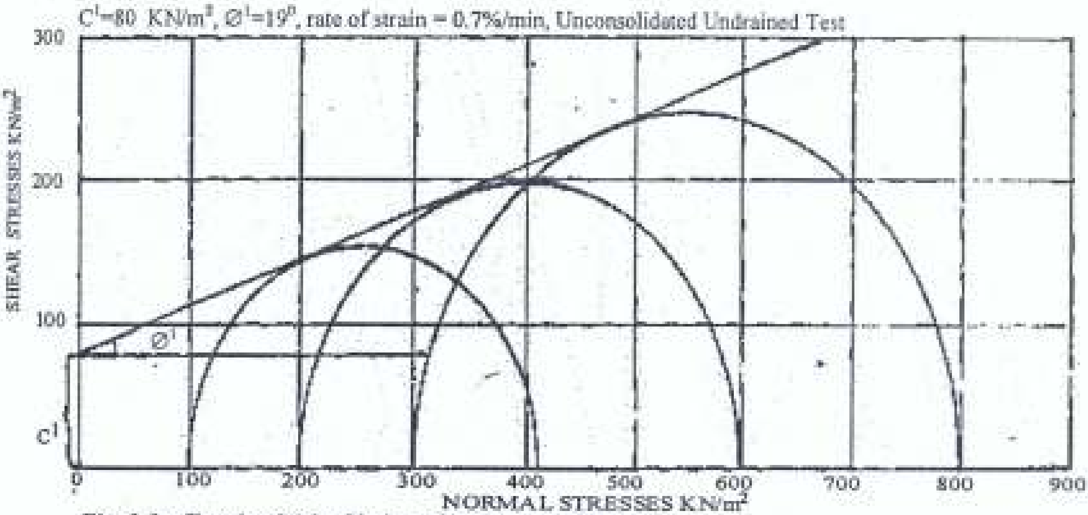


Fig. 5.5e: Showing Mohr Circles of location 1, TTRS 1

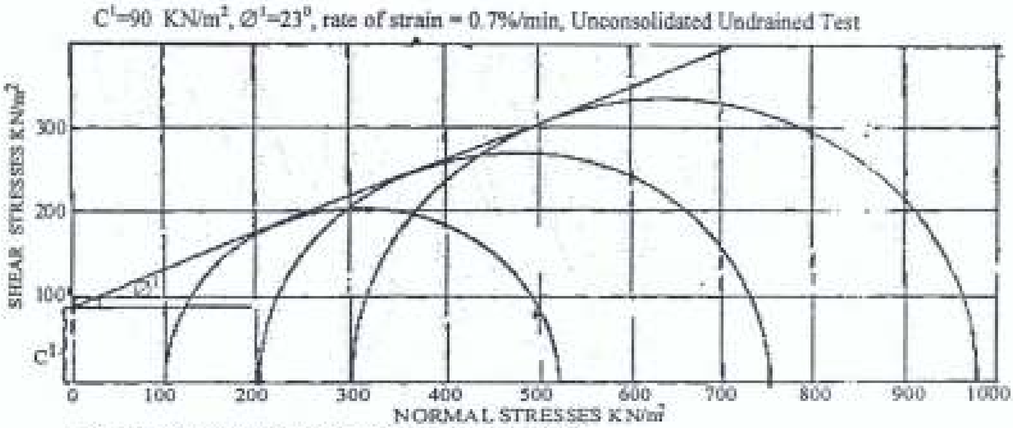


Fig. 5.5f: Showing Mohr Circles of location 1, TTRS 2

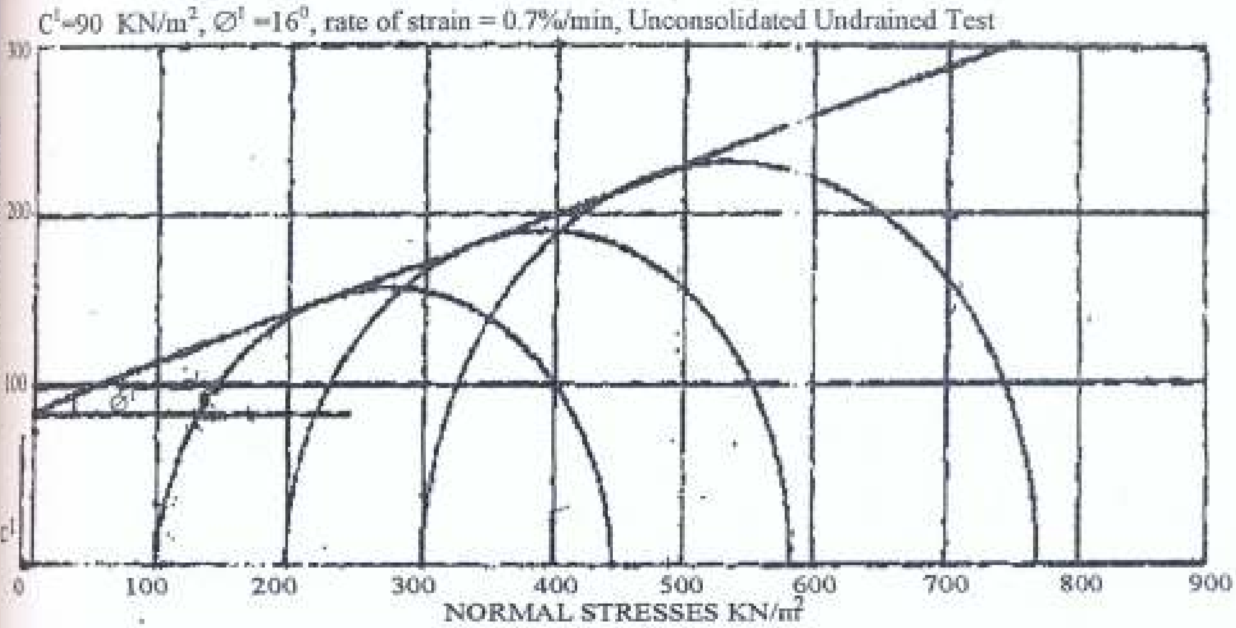


Fig. 5.5g: Showing Mohr Circles of location 1,QTRS 1

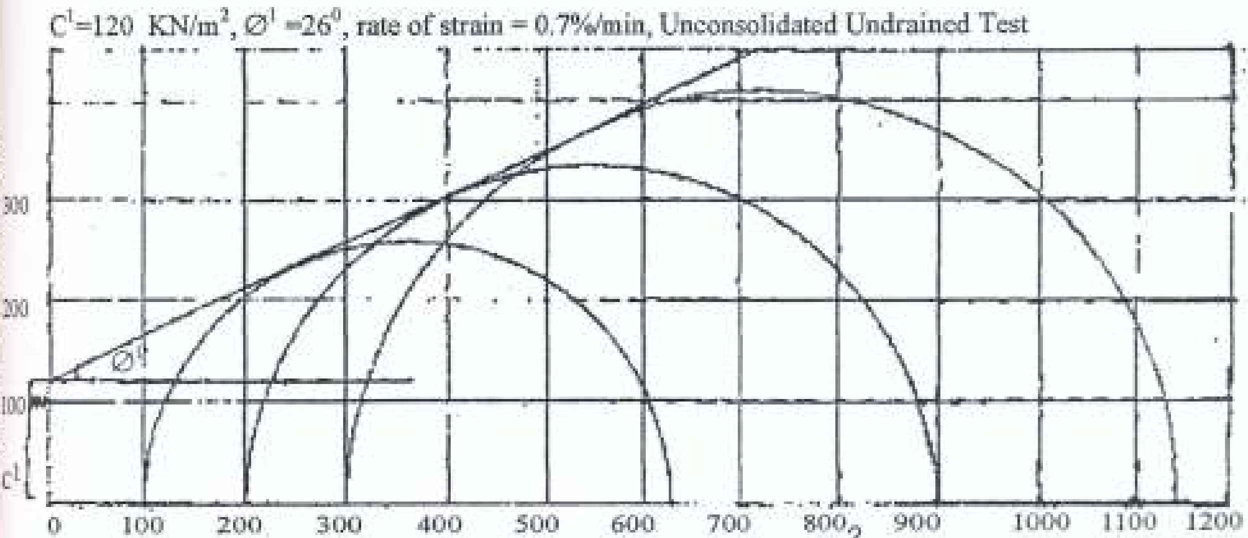


Fig. 5.5h: Showing Mohr Circles of location 1,QTRS 2

C¹=80 KN/m², Ø¹=34°, rate of strain = 0.7%/min, Unconsolidated Undrained Test

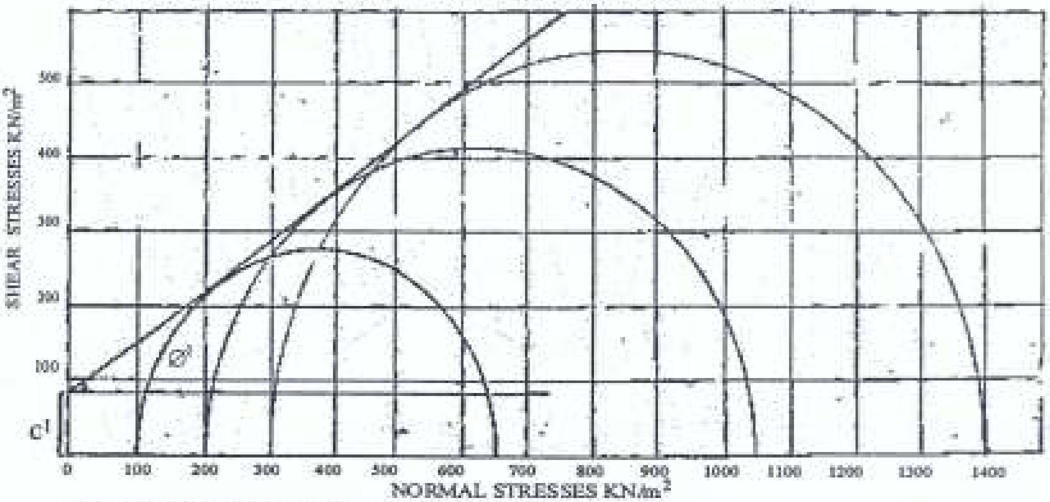


Fig. 5.5i: Showing Mohr Circles of location 1, BTRS 1

C¹=95 KN/m², Ø¹=22.5°, rate of strain = 0.7%/min, Unconsolidated Undrained Test

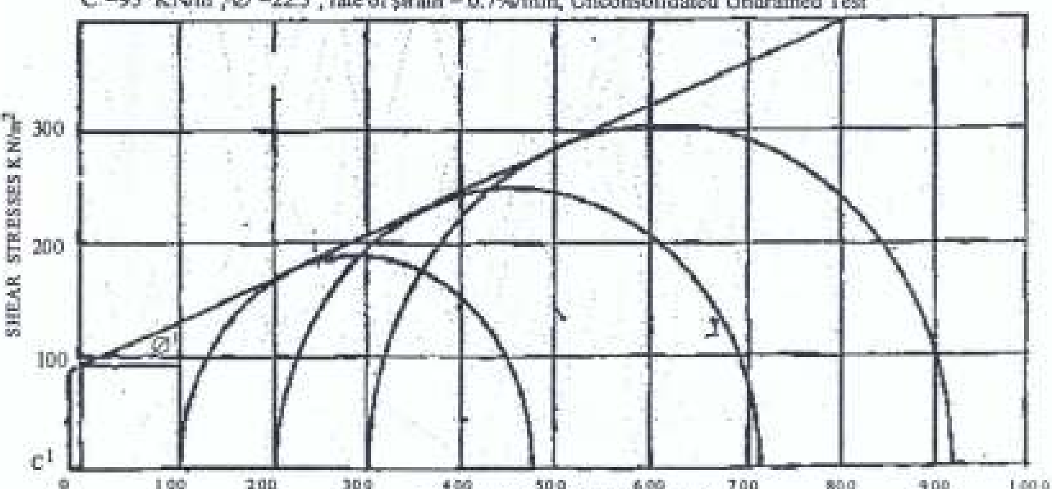


Fig. 5.5j: Showing Mohr Circles of location 1, BTRS 2

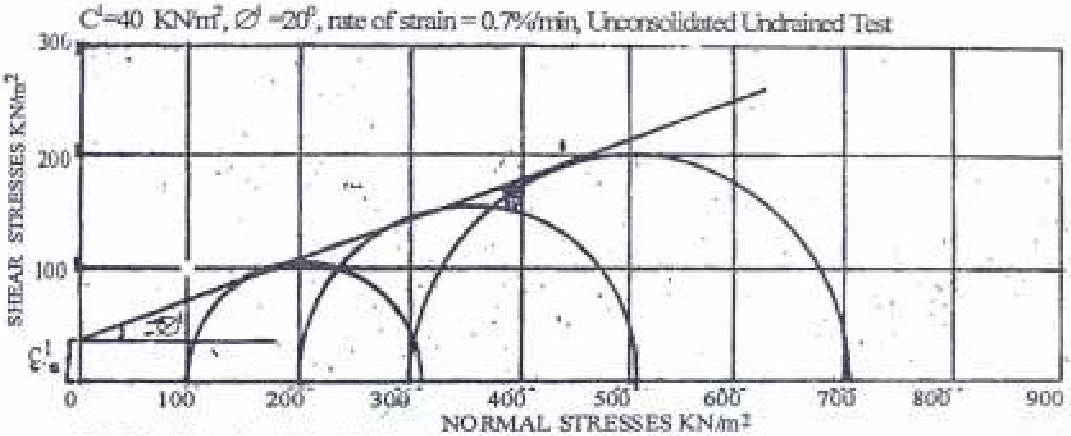


Fig. 5.6a: Showing Mohr Circles of location2, NRS 1

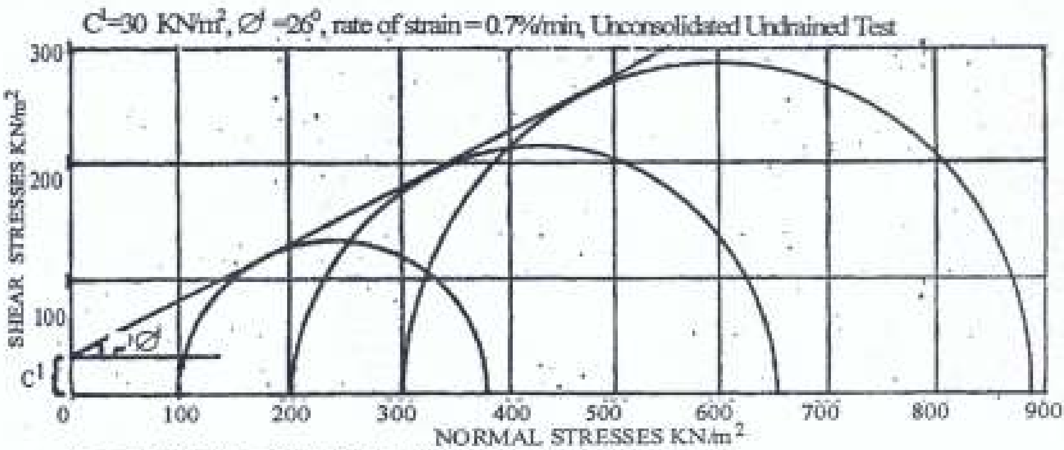


Fig. 5.6b: Showing Mohr Circles of location2, NRS 2

C'=20 KN/m², Ø' =30°, rate of strain = 0.7%/min, Unconsolidated Undrained Test

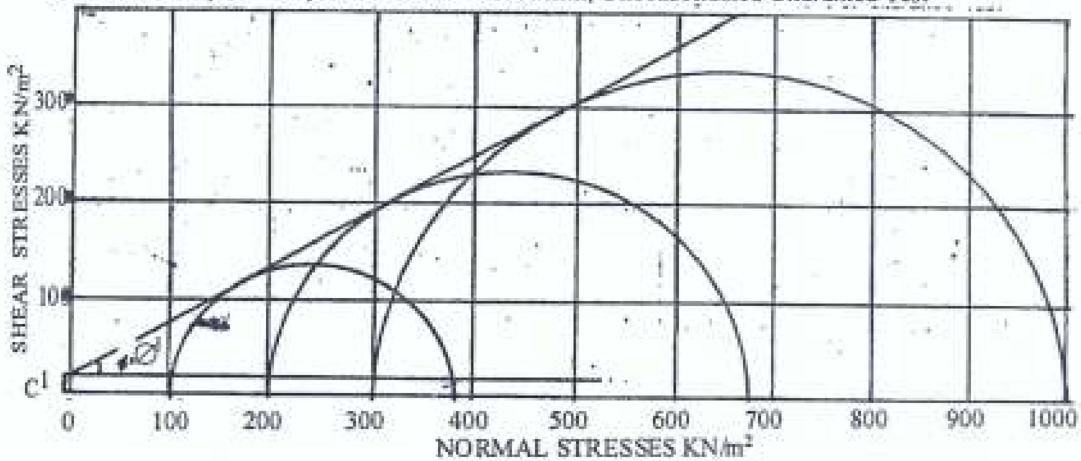


Fig. 5.6c: Showing Mohr Circles of location2, NRS 3

C'=20 KN/m², Ø' =30°, rate of strain = 0.7%/min, Unconsolidated Undrained Test

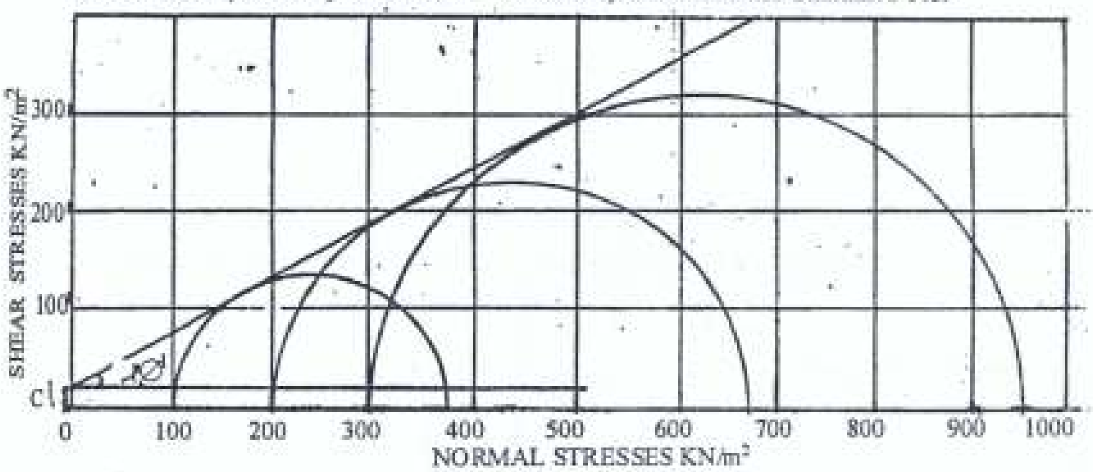


Fig. 5.6d: Showing Mohr Circles of location2, NRS 4

C¹=130 KN/m², Ø¹ =27°, rate of strain = 0.7% /min, Unconsolidated Undrained Test

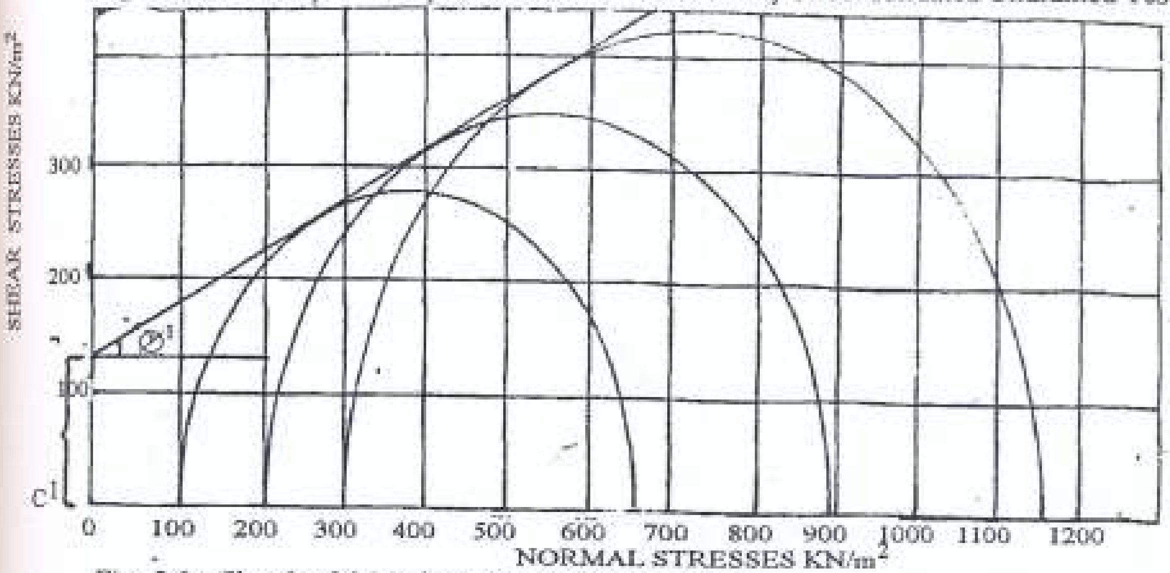


Fig. 5.6e: Showing Mohr Circles of location2, TTRS 1

C¹=80 KN/m², Ø¹=34°, rate of strain = 0.7%/min, Unconsolidated Undrained Test

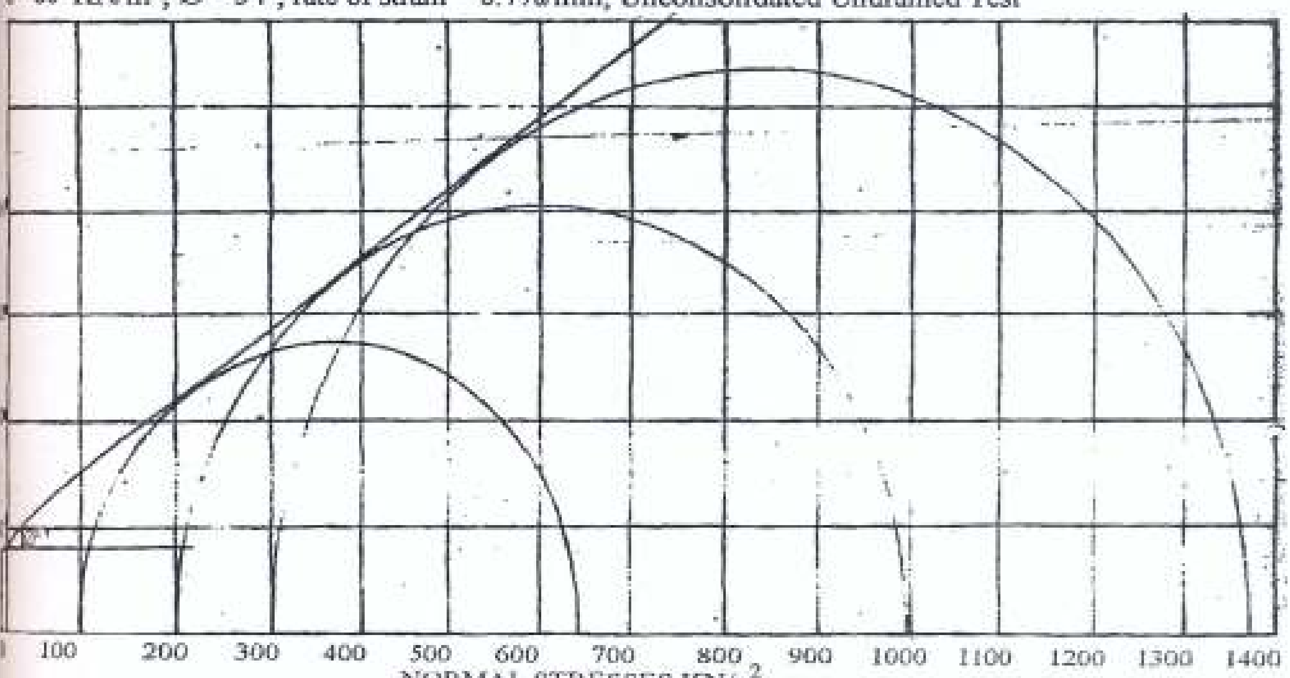


Fig. 5.6f: Showing Mohr Circles of location 2, TTRS 2

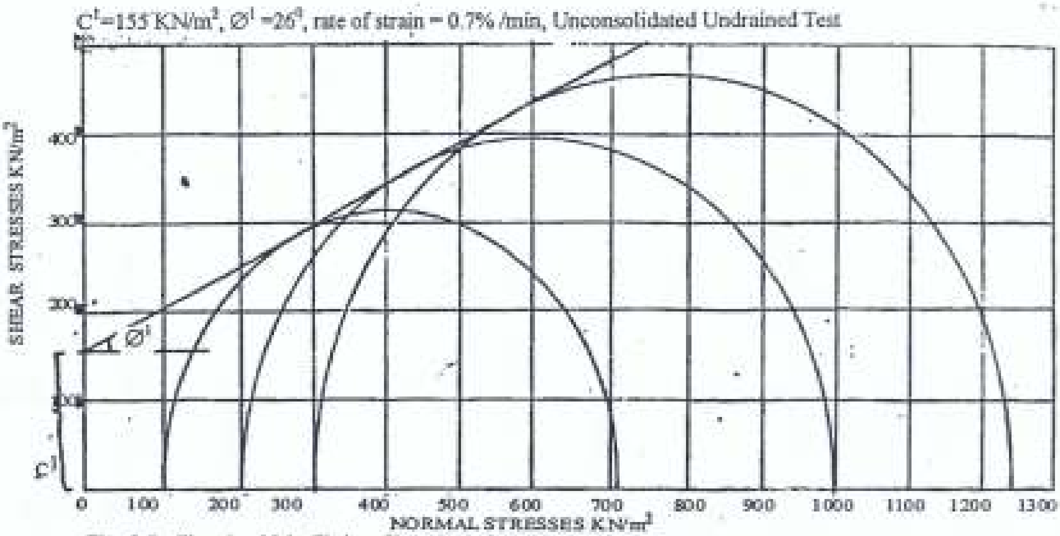


Fig. 5.6g: Showing Mohr Circles of location2, QTRS 1

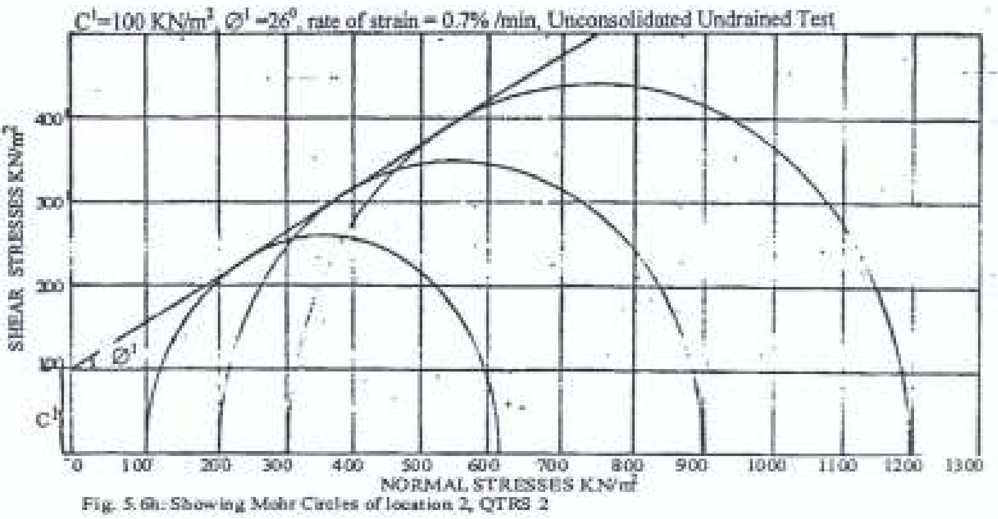


Fig. 5.6h: Showing Mohr Circles of location 2, QTRS 2

C^1=80 KN/m^2, Ø =34^0, rate of strain = 0.7% /min Unconsolidated Undrained Test

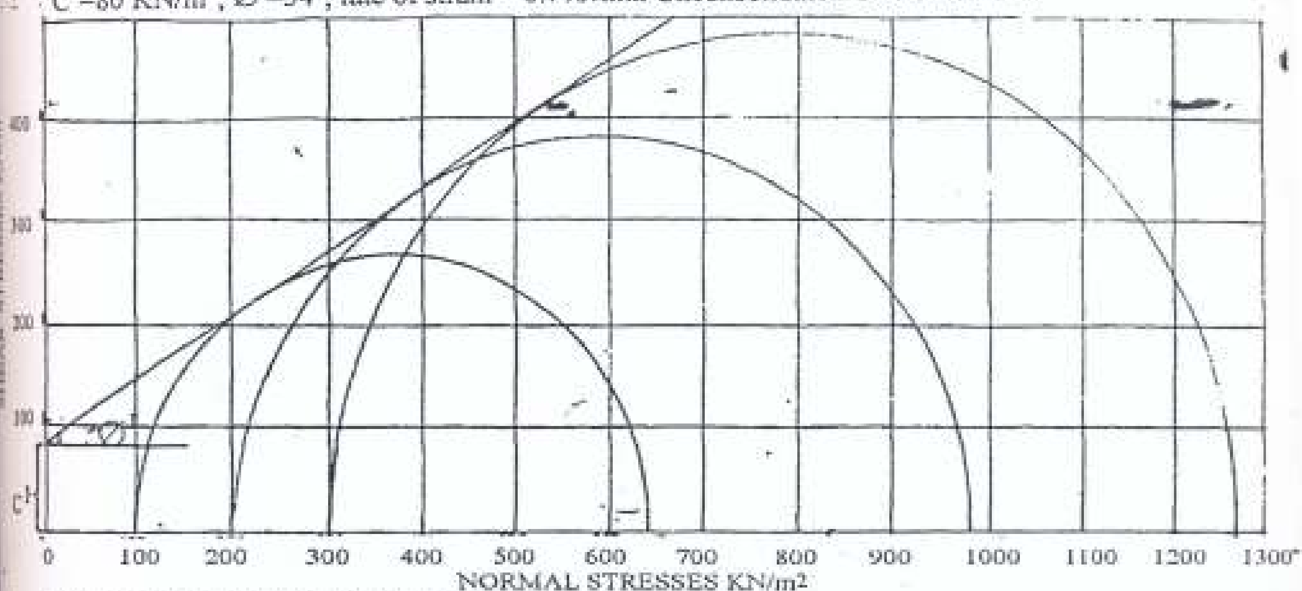


Fig. 5.6i: Showing Mohr Circles of location2, BTRS 1

C^1=125 KN/m^2, Ø^1 =27.5^0, rate of strain = 0.7% /min, Unconsolidated Undrained Test

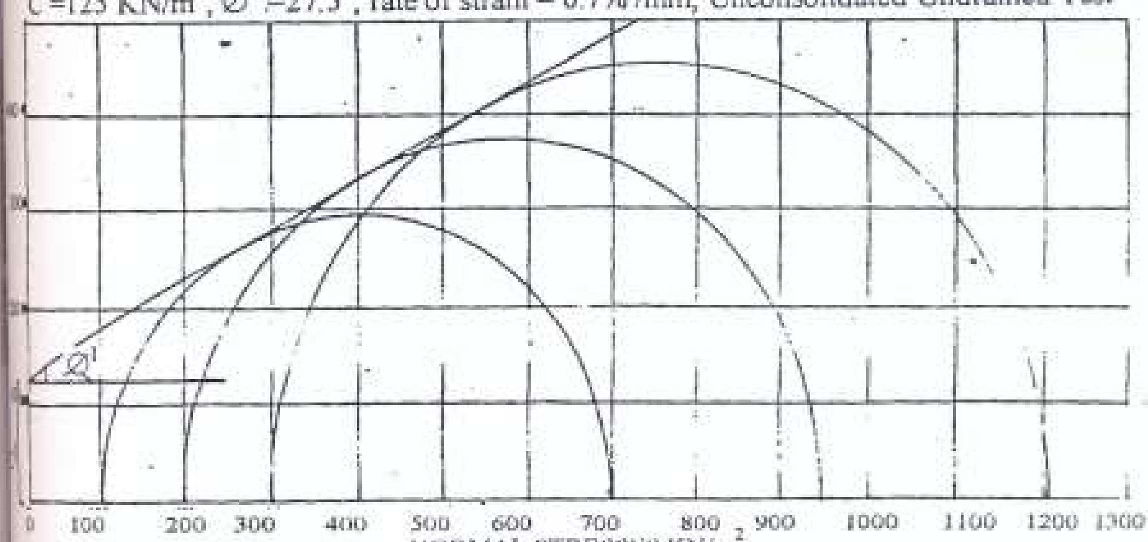


Fig. 5.6i: Showing Mohr Circles of location2, BTRS 2

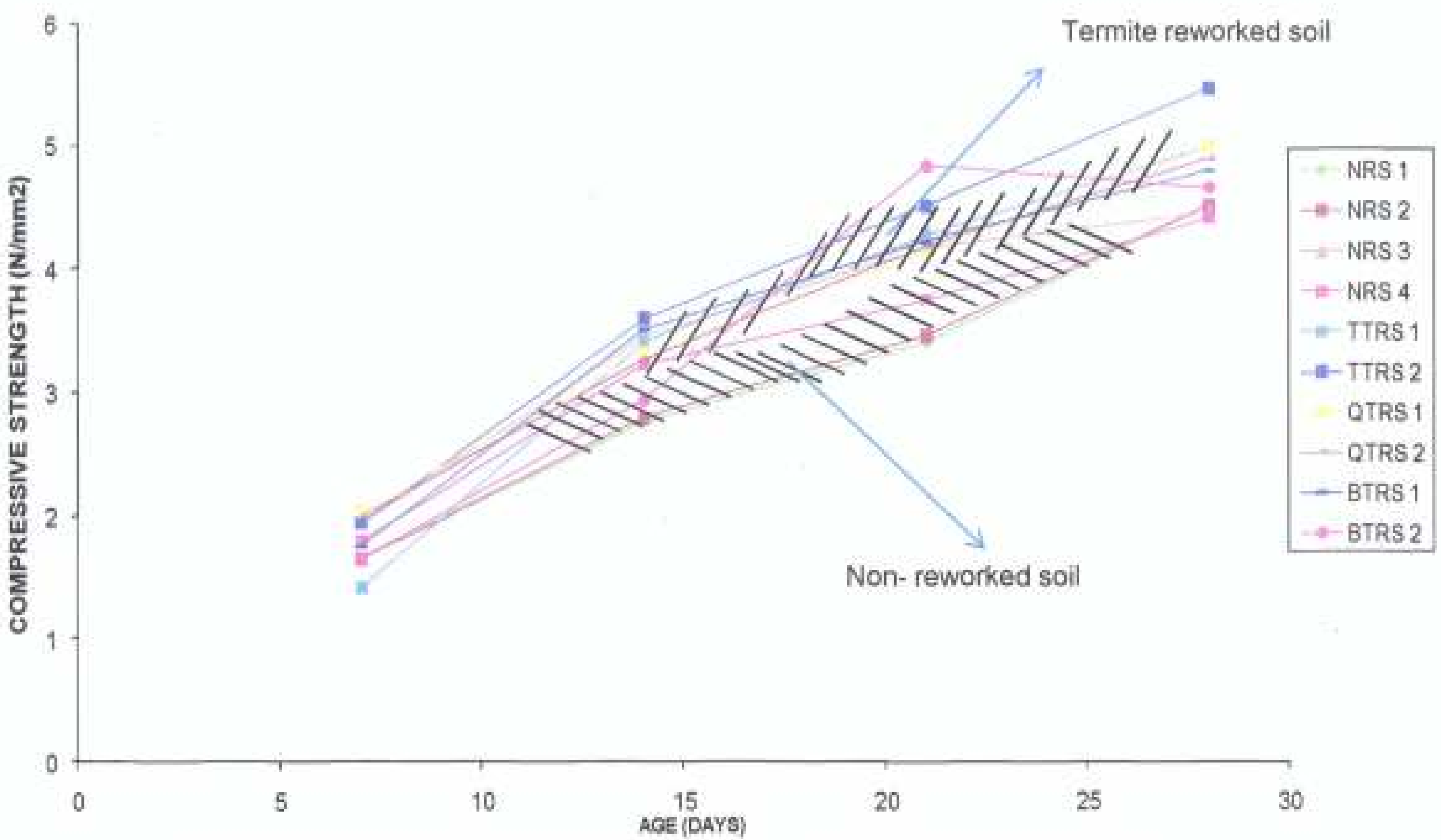


Fig. 5.7: Graph of compressive strength against age of moulded bricks for Location 1

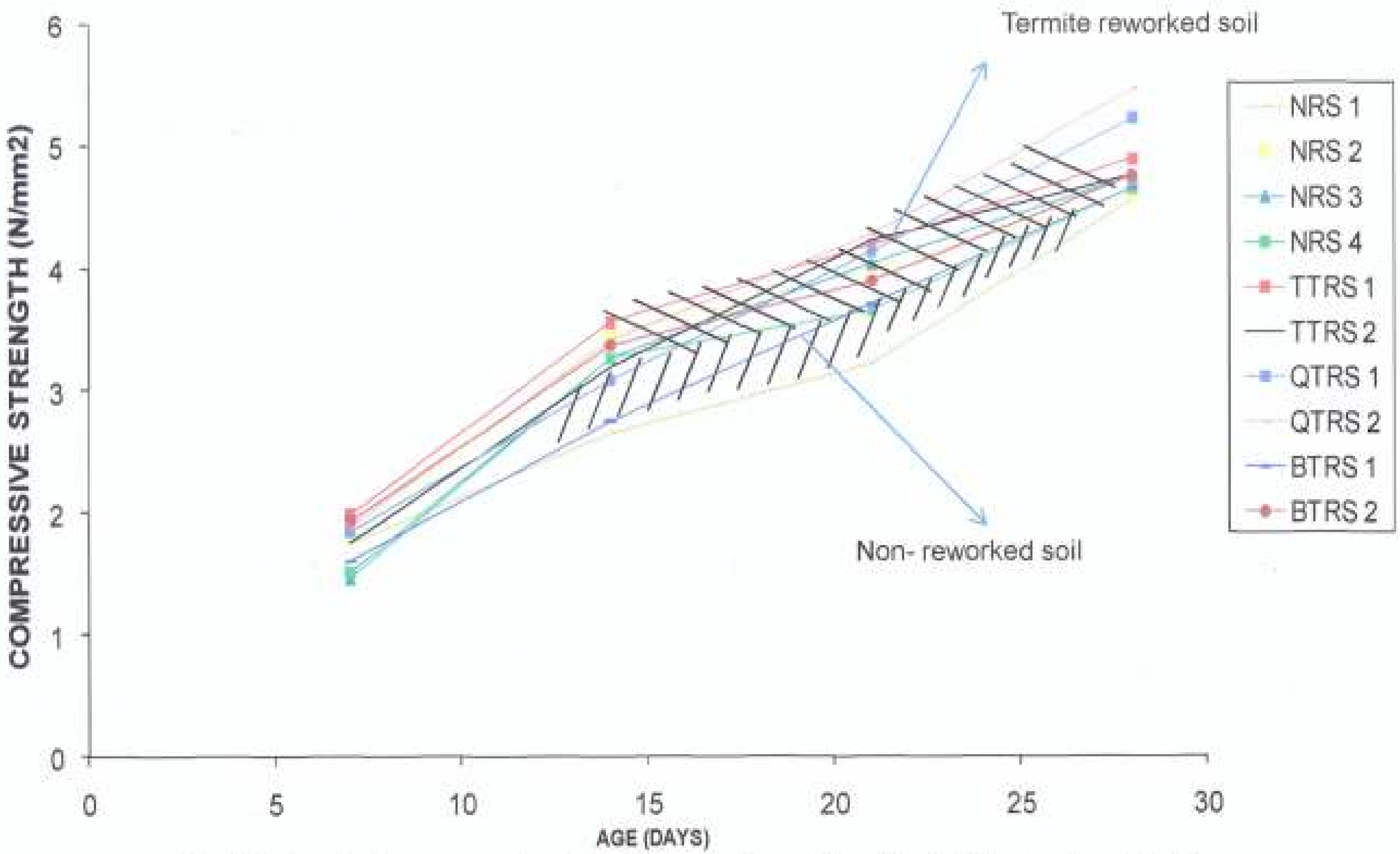


Fig. 5.8: Graph of compressive strength against age of moulded bricks for Location 2

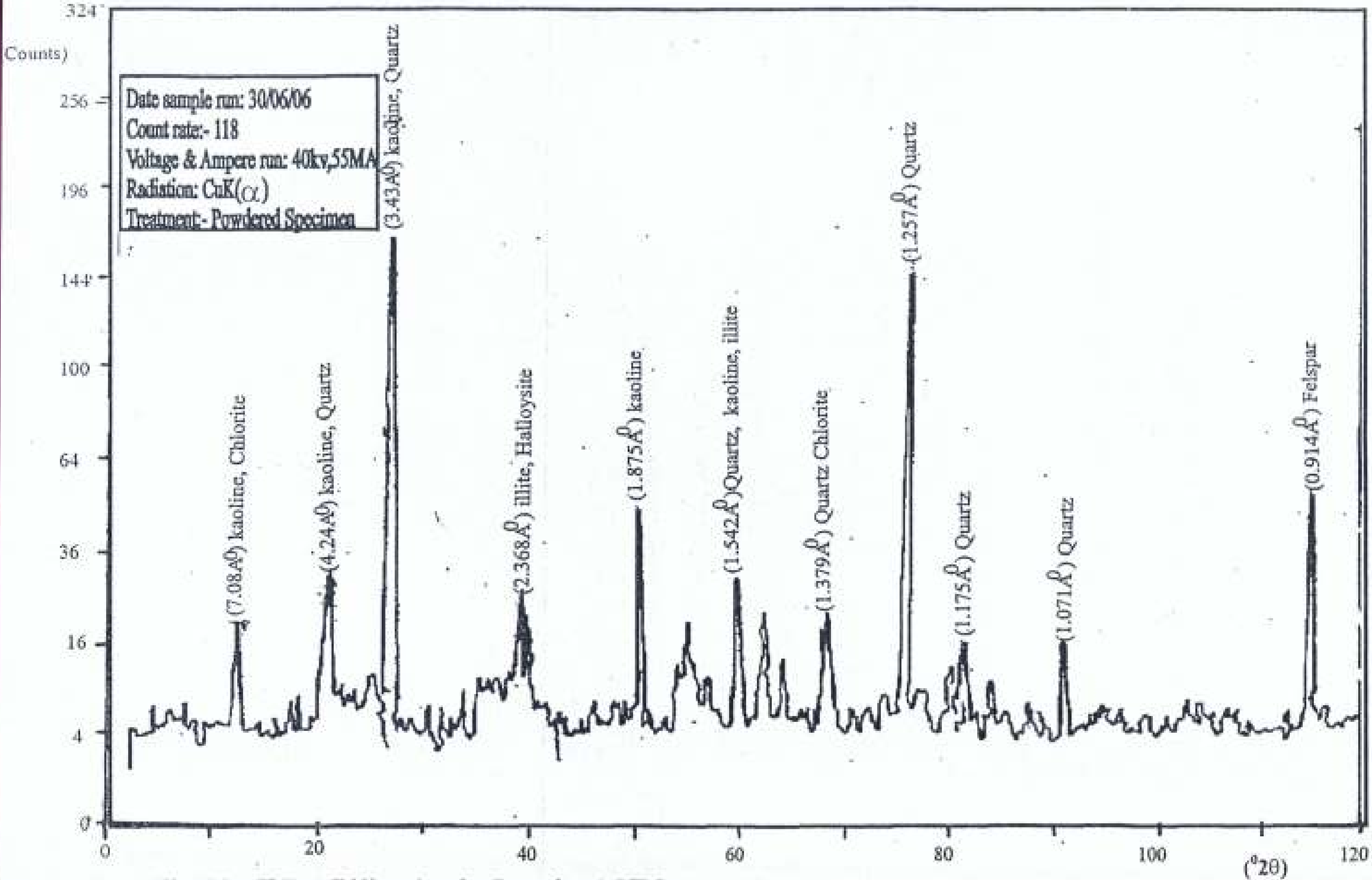


Fig. 5.9a: X-Ray Diffraction for Location 1, NRS

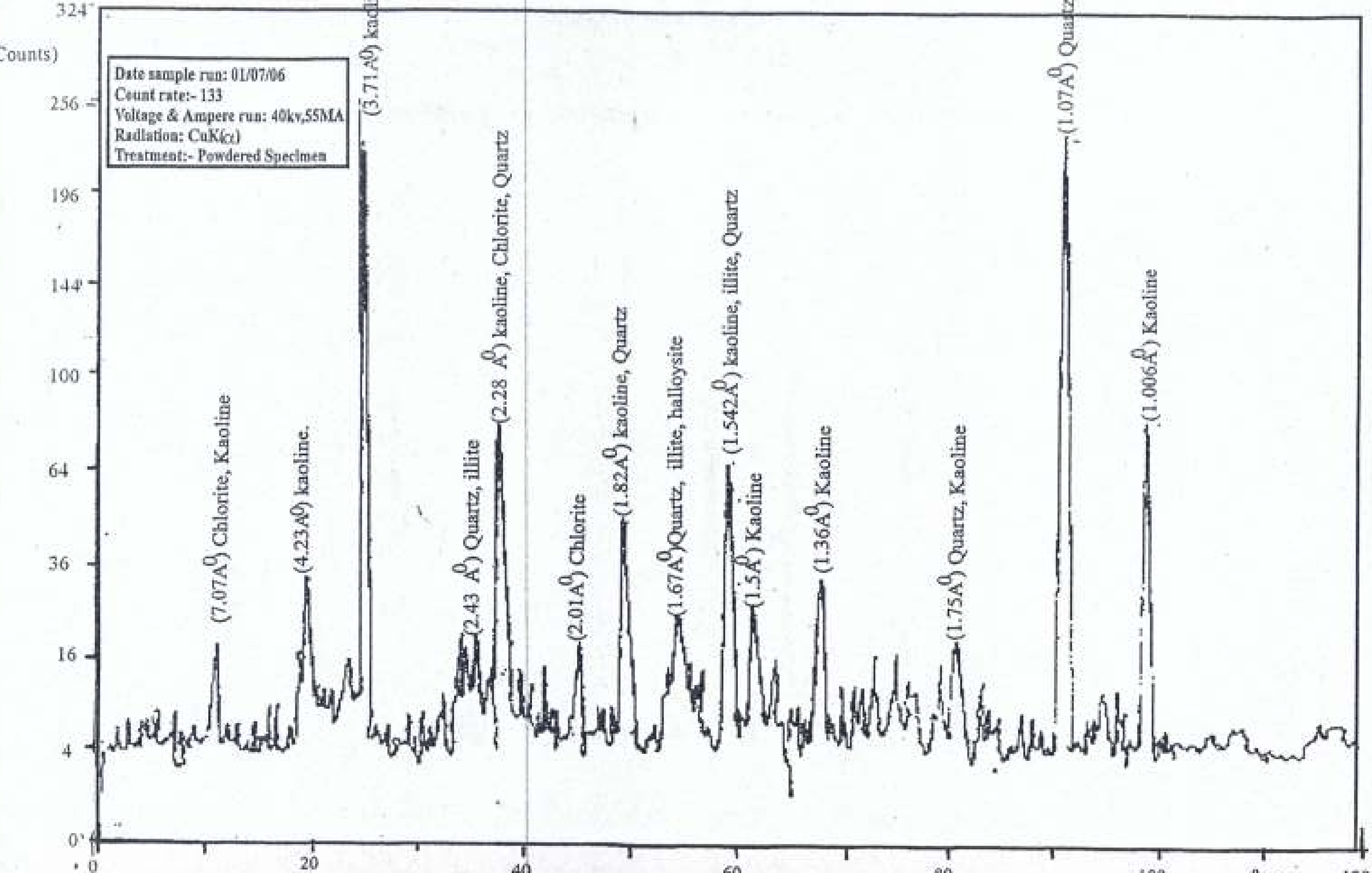


Fig. 5.9b: X-Ray Diffraction for Location 1,TRS

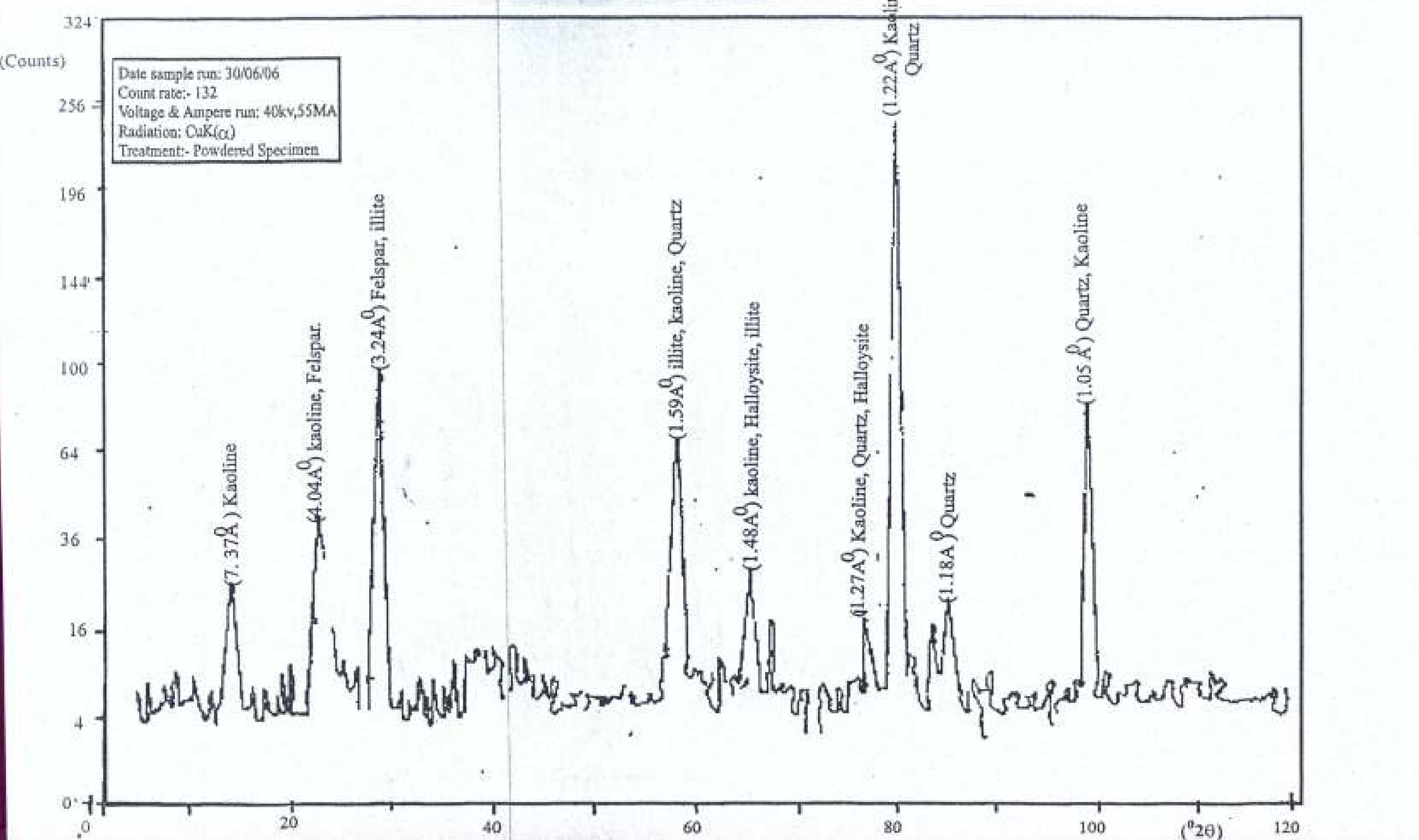


Fig. 5.10a: X-Ray Diffraction for Location 2, NRS

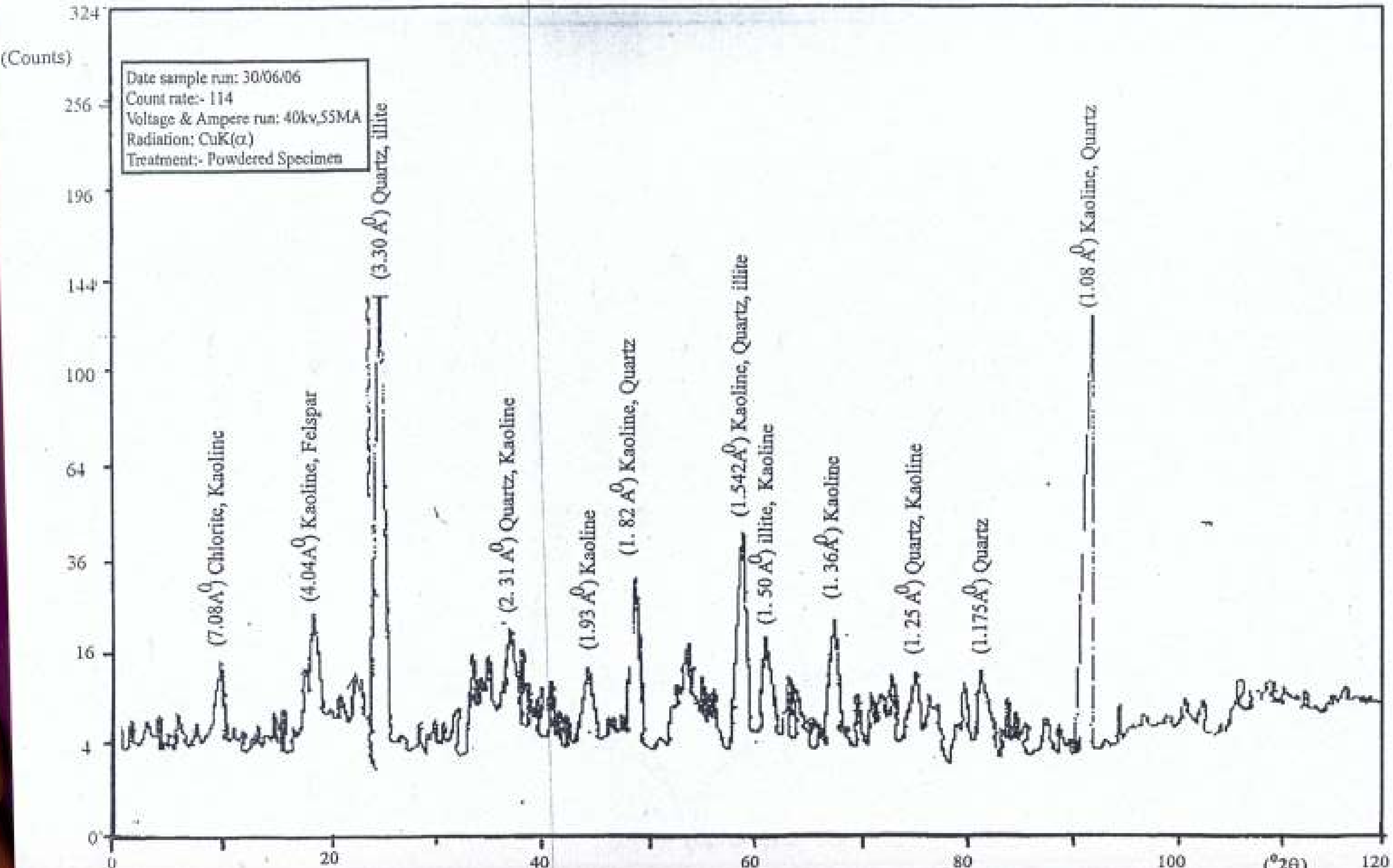
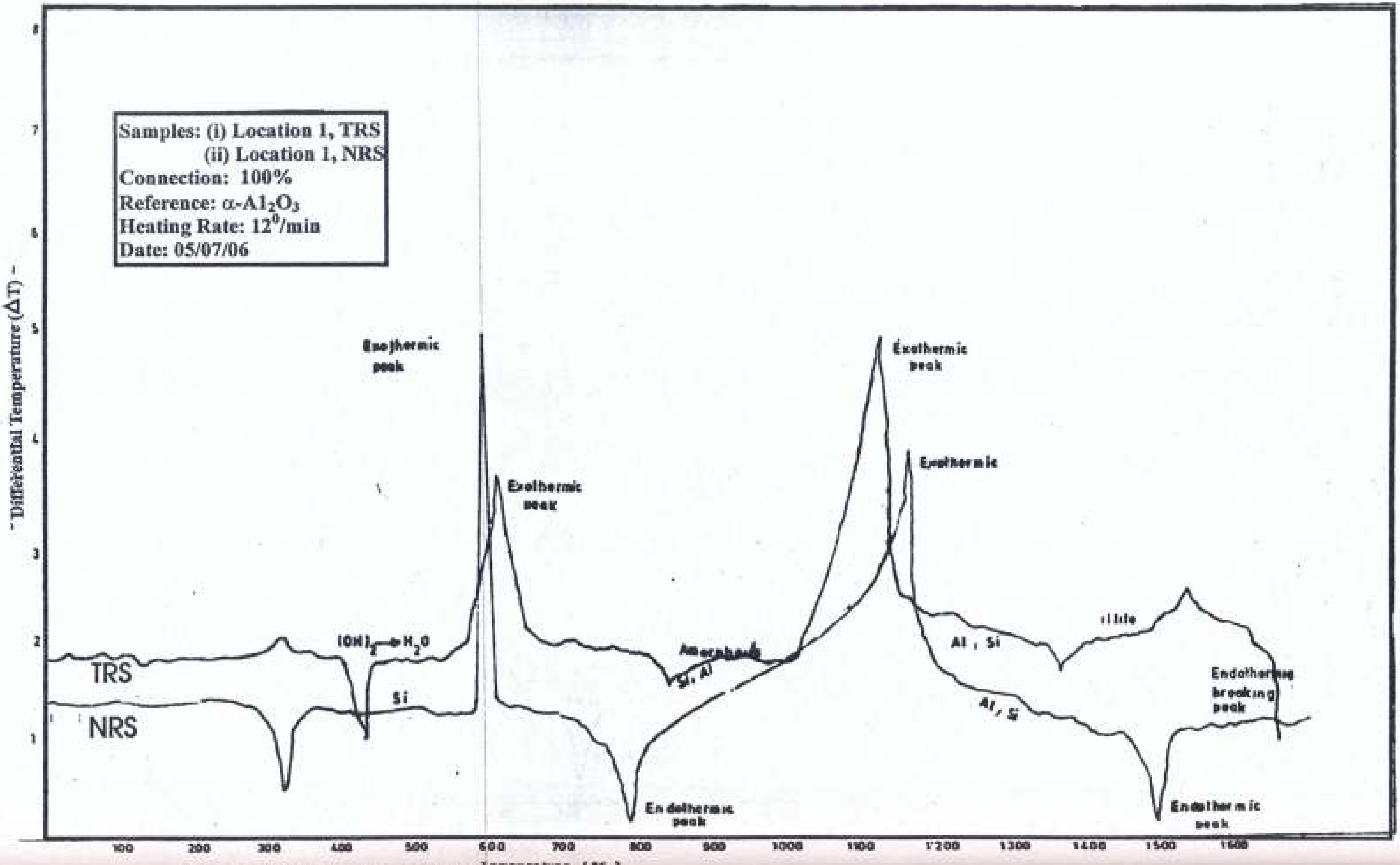


Fig. 5.10b: X-Ray Diffraction for Location 2, TRS



Samples: (i) Location 1, TRS
(ii) Location 1, NRS
Connection: 100%
Reference: α-Al₂O₃
Heating Rate: 12⁰/min
Date: 05/07/06
Differential Temperature (ΔT)
Exothermic peak
Exothermic peak
Exothermic peak
Exothermic
(OH)₂ → H₂O
Si
Amorphous
Si, Al
Al, Si
Al, Si
illite
Endothermic peak
Endothermic peak
Endothermic breaking peak
TRS
NRS
Temperature (°C)

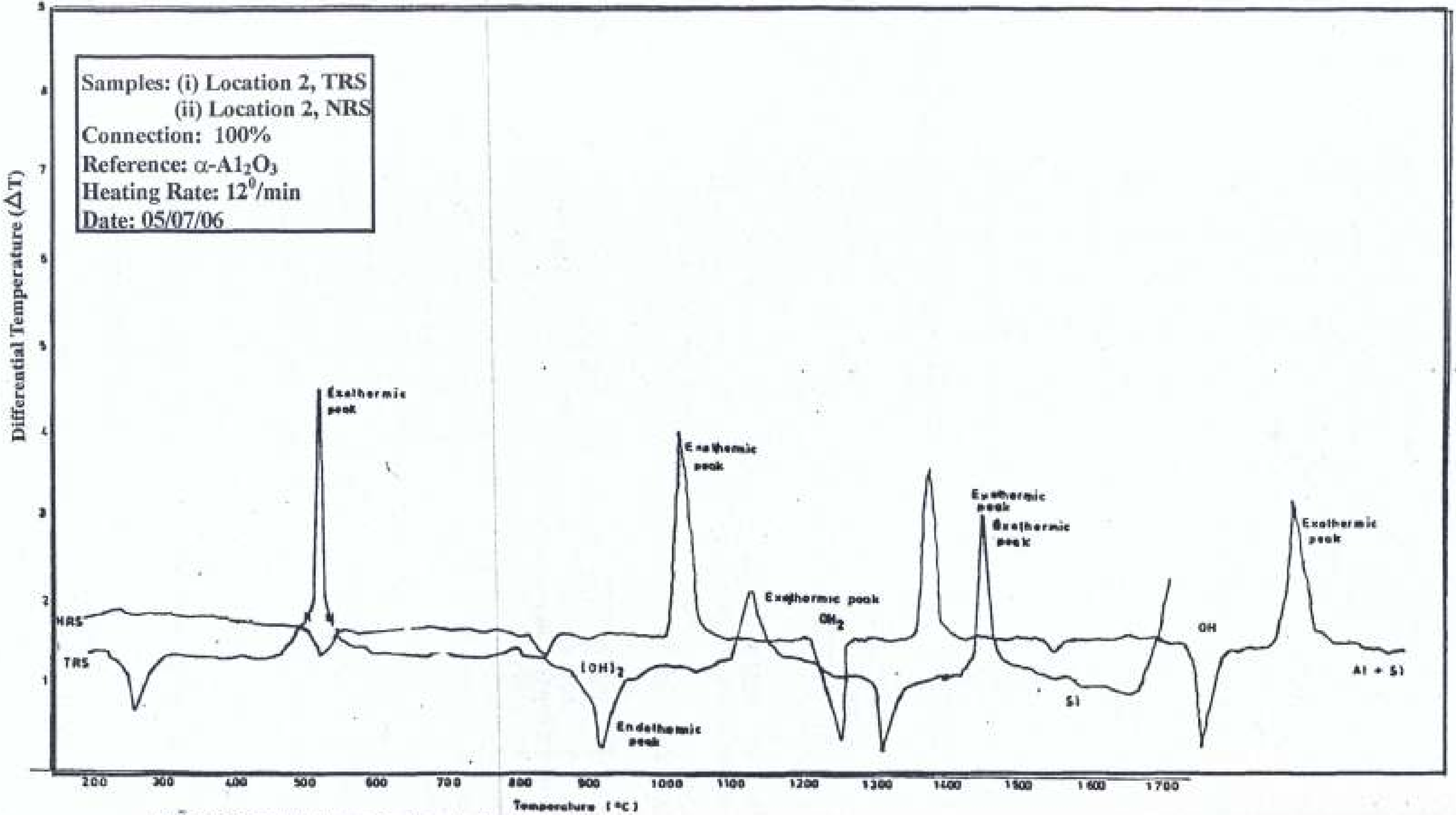


Fig 5-12 : Differential Thermal Analysis for location 2

CHAPTER SIX

STATISTICAL ANALYSIS OF STRENGTH TEST RESULTS

A statistical inference is a decision, prediction, estimate or generalization about the population based on information contained in samples selected from such population (Loveday 1969). The statistical methods used to analyse this research work are the t-test and the analysis of variance (ANOVA). The t-test is based on the assumption of a common parent variance, S^2_p, of the two samples (i.e. non reworked soils and termite reworked soils) which is estimated by:

$$S^2_p = \frac{(n_1-1)\,S^2_1+(n_2-1)\,S^2_2}{(n_1+n_2-2)}$$

Where S^2_1 and S^2_2 are the sample variances and n is the size of the samples.

Estimation of t_0 now follows where:

$$t_0 = \frac{\overline{x}_1-\overline{x}_2}{\sqrt{S^2_p\,(1/n_1+1/n_2)}}$$ and where

$\overline{x}$ is the mean

The value of t_o was therefore compared with that obtained from t-table at a significant level of 5% and from where a decision was made.

ANALYSIS OF COMPACTION TEST RESULTS

LOCATION 1

Maximum Dry Density (MDD)

(a) **Statement of Hypothesis**

$H_o : \mu_1 = \mu_2$

$H_1 : \mu_1 < u_2$

$\overline{x} = 1746.20$, $x_2 = 2148$

$S^2_1 = 13617$, $S^2_2 = 21736$

$n_1 = 4$, $n_2 = 6$

(b) **Test Statistics**

$$S^2_p = \frac{3(13617) + 5(21736)}{8}$$

$$= \frac{40851 + 108680}{8}$$

$$= 18691.375$$

$$t_0 = \frac{1746.25 - 2148}{\sqrt{18691.375\,(^1/_4 + {}^1/_6)}} = \frac{-401.75}{\sqrt{7788.073}}$$

$$= \frac{-401.75}{88.25} = -4.55$$

(c) **Significant level,** $\alpha, = 5\% = 0.05$

(d) **Critical region :-**

Reject H_o if $t_o < -t_{\alpha}, v$

$t_{\alpha}, v = t_{0.05}, 8 = 1.860$ (from t-distribution table)

$\therefore t_o = -4.55 < -1.860$

(e) **Decision**:

Since $t_0 < t_{\alpha}$, v, H_0 is rejected

Conclusion

It is therefore concluded that there is significant difference in maximum dry densities (MDD) of surrounding soils and maximum dry densities (MDD) of termite reworked soils. MDD (surrounding soil) is less than MDD (termite reworked soil)

OPTIMUM MOISTURE CONTENT (OMC)

(a) **Statement of Hypothesis**

$H_0 : \mu_1 = \mu_2$

$H_1 : \mu_1 > u_2$

$\overline{x} = 18.375$, $x_2 = 9.633$

$S^2_1 = 12.34$, $S^2_2 = 2.851$

$n_1 = 4$, $n_2 = 6$

(b) **Test Statistics**

$$S^2_p = \frac{3(12.34) + 6(2.851)}{8}$$

$$= 6.7658$$

$$t_0 = \frac{18.375\text{-}9.633}{\sqrt{6.7658\left(^1/_4 + {^1/_6}\right)}} = \frac{8.742}{\sqrt{2.819}}$$

$$= \frac{8.742}{1.679} = 5.21$$

(c) **Significant level,** α, = 5% = 0.05

(d) **Critical region**:-

Reject H_o if $t_o > t_\alpha, v$

$t_\alpha, v = t_{0.05}, 8 = 1.860$ (from t-distribution table)

$\therefore t_o = 5.21 > 1.860$

(e) **Decision**:

Since $t_0 > t_\alpha$, v, H_0 is rejected

Conclusion

There is significant difference in optimum maximum content (OMC) of the surrounding soils and that of the termite reworked soils samples. OMC (Surrounding soil) is higher than OMC (termite reworked soil).

LOCATION 2

MAXIMUM DRY DENSITY (MDD)

(a) Statement of Hypothesis

$H_o : \mu_1 = \mu_2$

$H_1 : \mu_1 < u_2$

$\overline{x}_1 = 1620$, $x_2 = 1778.33$

$S^2_1 = 600$, $S^2_2 = 1056.67$

$n_1 = 4$, $n_2 = 6$

(b) Test Statistics

$$S^2_p = \frac{3(600) + 5(1056.67)}{8}$$

$$= \frac{7083.35}{8}$$

$$= 885.42$$

$$t_0 = \frac{1620\text{-}1778.33}{\sqrt{885.42\ (^1/_4 + {}^1/_6)}} = \frac{-158.33}{\sqrt{368.925}}$$

$$= \frac{-158.33}{19.207} = -8.24$$

(c) Significant level, α, = 5% = 0.05

(d) Critical region:-

Reject H_o if $-t_o < -t_{\alpha}, v$

$t_{\alpha}, v = t_{0.05}, 8 = 1.860$ (from t-distribution table)

$\therefore t_o = -8.24 < -1.860$

(e) **Decision:**

Since $t_0 < t_{\alpha}, v$, H_0 is rejected

Conclusion

There is significant difference in the maximum dry density (MDD) of the non-reworked soils and termite reworked soil in location 2. Hence, MDD (non-reworked soil) is less than MDD (termite reworked soil)

OPTIMUM MOISTURE CONTENT (OMC)

(a) **Statement of Hypothesis**

$H_o : \mu_1 = \mu_2$

$H_1 : \mu_1 > u_2$

$\overline{x}_1 = 22.05$, $x_2 = 17.767$

$S^2_1 = 0.51$, $S^2_2 = 3.8507$

$n_1 = 4$, $n_2 = 6$

(b) **Test Statistics**

$$S^2_p = \frac{3(0.51) + 5(3.8507)}{8}$$

$$= \frac{20.7835}{8}$$

$$= 2.598$$

$$t_0 = \frac{22.05\text{-}17.767}{\sqrt{18691.375}\ (^1/_4 + {^1/_6})}$$

$$= \frac{4.283}{1.0404} \quad = 4.1165$$

(c) **Significant level,** α, = 5% = 0.05

(d) **Critical region:-**

Reject H_o if $t_o > t_{\alpha}, v$

$t_{\alpha}, v = t_{0.05,} 8 = 1.860$ (from t-distribution table)

$\therefore t_o = 4.1165 > 1.860$

(e) **Decision:**

Since $t_0 < t_{\alpha}, v$, H_0 is rejected

Conclusion

It is concluded that there is significant difference in OMC (non-reworked soil) and OMC (termite reworked soil). Hence, OMC (non reworked soil) is greater than OMC (termite reworked soil).

ANALYSIS OF CBR RESULTS

LOCATION 1

(a) **Statement of Hypothesis**

$H_o : \mu_1 = \mu_2$

$H_1 : \mu_1 < u_2$

$\overline{x}_1 = 35$, $x_2 = 52.67$

$S^2_1 = 4.5$, $S^2_2 = 87.87$

$n_1 = 4$, $n_2 = 6$

(b) **Test Statistics**

$$S^2_p = \frac{3(4.5) + 5(87.87)}{8}$$

$$= 56.61$$

$$t_0 = \frac{35-52.67}{\sqrt{56.61\,(^1/_4 + ^1/_6)}}$$

$$= -3.62$$

(c) **Significant level,** α, = 5% = 0.05

(d) **Critical region:-**

Reject H_o if $-t_o < -t_{\alpha}, v$

$\therefore t_o = -3.62 < -1.860$

(e) **Decision:**

Since $t_0 < t_{\alpha}, v$, H_0 is rejected

Conclusion

There is significant difference in the CBR of non-reworked soil and termite reworked soil. Hence CBR of termite reworked soil is higher than that of non-reworked soil.

LOCATION 2

(a) Statement of Hypothesis

$H_o : \mu_1 = \mu_2$

$H_1 : \mu_1 < u_2$

$\overline{x}_1 = 10.25$, $x_2 = 16.17$

$S^2_1 = 3.19$, $S^2_2 = 18.47$

$n_1 = 4$, $n_2 = 6$

(b) Test Statistics

$$S^2_p = \frac{3(3.19) + 5(18.47)}{8}$$

$$= 12.74$$

$$t_0 = \frac{10.24-16.17}{\sqrt{12.74\,(^1/_4 + {}^1/_6)}}$$

$$= -2.57$$

(c) Significant level, α, = 5% = 0.05

(d) Critical region:-

Reject H_o if $-t_o < -t_\alpha, v$

$t_\alpha, v = t_{0.05}, 8 = 1.860$ (from t-distribution table)

$\therefore t_o = -2.57 < -1.860$

(e) Decision:

Since $t_0 < t_\alpha, v$, H_0 is rejected

Conclusion

There is significant difference in the CBR of non-reworked soil and termite reworked soil. Hence, the CBR of termite reworked soil is higher than that of non-reworked soil.

ANALYSIS OF COMPRESSIVE STRENGTH TEST RESULTS ON MOULDED BRICKS

Analysis of variance (ANOVA) was used to analyse the result of this test because it involves analysis of both rows and columns.

LOCATION 1

Age (days)	Surrounding soil Strength (N/mm²)	Termite Reworked soil Strength (N/mm²)	Total T_i (N/mm²)
7	1.7675	1.8050	3.5725
14	3.0650	3.3520	6.4170
21	3.7100	4.3370	8.0470
28	4.4825	5.0020	9.4845
	13.0250	14.4960	27.5210

Statement of hypothesis:

$H_o : \alpha = 0$ (there is no significant difference)

$H_1 : \alpha \neq 0$ (there is significant difference)

Definitions

- Degree of freedom (Df) = n-1
- SS = Sum of squares
- MSE = Mean Square error = $\frac{SS}{Df}$
- F = f – ratio = $\frac{MSE}{MSE_{error}}$

Statistics

(a) $SS_{Tr} = \frac{\sum y^2_{i}}{b} - \frac{y^2..}{N}$ .... b = no of times when results were determined for each stream = 4.

$= \frac{(13.025)^2 + (14.496)^2}{4} - \frac{(27.521)^2}{8}$

$= 94.946 \quad - 94.676$

$= 0.27$

$Df = n-1 = 2-1 = 1$

(b) $SS_{Ti} = \frac{y^2_{i}}{a_2} - \frac{y^2..}{N}$

$= \frac{(3.5725^2+(6.417)^2+(8.047)^2+(9.4845)^2}{2} - \frac{(27.521)^2}{8}$

$= 104.325 - 94.676$

$= 9.649$

$Df = n-1 = 4-1 = 3$

(c) $SS_{Total} = y^2_{ij} - \frac{y^2...}{N}$

Where $y^2_{ij} = (1.7675)^2+(3.065)^2+(3.710)^2+(4.4825)^2+(1.805)^2+(3.352)^2+(4.337)^2+(5.002)^2$

$= 104.699$

$y^2... = \frac{(27.521)^2}{8} = 94.676$

$SS_{Total} = 104.699 - 94.676$

$= 10.023$

$Df = n-1 = 8-1 = 7$

$SS_{error} = SS_{Total} - SS_{Ti} = SS_{Tr}$

$= 10.023 - 9.649 - 0.27$

$= 0.104$

$Df_{error} = Df_{Total} - Df_{Ti} - Df_{Tr}$

$= 7-3 -1$

$= 3$

Statement of hypothesis:

$H_o : \alpha = 0$ (there is no significant difference)

$H_1 : \alpha \neq 0$ (there is significant difference)

ANOVA TABLE

Source	Df	S.S	MSE	F-ratio
Treatment	1	0.10675	0.10675	13.3438
Treatment	3	10.04895	3.34965	418.7063
Error	3	0.02410	0.0080	
Total	7	10.1798		

Critical Region:

Reject H_o if $f_{cal} > F_{\alpha,} v_1, v_2$

$f_{cal} = 13.3438$, $f_{\alpha}, v_1, v_2, = 10.13$ (from f-distribution table)

$\therefore$ 13.3438>10.13

Decision

Since $f_{cal} > f_{\alpha} v_1, v_2$, H_0 is rejected.

Conclusion

It is concluded that there is significant difference in the compressive strength of termite reworked soil and non-reworked soil. Hence, compressive strength of termite reworked soil is higher than that of non-reworked soil.

CHAPTER SEVEN

7.0 CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

Statistical treatments of the values of the determined geotechnical and geochemical parameters for termite reworked soils and the surrounding lateritic soils from the two locations in Ado-Ekiti, Southwestern Nigeria have confirmed the following:-

The specific gravity of grains of termite reworked soils are significantly higher than those of the surrounding soils. The influence of reworking by termites on the grain size distribution of the studied soils is that the amount of coarse (% coarse) of termite reworked soils are higher than that of the surrounding soils. Generally, all the studied soils have high amount of fines.

The liquid limits and plastic limits of the studied soils are generally high in both locations. Termite reworked soils from location 2 have lower plasticity indices (P.I) than those from location one. Generally, the plasticity indices of the surrounding soils are higher than that of the termite reworked soils. This fact makes termite reworked soils better for engineering purposes.

The linear shrinkage of termite reworked soils are also significantly lower than those of the surrounding soils.

The results of compaction characteristics of the studied soils showed that there was an increase in the values of the Maximum Dry Density

(MDD) with a consequent reduction in the Optimum Moisture Content (OMC) of termite reworked soils from both locations. This showed that there is an improvement in the compaction parameters of the termite reworked soils from the two locations after stabilization. It can be said that the termite reworked soils from both locations are biochemically stabilized as a result of termites activities.

The California Bearing Ratio (CBR) test indicated that there is an increase in the results of CBR values of termite reworked soils from both locations than their corresponding non reworked soils. Generally, the CBR of termite reworked soils are higher than those of the surrounding soils in both locations. Also, the triaxal compression test, which shows the shear strength parameters of soils showed that the values of cohesion (c) and angles of internal friction (Φ) for the termite reworked soils are higher than those for the surrounding soils. This indicates higher strength for termite reworked soils than the surrounding soils which makes termite reworked soils better engineering soils for estimating the bearing capacity of highway sub-grade and sub-base materials.

The result of chemical analysis also showed that Termite interaction with soil increases iron, aluminum, magnesium, potassium, manganese, zinc and phosphorus contents of the soils.

Furthermore, the compressive strength tests on moulded bricks showed that bricks made from termite reworked soils have higher strengths than those made using non reworked soils. Permeability tests showed that termite activities improve soils porosity and water infiltration into the soil.

Finally, X-ray and differential thermal analysis of the soil showed that termite reworked soils contain more kaolinite (a non-swelling clay mineral good for road construction) than the surrounding non reworked soils.

It can therefore be inferred from all the parameters studied that the engineering properties of termite reworked soils were improved upon by termites activities.

7.2 RECOMMENDATION

With the results obtained from this research work, it is recommended that termite reworked soils can be used for building of houses, construction of roads and even for agricultural purposes by mixing proportions of it with lateritic soils.

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APPENDICES

APPENDIX A

Results of Grain size and hydrometer analysis of the soils

KEY

NRS 1 – 4 :	**Non reworked soils**
TTRS 1-2 :	**termite reworked soils from top of termitarium**
QTRS 1-2 :	**Termite reworked soils from the queen of termite surrounding.**
BTRS 1-2 :	**Termite reworked soils from bottom of termitarium.**

TABLE A-1 GRAIN SIZE ANALYSIS OF THE SOILS

LOCATION 1: NRS 1 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	2.5	0.50	0.50	99.50
1.180	10.5	2.10	2.60	97.40
0.600	55.0	11.00	13.60	86.40
0.425	18.6	3.72	17.32	82.68
0.300	2.6	0.52	17.84	82.16
0.150	4.8	0.96	18.80	81.120
0.075	25.5	5.18	23.98	76.02

LOCATION 1: NRS 2 **Total wt = 500g**

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	1.0	0.20	0.20	99.80
1.180	13.5	2.70	2.90	97.10
0.600	19.8	3.98	6.86	93.14
0.425	21.5	4.30	11.16	88.84
0.300	32.5	6.50	17.66	82.34
0.150	24.3	4.86	22.52	77.48
0.075	14.0	2.80	25.32	74.68

LOCATION 1 NRS 3 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0.6	0.12	0.12	99.88
2.360	3.0	0.60	0.72	99.28
1.180	30.5	6.10	6.82	93.18
0.600	88.1	17.62	24.44	75.56
0.425	49.4	9.88	34.32	65.68
0.300	0	0	34.32	65.68
0.150	7.2	1.44	35.76	64.24
0.075	59.2	11.84	47.60	52.40

LOCATION 1 NRS 4 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	7.8	1.56	1.56	98.44
1.180	2.8	5.60	7.16	92.84
0.600	6.5	13.00	20.16	79.84
0.425	5.5	11.00	31.16	68.84
0.300	15.6	3.12	34.28	65.72
0.150	18.7	3.74	38.02	61.98
0.075	57.8	11.56	49.58	50.42

LOCATION 1 TTRS 1 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0.3	0.06	0.06	99.94
2.360	8.8	1.76	1.82	98.18
1.180	4.0	0.80	2.62	97.38
0.600	16.4	3.28	5.90	94.10
0.425	0	0	5.90	94.10
0.300	0	0	5.90	94.10
0.150	11.9	2.38	8.28	91.72
0.075		8.28	16.56	83.44

LOCATION 1 TTRS 2 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	8	1.6	1.6	98.4
2.360	35	7.0	8.6	91.4
1.180	42	8.4	17	83.0
0.600	55	11.0	28	72.0
0.425	61	12.2	40.2	59.8
0.300	73	14.6	54.8	45.2
0.150	81	16.2	71	29.0
0.075	71	14.2	85.2	14.8

LOCATION 1 QTRS 1 **Total wt = 500g**

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	10.0	2.00	2.00	98.00
2.360	5.7	1.14	3.14	96.86
1.180	6.2	1.24	4.38	95.62
0.600	15.8	3.16	7.54	92.46
0.425	17.5	3.50	11.04	88.96
0.300	27.0	5.40	16.44	83.56
0.150	9.0	1.80	18.24	81.24
0.075	29.6	5.92	24.16	75.16

LOCATION 1: QTRS 2 **Total wt = 500g**

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	19	3.8	3.8	96.2
1.180	35	7.0	10.8	89.2
0.600	24	4.8	15.6	84.4
0.425	45	9.0	24.6	75.4
0.300	73	14.6	39.2	60.8
0.150	55	11.0	50.2	49.8
0.075	48	9.6	59.8	40.2

LOCATION 1 BTRS 1 **Total wt = 500g**

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0.7	0.14	0.14	99.86
2.360	2.7	0.54	0.68	99.32
1.180	24.1	4.82	5.50	94.50
0.600	94.0	18.80	24.30	75.70
0.425	62.2	12.44	36.74	63.26
0.300	0	0	36.74	63.26
0.150	0.2	0.04	36.78	63.22
0.075	75.8	15.16	51.94	48.06

LOCATION 1 BTRS 2 **Total wt = 500g**

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100
2.360	21	4.2	4.2	95.8
1.180	50	10.0	14.2	85.8
0.600	27	5.4	19.6	80.4
0.425	56	11.2	30.8	69.2
0.300	85	17.0	47.8	52.5
0.150	65	13.0	50.8	39.5
0.075	41	8.2	59.0	31.3

LOCATION 2: NRS 1 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	4.5	0.90	0.90	99.10
4.750	4.6	0.92	1.82	98.18
2.360	7.7	1.54	3.36	96.64
1.180	16.0	3.20	6.56	93.44
0.600	25.0	5.00	11.56	88.44
0.425	7.3	1.46	13.02	86.98
0.300	15.3	3.06	16.08	83.92
0.150	20.8	4.16	20.24	76.76
0.075	18.5	3.70	23.94	76.06

LOCATION 2: NRS 2 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	2.6	0.52	0.52	99.48
4.750	5.8	1.16	1.68	98.32
2.360	8.9	1.78	3.46	96.54
1.180	18.3	3.66	7.12	92.88
0.600	27.0	5.40	12.52	87.48
0.425	9.2	1.84	14.36	85.64
0.300	15.8	3.16	17.52	82.48
0.150	22.8	4.56	22.08	77.92
0.075	20.6	4.12	26.20	73.80

LOCATION 2 NRS 3 **Total wt = 500g**

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	1.4	0.28	0.28	99.72
2.360	3.6	0.72	1.06	99.00
1.180	32.8	6.56	33.86	92.44
0.600	80.7	16.14	50.00	76.30
0.425	45.3	9.06	59.06	67.24
0.300	2.5	0.50	59.56	66.74
0.150	10.0	2.00	61.56	64.74
0.075	65.4	13.08	74.64	51.66

LOCATION 2 NRS 4 **Total wt = 500g**

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	10.6	2.12	2.12	97.88
1.180	25.0	5.00	7.12	92.88
0.600	58.0	11.60	18.72	81.28
0.425	65.0	13.00	31.72	68.28
0.300	18.5	3.70	35.42	64.54
0.150	20.4	4.08	39.50	60.50
0.075	49.9	9.80	49.30	50.70

LOCATION 2: TTRS 1 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	1.8	0.36	0.36	99.94
1.180	3.5	0.70	1.06	98.94
0.600	26.8	5.36	6.42	93.58
0.425	85.0	17.00	23.42	76.58
0.300	65.0	13.00	36.42	63.58
0.150	1.4	0.28	36.70	63.30
0.075	72.9	14.58	51.28	48.72

LOCATION 2 TTRS 2 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	22	4.4	4.4	95.6
1.180	31	6.2	10.6	89.4
0.600	45	9.0	19.6	80.4
0.425	71	14.2	33.8	66.2
0.300	82	16.4	50.2	49.8
0.150	55	11.0	61.2	38.8
0.075	63	12.6	73.8	26.2

LOCATION 2: QTRS 1 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	18	3.6	3.6	96.4
2.360	27	5.4	9.0	91.0
1.180	55	11.0	20.0	80.0
0.600	42	8.4	28.4	71.6
0.425	38	7.6	36.0	64.0
0.300	73	14.6	50.6	49.4
0.150	65	13.0	63.6	36.4
0.075	41	15.0	78.6	21.4

LOCATION 2: QTRS 2 Total wt = 500g

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	26	5.2	5.2	94.8
1.180	35	7.0	12.2	87.8
0.600	43	8.67	20.8	79.2
0.425	59	11.8	32.6	67.4
0.300	62	12.4	45.0	55.0
0.150	38	7.6	52.6	47.4
0.075	45	9.0	61.6	38.4

LOCATION 2: BTRS 1 **Total wt = 500g**

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	14.5	2.9	2.9	97.1
1.180	29	5.8	8.7	91.3
0.600	35	7.0	15.7	84.3
0.425	24	4.8	20.5	79.5
0.300	65	13.0	33.5	66.5
0.150	82	16.4	49.9	50.1
0.075	57	11.4	61.3	38.7

LOCATION 2: BTRS 2 **Total wt = 500g**

Sieve Opening (mm)	*Wt. Soil Retained (g)*	*% Retained (g)*	*Cum. % Retained*	*% Finer*
9.500	0	0	0	100.0
4.750	0	0	0	100.0
2.360	45	9	9	91
1.180	23	4.6	13.6	86.4
0.600	35	7	20.6	79.4
0.425	28	5.6	26.2	73.8
0.300	95	19	45.2	54.8
0.150	62	12.4	57.2	42.4
0.075	55	2.48	60.1	39.92

TABLE A-2 HYDROMETER ANALYSIS OF THE SOILS

LOCATION 1 NRS 1

Time (min)	Temp °c	Hydrometer Reading (Rh)	Ra (Rh + 0.5)	H(mm) 220-4.1Ra	D K √H./t	Corrected Hydrometer Reading Rc Rh – 1.7	N% (2Gs/Gs-1) Rc	N' N% x % Passing
0.5	25	31.0	31.5	90.85	0.00634	29.3	109.56	83.28
1	25	30.5	31.0	92.90	0.00602	28.8	107.69	81.86
2	25	30.0	30.5	94.95	0.00430	28.3	106.82	80.44
4	25	29.5	30.0	97.00	0.00308	27.8	103.95	79.02
8	25	28.5	29.0	101.10	0.00292	26.8	100.21	76.18
15	25	27.5	28.0	105.20	0.00165	25.8	96.47	73.34
30	25	26.0	26.5	111.35	0.00120	24.3	90.86	69.07
60	25	25.0	25.5	115.45	0.00087	23.3	87.12	66.23
120	25	24.0	24.5	119.55	0.00062	22.3	83.38	63.39
180	25	21.5	22.0	129.80	0.00053	19.8	74.03	56.28
1440	25	16.5	17.0	150.30	0.00020	14.8	55.34	42.07
1620	25	15.5	16.0	154.70	0.00019	13.8	51.60	39.23
1800	25	11.0	11.5	1721.82	0.00019	9.3	34.77	26.43

Gs = 2.65
K = 0.0153

LOCATION 1 NRS 2

Time (min)	Temp °c	Hydrometer Reading (Rh)	Ra (Rh + 0.5)	H(mm) 220-4.1Ra	D K √H./t	Corrected Hydrometer Reading Rc Rh – 1.7	N% (2Gs/Gs-1) Rc	N' N% x % Passing
0.5	25	30.5	31.0	92.90	0.00935	28.8		
1	25	30.5	31.0	92.90	0.00661	28.8		
2	25	30.0	30.5	94.95	0.00473	28.3		
4	25	29.5	30.0	97.00	0.00338	27.8		
8	25	29.0	29.5	99.05	0.00241	27.3		
15	25	28.0	28.5	103.15	0.00180	26.3		
30	25	27.0	27.5	107.25	0.00130	25.3		
60	25	26.0	26.5	111.35	0.00093	24.3		
120	25	24.5	25.0	117.50	0.00068	22.8	95.59	71.39
180	25	24.0	24.5	119.55	0.00056	22.3	91.54	68.36
1440	25	20.5	21.0	133.90	0.00021	18.8	77.17	57.63
1620	25	17.5	18.0	146.20	0.00021	15.8	64.86	48.44
1800	25	17.0	17.5	148.25	0.00019	15.3	62.81	46.90

Gs = 2.71
K = 0.0168

LOCATION 1 NRS 3

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	31.0	31.5	90.85	0.00925	29.3		
1	25	31.0	31.5	90.85	0.00654	29.3		
2	25	31.0	31.5	90.85	0.00462	29.3		
4	25	31.0	31.5	90.85	0.00327	29.3		
8	25	30.5	31.0	92.90	0.00234	28.8		
15	25	30.5	31.0	92.90	0.00171	28.8		
30	25	30.0	30.5	90.85	0.00119	28.3		
60	25	29.5	30.0	97.00	0.00087	27.8		
120	25	29.0	29.5	99.05	0.00062	27.3		
180	25	28.0	28.5	-103.15	0.00052	26.3		
1440	25	26.5	27.0	109.30	0.00019	24.8		
1620	25	26.0	26.5	111.35	0.00018	24.3	99.75	52.27
1800	25	26.0	26.5	111.35	0.00017	24.3	99.75	52.27

Gs = 2.76
K = 0.0168

LOCATION 1 NRS 4

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	30.0	30.5	94.95	0.00951	28.3		
1	25	29.5	30.0	97.00	0.00680	27.8		
2	25	28.5	29.0	101.10	0.00491	26.8		
4	25	27.5	28.0	105.20	0.00354	25.8		
8	25	26.5	27.0	109.30	0.00225	24.8		
15	25	25.5	26.0	113.40	0.00190	23.8	98.22	49.52
30	25	24.5	25.0	117.50	0.00137	22.8	94.10	47.44
60	25	23.5	24.0	121.60	0.00098	21.8	89.97	45.36
120	25	22.0	22.5	127.75	0.00071	20.3	83.78	42.24
180	25	21.5	22.0	129.80	0.00059	19.8	81.71	41.20
1440	25	18.5	19.0	142.10	0.00022	16.8	69.33	34.96
1620	25	17.5	18.0	146.20	0.00021	15.8	65.21	32.88
1800	25	17.0	17.5	148.25	0.00020	15.3	63.14	31.84

Gs = 2.70
K = 0.0169

LOCATION 1: TTRS 1

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	29.5	30	97.00	1.45×10^{-3}	27.8	91.5	76.35
1	25	29.0	29.5	99.05	1.64×10^{-3}	27.3	89.8	74.93
2	25	28.5	29	101.10	1.66×10^{-3}	26.8	88.2	73.59
4	25	28.0	28.5	103.15	2.38×10^{-3}	26.3	86.5	72.18
8	25	27.5	2.8	105.20	1.07×10^{-3}	25.8	84.9	70.84
15	25	27.0	27.5	107.25	1.72×10^{-3}	25.3	83.2	69.42
30	25	26.0	26.5	111.35	9.57×10^{-3}	24.3	79.9	66.67
60	25	25.0	25.5	115.45	1.38×10^{-2}	23.3	76.6	63.92
120	25	23.0	23.5	123.65	2.02×10^{-2}	21.3	70.1	58.49
180	25	20.0	20.5	135.95	1.93×10^{-3}	18.3	60.2	50.23
1440	25	17.0	17.5	148.25	7.66×10^{-2}	15.3	50.3	41.97
1620	25	14./0	14.5	160.55	8.44×10^{-2}	12.3	40.5	33.79
1800	25	11.0	11.5	172.85	2.174×10^{-2}	9.3	30.6	25.53

Gs = 2.76
K = 0.0133

LOCATION 1: TTRS 2

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	30.0	30.5	94.95	1.14×10^{-3}	28.3	91.4	13.53
1	25	29.5	30	97.00	1.63×10^{-3}	27.8	89.7	13.28
2	25	28.5	29	101.10	2.35×10^{-3}	26.8	86.56	12.81
4	25	28.0	28.5	103.15	3.36×10^{-3}	26.3	85.0	12.58
8	25	27.0	27.5	107.25	4.85×10^{-3}	25.3	81.7	12.09
15	25	26.0	26.5	111.35	6.77×10^{-3}	24.3	78.5	11.62
30	25	23.0	23.5	123.65	1.01×10^{-2}	21.3	68.8	10.18
60	25	20.0	20.5	135.95	1.49×10^{2}	18.3	59.1	08.75
120	25	18.0	18.5	144.15	2.18×10^{2}	16.3	52.6	
180	25	16.0	16.5	152.35	2.74×10^{2}	14.3	46.2	
1440	25	13.0	13.5	164.65	6.51×10^{3}	11.3	36.5	
1620	25	10.0	10.5	176.95	7.86×10^{3}	8.3	26.8	
1800	25	07.0	07.5	189.25	9.18×10^{2}	5.3	17.1	

Gs = 2.74
K = 0.0135

LOCATION 1: QTRS 1

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	29.0	29.5	99.05	0.00661	26.8	80.13	60.23
1	25	28.0	28.5	103.15	0.00477	26.3	78.64	59.11
2	25	27.5	28.0	105.20	0.00340	25.8	77.14	57.98
4	25	26.0	26.5	111.35	0.00248	24.3	72.66	54.61
8	25	25.5	26.0	113.40	0.00117	23.8	71.16	53.48
15	25	25.0	25.5	115.45	0.00130	23.3	69.67	52.3
30	25	23.0	23.5	123.65	0.00095	21.3	63.69	
60	25	21.5	22.0	129.80	0.00069	19.8	59.20	
120	25	21.0	21.5	131.85	0.00049	19.3	57.71	
180	25	20.5	21.0	133.90	0.00040	18.8	56.21	
1440	25	18.0	18.5	144.15	0.00015	16.3	48.74	
1620	25	16.5	17.0	150.30	0.00014	14.8	44.25	
1800	25	16.0	16.5	152.135	0.00014	14.3	42.76	

Gs = 3.02
K = 0.0115

LOCATION 1: QTRS 2

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	28	28.5	103.15	0.00118	26.3	85.5	34.37
1	25	27.5	28	105.20	0.00215	25.8	83.19	33.44
2	25	27.0	27.5	107.25	0.00243	25.3	82.2	33.04
4	25	26.0	26.5	111.35	0.00349	24.3	78.9	31.72
8	25	25.0	25.5	115.45	0.00503	23.3	73.7	29.63
15	25	24.0	24.5	119.55	0.00701	22.3	72.5	29.15
30	25	22.0	22.5	127.75	0.01055	20.3	65.9	
60	25	20.5	20.5	135.95	0.01496	18.3	59.5	
120	25	18.5	18.5	144.15	0.02179	16.3	52.9	
180	25	16.0	16.5	152.35	0.02736	14.3	46.48	
1440	25	14.0	14.5	160.55	0.07965	12.3	39.9	
1620	25	12.0	12.5	165.75	0.00750	10.3	33.5	
1800	25	10.0	10.5	176.95	0.00874	8.3	26.9	

Gs = 2.81
K = 0.0131

LOCATION 1: BTRS 1

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	29.0	29.5	99.05	0.00117	27.7	89.5	43.01
1	25	28.5	29	101.10	0.00167	26.8	86.6	41.62
2	25	28.0	28.5	103.15	0.00237	26.3	84.9	40.80
4	25	27.0	27.5	107.25	0.00341	25.3	81.7	39.27
8	25	26.5	27	109.30	0.00489	24.8	80.1	38.50
15	25	25.5	26	113.40	0.00683	23.8	76.8	36.91
30	25	25.0	25.5	115.45	0.00975	23.3	75.3	
60	25	24.0	24.5	119.55	0.01403	22.3	72.0	
120	25	23.0	23.5	123.65	0.02018	21.3	68.8	
180	25	22.0	22.5	127.75	0.02568	20.3	65.6	
1440	25	18.0	18.5	144.15	0.07547	16.3	52.6	
1620	25	15.0	15.5	156.45	0.00695	13.3	42.9	
1800	25	12.0	12.5	168.75	0.00833	10.3	33.3	

Gs = 2.83
K = 0.0135

LOCATION 1: BTRS 2

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	25.5	26.0	113.40	0.00953	23.8	90.44	28.31
1	25	24.5	25.0	117.50	0.00686	22.8	88.64	27.74
2	25	23.0	23.5	123.65	0.00498	21.3	80.94	25.33
4	25	22.5	23.0	125.75	0.00355	20.8	79.04	24.74
8	25	22.0	22.5	127.75	0.00253	20.3	77.14	24.14
15	25	21.5	22.0	129.80	0.00186	19.8	75.24	23.55
30	25	21.0	21.5	131.85	0.00133	19.3	73.34	
60	25	20.5	21.0	133.90	0.00095	18.8	71.44	
120	25	20.5	21.0	133.90	0.00067	18.8	71.44	
180	25	19.5	20.0	138.00	0.00055	17.8	67.64	
1440	25	19.0	19.5	140.05	0.00020	17.3	65.74	
1620	25							
1800	25							

Gs = 2.80
K = 0.015

LOCATION 2: NRS 1

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H.L/t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	28.0	28.5	103.15	0.01155	26.3		
1	25	27.5	28.0	105.2	0.00825	25.8		
2	25	27.0	27.5	107.25	0.00589	25.3		
4	25	26.0	26.5	111.35	0.00424	24.3		
8	25	25.5	26.0	113.40	0.00303	23.8		
15	25	24.0	24.5	119.55	0.00227	22.3		
30	25	23.0	23.5	123.65	0.00163	21.3		
60	25	21.5	22.0	129.80	0.00118	19.8		
120	25	20.5	21.0	133.90	0.00085	18.8	92.12	70.07
180	25	19.0	19.5	140.05	0.00071	17.3	84.71	64.48
1440	25	18.5	19.0	142.10	0.00025	16.8	82.32	62.61
1620	25							
1800	25							

Gs = 2.75
K = 0.0197

LOCATION 2: NRS 2

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H.L/t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	30.0	30.5	94.95	0.00821	28.3		
1	25	30.0	30.5	94.95	0.00581	28.3		
2	25	29.5	30.0	97.00	0.00415	27.8		
4	25	29.5	29.5	99.05	0.00300	27.3		
8	25	28.5	29.0	101.10	0.00212	26.8		
15	25	28.0	28.5	103.15	0.00156	26.3	96.13	70.94
30	25	27.5	28.0	105.20	0.00112	25.8	92.54	68.29
60	25	27.0	27.5	107.20	0.00080	25.3	90.75	66.97
120	25	26.5	27.0	109.30	0.00057	24.8	88.96	65.65
180	25	25.5	26.0	113.40	0.00047	23.8	85.37	63.00
1440	25	24.5	25.0	117.50	0.00020	22.8	81.78	60.35
1620	25	22.5	23.0	125.70	0.00017	20.8	74.61	
1800	25	20.5	21.0	133.90	0.00016	18.8	67.44	

Gs = 2.72
K = 0.0146

LOCATION 2: NRS 3

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K $\sqrt{H/t}$*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	31.0	31.5	90.85	0.00885	29.3		
1	25	31.0	31.5	90.85	0.00626	29.3		
2	25	30.5	31.0	92.90	0.00448	28.8		
4	25	30.5	31.0	92.90	0.00317	28.8		
8	25	30.5	31.0	92.90	0.00224	28.8		
15	25	30.0	30.5	94.95	0.00165	28.3		
30	25	29.5	30.0	97.00	0.00118	27.8		
60	25	29.0	29.5	99.05	0.00084	27.3		
120	25	27.5	28.0	105.20	0.00062	25.8		
180	25	25.0	25.5	115.45	0.00053	23.3	91.80	47.42
1440	25	23.5	24.0	121.60	0.00019	21.8	85.89	44.37
1620	25	21.5	27.0	129.80	0.00019	19.8	78.01	40.30
1800	25	21.0	21.5	131.85	0.00018	19.3	76.01	39.28

Gs = 2.79
K = 0.0161

LOCATION 2: NRS 4

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K $\sqrt{H/t}$*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	33.0	33.5	82.65	0.00845	31.3		
1	25	32.5	33.0	84.70	0.00603	30.8		
2	25	31.5	32.0	88.80	0.00338	29.8		
4	25	31.0	31.5	90.85	0.00312	29.3		
8	25	31.0	31.5	90.85	0.00221	29.3		
15	25	30.0	30.5	94.95	0.00165	28.3		
30	25	29.5	30.0	97.00	0.00118	27.8		
60	25	28.5	29.0	101.10	0.00085	26.8		
120	25	27.5	28.0	105.20	0.00062	25.8		
180	25	26.5	27.0	109.30	0.00051	24.8	97.22	49.29
1440	25	25.0	25.5	115.45	0.00019	23.3	91.34	46.31
1620	25	24.5	25.0	117.50	0.00018	22.8	89.28	45.31
1800	25	24.0	24.5	119.55	0.00018	22.3	87.42	44.32

Gs = 2.76
K = 0.0161

LOCATION 2: TTRS 1

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	27.5	28	105.20	0.00120	25.8	83.3	40.58
1	25	27.0	27.5	107.25	0.00172	25.3	81.5	39.71
2	25	25.5	26	113.40	0.00249	23.8	76.8	37.42
4	25	25.0	25.5	115.45	0.00356	23.3	75.3	36.69
8	25	24.5	25	117.50	0.00508	22.8	73.6	35.86
15	25	23.5	24	121.60	0.00707	21.8	70.4	34.30
30	25	23.0	23.5	123.65	0.01008	21.3	68.8	
60	25	22.0	22.5	127.75	0.02103	20.3	65.6	
120	25	20.0	20.5	135.95	0.02116	18.3	59.11	
180	25	18.0	18.5	144.15	0.02668	16.3	52.6	
1440	25	16.0	16.5	152.35	0.07758	14.3	46.2	
1620	25	13.0	13.5	164.65	0.08555	11.3	36.5	
1800	25	10.0	10.5	176.95	0.09348	8.3	26.8	

Gs = 2.79
K = 0.0135

LOCATION 2: TTRS 2

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	28.0	28.5	103.15	0.00119	26.3	81.5	21.4
1	25	27.5	28	105.20	0.00169	25.8	79.7	20.88
2	25	27.0	27.5	107.25	0.00243	25.3	77.9	20.41
4	25	26.5	27	109.30	0.00346	24.8	76.4	20.02
8	25	25.5	26	113.40	0.00499	23.8	73.3	19.20
15	25	24.0	24.5	119.55	0.00702	22.3	68.6	17.97
30	25	23.0	23.5	123.65	0.01009	21.3	65.6	
60	25	21.0	21.5	131.85	0.01474	19.3	59.4	
120	25	18.0	18.5	144.15	0.02179	16.3	50.2	
180	25	16.0	16.5	152.35	0.02743	14.3	44.0	
1440	25	14.0	14.5	160.55	0.07966	12.3	37.9	
1620	25	12.0	12.5	168.175	0.00750	10.3	31.7	
1800	25	09.0	09.5	181.05	0.09457	7.3	22.5	

Gs = 2.85
K = 0.012

LOCATION 2: QTRS 1

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220- 4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	26.5	27.0	109.3	0.00700	24.8	74.4	15.92
1	25	26.0	26.5	111.35	0.00500	24.3	72.9	15.60
2	25	25.0	25.5	115.45	0.00360	23.3	69.9	14.96
4	25	24.0	24.5	117.50	0.00257	22.8	68.4	14.64
8	25	23.5	24.0	121.60	0.01850	21.8	65.4	14.00
15	25	22.5	23.0	125.70	0.00137	20.8	62.4	13.35
30	25	22.0	22.5	127.75	0.00098	20.3	60.9	
60	25	21.0	21.5	131.85	0.00070	19.3	57.9	
120	25	20.5	21.0	133.90	0.00050	18.18	56.4	
180	25	20.0	20.5	135.95	0.00041	18.3	54.9	
1440	25	19.0	19.5	140.05	0.00015	17.3	51.9	
1620	25							
1800-	25							

Gs = 3.00
K = 0.0116

LOCATION 2: QTRS 2

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220- 4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	30.5	31	91.90	0.00112	28.8	89.6	34.41
1	25	29.5	30	97.100	0.00163	27.8	86.5	33.22
2	25	29.0	29.5	99.05	0.00233	27.3	84.9	32.60
4	25	28.0	28.5	103.15	0.00336	26.3	81.8	31.41
8	25	27.0	27.5	107.25	0.00485	25.3	78.7	30.22
15	25	27.0	26.5	111.35	0.00677	24.3	75.6	29.03
30	25	25.0	25.5	115.45	0.00975	23.3	72.5	
60	25	23.0	23.5	123.65	0.01427	21.3	66.2	
120	25	21.0	21.5	131.85	0.02083	19.3	60.0	
180	25	19.0	19.5	140.05	0.02630	17.3	53.8	
1440	25	17.0	17.5	148.25	0.00645	15.3	47.6	
1620	25	15.0	15.5	156.45	0.00696	13.3	41.4	
1800	25	13.0	13.5	164.65	0.00813	11.3	35.14	

Gs = 2.80
K = 0.0123

LOCATION 2: BTRS 1

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	27.0	27.5	107.25	0.00121	25.3	81.7	31.62
1	25	27	27	109.30	0.00173	24.8	80.1	30.99
2	25	25.0	25.5	115.45	0.00252	23.3	75.3	29.14
4	25	24.0	24.5	119.55	0.00362	22.3	72.03	27.88
8	25	23.5	24	121.60	0.00517	21.8	70.4	27.24
15	25	22.0	22.5	127.75	0.00725	20.8	67.2	26.01
30	25	21.0	21.5	131.85	0.01042	19.3	62.3	24.11
60	25	20.0	20.5	135.95	0.01496	18.3	59.1	22.87
120	25	19.0	19.5	140.05	0.02147	17.3	55.9	21.L63
180	25	18.0	18.5	144.15	0.02668	16.3	52.6	20.36
1440	25	16.0	16.5	152,35	0.07759	14.3	46.2	17.88
1620	25	14.0	14.5	160.55	0.08447	12.3	39.7	15.36
1800	25	12.0	12.5	168.75	0.09129	10.3	33.3	12.88

Gs = 2.82

K = 0.0131

LOCATION 2: BTRS 2

Time (min)	*Temp °c*	*Hydrometer Reading (Rh)*	*Ra (Rh + 0.5)*	*H(mm) 220-4.1Ra*	*D K √H./t*	*Corrected Hydrometer Reading Rc Rh – 1.7*	*N% (2Gs/Gs-1) Rc*	*N' N% x % Passing*
0.5	25	27.0	27.5	107.25	0.01020	25.3		
1	25	26.5	27.0	109.30	0.00730	24.8	93.39	37.28
2	25	26.0	26.5	111.35	0.00521	24.3	94.45	36.94
4	25	25.5	26.0	113.40	0.00372	23.8	92.51	36.93
8	25	25.0	25.5	115.45	0.00265	23.3	90.56	36.15
15	25	23.5	24.0	121.60	0.00199	21.8	84.74	33.83
30	25	23.0	23.5	123.65	0.00142	21.3	82.79	33.05
60	25	22.0	22.5	127.75	0.00102	20.3	78.91	
120	25	21.5	22.0	129.80	0.00073	19.8	76.96	
180	25	20.5	21.0	133.90	0.00060	18.8	73.08	
1440	25	19.5	20.0	138.00	0.00022	17.8	69.18	
1620	25	18.5	19.0	142.10	0.00020	16.8	65.30	
1800	25							

Gs = 2.81

K = 0.0171

APPENDIX B

Graphs of California Bearing Ratio

KEY

NRS 1 – 4 :	**Non reworked soils**
TTRS 1-2 :	**Termite reworked soils from top of termitarium**
QTRS 1-2 :	**Termite reworked soils from the queen of termite surrounding.**
BTRS 1-2 :	**Termite reworked soils from bottom of termitarium.**

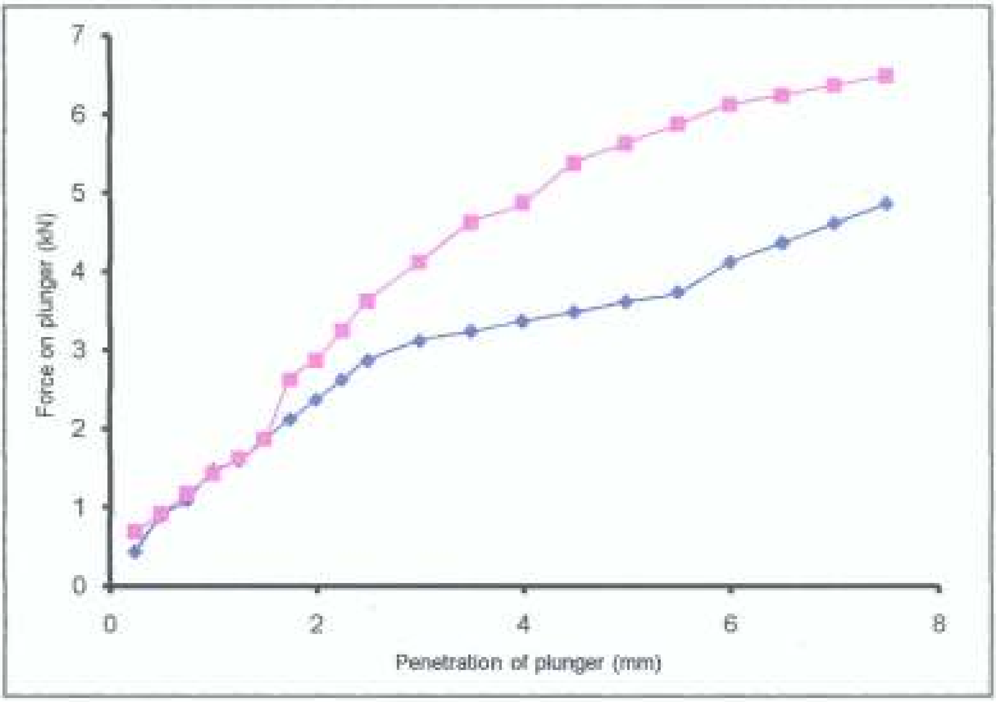

Fig. B-1: Graph of California Bearing Ratio for Location 1: NRS1

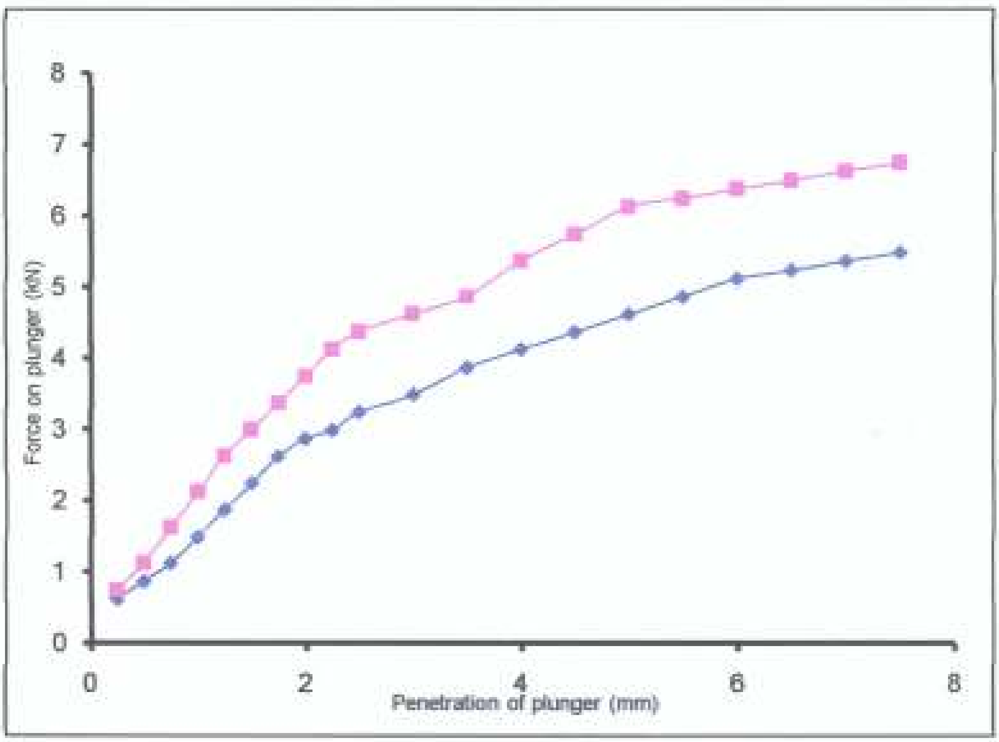

Fig. B-2: Graph of California Bearing Ratio for Location 1: NRS 2

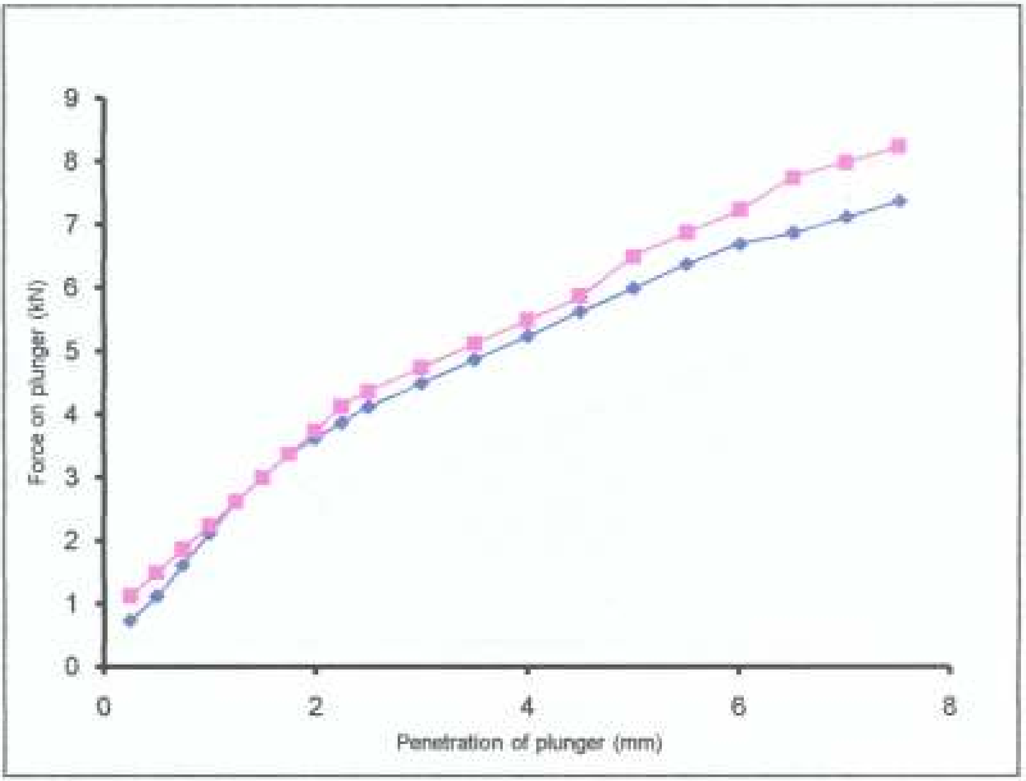

Fig. B-3: Graph of California Bearing Ratio for Location 1: NRS 3

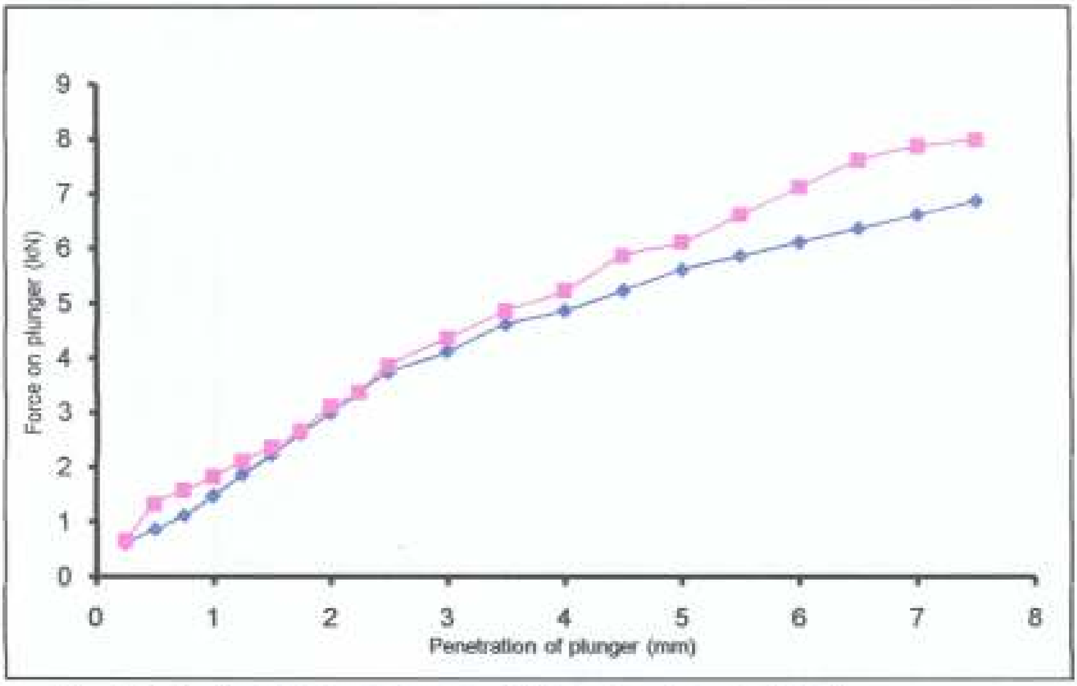

Fig. B-4: Graph of California Bearing Ratio for Location 1: NRS 4

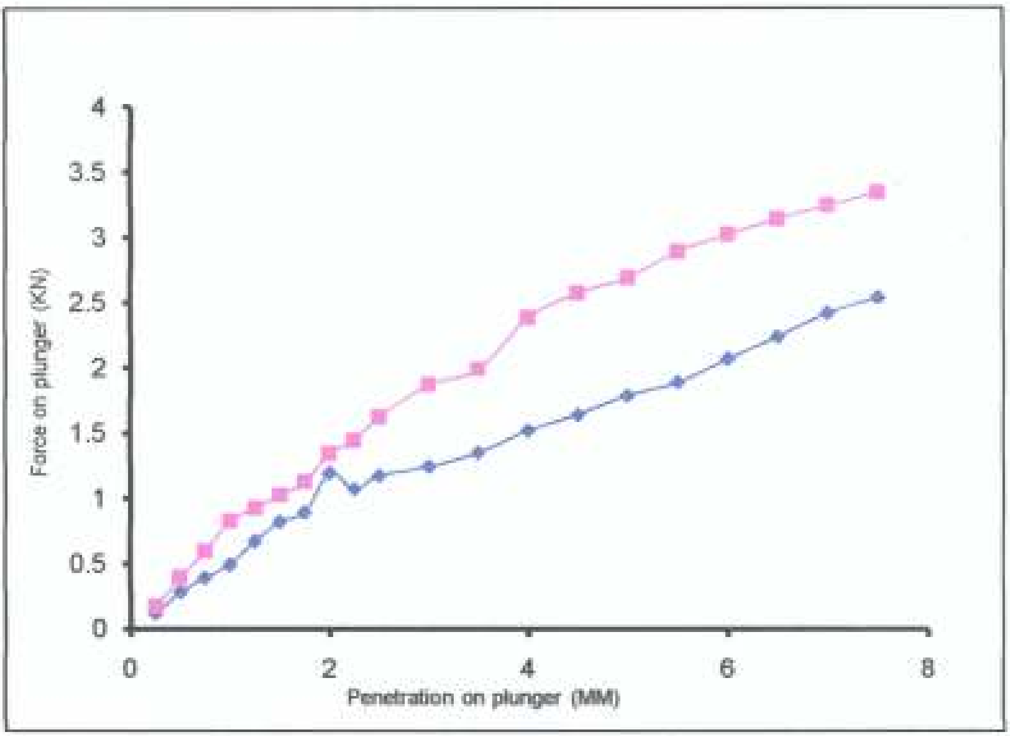

Fig. B-5: Graph of California Bearing Ratio for Location 1: TTRS 1

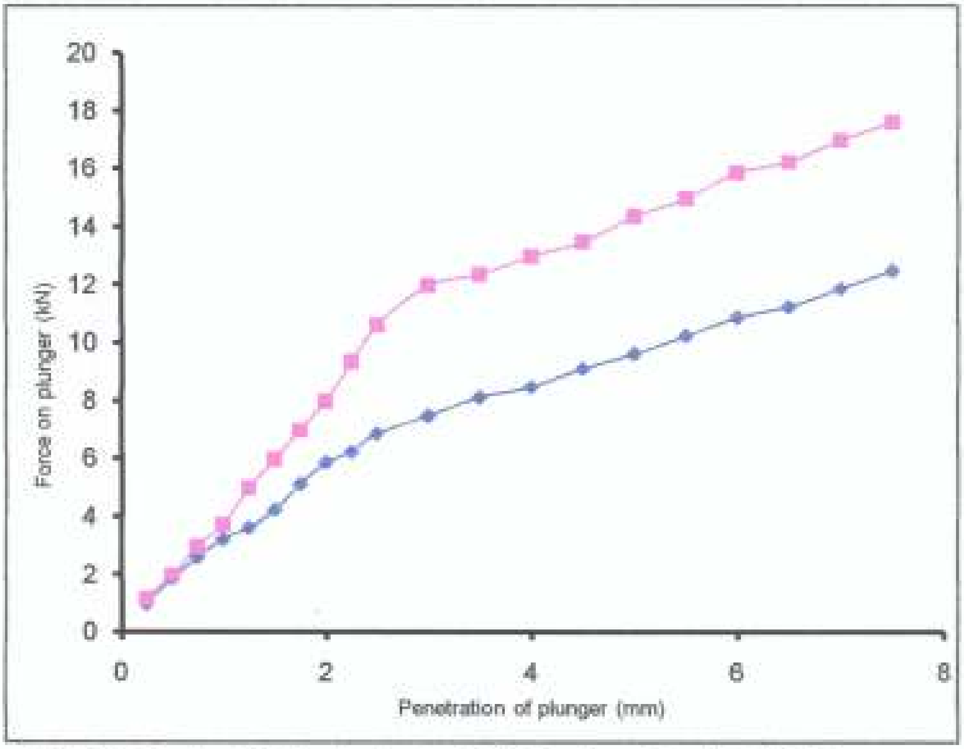

Fig. B-6: Graph of California Bearing Ratio for Location 1: TTRS 2

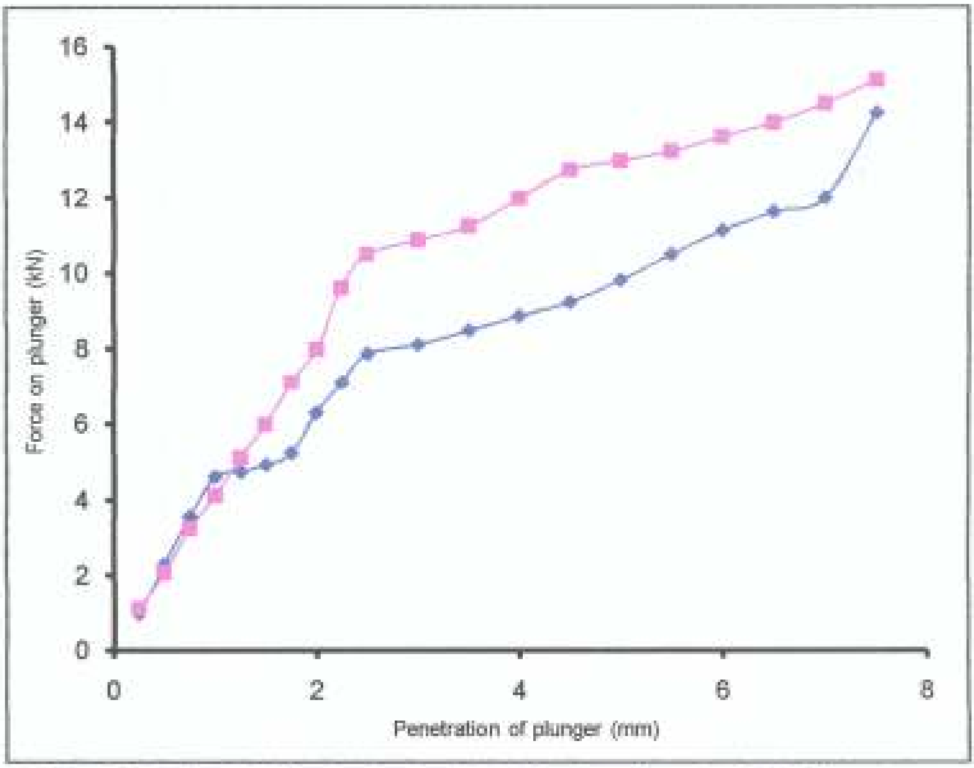

Fig. B-7: Graph of California Bearing Ratio for Location 1: QTRS 1

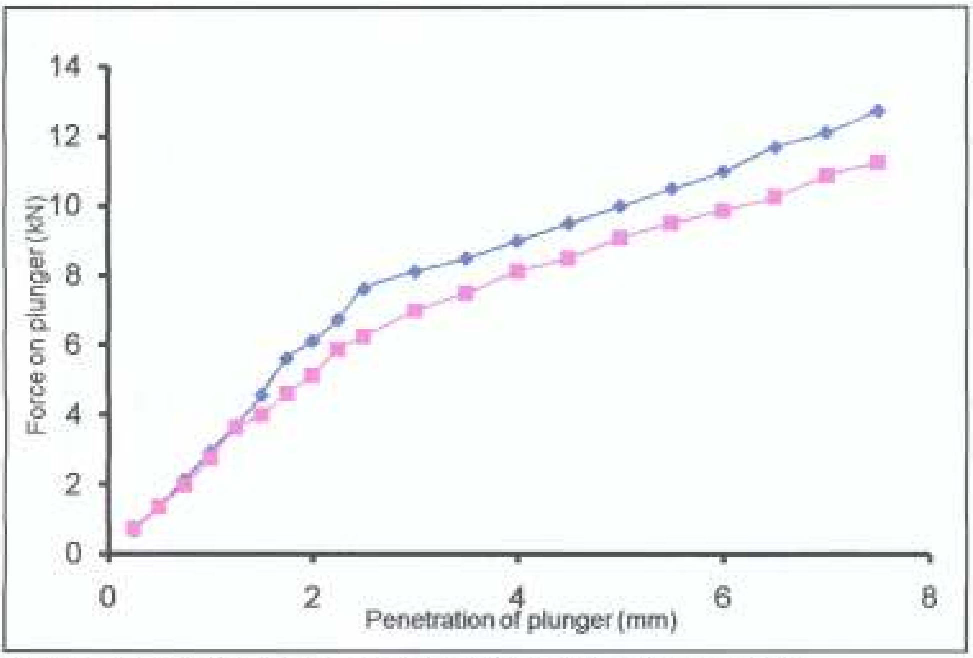

Fig. B-8: Graph of California Bearing Ratio for Location 1: QTRS 2

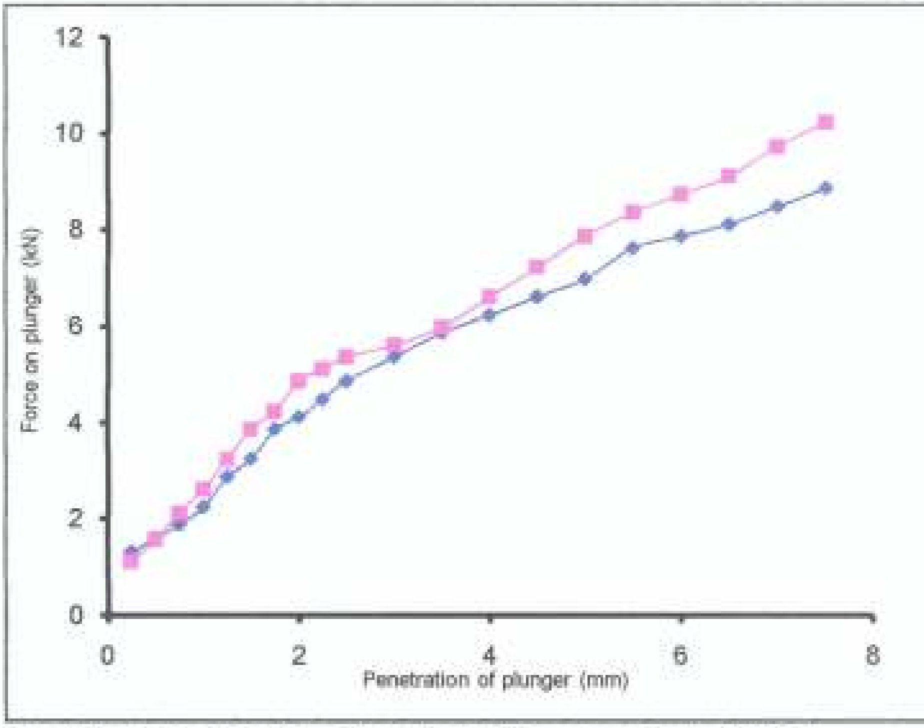

Fig. B-9: Graph of California Bearing Ratio for Location 1: BTRS 1

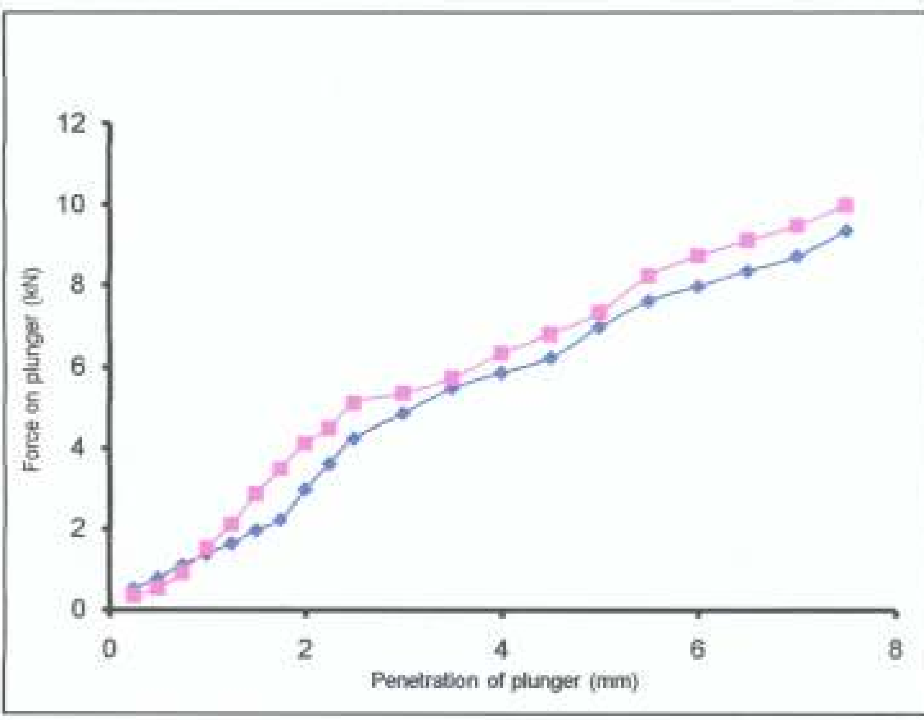

Fig. B-10: Graph of California Bearing Ratio for Location 1: BTRS 2

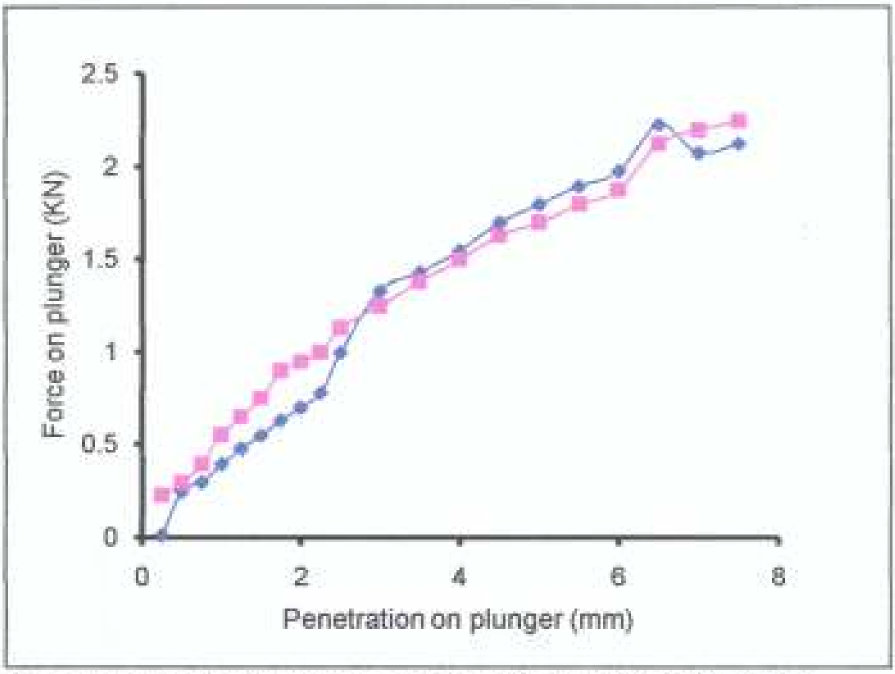

Fig. B-11: Graph of California Bearing Ratio for Location 2: NRS 1

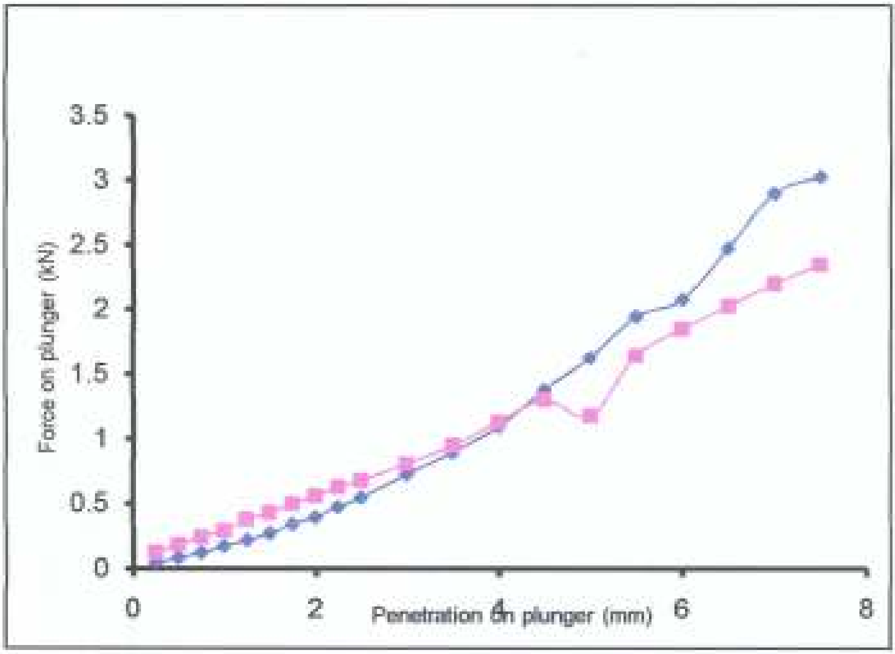

Fig. B-12: Graph of California Bearing Ratio for Location 2: NRS 2

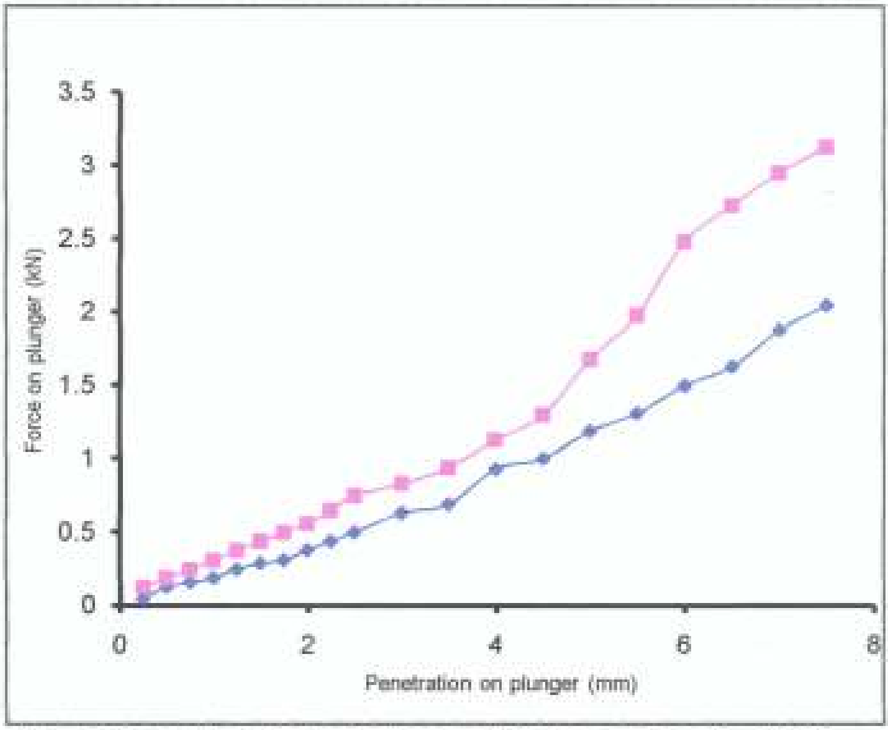

Fig. B-13: Graph of California Bearing Ratio for Location 2: NRS 3

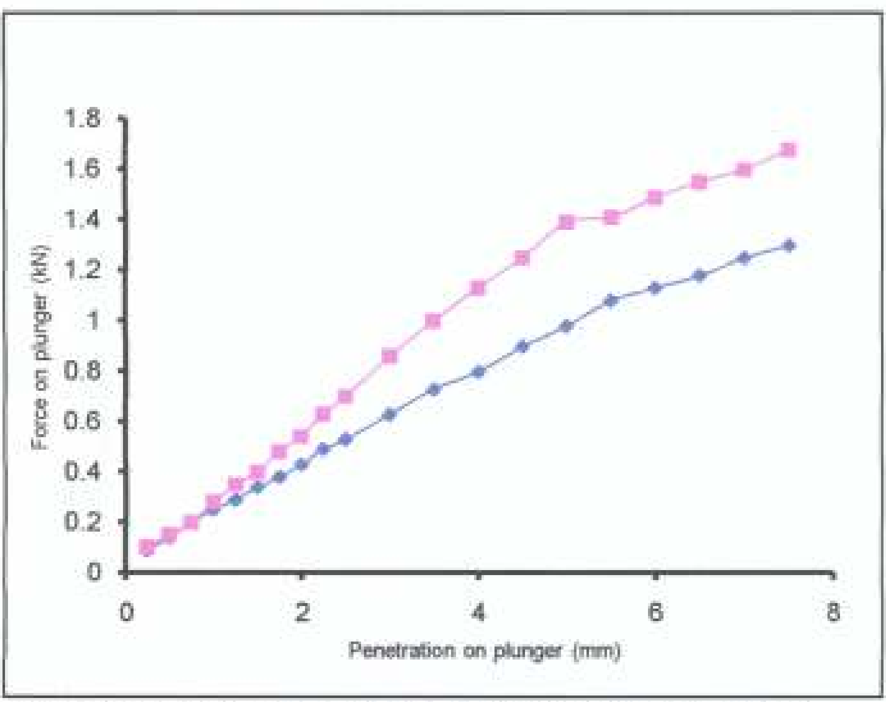

Fig. B-14: Graph of California Bearing Ratio for Location 2: NRS 4

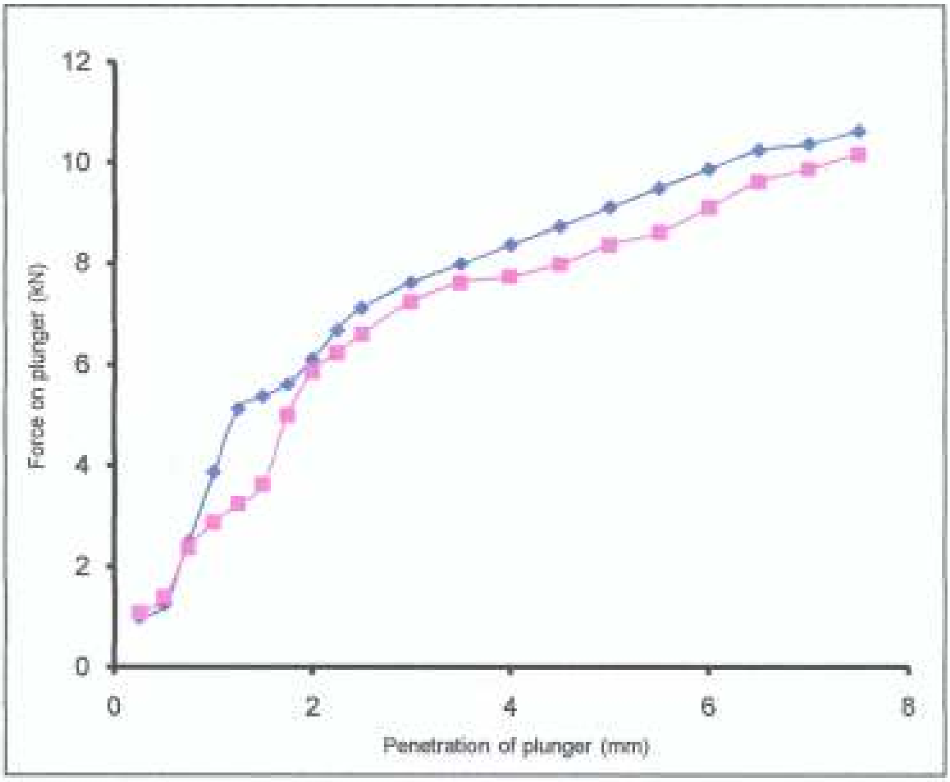

Fig. B-15: Graph of California Bearing Ratio for Location 2: TTRS 1

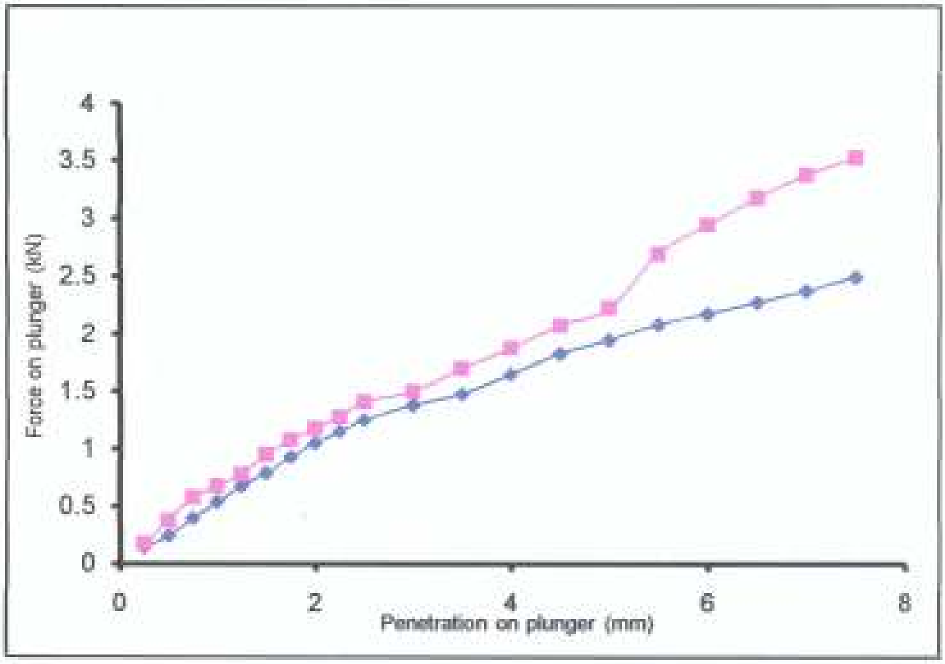

Fig. B-16: Graph of California Bearing Ratio for Location 2: TTRS 2

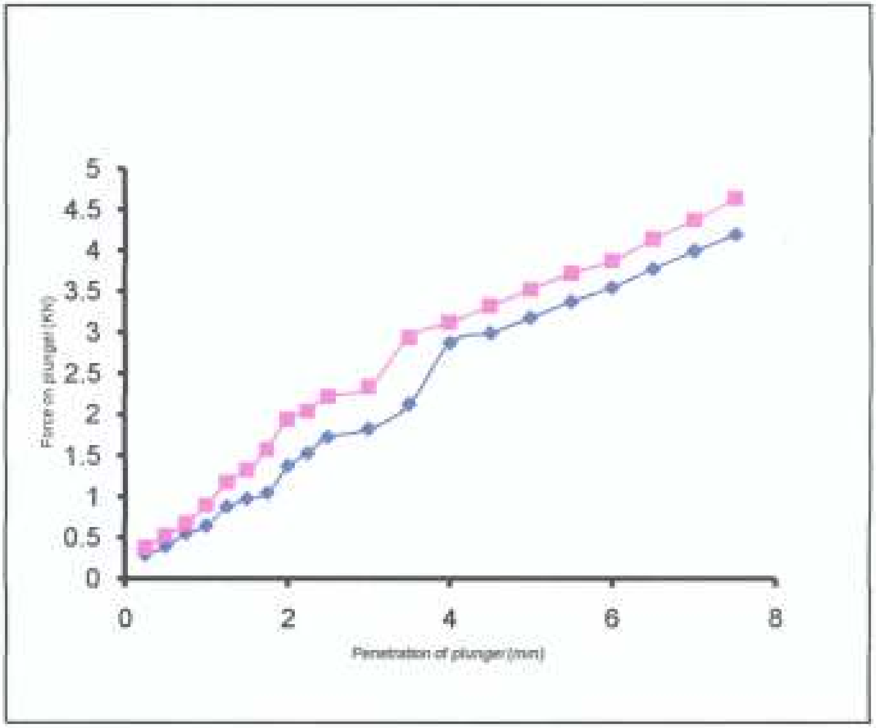

Fig. B-17: Graph of California Bearing Ratio for Location 2: QTRS 1

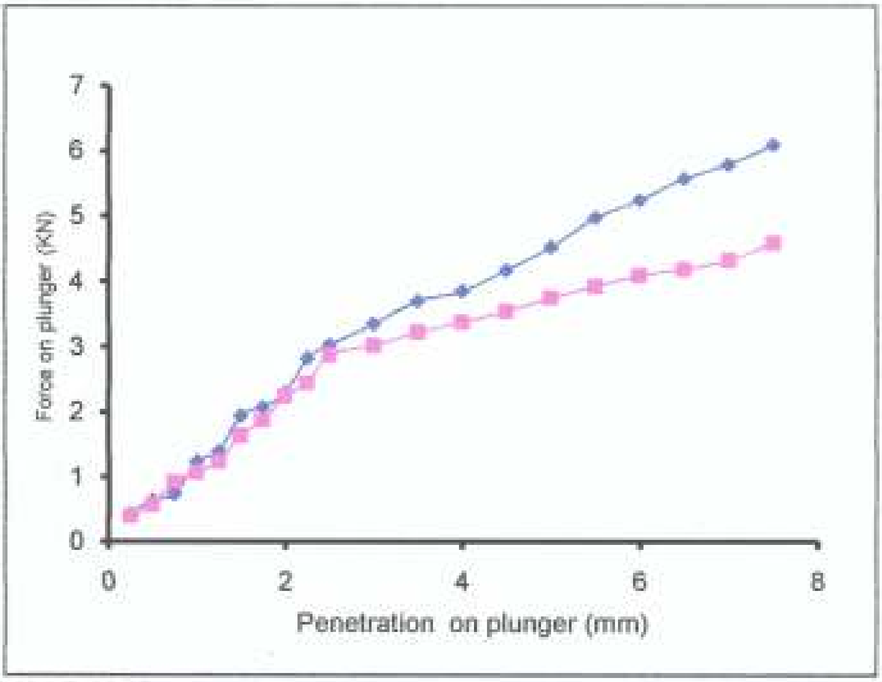

Fig. B-18: Graph of California Bearing Ratio for Location 2: QTRS 2

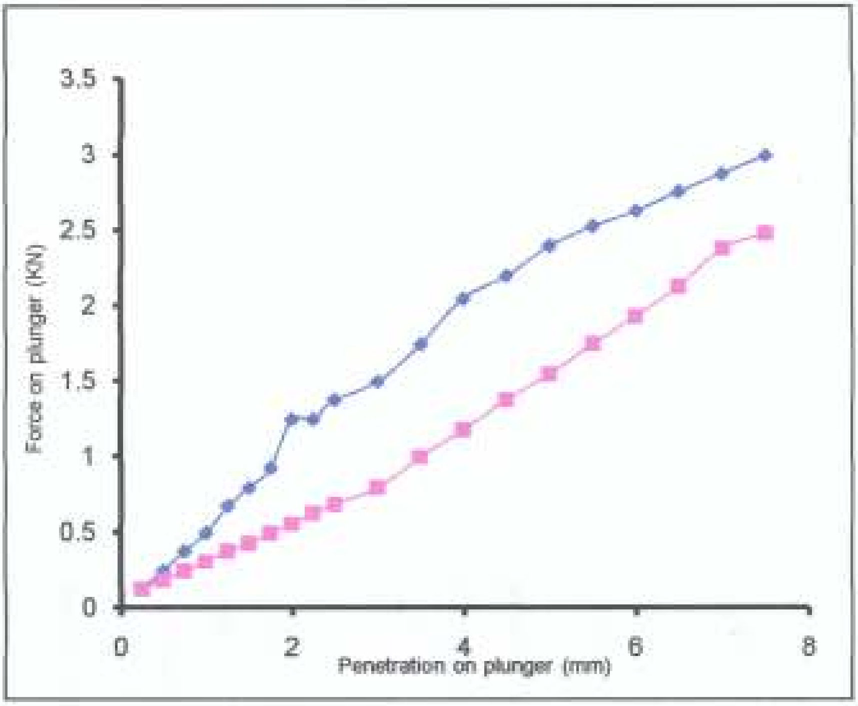

Fig. B-19: Graph of California Bearing Ratio for Location 2: BTRS 1

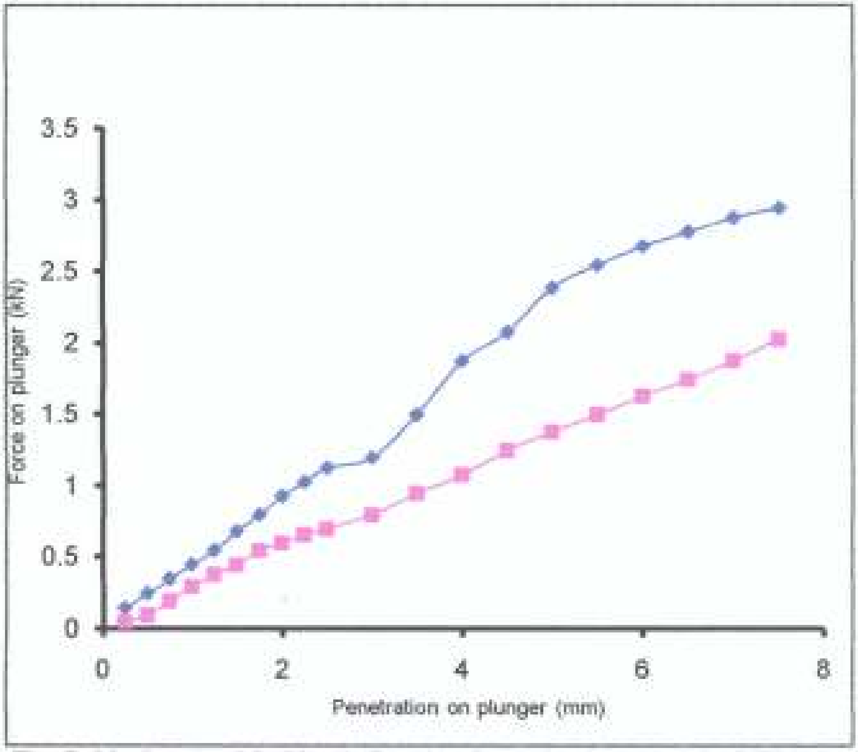

Fig. B-20: Graph of California Bearing Ratio for Location 2: BTRS 2

APPENDIX C

Results of Compressive strength on moulded bricks

KEY

NRS 1 – 4 : **Non reworked soils**

TTRS 1-2 : **Termite reworked soils from top of termitarium**

QTRS 1-2 : **Termite reworked soils from the queen of termite surrounding.**

BTRS 1-2 : **Termite reworked soils from bottom of termitarium.**

TABLE C-1 : RESULT OF COMPRESSIVE STRENGTH TEST ON MOULDED BRICKS

LOCATION 1: NRS I

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	2.9	35	1.66
14	3.3	58	2.76
21	3.1	72	3.42
28	2.8	95	4.52

LOCATION 1: NRS 2

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.3	35	1.66
14	3.2	59	2.80
21	3.1	73	3.47
28	3.3	95	4.52

LOCATION 1: NRS 3

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.3	41	1.95
14	3.2	73	3.47
21	3.4	88	4.19
28	3.1	94	4.47

LOCATION 1: NRS 4

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.1	38	1.80
14	3.0	68	3.23
21	3.2	79	3.76
28	3.3	93	4.42

LOCATION 1: TTRS 1

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.2	30	1.42
14	3.3	72	3.42
21	3.0	90	4.28
28	3.1	105	5.00

LOCATION 1: TTRS 2

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.0	41	1.95
14	3.1	76	3.61
21	3.2	95	4.52
28	3.1	115	5.47

LOCATION 1: QTRS 1

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.0	43	2.04
14	3.2	70	3.33
21	3.1	87	4.14
28	3.1	105	5.00

LOCATION 1: QTRS 2

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.1	42	2
14	3.1	69	3.28
21	3.3	88	4.19
28	3.2	103	4.90

LOCATION 1: BTRS 1

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.2	37	1.76
14	3.0	74	3.52

21	3.1	89	4.23
28	3.0	101	4.80

LOCATION 1: BTRS 2

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.1	35	1.66
14	3.2	62	2.95
21	3.4	85	4.84
28	3.1	98	4.66

LOCATION 2: NRS 1

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	2.9	37	1.76
14	3.3	56	2.66
21	3.2	68	3.23
28	3.0	96	4.57

LOCATION 2: NRS 2

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.2	38	1.80
14	3.1	73	3.47
21	3.3	84	4
28	3.2	97	4.61

LOCATION 2: NRS 3

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.0	31	1.47
14	3.2	69	3.28
21	3.3	85	4.04
28	3.4	100	4.76

LOCATION 2: NRS 4

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.3	32	1.52
14	3.2	69	3.28
21	3.1	77	3.66
28	3.2	98	4.66

LOCATION 2: TTRS 1

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.3	42	2
14	3.2	75	3.57
21	3.3	88	4.19
28	3.3	103	4.90

LOCATION 2: TTRS 2

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.2	37	1.76
14	3.2	67	3.19
21	3.1	89	4.23
28	3.3	100	4.76

LOCATION 2: QTRS 1

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.1	39	1.85
14	3.3	65	3.09
21	3.2	87	4.14
28	3.0	110	5.23

LOCATION 2: QTRS 2

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.1	40	1.90
14	3.1	72	3.42

21	3.2	90	4.28
28	3.0	115	5.47

LOCATION 2: BTRS 1

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.2	34	1.61
14	3.0	58	2.76
21	3.1	78	3.71
28	3.3	98	4.66

LOCATION 2: BTRS 2

AGE (DAYS)	WEIGHT	AVG. LOAD	STRENGTH (N/mm^2)
7	3.0	4.1	1.94
14	2.9	71	3.38
21	3.1	82	3.90
28	2.8	100	4.76