# EFFECT OF ELAPSE TIME AFTER MIXING ON THE PROPERTIES OF STABILIZED LATERITE

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# DECLARATION

I hereby declare that this thesis has been composed by myself and that it is a record of my own research. It has not been accepted in any previous application for a higher degree.

All quotations and their sources of information are specifically acknowledged by means of references.

KATTE, Valentine Yato
1996

# CERTIFICATION

This thesis entitled "EFFECT OF ELAPSE TIME AFTER MIXING ON THE PROPERTIES OF STABILIZED LATERITE" by KATTE, Valentine Yato meets the regulations governing the award of the degree of Master of Science (GEOTECHNICS) of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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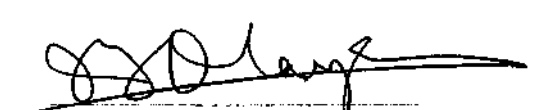

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# DEDICATION

To Mum, Mrs. Mary Chakunte Katte

Jean Clude Njabou Katte

Larry Chamfor Tondjo

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I am thankful to the Almighty God for sustaining me during my studies and throughout this research.

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# ABSTRACT

The results obtained from the investigation of the effect of cement and time on the properties of laterite soil with respect to the elapse time after mixing as well as the compactive energy levels (Proctor and West African) are highlighted. The material was classified as an A-7-6 soil according to AASHTO classification system and was treated with 0%, 3%, 5% and 8% stabilizer contents. Tests such as the X-Ray diffraction (XRD). Differential Thermal Analysis (DTA) and specific gravity were carried out on the untreated laterite while particle size distribution, Atterberg limits, compaction tests, unconfined compressive strength (UCS) and California Bearing Ratio (CBR) were performed at elapse periods of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 hours on both the treated and untreated laterite.

The results of the X RD and DTA show that Kaolinite is the predominant clay mineral in the soil. Stabilization improved the above mentioned properties with changes observed which differ from that of the untreated laterite.

Increase in elapse time after mixing caused reductions in the values of the test result. The Highway Research Board (1943) requirements, Millard and O'Reilly (1965) criterion of free flow and the Nigerian General Specification for Roads and Bridges (1970) were used to evaluate the suitability of the stabilized laterite for use as a pavement material at the various elapse times.

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# ABBREVIATION

| | | | |
|---|---|---|---|
| 1. | AASHTO | - | American Association Of State Highway and Transportation Officials |
| 2. | ASTM | - | American Society of Testing and Materials |
| 3. | CBR | - | California Bearing Ratio |
| 4. | DTA | - | Differential Thermal Analysis |
| 5. | HRB | - | Highway Research Board |
| 6. | HRS | - | Hours |
| 7. | LL | - | Liquid Limit |
| 8. | MDD | - | Maximum Dry Density |
| 9. | MO | - | Millard and O'Reilly |
| 10. | NGSRB | - | Nigerian General Specification for Roads and Bridges |
| 11. | OMC | - | Optimum Moisture Content |
| 12. | PI | - | Plasticity Index |
| 13. | PL | - | Plastic Limit |
| 14. | S | - | Soaked |
| 15. | UCS | - | Unconfined Compressive Strength |
| 16. | UN | - | Unsoaked |
| 17. | XRD | - | X-Ray Diffraction |

# CHAPTER ONE

# INTRODUCTION

## *1.1 INTRODUCTION*

Laterites are broadly distributed in the tropical and subtropical regions of the world and they have been identified and given different names in their various places of occurrence. It is generally accepted as a leached soil of tropical origin resulting from the process of laterization.

The name laterite is derived from the Latin word "later" meaning brick and was first applied by Buchanan to a ferruginous clay like deposit found in south India in 1807. Since then many other individuals have endeavoured to define laterites.

In the developing countries of tropical regions laterites are encountered in engineering projects. However, these laterites might not meet the general engineering criteria for their intended use, thus methods are required to enable the material conform with the required specification.

Soil stabilization covers the alteration or control of any soil property. Soil stabilization thus is thought to include not only improvement in soil strength but also the alteration of such soil properties as permeability, compressibility, water sensitivity and frost susceptibility. Soil stabilization covers not only the increase or decrease of any soil property, but also the variation of any property with changes in environmental conditions, mainly moisture or pressure (Lambe, 1957). It has been found useful in road construction, aircraft runways, earth dams, embankments, leeves etc. The stabilization process can be said to be any of the following:

i. Increasing the soil density

ii. Addition of materials to affect a chemical and/or physical changes in the soil material.

iii. Lowering the water table.

iv. Removal or replacement of poor soil

These thesis is connected with items (i) and (ii) listed above.

## *1.2 LITERATURE REVIEW*

### *1.2.1 Definition*

Laterite has got many definitions in an attempt to precisely describe it. Buchanan's (1809) definition was restricted to a material of soft consistency which hardened on exposure to air. Mallet (1883) suggested that laterite was ferruginous and aluminous. Geologist then became interested in laterite as a possible source of aluminium and manganese (Femor 1911). This further compounded the problem of definition and much controversy resulted as to the nature of the various properties of the ores. Consequently the physical definitions of laterite was abandoned.

Martin and Doyne (1927) proposed the use of the silica/alumina ratio ($SiO_2/Al_20_3$) and defined three grades of laterite. Ratios less than 1.33 are indicative of true laterites, ratios between 1.33 and 2.0 represent lateritic soils and those greater than 2.0 represent non lateritic tropically weathered soils. this definition did not consider iron as an essential element. Joachin and Kandiah (1941) adopted the silica-sesquioxides ratio ($SiO_2/Al_20_3 + Fe_20_3$) with the same limiting values as those proposed by Martin and Doyne (1927).

Inspite of its checkered historical definitions, Alexander and Cady (1962) summarized the various definitions as follows: "Laterite is a highly weathered material rich in secondary oxides of iron, aluminium or both. It is nearly void of bases and primary silicates but may contain large amounts of quartz and kaolinite. It is either hard or capable of hardening on exposure to wetting and drying".

### *1.2.2 Morphological and Physical Characteristics of Laterites*

**COLOUR:** Laterites vary in colour due to the presence of many elements which radiate their own characteristic wavelength. Colours commonly encountered are pink, red and brown. However, some variety are mottled and streaked with violet and greenish colour. Generally, the reddish-brown colouration of laterite is the first physical identification criterion and this results from the presence of iron and manganese oxides in its various oxidation and hydration states.

**DENSITY:** The density of laterite vary between 2.50 and 3.60 depending upon its chemical composition. It increases with increasing iron content. Maignien, (1958) stated that the old crusts are denser than recent ones. The denser the structure the lower will be the density to be of the laterite of the same composition. Cemented formations are denser than those of scoriaceous structure which are in turn denser than those of alveolar structure.

**HARDNESS:** This characteristic is subjective because it depends on the person sampling the material. However, differences occur in hardness between laterite exposed at the surface and those buried. The following factors affect the hardness of laterites:

i. Composition and the extent of crystallization of the components. The higher the sesquioxide content the harder the laterite.

ii. The arrangement of the various constituents.

iii. The extent of ageing.

**STRUCTURE:** Maignien (1958) classifies the structure of laterites into three types.

i. **Indurated elements which form a continuous coherent skeleton.**

ii. Indurated element which are free concretions of nodules in an earthly matrix.

iii. Indurated elements that cement pre-existing materials.

### *1.2.3 Mineralogical and Chemical Characteristics of Laterites*

Laterites have a high content of sesquioxides of iron and/or aluminium relative to other chemical constituents in their various percentages. Presently, pedologists use the Joachin and Kandian (1941) criterion in evaluation the extent of laterization. When the ($SiO_2$ / $R_2O_3$) ratio exceeds 50% it is assumed that the material is a laterite.

Many elements have been found occurring in mineralogical form. Iron occurs in laterite in various forms as oxides, the most common being hematite, geothite and limonite. Aluminium occurs as hydrates of alumina and in alumino silica. Manganese occurs in various forms, with Lithiophorite and birnessite being the most common. Titanium occurs only in limited quantities as titanium oxides. So far zinc, chromium, nickel, cobalt, molybdenum, vanadium, cobalt and other trace elements have been identified.

### *1.2.4 Occurrence and Genesis of Laterites*

Laterites occur in the tropics and subtropical regions of the world and deposits have been identified in Australia, Asia, Africa as well as in Central and South America. They are formed under weathering systems, being the product of the process of laterization. Three stages have been identified in their formation.

i. The decomposition of ferro-alumino silicate minerals which is characterized by the physico-chemical breakdown of the primary minerals and the release of constituent elements ($SiO_2$, $Al_2o_3$, $Fe_2O_3$, Ca0, Mg0, $K_20$, $Na_20$ etc.) which appear in simple ionic forms (Loughnan, 1969).

ii. Laterization: This involves the leaching of combined silica and bases and the relative accumulation or enrichment from outside sources of oxides and hydroxides of sesquioxides mainly $Al_20_3$, $Fe_20_3$ and $Ti0_2$. This is achieved by a good drainage condition and also on the pH of the leaching fluid. The enrichment could be achieved through vertical leaching, capillary rise and a fluctuating water table. Meanwhile accumulation results from the movement of minerals from adjacent soils through lateral transport.

iii. Induration: This involves the partial or complete dehydration, which sometimes involve desiccation, of the sesquioxide rich minerals and secondary minerals. Iron plays an important role in the induration process (D'Hoore, 1954: Alexander et al., 1956: Maignien, 1958). The absolute value of iron does not count, what matters is its arrangement in the soil profile in relation to the constituent materials.

The factors encouraging and affecting the results of laterization (Wooltorton, 1975) are:

1. A basic or intermediate parent rock material rich in ferro-alumino silicates.
2. The amount and kind of vegetation and of organic matter and humic residues formed.
3. A permeable profile.
4. Climate - A heavy rainfall (preferably of a monsoon type) high humidity, a hot temperature with cool nights and a fluctuating water table.
5. A flat topography
6. A combination of alternate leaching by an effective alkaline solution and an acid soil solution. Silica is removed by the alkaline solution while the sesquioxides are mobilized by the acid solution.

A variety of explanations have been suggested in the past concerning the genesis of laterites such as the action of Sulphuric acid on feldspars (Du Bois, 1903), the upward percolation of subterranean water (Maclaren, 1906) and the action of micro-organism (Erthart,

1951). Nevertheless, the factors proposed by Wooltorton (1975) which are listed above cannot be doubted and laterite formation in any locality could be explained in terms of a combination of some of these factors.

### *1.2.5 Economic Importance of Laterites*

Laterites act as raw materials for the extraction of minerals. Aluminium is extracted from the ores in Guinea Republic for commercial purposes while iron is extracted from laterite found in the North west province in Cameroon by primitive methods for the manufacture of cutlasses and hoes. No commercial activity has been reported because of its unprofitability. Manganese has been extracted from the deposits in Gabon. Indurated laterites have been used as building blocks in India and Thailand. Stabilized blocks are in common use almost everywhere now. Laterites are won and used in road construction. Laterites form good water storage facilities especially those constructed from rock made up of lateritic especially those constructed from rock made up of lateritic alteration products. The exposed crust are very permeable and thus form potential sites for ground water recharge.

### *1.2.6 Engineering Classification of Laterites*

Because of the variability of laterites, no known procedure has been established for its engineering classification. However, the use of conventional soil mechanics tests and procedures has proved effective in research and geotechnical experience. This has enabled engineers to economically use laterites and predict their field performances. So far, particle size distribution and plasticity characteristics have been used.

The geotechnical characteristics of laterites are influenced considerably by their genesis, degree of weathering, morphology, chemical and mineralogical composition and environmental

factors (Gidigasu, 1972, 1974). For field work, existing classification systems such as the Unified Soil Classification System, the Highway Research Board (HRB) and the American Association of State Highway and Transportation officials (AASHTO) specifications are used.

### *1.2.7 Stabilization of Laterites*

Work on laterite stabilization for engineering purposes started with Winterkorn and Chandrasekhara, (1951). Other researchers include (Remilton, 1955: Meclina, 1956: Shoefield, 1957: Evans, 1958: etc). The research findings of laterite stabilization can be interpreted in the light of the following factors:

i) Genetic Characteristics.

ii) Compositional factors such as particle size distribution, organic matter content, chemical and mineralogical composition and the physico-chemical characteristics.

iii) Method of sample preparation prior to stabilization and stabilization procedures.

Common stabilizing agents used are cement, lime and bitumen. Yoder, (1959) categorized the various types of stabilizers according to the property they impart on the soil such as cementing agents, modifiers, water proofing, water retaining and miscellaneous chemicals.

**CEMENT STABILIZATION:** This is the addition of a known quantity of cement to the soil to achieve a desired property. The technique involves breaking up the soil thoroughly mixing it with cement before adding a known amount of water with thorough mixing again and compacting it in a conventional manner. Cement stabilization is restricted to soils with less than 40 per cent fines and liquid limit less than 45. Typical values of cement content by weight range from 2 - 4% for granular soils to 10 - 15% for clays (Ingles and Metcalf, 1972). Cement should not be used on soils with an appreciable sulphate or organic matter content, since in the

former case it leads to a deleterious effect and in the latter; case a reduction in the strength development process. The product of cementation is likened to low grade concrete which is much less expensive.

When water is added to the soil-cement mixture, cement hydrates producing a cementitious compound independent of the soil. This is the first stage of the reaction. These cementitious compounds namely calcium silicate hydrates and aluminium hydrates contribute to the early strength development characteristics of cement stabilization by developing dementitious linkages between those hydration products and the soil particles. Lime is released during the second stage of the hydration and it reacts with any pozzolanic material present in the soil such as the clay mineral to form secondary cementitious compound. Those secondary cementitious compounds contributes to latter strength.

**LIME STABILIZATION:** This is carried out by using hydrated lime (Calcium hydroxide) and to a lesser extent with quicklime (Calcium oxide). To achieve effective stabilization with lime, the percentage should be above the fixation point which is about 3 - 4% by weight. Lime content below 4% results in a modification process. This is particularly effective in the treatment of clay soils producing a flocculation and cementing of the clay mineral particles into larger clusters and thereby creating a more friable soil structure with improved workability, increased strength, decrease in liquid limit and plasticity index of many clays and reduction of the volume change potential. The strength of soil-lime mixes depends on many variables such as the soil type, lime content, curing time and method, temperature and water content, elapse time and level of compaction.

Lime reactivity has been defined by Aloysius et al., (1979) as the difference between the maximum compressive strength of the lime stabilized soil and the compressive strength of

natural soil. This definition is assumed based on the pozzolatic reaction between the clay and lime. The following factors affect it:

i. The amount and type of clay.

ii. The increase in pH on addition of lime due to partial dissociation of calcium hydroxide.

iii. The amount of silica and alumina present for the formation of cementitious agents.

The dissociation of lime into calcium and hydroxide ions increases the soil pH. The free ions engage in a complex form of cation exchange depending particularly on the type of clay minerals resulting in flocculation and agglomeration. The second stage reaction is the pozzolanic reaction.

Brandl (1980) outlined eight possible reactions that can take place in soil-lime mixes. These are:

i. Exchange, adsorption, and chemosorption of cations and anions.

ii. Proton exchange.

iii. Potential alteration, neutralizations, or change of salts or all.

iv. Jelly developments and crystal growth and felts.

v. Development of chemical compounds, new minerals and cementation.

vi. Alteration of the soil waters (free, adsorbed, chemically bound).

vii. Alteration of pH value, viscosity and capillary attractions.

viii. Alteration in the electrical surface tensions of clay minerals.

### *1.3 ELAPSE TIME*

Elapse time is the period between the end of mixing the laterite-stabilizer water mixture and the time it is tested.

A number of researchers have investigated the effect of elapse time on the strength of cement stabilized laterite. Daniel 1959 reported a loss of 13 - 15% strength for an elapse time of 50 minutes. West (1959) reported a loss of between 50 and 60% strength after an elapse time of 2 hours. Obeahaon (1993) reported a change in the gradation of particle sizes upon modification with lime and cement, with increase in elapse time after mixing. Also recorded are decreases in the MDD, OMC, shear strength characteristics and Atterberg limits with increase in elapse time.

## *1.4 AIM OF RESEARCH*

The aim of this work is to investigate the effect of elapse time after mixing on the properties of stabilized laterite.

## *1.5 OBJECTIVES*

In order to achieve the above aim, the following objectives are to be met.

i. Stabilize a known laterite

ii. Compare cement and lime as stabilizers using two compactive energies - Proctor and West African.

iii. Determine the effect of elapse time on the known laterite using cement and lime as stabilizers with respect to the two compactive energies.

iv. Compare the change in the properties of the stabilized laterite with respect to the Highway Research Board (1943) requirement, Millard and O'Reilly (1965) criteria and the Nigerian specification for Bridges and Roadworks (1970).

## *1.6 SCOPE OF RESEARCH*

Laterite was collected from Shika area along Zaria - Sokoto road and was stabilized with 3%, 5% and 8% cement and lime contents respectively. Two compactive efforts - Proctor and West Africa - were used and time intervals of thirty minutes each were used to investigate the effect of elapse time between mixing and compaction. The maximum time lapse between mixing and compaction, lapse was 3.0 hours while the minimum was 0.0 minute. The following tests were performed on the natural soil namely:

i. Grain size distribution.

ii Atterberg limits

iii. Compaction (Proctor and West African Energy levels)

iv. Unconfined compressive strength

v. California Bearing Ratio.

# CHAPTER TWO

# METHODOLOGY, LABORATORY TESTS AND RESULTS

## *2.1 LOCATION OF STUDY AREA AND ITS GEOLOGY*

The soil samples used for the study were collected from a borrow pit at about Km 15 along the Zaria-Sokoto road. The geological map of Nigeria shown in fig. 2.1 and the soil map shown in fig 2.2 reveal that the soil belongs to the group of ferruginous tropical soil derived from acid igneous and metamorphic rocks.

Ferruginous soils occur widely between the 500 and 1200mm isohyets in area having contrasting wet and dry season regime. They are usually formed on parent materials rich in quartz, that is, on the crystalline rocks of the basement complex, on granite and on aeolian and many sedimentary deposits but not on volcanic or ultrabasic or calcareous rocks (D'Hoore 1954).

Leaching of clay within the soil profile produces a sandy surface soil which is low in organic matter and base exchange capacity with the formation of a compact sub-soil where the clay has accumulated. Later there is the separation of free oxides which are deposited in the profile to form mottles, concretions or ferruginous hardpan.

Ferruginous soils are not deep lying. Kaolinite appears to be the predominant clay minerals sometimes with small amounts of illite but there is the absence of montmorillonite. Clay contents are low but variable (0-25%) on the surface but this depends on the parent material. For the soil investigated the clay content is 13% and this falls within the range mentioned above.

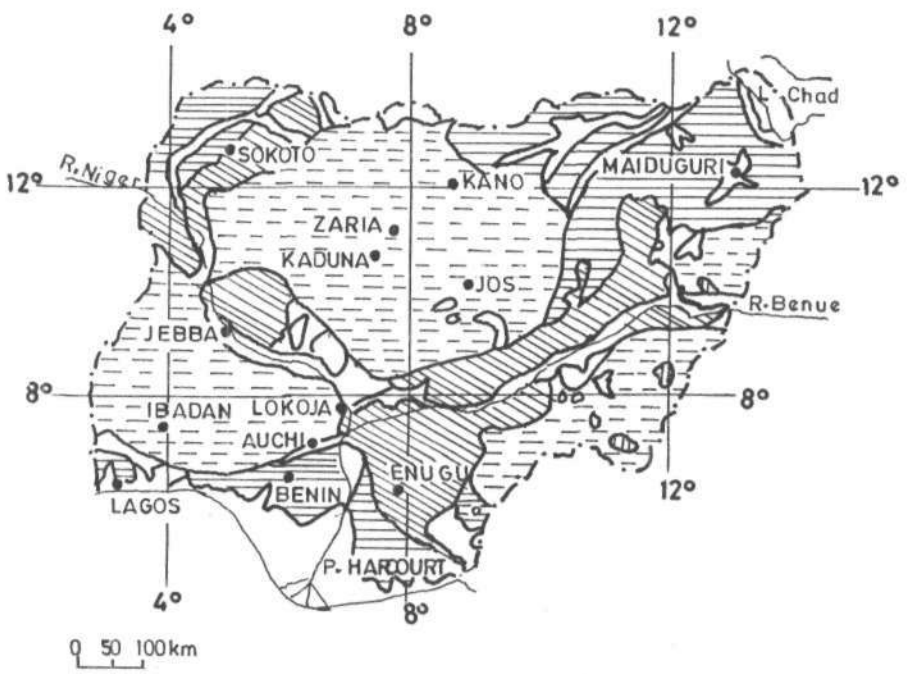
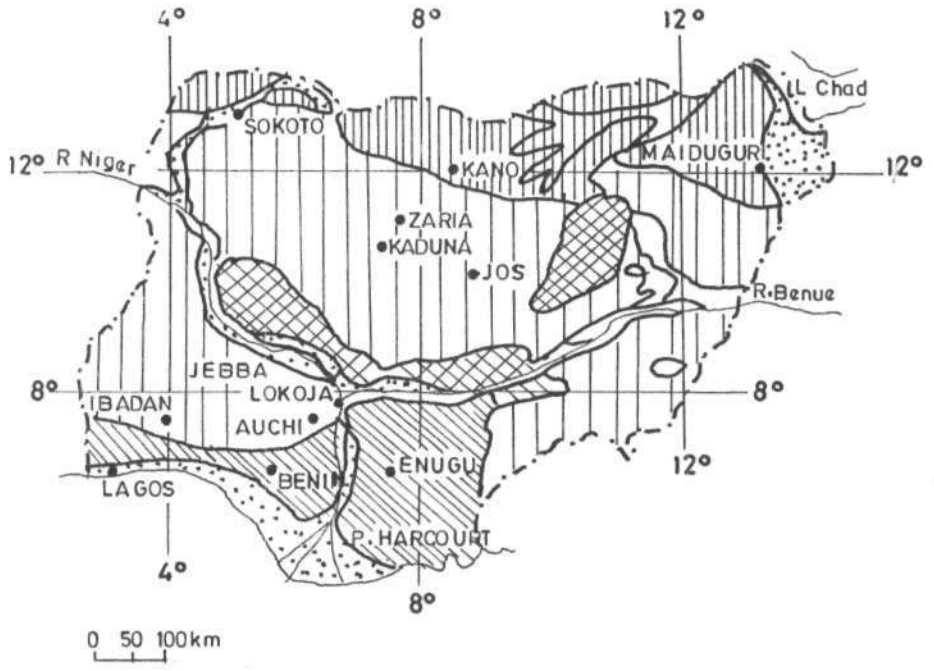



FIG. 2.1: GEOLOGICAL MAP OF NIGERIA (After Akintola, 1982 )




LEGEND

- Mainly ferruginuos tropical soils
- Ferralsols
- Ferrisols
- Weakly developed soils
- Hydromorphic and alluvial soils

FIG.2.2: SOIL MAP OF NIGERIA ( After Areola, 1982 )

## *2.2 LABORATORY TESTING*

### *2.2.1 X-Ray Diffraction and Differential Thermal Analysis*

The X-ray diffraction (XRD) analysis was performed on the soil fraction passing B.S. No 200 sieve. The powdered material was placed in a beam of X-rays which was diffracted through by the crystal lattice of the soil sample. The X-ray diffractograph is shown in Fig. 2.3 and indicates the type of minerals present in the soil. Kaolinite seems to be the predominant mineral present and was detected at reflections of 1.88, 2.39, 2.58, and 3.51Å. There is combination of quartz and Kaolionite at 3.51 and 2.20Å . Attapulgite was confirmed by 4.672 and 1.58Å reflections

The differential thermal analysis (DTA) is a technique of recording the difference in temperature between a substance and a reference material against either time or temperature as the two specimens are subjected to identical temperature regimes in an environment heated or cooled at a controlled rate (ASTM E 473, E37). The DTA was performed on the soil fraction passing BS No. 200 sieve using calcinated alumina as the reference. Fig. 2.4 shows that a high endothermic peak was obtained at 620°c while a dehydroxylation or exothermic peak occurred between 760°c and 820°c. This agrees with the range for Kaolin materials obtained by Dumbleton (1963).

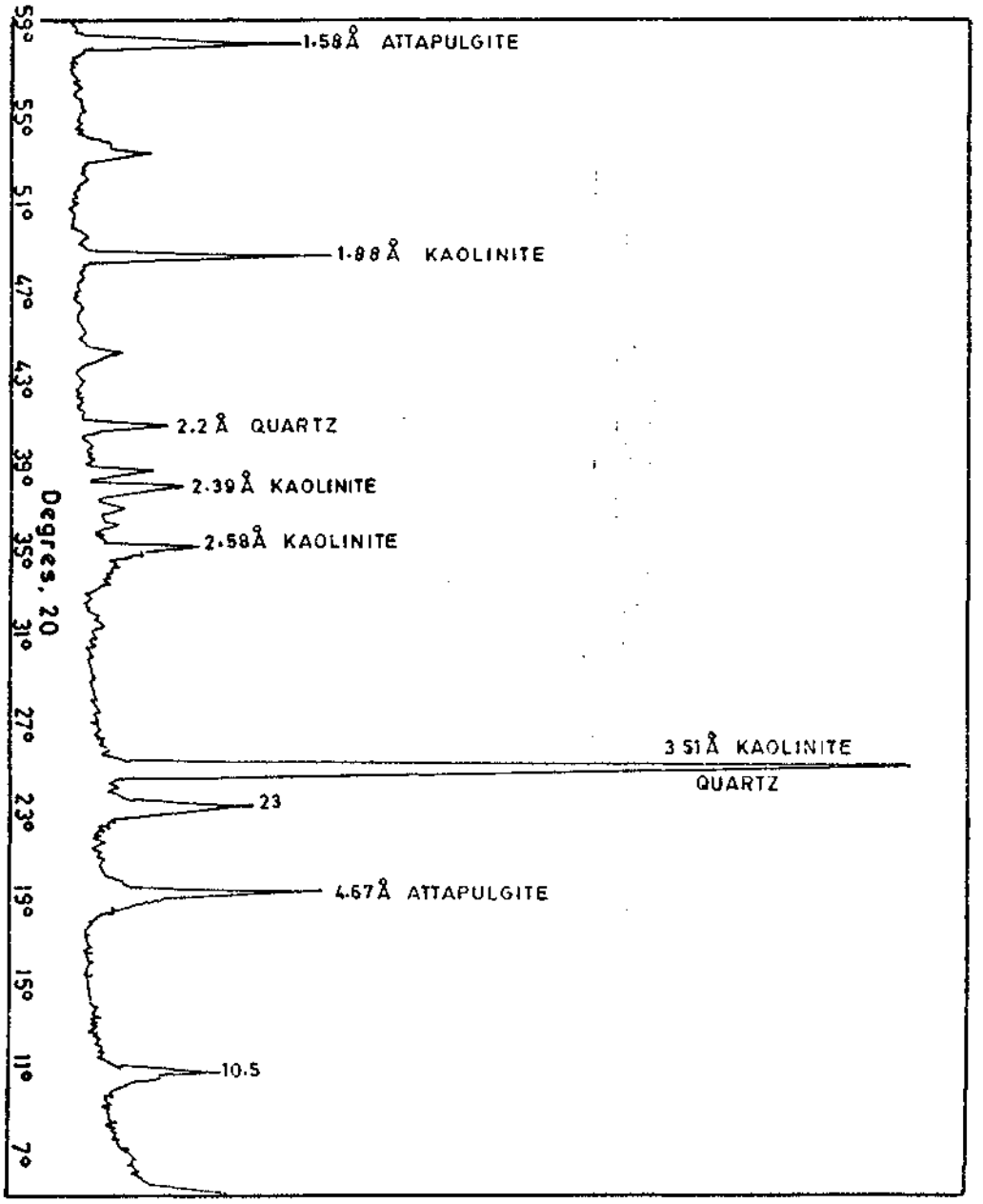



FIG. 2·3 : X-RAY DIFFRACTOGRAPH FOR SOIL FRACTION PASSING BS NO 200

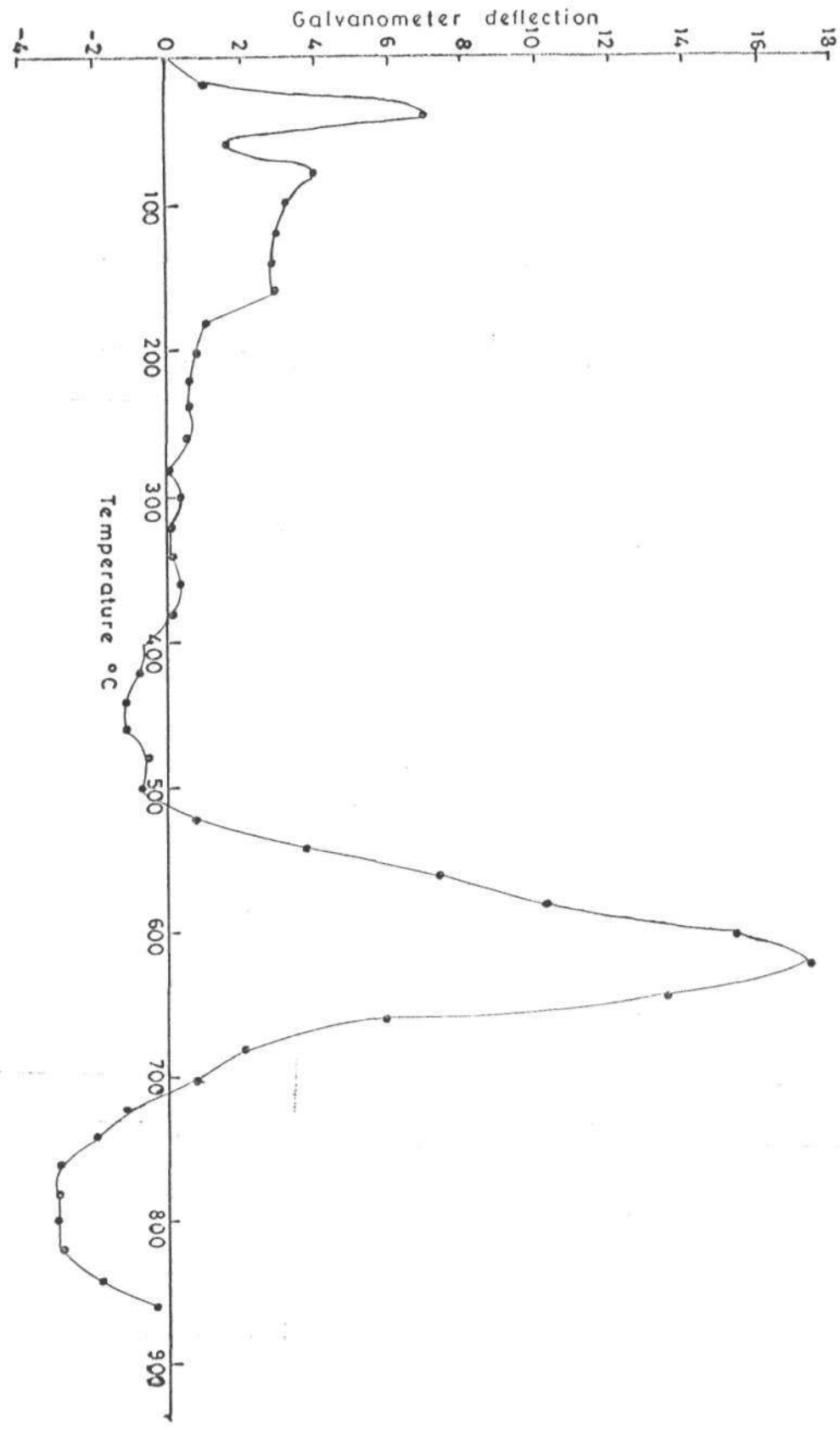



FIG. 2.4 : DIFFERENTIAL THERMOGRAM FOR SOIL PASSING BS NO 200 SIEVE

### *2.2.2 Natural Moisture Content*

The freshly dug sample was placed in two metal containers of known weight and weighed. They were then placed in a drying oven at a controlled temperature of between 105°c to 110°c and left for 24 hours. The moisture content is expressed as

$$W = \frac{W_W - W_d}{W_d - W_c} 100\%$$

Where W = moisture content (%) $W_c$ = weight of container (g)

$W_d$ = weight of container and dry soil (g) $W_w$ = weight of container and wet soil (g)

The procedure for oven drying soil specimens is in accordance with BS 1377: (1990) Test 1A. The average moisture content is shown in Table 2.1.

### *2.2.3 Specific Gravity*

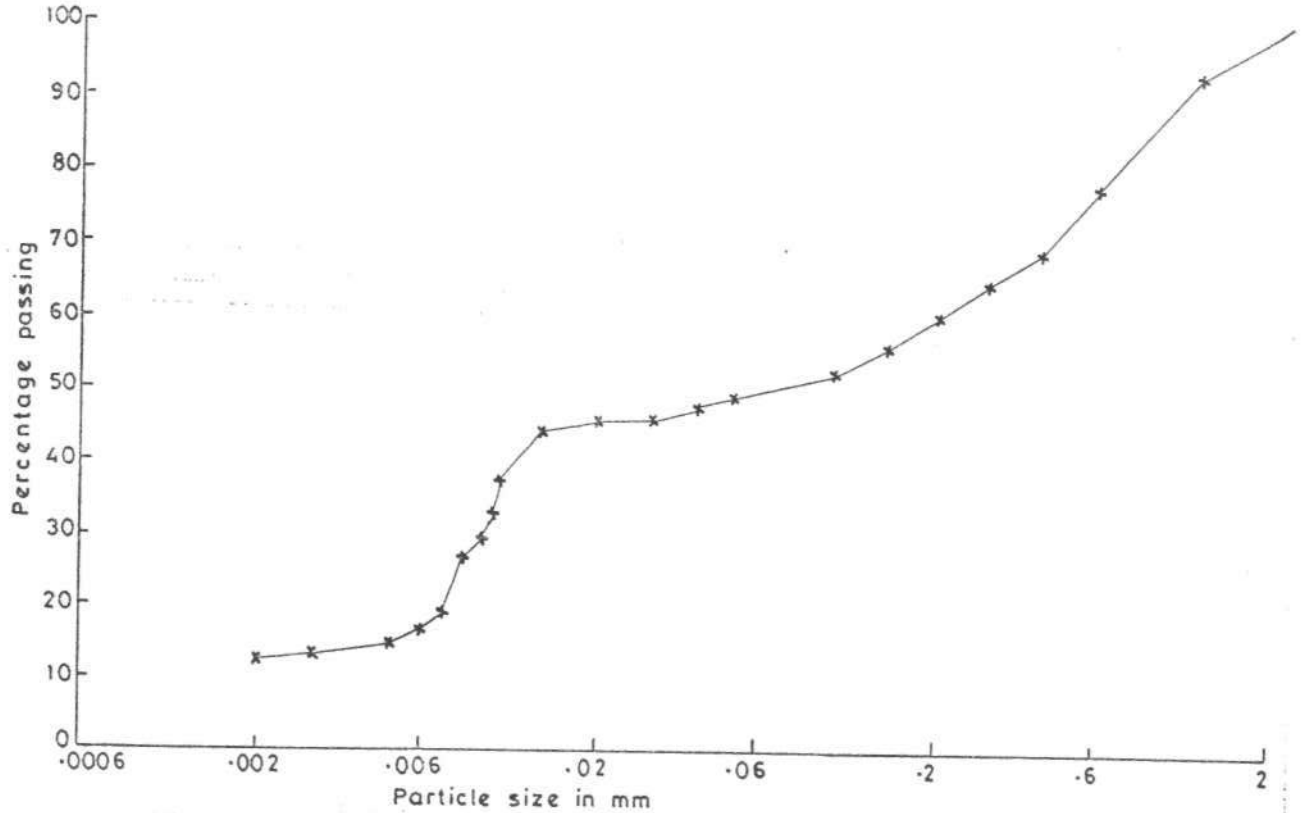
The specific gravity of the sample w as carried out in accordance with BS 1377; (1990) Test 6B. Air dried sample was placed a 50ml density bottle with a stopper and weighed ($M_2$) water was then topped in the bottle and weighed ($M_3$). The bottle was emptied and washed clean and its weight full of water was recorded ($M_4$). The weight of the empty density bottle being ($M_1$), the specific gravity was expressed as

$$\rho_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

### *2.2.4 Particle Size Analysis*

The particles size analysis was carried out in accordance with BS 1377: (1990) Test 2D. A solution of sodium hexametaphosphate (the dispersing agent used) was prepared by dissolving 40g of the sodium hexametaphosphate in a litre of distilled water, 20ml of this solution was then used in each determination of the particle size. 50g of the soil was mixed with the given stabilizer content at the given optimum moisture content obtained from the compaction test results. The soil-stabilizer mixture was then washed into a 1000ml cylinder after its required elapse time and left in a temperature bath to attain a constant temperature. The cylinder was then removed and the palm placed squarely at the open end and agitated for 2 minutes. It was then placed on the table and the hydrometer inserted into the cylinder and readings of the hydrometer were recorded at 20 sec, 30sec, 1 min., 2 min., 5 min., 10 min., 30 min., 1 hour, 7 hours, 12 hours and 24 hours. The cylinder was completely emptied into the BS No. 200 sieve and the soil washed clean. The clean soil sample was then transferred to a container and dried in the drying oven.

The dried samples were then passed through a series of sieves with aperture sizes 1.18mm, 600, 425, 300, 212, 150 and 75$\mu$m. The percentage passing each sieve size was calculated. A graph was plotted consisting of course and fine materials which were obtained from the sieving and hydrometer analysis respectively. The distribution curve for the untreated soil is shown in Fig. 2.5.




FIG·2.5 : GRAIN SIZE DISTRIBUTION FOR UNTREATED LATERITE

### *2.2.5 Atterberg Limits*

The liquid limit test was performed on soil passing through sieve with aperture 425$\mu$ m. The soil was mixed with water on a flat glass plate and placed in the bowl of the Casagrande apparatus and pressed from the middle outwards to prevent air being trapped. It was then cut with a grooving tool into two equal halves, from the hinge of the bowl to the opposite edge. The crank handle of the Casagrande apparatus was turned until the groove formed in the bowl closed. The number of blows required to close the groove was recorded and the moisture content determined as prescribed by BS 1377; (1990) Test 1A. The same procedure was repeated for varying blows such that it was spaced between 10 and 50 and two counts performed on each side of 25.

The results were plotted on a semi- logarithmic chart with moisture content as ordinate and the corresponding number of blows as abscissa. The moisture content at 25 blows was read off and its moisture content value gave the liquid limit of the soil sample or the liquid limit of the soil stabilizer moisture.

The plastic limit was performed on a little of the soil taken from the bulk used in the liquid limit test. The sample was rolled into balls between the palms and divided into 4 parts; each part was then rolled into threads on the glass plate until threads about 3mm diameter began to crumble. The first crumbling point is the plastic limit. The crumbled threads were placed in a moisture content container and the moisture content determined as explained in paragraph 2.2.2. The value of the moisture content obtained gave the value of the plastic limit.

The plasticity index is the difference between the liquid limit and the plastic limit, that is,

$$PI = LL - PL$$

The average results of the Atterberg limits are recorded in Table 2.1 for the unstabilized laterite and Tables 2.2, 2.3, 2.4 and 2.5, for the stabilized laterite

TABLE 2.1 Test Results For Untreated Laterite

| | |
|---|---|
| COLOUR | REDDISH BROWN |
| Specific gravity | 2.65 |
| Natural Moisture Content, % | 7.10 |
| Liquid limit, % | 44.0 |
| Plastic limit, % | 24.0 |
| Plasticity Index, % | 20.0 |
| Linear shrinkage, % | 9.5 |
| Percentage Passing BS No. 200 sieve, % | 52.0 |
| Group Index, | 6.0 |
| Coefficient of Uniformity, Cu | 1.40 |
| Coefficient of Curvatucre Cc, | 0.98 |
| AASHTO Classification, | A-7-6 |
| Maximum Dry Density (MOD) Proctor, $Mg/m^3$ | 1.84 |
| Optimum Moisture content (OMC) Proctor, % | 19.1 |
| Maximum Dry Density (MDD) West African $Mg/m^3$ | 1.89 |
| Optimum Moisture Content (OMC) West African, % | 15.7 |
| Califorina Bearing Ratio (CBR) Proctor Soaked, % | 4.0 |
| Califorina Bearing Ratio (CBR) Proctor Unsoaked, % | 8.0 |
| Califorina Bearing Ratio (CBR) West African, Soaked, % | 8.0 |
| Califorina Bearing Ratio (CBR) Proctor Unsoaked, % | 13.0 |
| Unconfined Compressive Strength (U.C.S.) Proctor, $KN/m^2$ | 310.0 |
| Unconfined Compressive Strength (U.C.S.) West African, $KN/m^2$ | 400.0 |

Table 2.2: Effect Of Elapse Time After Mixing On The Atterberg Limits For Cement Stabilized Laterite For Proctor Compaction.

| Cement Content (%) | 3 | | | 5 | | | 8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Elapse Time (Hrs) | LL (%) | PL (%) | PI (%) | LL (%) | PL (%) | PI (%) | LL (%) | PL (%) | PI (%) |
| 0.0 | 39.8 | 29.5 | 10..3 | 40.0 | 29.0 | 11.0 | 43.6 | 31.0 | 17.6 |
| 0.5 | 39.2 | 24.5 | 14.7 | 39.0 | 30.0 | 10.2 | 42.7 | .32.0 | 10.7 |
| 1.0 | 38.5 | 24.4 | 14.1 | 39.6 | 30.0 | 9.6 | 41.7 | 32.4 | 9.3 |
| 1.5 | 37.0 | 24.0 | 13.0 | 39.4 | 30.3 | 9.1 | 40.5 | 32.4 | 8.1 |
| 2.0 | 37.0 | 24.0 | 13.0 | 39.3 | 31.0 | 8.3 | 39.3 | 33.0 | 6.3 |
| 2.5 | 36.4 | 24.0 | 12.4 | 38.7 | 32.0 | 6.7 | 38.6 | .34.0 | 4.6 |
| 3.0 | 35.2 | 25.3 | 12.2 | 37.4 | 32.0 | 5.4 | 37.6 | 33.8 | 3.8 |

TABLE 2.3 Effect Of Elapse Time After Mixing On The Atterberg Limits For Cement Stabilized Laterite For West African Compaction.

| Cement Content (%) | 3 | | | 5 | | | 8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Elapse time (Hrs) | LL (%) | PL (%) | PI (%) | LL (%) | PL (%) | PI (%) | LL (%) | PL (%) | PI (%) |
| 0.0 | 41.7 | 24.9 | 16.8 | 38.7 | 28.0 | 10.7 | 40.8 | 32.4 | 8.4 |
| 0.5 | 41.0 | 25.6 | 15.4 | 38.2 | 28.0 | 10.2 | 39.0 | 32.4 | 6.6 |
| 1.0 | 40.0 | 25.9 | 14.1 | 37.7 | 28.0 | 9.7 | 37.8 | 32.4 | 5.4 |
| 1.5 | 39.7 | 26.9 | 12.8 | 37.4 | 28.2 | 9.2 | 36.6 | 32.4 | 4.2 |
| 2.0 | 39.3 | 27.8 | 11.5 | 37.1 | 28.7 | 8.4 | 36.3 | 32.4 | 3.9 |
| 2.5 | 39.0 | 28.4 | 10.6 | 37.0 | 29.4 | 7.6 | 36.0 | 32.8 | 3.2 |
| 3.0 | 38.8 | 29.1 | 9.7 | 37.0 | 30.2 | 6.8 | 36.0 | 33.0 | 3.0 |

TABLE 2.4 Effect of Elapse time after mixing on the Atterberg limits for lime stabilized laterite for Proctor Compaction.

| Lime Content (%) | 3 | | | 5 | | | 8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Elapse time (Hrs) | LL (%) | PL (%) | PI (%) | LL (%) | PL (%) | PI (%) | LL (%) | PL (%) | PI (%) |
| 0.0 | 34.6 | 24.8 | 9.8 | 31.2 | 25.5 | 5.5 | 30.0 | 27.0 | 3.0 |
| 0.5 | 34.4 | 25.4 | 8.7 | 30.6 | 25.5 | 5.1 | 29.5 | 27.2 | 2.3 |
| 1.0 | 34.2 | 26.6 | 7.6 | 30.5 | 25.5 | 5.0 | 29.5 | 27.4 | 2.1 |
| 1.5 | 34.0 | 27.5 | 6.5 | 30.0 | 25.5 | 4.5 | 29.0 | 27.4 | 1.6 |
| 2.0 | 33.0 | 28.2 | 4.8 | 30.0 | 26.0 | 4.0 | 29.0 | 27.5 | 1.5 |
| 2.5 | 32.0 | 29.2 | 2.8 | 29. 5 | 26.0 | 3.5 | 28.0 | 27.5 | .0.5 |
| 3.0 | 30.6 | 30.0 | 0.6 | 29.2 | 26.0 | 3.2 | 28.0 | 27.5 | .0.5 |

TABLE 2.5 Effect of Elapse time after mixing on the Atterberg limits for lime stabilized laterite for West African Compaction.

| Lime Content (%) | 3 | | | 5 | | | 8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Elapse time (Hrs) | LL (%) | PL (%) | PI (%) | LL (%) | PL (%) | PI (%) | LL (%) | PL (%) | PI (%) |
| 0.0 | 40.6 | 24.5 | 16.1 | 39.2 | 25.0 | 14.2 | 39.0 | 26.5 | 12.5 |
| 0.5 | 40.3 | 26.8 | 13.5 | 39.0 | 25.2 | 13.8 | 38.4 | 26.5 | 11.9 |
| 1.0 | 39.7 | 29.5 | 10.2 | 39.0 | 25.4 | 13.6 | 38.0 | 26.5 | 11.5 |
| 1.5 | 39.2 | 31.4 | 7.8 | 37.6 | 27.2 | 10.4 | 36.6 | 26.6 | 10.0 |
| 2.0 | 38.2 | 32.6 | 5.6 | 36.4 | 28.8 | 7.6 | 34.7 | 26.6 | 8.1 |
| 2.5 | 37.0 | 33.3 | 3.7 | 34.4 | 30.0 | 4.4 | 32.0 | 26.6 | 5.4 |
| 3.0 | 35.8 | 34.0 | 1.8 | 32.2 | 31.0 | 1.5 | 29.0 | 28.0 | 1.0 |

### *2.2.6 Compaction Tests*

The Compaction test was carried out using the standard Proctor in accordance with BS 1924: 1990 test 3 and the West African Compaction in accordance with the Nigerian general specification for Roadworks and Bridges (1970).

Five batches of soil passing 20mm sieve each weighing 2.5kg were placed in mixing again with about 3 - 4% water and compacted in 3 layers in a BS mould of volume 100 $cm^3$ with 27 blows per layer using the 2.5kg rammer. This is the Standard Proctor Compaction. At the West African Compative level, 18 blows per layer were applied for 3 layers using a 4.5kg rammer. For each case, the extension to the mould was removed and the compacted specimen trimmed to level off carefully with the top of the mould using a straight edge. The mould containing the soil was weighed to the nearest 1g ($W_2$). The empty mould was also weighed ($W_1$). The soil sample was then removed from the mould using an extruder and some of it was placed in moisture content containers for the determination of the moisture content in accordance with BS 1377 (1990) Test 1A.

The procedure was repeated each time increasing the percentage of water added to the mixture. Until at about two or three weighings lower than the maximum weight obtained from the soil plus mould ($W_2$). The calculation was carried out as follows:

$$BD = \frac{W_2 - W_1}{1000}$$

$$DD = \frac{1000 \times BD}{100 + W}$$

Where BD = Bulk density DD = Dry density W = Moisture content

The results of the compaction test was plotted with the dry density as ordinate and the moisture content as abscissa. The peak value of the curve was the maximum dry Density

(MDD) and the corresponding value of the moisture content was the optimum moisture content (OMC). The results of the compaction tests are recorded in Tables 2.1 for the natural soil and Tables 2.6, 2.7, 2.8 and 2.9 for the stabilized laterite.

TABLE 2.6 Effect of Elapse time after mixing on Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for cement stabilized laterite using Proctor Compaction.

| Cement Content (%) | 3 | | 5 | | 8 | |
|---|---|---|---|---|---|---|
| Elapse Time (Hrs) | MDD ($Mg/m^3$) | OMC (%) | MDD ($Mg/m^3$) | OMC (%) | MDD ($Mg/m^3$) | OMC (%) |
| 0.0 | 1.805 | 17.0 | 1.797 | 19.2 | 1.818 | 18.6 |
| 0.5 | 1.757 | 16.4 | 1.744 | 17.8 | 1.740 | 18.0 |
| 1.0 | 1.730 | 16.1 | 1.717 | 17.6 | 1.705 | 17.8 |
| 1.5 | 1.714 | 15.4 | 1.697 | 17.5 | 1.671 | 16.4 |
| 2.0 | 1.700 | 14.9 | 1.683 | 17.0 | 1.646 | 15.6 |
| 2.5 | 1.690 | 13.8 | 1.670 | 15.9 | 1.630 | 14.9 |
| 3.0 | 1.684 | 13.0 | 1.66.1 | 15.7 | 1.614 | 14.9 |

TABLE 2.7 Effect of Elapse time after mixing on maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for cement stabilized laterite using for West African Compaction.

| Cement Content (%) | 3 | | 5 | | 8 | |
|---|---|---|---|---|---|---|
| Elapse time (Hrs) | MDD ($Mg/m^3$) | OMC (%) | MDD ($Mg/m^3$) | OMC (%) | MDD ($Mg/m^3$) | OMC (%) |
| 0.0 | 1.866 | 19.1 | 1.861 | 17.8 | 1.896 | 16.3 |
| 0.5 | 1.859 | 17.5 | 1.859 | 16.9 | 1.833 | 13.8 |
| 1.0 | 1.845 | 17.0 | 1.854 | 16.8 | 1.773 | 13.5 |
| 1.5 | 1.843 | 16.8 | 1.827 | 16.6 | 1.743 | 13.5 |
| 2.0 | 1.822 | 16.2 | 1.824 | 16.4 | 1.714 | 13.4 |
| 2.5 | 1.816 | 16.0 | 1.821 | 16.3 | 1.709 | 13.3 |
| 3.0 | 1.794 | 15.5 | 1.792 | 15.5 | 1.708 | 13.0 |

TABLE 2.8 Effect of Elapse time after mixing on Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for Lime stabilized laterite using for Proctor Compaction.

| Lime Content (%) | 3 | | 5 | | 8 | |
|---|---|---|---|---|---|---|
| Elapse time (Hrs) | MDD ($Mg/m^3$) | OMC (%) | MDD ($Mg/m^3$) | OMC (%) | MDD ($Mg/m^3$) | OMC (%) |
| 0.0 | 1.747 | 17.8 | 1.789 | 18.3 | 1.734 | 20.3 |
| 0.5 | 1.703 | 16.8 | 1.710 | 17.6 | 1.693 | 16.0 |
| 1.0 | 1.693 | 16.5 | 1.706 | 16.9 | 1.679 | 15.8 |
| 1.5 | 1.679 | 16.4 | 1.687 | 16.2 | 1.650 | 15.6 |
| 2.0 | 1.677 | 16.2 | 1.654 | 15.9 | 1.633 | 15.0 |
| 2.5 | 1.673 | 16.0 | 1.641 | 15.5 | 1.619 | 14.9 |
| 3.0 | 1.665 | 15.5 | 1.624 | 15.3 | 1.607 | 14.8 |

TABLE 2.9 Effect of Elapse time after mixing on Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for Lime stabilized laterite using for Proctor Compaction.

| Lime Content (%) | 3 | | 5 | | 8 | |
|---|---|---|---|---|---|---|
| Elapse time (Hrs) | MDD ($Mg/m^3$) | OMC (%) | MDD ($Mg/m^3$) | OMC (%) | MDD ($Mg/m^3$) | OMC (%) |
| 0.0 | 1.803 | 17.7 | 1.819 | 18.2 | 1.500 | 18.3 |
| 0.5 | 1.785 | 16.6 | 1.795 | 17.0 | 1.745 | 16.8 |
| 1.0 | 1.775 | 16.6 | 1.772 | 16.0 | 1.735 | 16.2 |
| 1.5 | 1.77 | 16.5 | 1.757 | 16.0 | 1.726 | 15.7 |
| 2.0 | 1.765 | 16.5 | 1.748 | 15.6 | 1.723 | 15.1 |
| 2.5 | 1.763 | 15.4 | 1.741 | 15.5 | 1.713 | 14.4 |
| 3.0 | 1.759 | 15.0 | 1.741 | 15.3 | 1.711 | 12.8 |

### *2.2.7 Unconfined Compressive Strength*

Each specimen for the test was prepared by mixing 3kg of soil with the stabilizer of known percentage and at the Optimum moisture content of their various percentages obtained

from the compaction test results. The mixture was compacted into cubic moulds 10cm x 10cm x 10cm using the same compactive levels as in the compaction tests.

Each specimen was trimmed off carefully using a straight edge. They were removed from the mould and wax-cured. A set of the specimen was allowed to wax cure for 7 days, another set for 14 days while the last batch was wax cured for 7 days and thereafter de-waxed and soaked in water for another 7 days.

The specimens were then placed on the platens of the universal testing machine and the cubes crushed at the rate of 1723kn/m$^2$ per minute until the failure load for each specimen was recorded. The compressive stress for each specimen was calculated as follows:

$$\text{Compressive stress} = \frac{Failure\ Load}{Area\ of\ Surface} \ (\text{KNm}^{-2})$$

The results are recorded in Tables 2.1 for untreated laterite and in Tables 2.10, 2.11, 2.12 and 2.13 for the stabilized laterite.

TABLE 2.10: Effect of Elapse time after mixing on the UCS of Cement Stabilized laterite for Proctor.

| Cement Content (%) | 3 | | | 5 | | | 8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Elapse Time (Hrs) | 7 days Unsoaked (KN/m$^2$) | 7 days Unsoaked + 7 days Soaked (KN/m$^2$) | 14 days Unsoaked (KN/m$^2$) | 7 days Unsoaked (KN/m$^2$) | 7 days Unsoaked + 7 days Soaked (KN/m$^2$) | 14 days Unsoaked (KN/m$^2$) | 7 days Unsoaked (KN/m$^2$) | 7 days Unsoaked + 7 days Soaked (KN/m$^2$) | 14 days Unsoaked (KN/m$^2$) |
| 0.0 | 1,025 | 450 | 1,325 | 1,100 | 475 | 1,575 | 1,275 | 600 | 1,775 |
| 0.5 | 900 | 385 | 1,250 | 1,080 | 440 | 1,500 | 1,200 | 560 | 1,680 |
| 1.0 | 825 | 325 | 1,225 | 1,000 | 425 | 1,425 | 1,175 | 500 | 1,575 |
| 1.5 | 770 | 320 | 1,120 | 980 | 400 | 1,340 | 1,020 | 480 | 1,585 |
| 2.0 | 725 | 300 | 1,000 | 950 | 375 | 1,250 | 975 | 400 | 1,400 |
| 2.5 | 660 | 280 | 910 | 900 | 300 | 1,170 | 910 | 380 | 1,320 |
| 3.0 | 650 | 250 | 825 | 725 | 275 | 1,100 | 875 | 375 | 1,225 |

TABLE 2.11: Effect of the Elapse time after mixing on the UCS of Cement Stabilized laterite for West African Compaction.

| Cement Content (%) | 3 | | | 5 | | | 8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Elapse Time (Hrs) | 7 days Unsoaked ($KN/m^2$) | 7 days Unsoaked + 7 days Soaked ($KN/m^2$) | 14 days Unsoaked ($KN/m^2$) | 7 days Unsoaked ($KN/m^2$) | 7 days Unsoaked + 7 days Soaked ($KN/m^2$) | 14 days Unsoaked ($KN/m^2$) | 7 days Unsoaked ($KN/m^2$) | 7 days Unsoaked + 7 days Soaked ($KN/m^2$) | 14 days Unsoake ($KN/m^2$) |
| 0.0 | 1,100 | 500 | 1,475 | 1,425 | 600 | 1,725 | 1,650 | 725 | 2,250 |
| 0.5 | 1,050 | 450 | 1,400 | 1,350 | 575 | 1,650 | 1,550 | 620 | 2,125 |
| 1.0 | 1,025 | 425 | 1,300 | 1,250 | 525 | 1,575 | 1,425 | 600 | 2,025 |
| 1.5 | 950 | 375 | 1,250 | 1,200 | 475 | 1,450 | 1,350 | 550 | 1,950 |
| 2.0 | 900 | 325 | 1,225 | 1,150 | 425 | 1,400 | 1,200 | 500 | 1,875 |
| 2.5 | 850 | 300 | 1,150 | 1,050 | 400 | 1,325 | 1,150 | 470 | 1,800 |
| 3.0 | 775 | 275 | 975 | 925 | 275 | 1,275 | 1,125 | 425 | 1,650 |

TABLE 2.12: Effect of the Elapse time after mixing on the UCS of Lime Stabilized laterite for Procotor Compaction.

| Lime Content (%) | 3 | | | 5 | | | 8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Elapse Time (Hrs) | 7 days Unsoaked ($KN/m^2$) | 7 days Unsoaked + 7 days Soaked ($KN/m^2$) | 14 days Unsoaked ($KN/m^2$) | 7 days Unsoaked ($KN/m^2$) | 7 days Unsoaked + 7 days Soaked ($KN/m^2$) | 14 days Unsoaked ($KN/m^2$) | 7 days Unsoaked ($KN/m^2$) | 7 days Unsoaked + 7 days Soaked ($KN/m^2$) | 14 days Unsoak ($KN/m^2$) |
| 0.0 | 575 | 375 | 850 | 800 | 475 | 1,050 | 875 | 450 | 1,075 |
| 0.5 | 540 | 300 | 800 | 700 | 460 | 950 | 850 | 420 | 990 |
| 1.0 | 475 | 275 | 775 | 675 | 425 | 900 | 825 | 400 | 950 |
| 1.5 | 460 | 220 | 740 | 620 | 380 | 875 | 800 | 360 | 910 |
| 2.0 | 425 | 200 | 625 | 550 | 322 | 775 | 725 | 325 | 850 |
| 2.5 | 400 | 185 | 540 | 500 | 260 | 725 | 680 | 280 | 820 |
| 3.0 | 325 | 175 | 450 | 475 | 225 | 700 | 625 | 250 | 725 |

TABLE 2.13: Effect of the Elapse time after mixing on the UCS of Lime Stabilized laterite for West African Compaction.

| Lime Content (%) | 3 | | | 5 | | | 8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Elapse Time (Hrs) | 7 days Unsoaked ($KN/m^2$) | 7 days Unsoaked + 7 days Soaked ($KN/m^2$) | 14 days Unsoaked ($KN/m^2$) | 7 days Unsoaked ($KN/m^2$) | 7 days Unsoaked + 7 days Soaked ($KN/m^2$) | 14 days Unsoaked ($KN/m^2$) | 7 days Unsoaked ($KN/m^2$) | 7 days Unsoaked + 7 days Soaked ($KN/m^2$) | 14 days Unsoaked ($KN/m^2$) |
| 0.0 | 800 | 365 | 975 | 825 | 725 | 1,475 | 1,025 | 600 | 1,275 |
| 0.5 | 675 | 365 | 900 | 800 | 700 | 1,440 | 980 | 520 | 1,095 |
| 1.0 | 625 | 365 | 875 | 725 | 525 | 1,400 | 900 | 450 | 950 |
| 1.5 | 550 | 340 | 825 | 650 | 495 | 1,260 | 860 | 420 | 900 |
| 2.0 | 525 | 325 | 800 | 625 | 450 | 1,150 | 825 | 375 | 875 |
| 2.5 | 450 | 320 | 775 | 600 | 400 | 1,100 | 810 | 340 | 850 |
| 3.0 | 425 | 300 | 750 | 550 | 325 | 1,025 | 800 | 300 | 800 |

### *2.2.5. California Bearing Ratio (CBR)*

The California Bearing ration was carried out in accordance with BS 1924; (1990) Test 13 and the West African Compaction, with slight modification, according to the Nigerian General specification for Roadworks and Bridges (1970) clause 6228.

The moulds were arranged in place and 5kg of soil sample was weighed into mixing trays and mixed with the required stabilizer content thoroughly and at the OMC. The soil was compacted in 3 levels in the CBR mould with 62 blows applied per layer using the 2.5kg rammer for Proctor Compaction, For the West African Compaction the mixture was compacted in 5 layers in the CBR mould with 25 blows applied per layer using the 4.5kg rammer.

The soil specimen in the mould was trimmed off carefully using a straight edge upon removal of the mould extension. The bottom cover of the mould was removed and both faces of the mould were covered with wax. The wax cured samples were left to cure for 6 days in the humidity room at a temperature of 20 ± 2°C and 100% humidity. After 6 days they were de-waxed and soaked in water for 24 hours. These are the unsoaked specimens. The other set was soaked in water immediately after compaction and trimming off excess soil, for 6 days. Thereafter, the specimens were air cured for 24 hours before testing. The California Bearing Ratio machine was thoroughly cleaned and the mould containing the specimen with the base plate in position was placed on the lower plate. Surcharge rings were placed on the exposed surface and carefully arranged such that the plunger penetrated at a uniform rate of 1.3 mm/min. according to AASHTO specification until the specimen failed. Later it was inverted and tested again.

A force - penetration curve was drawn with the values of the force plotted on the ordinate and the penetration on the abscissa. A correction was made where the curve was concave upwards by drawing a tangent to the curve of the point of greatest slope. The point where this tangent cuts the penetration axis served as the new origin.

The value of the force of penetration of 2.5mm and 5.0mm were read off. The CBR was expressed as

$$\text{CBR} = \frac{\text{measured force}}{\text{standand force}} \times 100\%$$

The results of the CBR is recorded as the mean of the top and bottom results if that mean falls within 10% of the top and bottom values respectively otherwise the higher CBR value obtained at penetration of 1.3cm and 5.0cm is recorded respectively.

The results obtained are recorded in Table 2.1 for untreated laterite on Tables 2.14, 2.15, 2.16 and 2.17 for stabilized laterite.

TABLE: 2.14: Effect of Elapse time after mixing on the CBR of Cement Stabilized laterite using Proctor Compaction.

| Cement Content (%) | 3 | | 5 | | 8 | |
|---|---|---|---|---|---|---|
| Elapse time (Hrs) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) |
| 0.0 | 63 | 61 | 90 | 87 | 100 | 98 |
| 0.5 | 38 | 46 | 91 | 77 | 92 | 88 |
| 1.0 | 33 | 44 | 88 | 67 | 98 | 82 |
| 1.5 | 29 | 39 | 80 | 56 | 88 | 75 |
| 2.0 | 24 | 29 | 79 | 52 | 77 | 68 |
| 2.5 | 23 | 25 | 76 | 49 | 67 | 64 |
| 3.0 | 23 | 21 | 72 | 39 | 58 | 60 |

TABLE: 2.15: Effect of Elapse time after mixing on the CBR of Cement Stabilized laterite using West African Compaction.

| Cement Content (%) | 3 | | 5 | | 8 | |
|---|---|---|---|---|---|---|
| Elapse time (Hrs) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) |
| 0.0 | 95 | 90 | 120 | 170 | 150 | 180 |
| 0.5 | 95 | 85 | 160 | 120 | 160 | 170 |
| 1.0 | 90 | 80 | 140 | 110 | 140 | 160 |
| 1.5 | 70 | 75 | 130 | 110 | 120 | 140 |
| 2.0 | 60 | 65 | 120 | 100 | 110 | 125 |
| 2.5 | 55 | 60 | 110 | 98 | 180 | 90 |
| 3.0 | 50 | 60 | 95 | 97 | 90 | 60 |

TABLE: 2.16: Effect of Elapse time after mixing on the CBR of Lime Stabilized laterite using Proctor Compaction.

| Lime Content (%) | 3 | | 5 | | 8 | |
|---|---|---|---|---|---|---|
| Elapse time (Hrs) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) |
| 0.0 | 52 | 66 | 58 | 70 | 65 | 75 |
| 0.5 | 49 | 65 | 50 | 64 | 58 | 65 |
| 1.0 | 46 | 64 | 45 | 60 | 53 | 60 |
| 1.5 | 45 | 60 | 40 | 55 | 46 | 50 |
| 2.0 | 43 | 57 | 35 | 50 | 40 | 40 |
| 2.5 | 42 | 52 | 32 | 46 | 35 | 35 |
| 3.0 | 42 | 47 | 30 | 42 | 30 | 29 |

TABLE: 2.17: Effect of Elapse time after mixing on the CBR of Lime Stabilized laterite using West African Compaction.

| Lime Content (%) | 3 | | 5 | | 8 | |
|---|---|---|---|---|---|---|
| Elapse time (Hrs) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) |
| 0.0 | 58 | 86 | 65 | 88 | 70 | 90 |
| 0.5 | 56 | 83 | 57 | 77 | 59 | 70 |
| 1.0 | 54 | 79 | 52 | 70 | 54 | 65 |
| 1.5 | 53 | 75 | 47 | 64 | 52 | 65 |
| 2.0 | 51 | 72 | 43 | 59 | 49 | 65 |
| 2.5 | 50 | 71 | 39 | 56 | 40 | 65 |
| 3.0 | 48 | 70 | 35 | 53 | 44 | 65 |

TABLE: 2.17: Effect of Elapse time after mixing on the CBR of Lime Stabilized laterite using West African Compaction.

| Lime Content (%) | 3 | | 5 | | 8 | |
|---|---|---|---|---|---|---|
| Elapse time (Hrs) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) | Unsoaked (%) | Soaked (%) |
| 0.0 | 58 | 86 | 65 | 88 | 70 | 90 |
| 0.5 | 56 | 83 | 57 | 77 | 59 | 70 |
| 1.0 | 54 | 79 | 52 | 70 | 54 | 65 |
| 1.5 | 53 | 75 | 47 | 64 | 52 | 65 |
| 2.0 | 51 | 72 | 43 | 59 | 49 | 65 |
| 2.5 | 50 | 71 | 39 | 56 | 40 | 65 |
| 3.0 | 48 | 70 | 35 | 53 | 44 | 65 |

# CHAPTER THREE

## DISCUSSION OF TEST RESULTS

### *3.1 PRELIMINARY TESTS*

The results obtained from the preliminary tests performed on the soil are presented in Table 2.1. The X-ray diffractograph in Fig. 2.3 show that the predominant mineral present in the soil is Kaolinite with a peak of 3.51A°. The Differential thermogram shown in Fig. 2.4 with an endothermic peak at 620°C indicates that the predominant mineral present in the soil is kaolinite. This is in agreement with Dumbleton (1963). The grain size distribution curve for the natural soil is shown in figure 2.4. From the grain size distribution curve, the coefficient of uniformity of 1.4 indicates that the soil particles are almost of the same diameter. The coefficient of curvature of 0.98 indicates that the curve is irregular. The soil is classified as an A-7-6 soil according to the AASHTO classification system.

With reference to the Nigerian General specification for Roads and Bridges (1970), the material is unsuitable for direct use as a base or sub-base course. Using both the Millard and O'Reilly (1965) product of plasticity index and the percentage passing sieve 425μm not exceeding 1000 as well as the Highway Research Board (1943) suitability limits of 50% passing BS No. 200 sieve, 40% liquid limit and 18% plasticity index requirements, the soil can be described as being unsuitable for road construction purposes in its natural state. Furthermore, the low CBR values and the values of the 7 day unconfined compressive strength are indicative of a poor material. The cubes disintegrated after being immersed in water for; 72 hours. Consequently, the soil will require stabilization in order to be used for road construction purposes.

## *3.2 EFFECT OF ELAPSE TIME AFTER MIXING ON STABILIZED LATERITE*

### *3.2.1 Particle Size Distribution*

CEMENT STABILIZED SOIL: The grain size distribution 0.0 hour after mixing for 3%, 5% and 8% cement mixed at the OMC obtained from their various compaction tests results for Proctor Compaction are shown in Figure 3.1. The silt fraction at 3%, 5% and 8% cement content are 13%, 4% and 1% respectively. The variation of grain size distribution with elapse time after mixing for 3%, 5% and 8% cement content at the energy level of standard Proctor are shown in Figs 3.2 - 3.4. The grain size distributions for 0.0 hour after mixing for 3%, 5% and 8% cement content for West African Compaction are shown in figure 3.5. The clay fraction was also not detected after stabilization. At 3%, 5% and 8% cement content the silt fractions are 10%, 6% and 2% respectively. (See Fig. 3.2 - 3.4). The variation of grain size distribution with elapse time after mixing for 3%, 5% and 8% cement content for West African compaction are shown in Fig. 3.5 - 3.8. The shapes of the curves cement stabilized soil for Proctor and West African compactions are identical in the 0.06 - 2.0 mm particle diameter range. There is a significant change as from the 0.075mm particle diameter indicating that the reaction taking place in the soil is between the clay minerals present in the soil and cement. The cement particles act as nucleus to which the soil particles adhere. As the cement content in the soil is increased, the quantity of free silt and clay is progressively reduced and a coarser material is formed. This is in agreement with 0'Flaherty (1974).

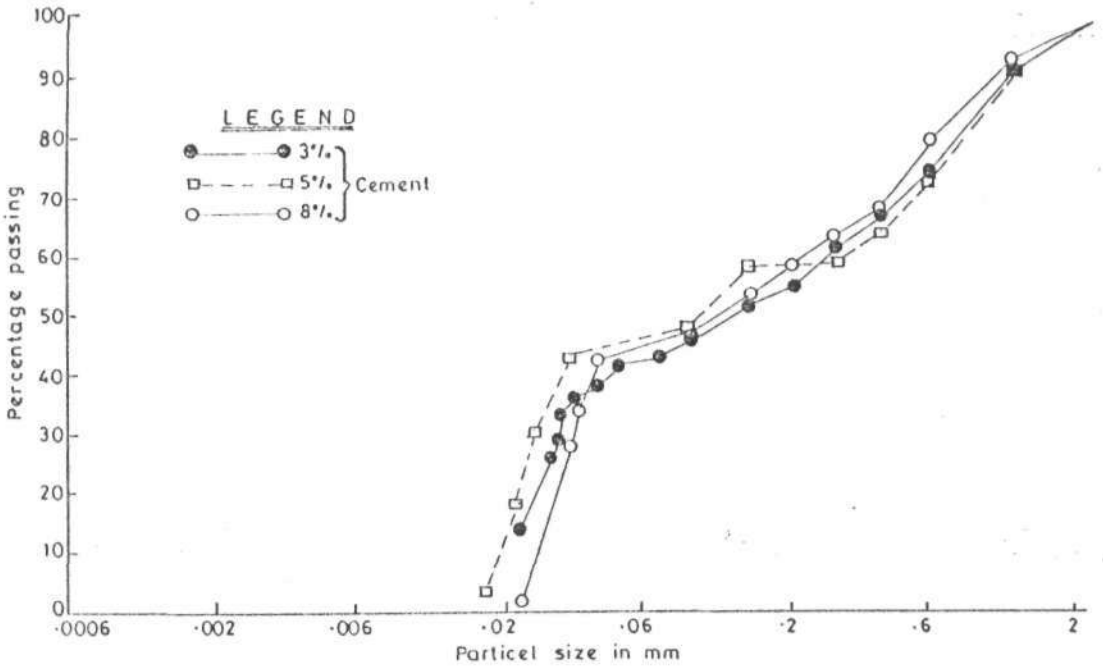
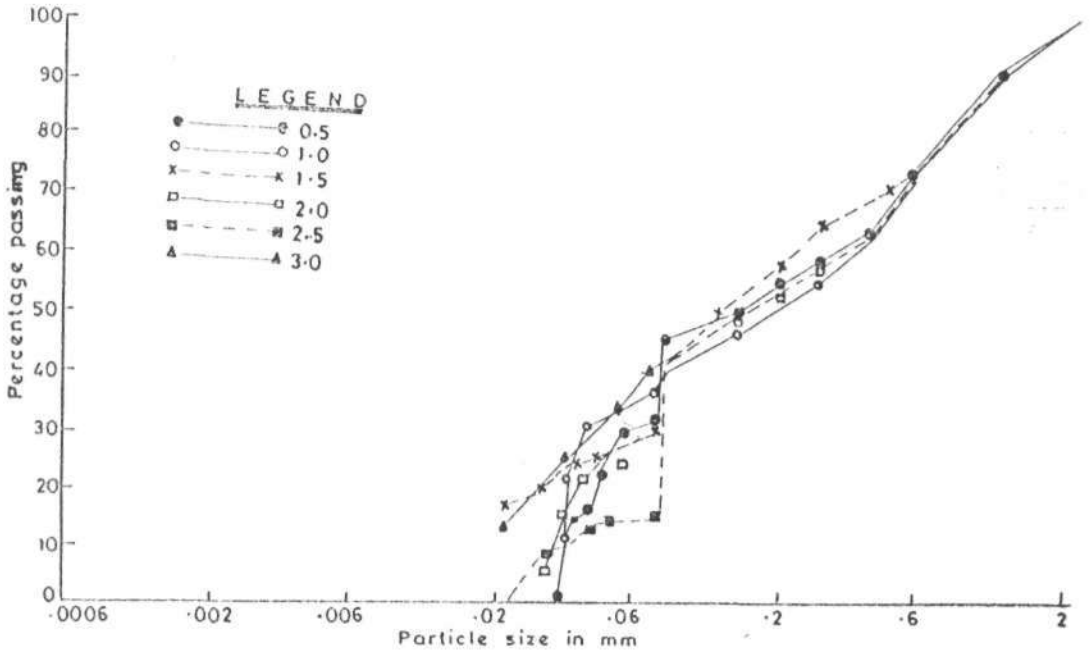



FIG.3.1: GRAIN SIZE DISTRIBUTION FOR CEMENT STABILIZED LATERITE 0.0 HOUR AFTER MIXING (Proctor Compaction)




FIG·3·2: VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME AFTER MIXING FOR 3% CEMENT STABILIZED LATERITE (Procter Compaction)

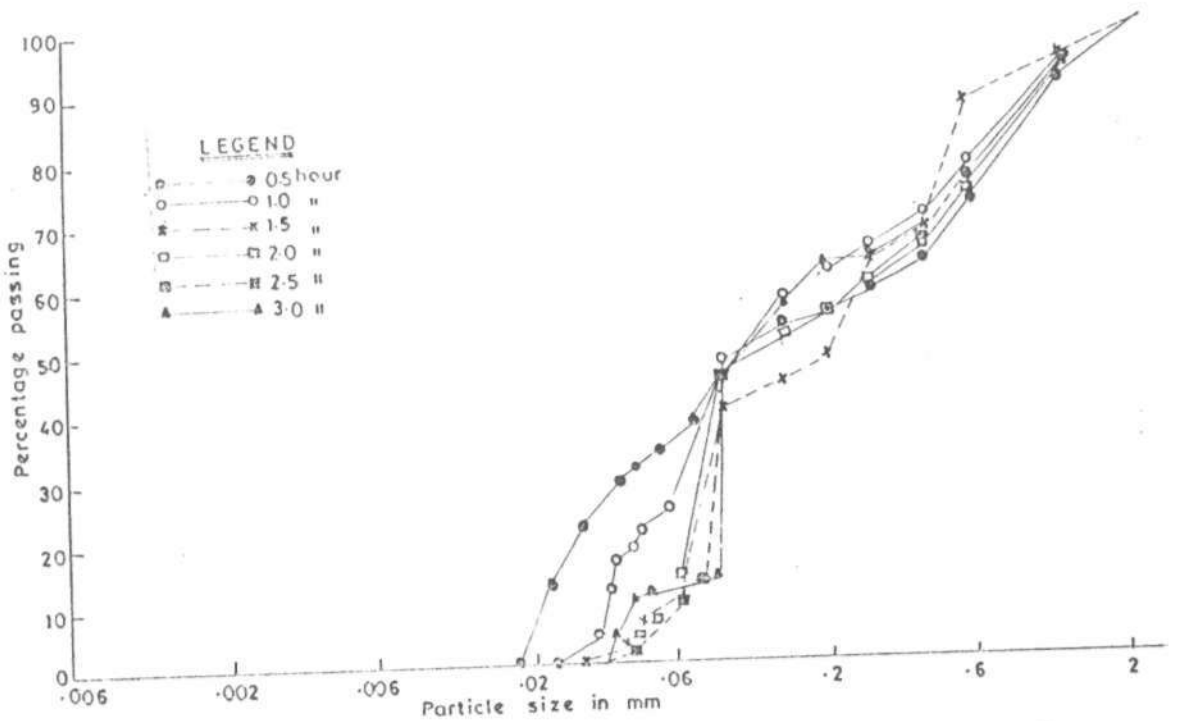
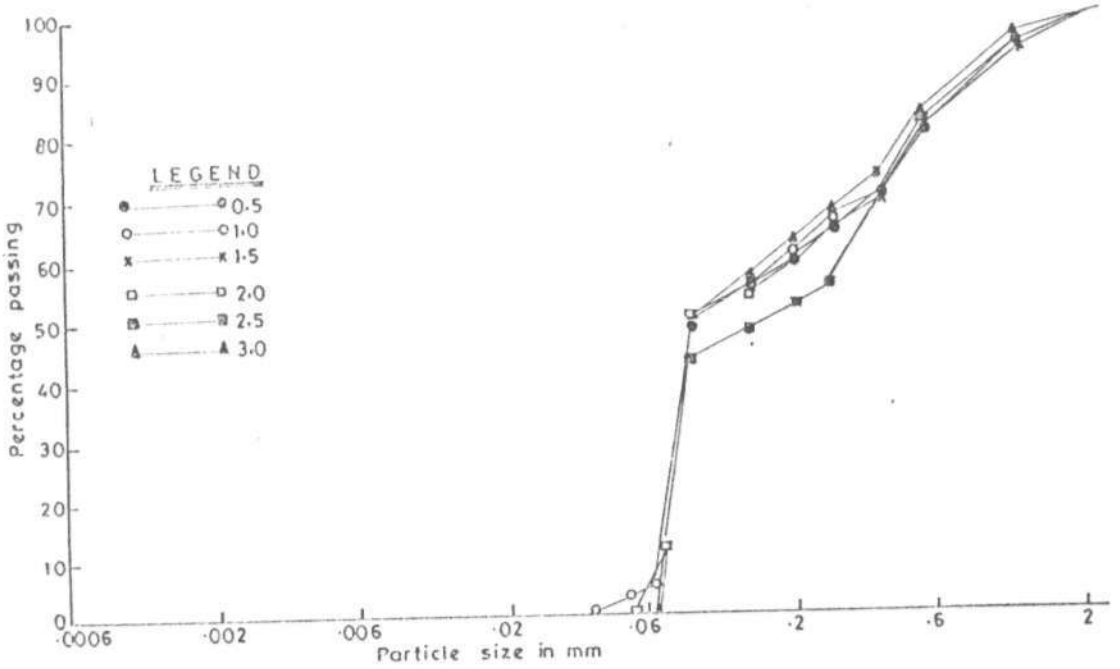



FIG-3·3 : VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME AFTER MIXING FOR 5% CEMENT STABILIZED LATERITE (Proctor Compaction)




FIG·3·4 ; VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME AFTER MIXING FOR 8% CEMENT STABILIZED LATERITE (Proctor Compaction)

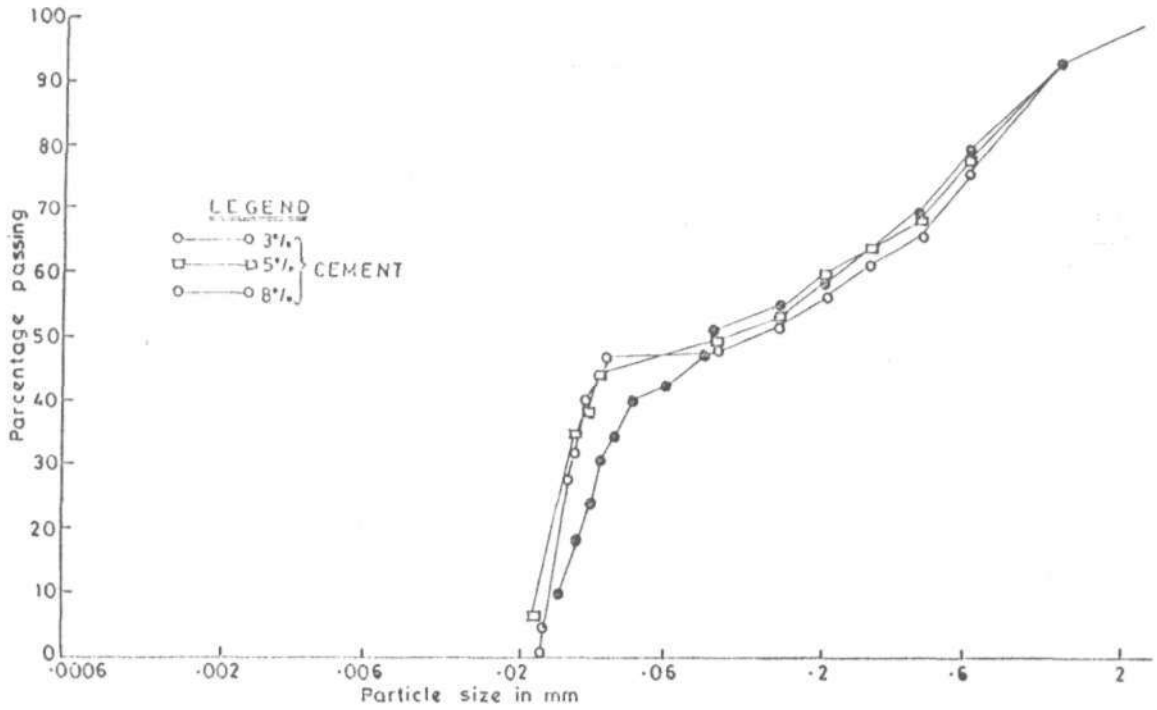
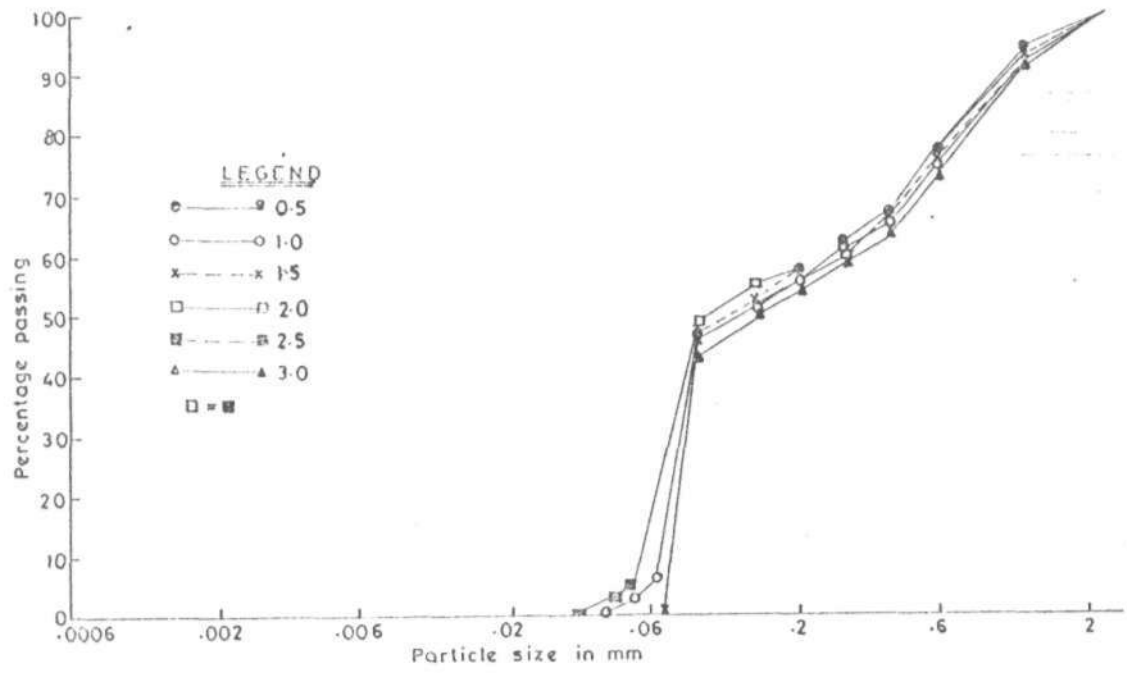



FIG. 3·5 ; GRAIN SIZE DISTRIBUTION FOR CEMENT STABILIZED LATERITE 0·0 HOUR AFTER MIXING (West African Compaction)




FIG·3·6 ; VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME AFTER MIXING FOR 3% CEMENT STABILIZED LATERITE (West African Compaction)

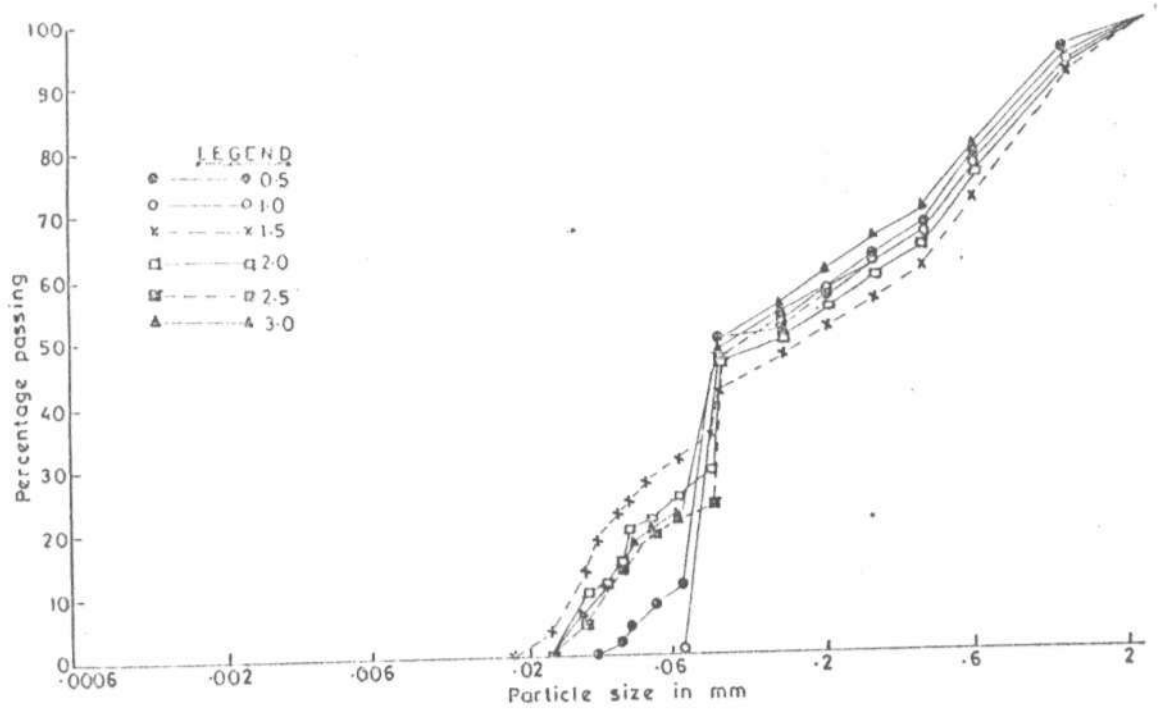
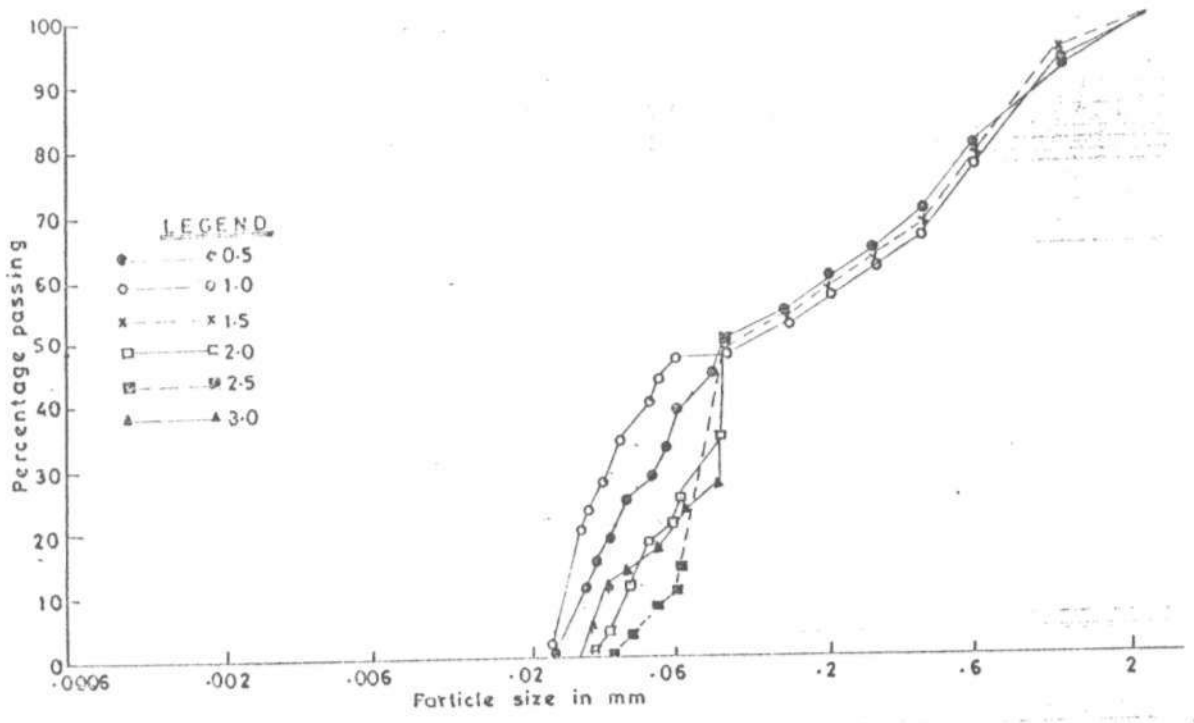



FIG.3.7: VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME AFTER MIXING FOR 5% CEMENT STABILIZED LATERITE (West African Compaction)




FIG·3·8: VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME AFTER MIXING FOR 8% CEMENT STABILIZED LATERITE (West African Compaction)

From the plots in Fig. 3.2 for 3% cement content, a substantial amount of particles were detected by the hydrometer in the (0.02 - 0.06)mm particle diameter range. This is likely due to the formation of lighter pseudo sand sizes with no regular pattern for the different stabilizer contents. The mixture for 5% cement content shown in Fig. 3.3 is similar to the one shown in Fig. 3.2. However, the pattern of the curves for 8% cement content as shown in fig. 3.4 are different from the curves of 3% and 5% cement content. This is due to the higher cement content. Most of the silt is coated with cement to form pseudo sand sizes consequently, the hydrometer detects only a small-fraction of the unreacted silt and the lighter pseudo sand particles formed. However, the higher percentage of cement in the mixture facilitates the formation of heavier pseudo sand particles which settle faster.

For samples mixed at the OMC, for West African Compaction, the 3% cement content, grain size distribution shown curve shown in Fig. 3.5 significantly differs from the grain size distribution of soil with 3% cement content compacted at the energy of the Proctor (compare with Fig. 3.1). This could have been due to the higher OMC of the West African Compaction which altered the grain size distribution pattern. For the 8% cement content, the patterns of the particle size distribution curves are different for the Proctor and West African Compaction. This is due to the different OMC at which the mixtures were prepared. The Optimum moisture contents for the West African Compaction is lower than that of the Proctor Compaction. It is very interesting to note that at 5% cement content and different Optimum moisture contents both cases had similar curve patterns for the (0.006 - 0.06mm) range. See Figs 3.3 and 3.7.

**LIME STABILIZED LATERITES:** The curves of the grain size distribution 0.0 hour after mixing for 3%, 5% and 8% lime content mixed at their various optimum moisture contents

obtained from their respective compaction test results are shown in fig 3.9. While the grain size distribution with respect to elapse time after mixing are shown in Figs 3.10 - 3.12 for Proctor compaction. Fig. 3.13 shows the grain size distribution, 0.0 hour after mixing while Figs 3.14 - 3.16 show the effect of elapse time after mixing on grain size distribution for West African Compaction. From Fig. 3.9 and 3.13 it is evident that at 3% and 5% lime content the silt fraction reduced from 12% to 1% while the silt fraction was reduced to 5% at 8% lime content. The shape of the curves in the (0.06 - 2.0mm) range are similar but in the range (0.02 - 0.08mm) there are molecular interactions between the clay minerals and lime resulting in their various grain size distribution patterns. The lime hardly affected the sand fraction since the time required for pozzolanic reaction to take place was not sufficient (O'Flaherty 1974). A comparison of Figs 3.10 - 3.15 shows that the shapes of the grain size distribution in the (0.075 - 2.0mm) range are similar. However for particles smaller, than the 0.075mm sieve, the various shapes of the grain size distribution are due to the clay-lime reactions. Pozzolanic reaction of lime cannot be attributed to any of these patterns because in order to achieve the reaction a longer time interval more than the 3.0 hours considered in this work is required (O'Flaherty 1974). However, these patterns could be attributed to the complexity in the reaction mechanism by Brandl (1980).

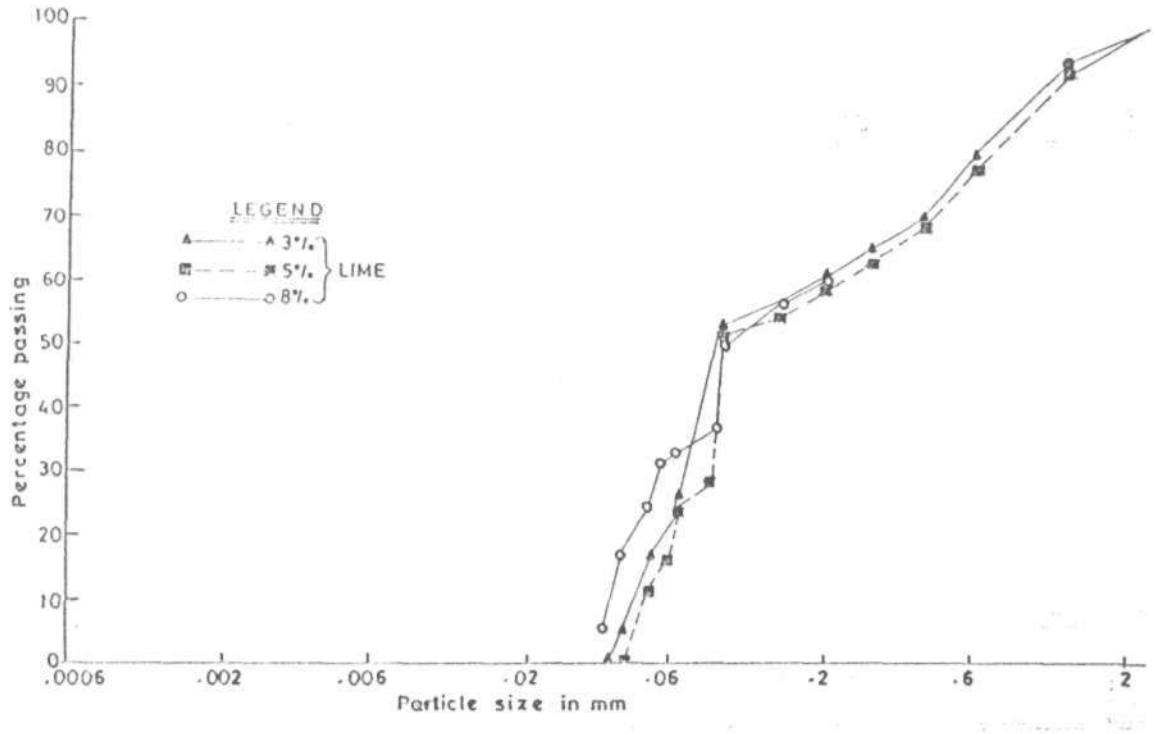



FIG. 3.9 : GRAIN SIZE DISTRIBUTION FOR LIME STABILIZED LATERITE 0.0 HOUR AFTER MIXING (Proctor Compaction)

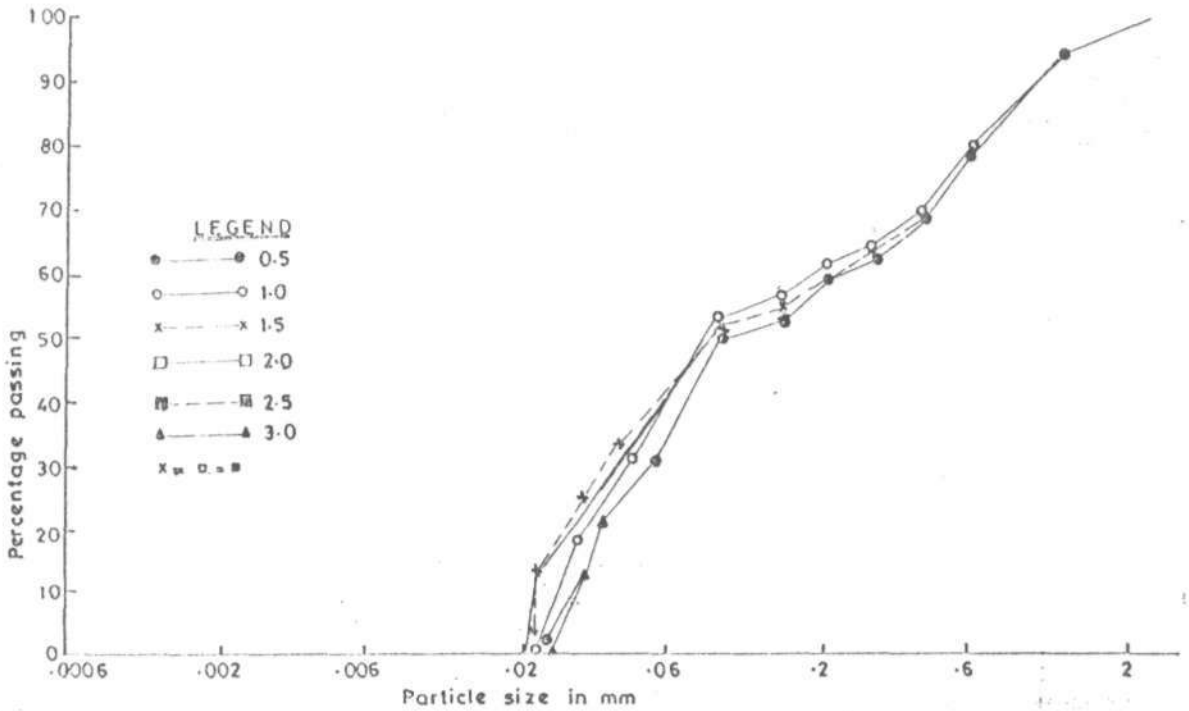



FIG. 3.10 : VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME AFTER MIXING FOR 3% LIME STABILIZED LATERITE (Proctor Compaction)

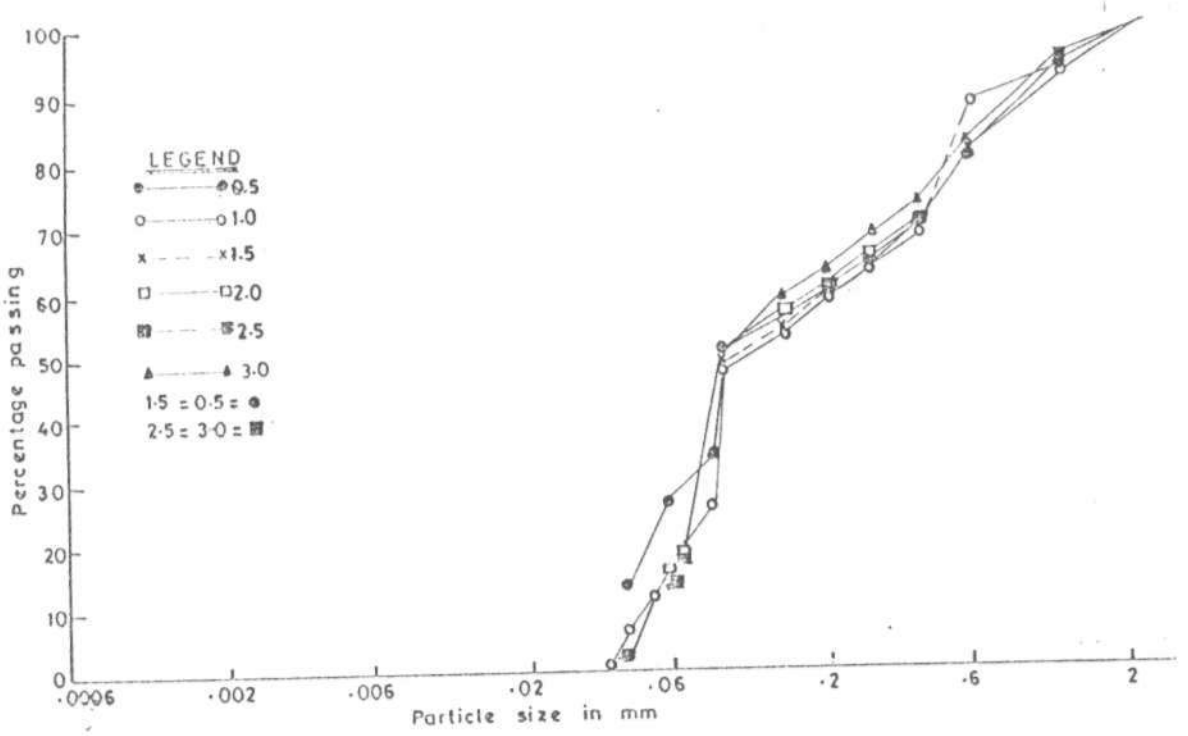
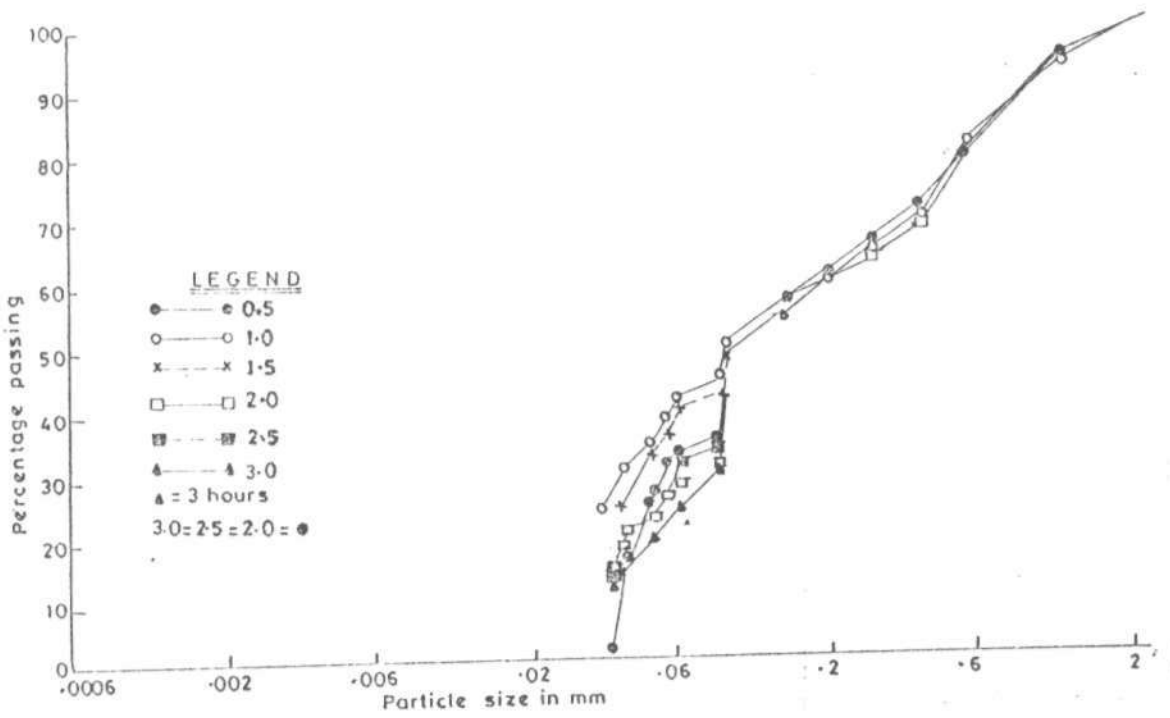



FIG. 3.11 ; VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME AFTER MIXING FOR 5% LIME STABILIZED LATERITE (Proctor Compaction)




FIG·3.12 : VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME AFTER MIXING FOR 8% LIME STABILIZED LATERITE (Proctor Compaction)

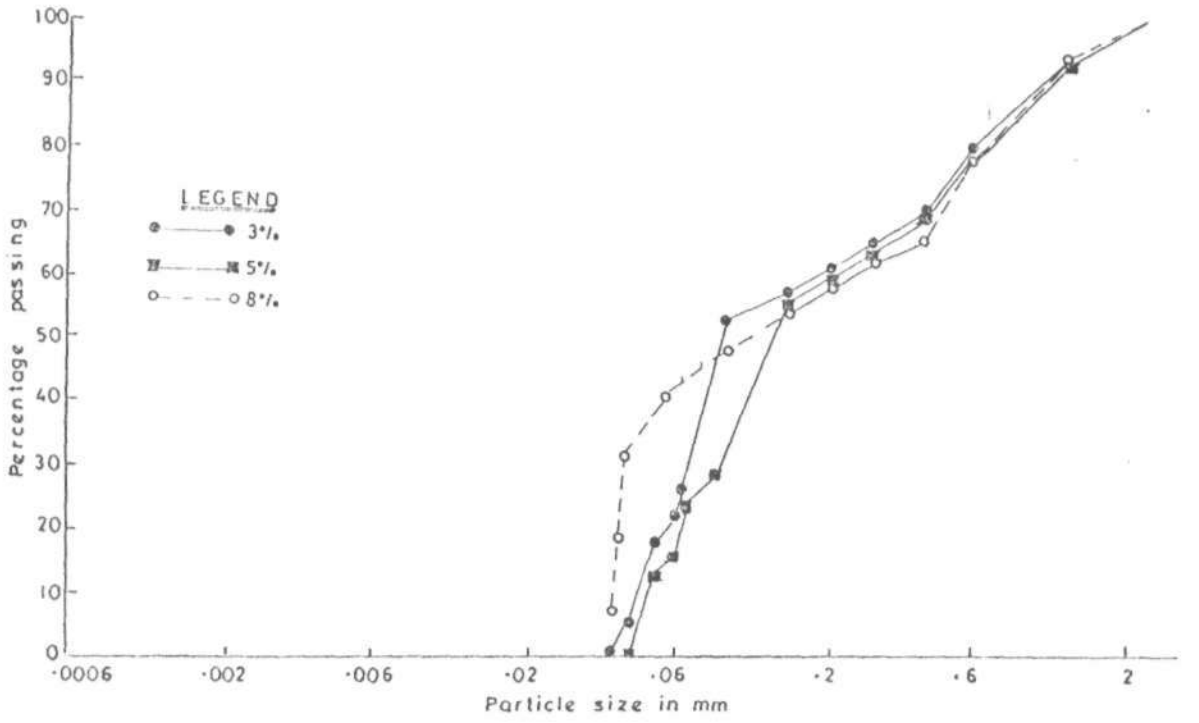



FIG. 3·13 : GRAN SIZE DISTRIBUTION FOR LIME STABILIZED LATERITE 0·0 HOUR AFTER MIXING (West African Compaction)

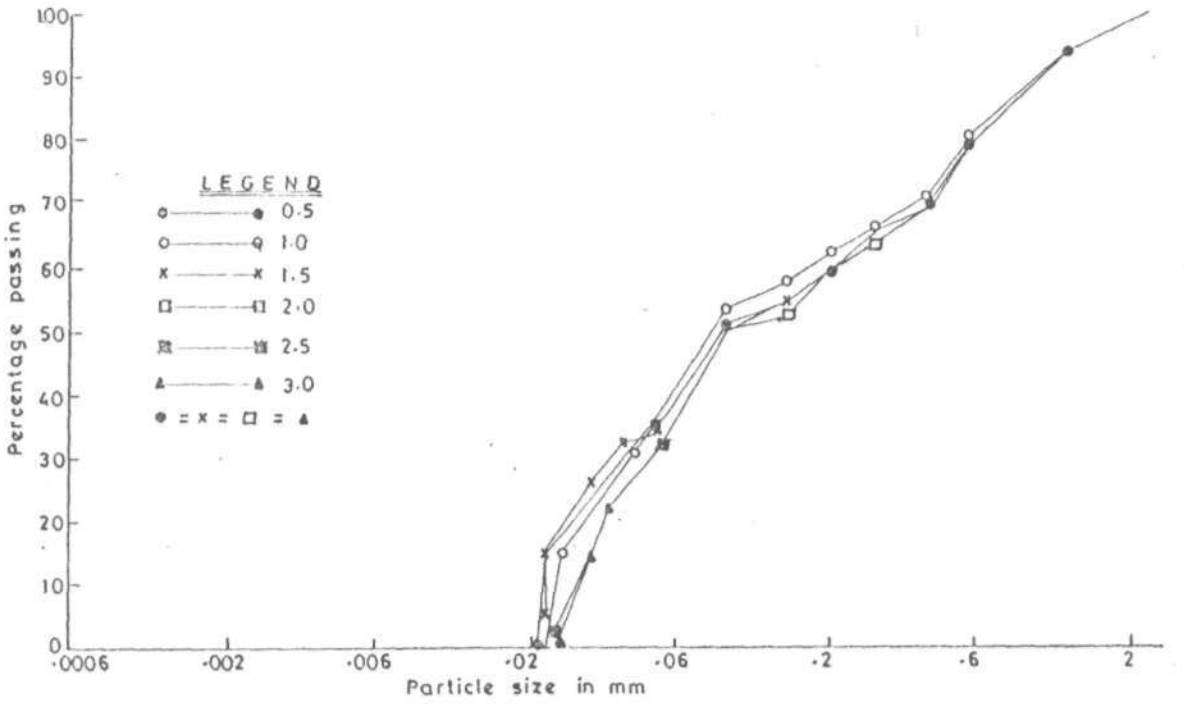



FIG. 3·14 : VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE LIME AFTER MIXING FOR 3% LIME STABILIZED LATERITE (West African Compaction)

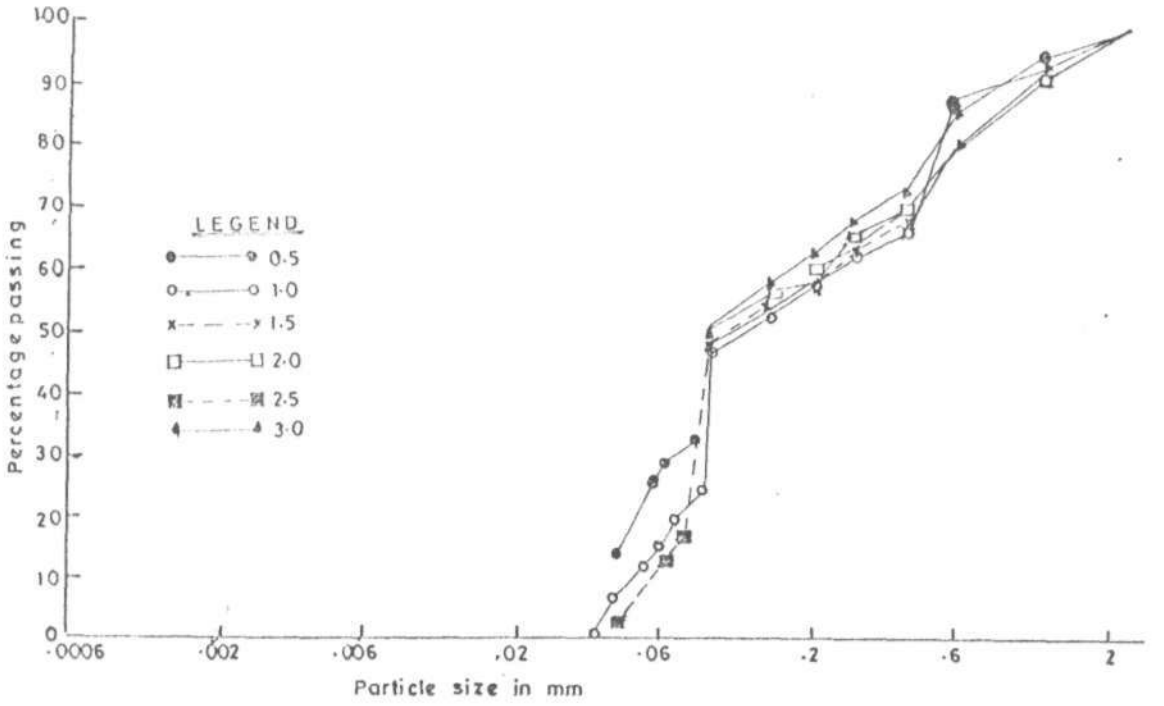



FIG. 3·15 : VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE FOR 5% LIME STABILIZED LATERITE (West African Compaction)

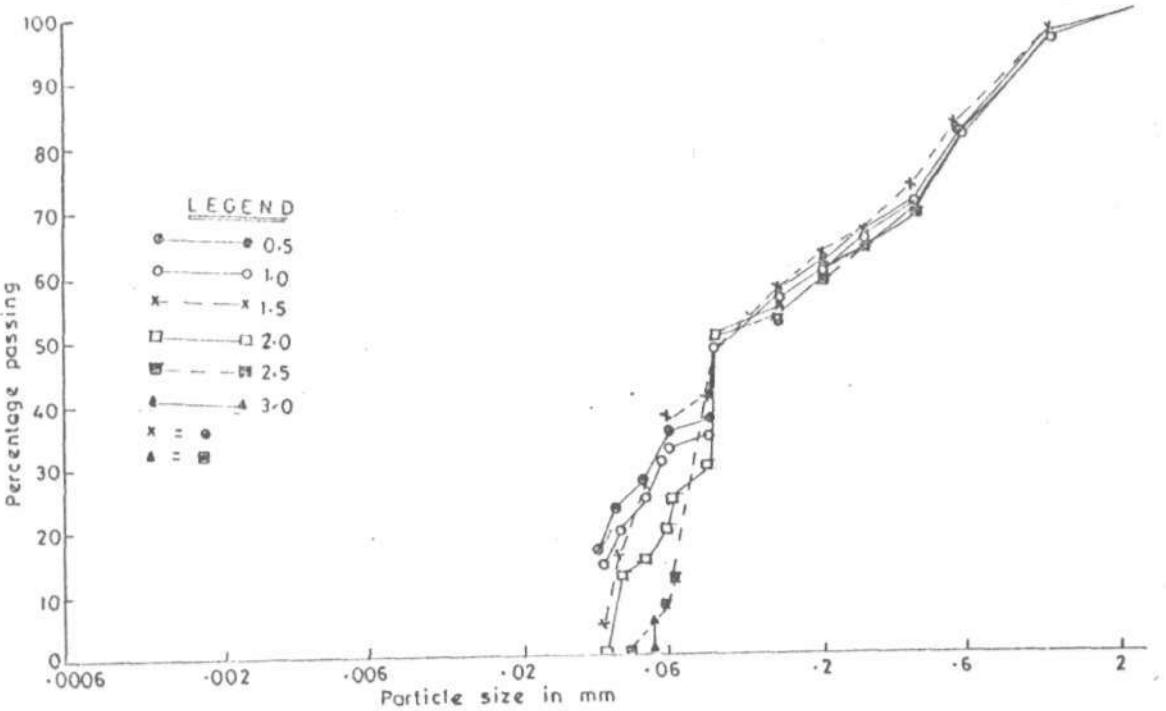



FIG. 3·16 : VARIATION OF GRAIN SIZE DISTRIBUTION WITH ELAPSE TIME FOR 8% LIME STABILIZED LATERITE (West African Compact)

### *3.2.2 Atterberg Limits*

**CEMENT STABILIZED LATERITE:** The effect of cement on the liquid limit (LL), Plastic limit (PL) and plasticity index (PI) of laterite 0.0 hour after mixing is shown in fig. 3.17 for the specimens prepared at the OMC's, obtained from Proctor and West African Compactions respectively. For both compaction energy levels the liquid limits initially decrease with increase in cement content to their maximum values at 3% cement content for Proctor compaction and 5% cement content for West African Compaction. Thereafter, the liquid limits increase for the Proctor and West African Compactions. Irrespective of the increases in the liquid limits, the values recorded at 8% cement content for both cases are less than the Liquid limit for the untreated soil. For the Proctor and West African Compactions, the plastic limits increase with higher cement content while there are corresponding decreases in the plasticity indices. This is so because the cement-clay reaction causes the clay and silt in the soil to form coarser particles which resemble sand in nature and thus can roll over one another easily thus reducing the liquid limit. The coarser particles have higher water retaining capacities which lead to increases in the plastic limit.

The variation of liquid limit, plastic limit and plasticity index with respect to elapse time after mixing are shown in Figs 3.18 and 3.19 for Proctor and West African compactions respectively. The liquid limits decrease with increase in elapse time, while the plastic limit increases with increase in elapse time after mixing. The plasticity index for both cases decrease with increase in elapse time, since the plasticity index is obtained by subtracting the plastic limit from the corresponding liquid limit.

The Nigerian General Specification for Roads and Bridges (1970) states that "At the Engineer's representative's discretion material with a liquid limit greater; than 30 and a plasticity index greater than 12 may be disallowed for use as sub-base course or base course." Using this

criterion, the cement stabilized laterite failed the test.

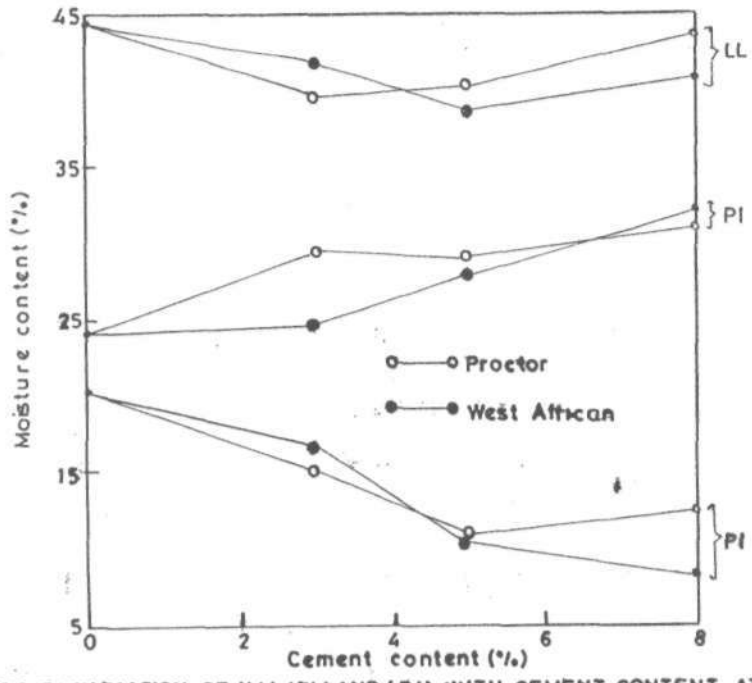



FIG-3-17: VARIATION OF (LL), (PL) AND (PI) WITH CEMENT CONTENT AT 0-0 HOUR

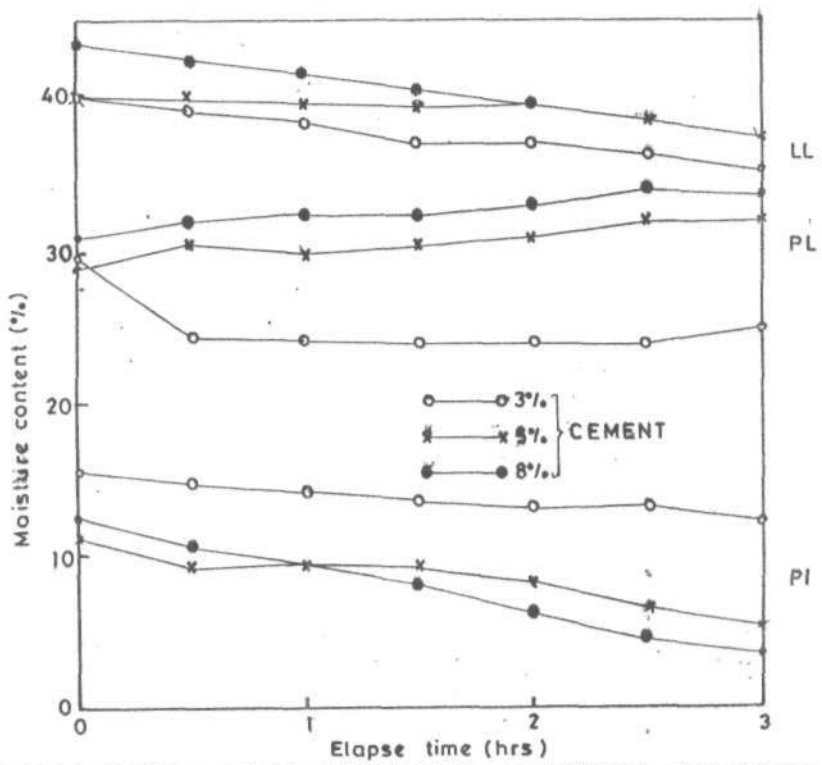



FIG.3.18: VARIATION OF (LL), (PL) AND (PI) WITH ELAPSE TIME FOR CEMENT STABILIZED LATERITE (Proctor Compaction)

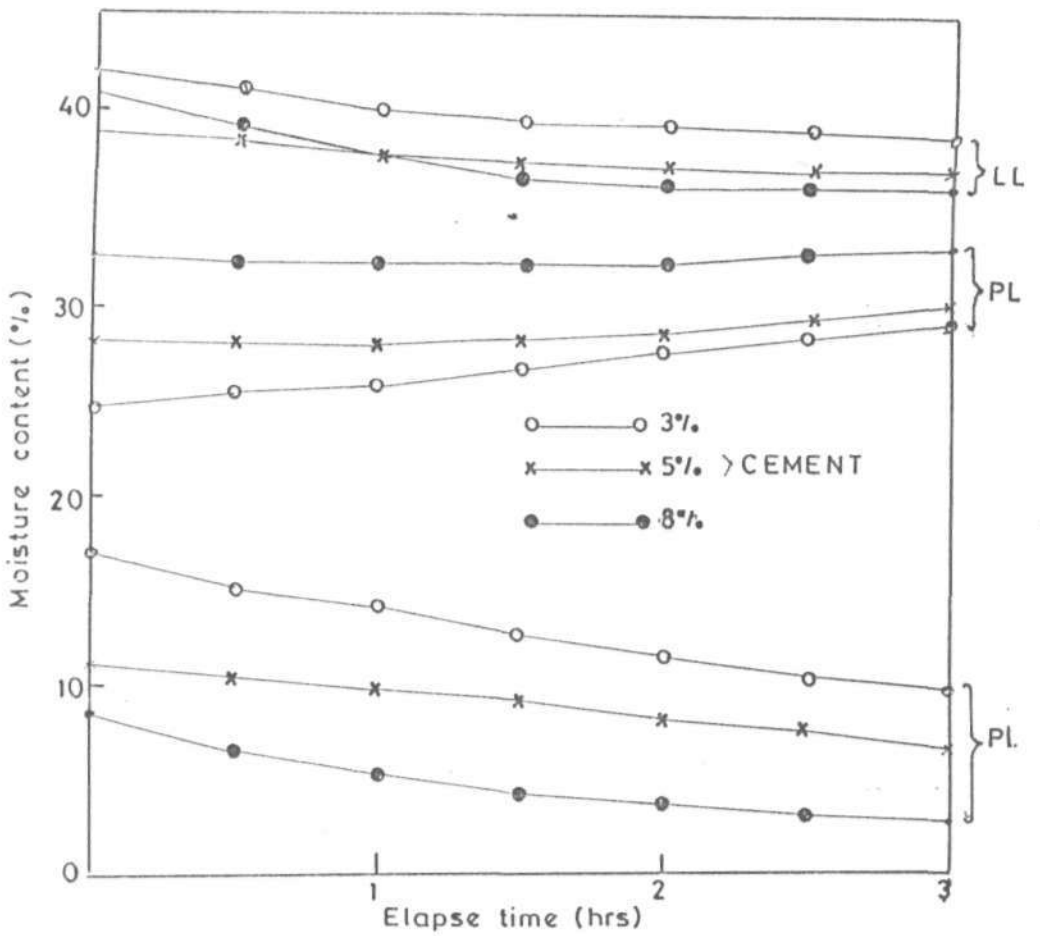



FIG.3·19: VARIATION OF(LL) (PL) AND (PI) WITH ELAPSE TIME FOR CEMENT STABILIZED LATERITE (West African Compaction)

A summary of suitability of cement stabilized laterite using the Highway Research Board (1943), Millard and O'Reilly (1963) criterion for free flow and the Nigerian general Specification for Roads and Bridges (1970) are shown in tables 3.1 and 3.2.

TABLE 3.1 Summary Of Effect Of Elapse Time After Mixing On Grain Size And Atterberg Limits For Cement Stabilized Laterite For Proctor Compaction

| CEMENT CONTENT | ELAPSE TIME | PASSING BS NO 200 SIEVE | PASSING 425$\mu$ m | LL | PI | HRB | MILLARD AND O'REILLY | NGSRB |
|---|---|---|---|---|---|---|---|---|
| 3 | 0.0 | 46.7 | 66.5 | 39.8 | 18.3 | v | x | x |
| | 0.5 | 45.3 | 64.0 | 39.2 | 14.8 | v | v | x |
| | 1.0 | 39.8 | 62.0 | 38.5 | 14.1 | v | v | x |
| | 1.5 | 42.3 | 64.0 | 37.7 | 13.5 | v | v | x |
| | 2.0 | 42.3 | 63.0 | .37.0 | 14.1 | v | v | x |
| | 2.5 | 42.8 | 63.0 | 36.4 | 14.2 | v | v | x |
| | 3.0 | 41.3 | 62.0 | 35.2 | 12.2 | v | v | x |
| 5 | 0.0 | .50.0 | 64.5 | 40.0 | 11.0 | v | v | x |
| | 0.5 | 46.5 | 63.5 | 39.8 | 9.2 | v | v | x |
| | 1.0 | .50.0 | 69.7 | 39.6 | 9.6 | v | v | x |
| | 1.5 | .50.0 | 68.5 | 39.4 | 9.1 | v | v | x |
| | 2.0 | .47.5 | 65.0 | 39.3 | 6.3 | v | v | x |
| | 2.5 | .47.0 | 66.5 | 38.7 | 6.7 | v | v | x |
| | 3.0 | .47.0 | 68.0 | 37.4 | 3.5 | v | v | x |
| 8 | 0.0 | .46.0 | 69.0 | 43.6 | 12.6 | v | v | x |
| | 0.5 | .49.0 | 70.0 | 42.7 | 10.7 | v | v | x |
| | 1.0 | .50.0 | 72.0 | 41.7 | 9.7 | v | v | x |
| | 1.5 | .49.0 | 69.0 | 40.5 | 8.1 | v | v | x |
| | 2.0 | .50.0 | 70.0 | 39.3 | 6.3 | v | v | x |
| | 2.5 | .44.0 | 70.0 | 38.6 | 4.6 | v | v | x |
| | 3.0 | .50.0 | 72.0 | 37.6 | 3.8 | v | v | x |

x Failed Test

v Passed Test

TABLE 3.2 Summary Of Effect Of Elapse Time After Mixing On Grain Size And Atterberg Limits For Cement Stabilized Laterite For West African Compaction

| CEMENT CONTENT | ELAPSE TIME | PASSING BS NO 200 SIEVE | PASSING 425$\mu$ m | LL | PI | HRB | MILLARD AND O'REILLY | NGSRB |
|---|---|---|---|---|---|---|---|---|
| 3 | 0.0 | 50.0 | 70.0 | 41.7 | 16.8 | v | x | x |
| | 0.5 | 48.0 | 68.0 | 41.0 | 15.4 | v | v | x |
| | 1.0 | 48.0 | 66.0 | 40.0 | 14.1 | v | v | x |
| | 1.5 | 47.0 | 67.0 | 37.7 | 12.8 | v | v | x |
| | 2.0 | 49.0 | 68.0 | 39.3 | 11.5 | v | v | x |
| | 2.5 | 49.0 | 68.0 | 39.0 | 10.6 | v | v | x |
| | 3.0 | 44.0 | 64.0 | 38.8 | 9.7 | v | v | x |
| 5 | 0.0 | 50.0 | 49.0 | 38.7 | 10.7 | v | v | x |
| | 0.5 | 50.0 | 70.0 | 38.2 | 10.7 | v | v | x |
| | 1.0 | 49.0 | 67.0 | 37.7 | 9.7 | v | v | x |
| | 1.5 | 42.0 | 62.0 | 37.4 | 9.2 | v | v | x |
| | 2.0 | 47.0 | 64.0 | 32.1 | 8.4 | v | v | x |
| | 2.5 | 49.0 | 68.0 | 37.0 | 7.6 | v | v | x |
| | 3.0 | 50.0 | 67.0 | 37.0 | 6.8 | v | v | x |
| 8 | 0.0 | 48.0 | 66.0 | 40.8 | 6.4 | v | v | x |
| | 0.5 | 50.0 | 70.0 | 39.0 | 6.0 | v | v | x |
| | 1.0 | 48.0 | 66.0 | 37.8 | 5.4 | v | v | x |
| | 1.5 | 49.0 | 68.0 | 36.6 | 4.2 | v | v | x |
| | 2.0 | 50.0 | 68.0 | 36.3 | 3.9 | v | v | x |
| | 2.5 | 49.0 | 67.0 | 36.0 | 3.2 | v | v | x |
| | 3.0 | 49.0 | 70.0 | 36.0 | .3.0 | v | v | x |

x Failed Test

v Passed Test

LIME STABILIZED LATERITE: The effects of lime content on the liquid limit, plastic limit and plasticity index of lime stabilized soil for samples prepared at the optimum moisture contents of their various percentages obtained from Proctor and West African Compaction tests are shown in Fig. 3.20. The liquid limits for the Proctor Compaction decreases rapidly with increase in lime content while that of the West African compaction decreases gently. For

both the Proctor and West African Compactions, the plastic limits increase with increase in lime content, while there is corresponding decrease in the plasticity indices.

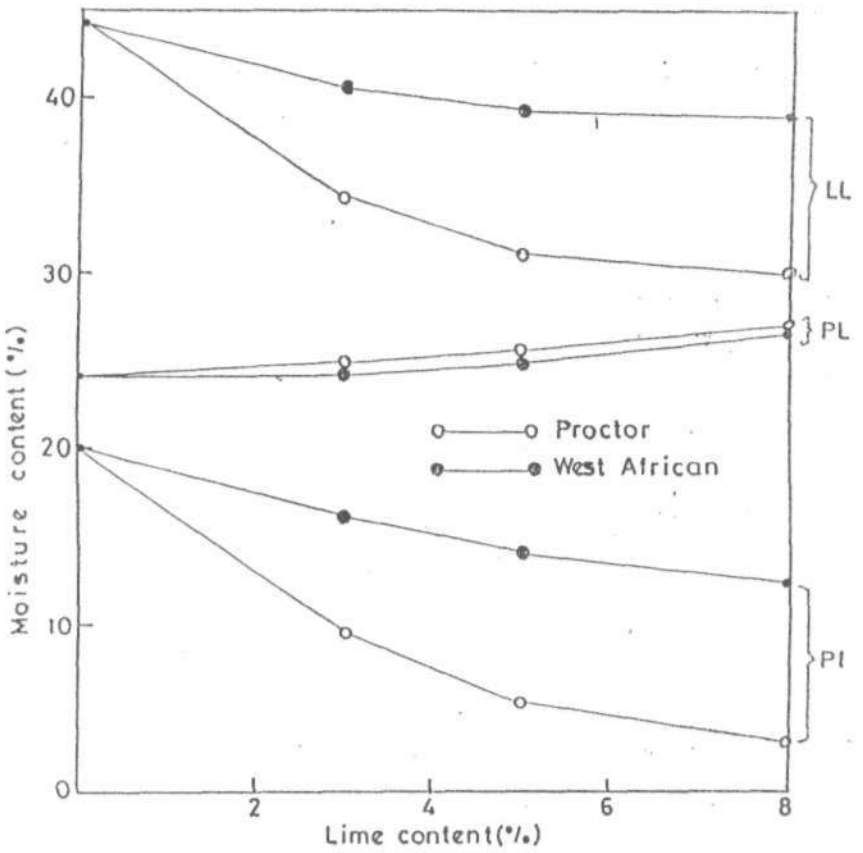



FIG-3·20: VARIATION OF(LL) (PL)AND(PI) WITH LIME CONTENT AT 0.0 HOUR

The increase in the plastic limit with increase in lime content can be explained in terms of the reactivity of soil-lime mixes. A cation exchange reaction occurs with the bivalent calcium ions supplied by the lime replacing less firmly attached monovalent ions in the double layer surrounding the clay particles. This tends to decrease the thickness of the double layer and to depress the zeta potential (a measure of the effectiveness of the particle negative charges in repelling a second particle), thereby causing flocculation. As the clay flocculates under this action water which has become separated from the particles concentrates in the cavities between the coagulated particles (O'Flaherty, 1974).

The variation of the liquid limit, plastic limit and plasticity index with respect to elapse time after mixing are shown in Figs. 3.21 and 3.22 for samples prepared at their optimum moisture contents for Proctor and West African Compactions respectively. There was a decrease in the liquid limit with increase in elapse time due to the clay-lime reaction which is time dependent. As the reaction takes place water is lost by evaporation aided by the exothermic nature of the reaction. There was an increase in the plastic limit with respect to elapse time with a corresponding decrease in the plasticity index. The variation in the curve patterns may be attributed to the varying moisture contents at which the samples were prepared.

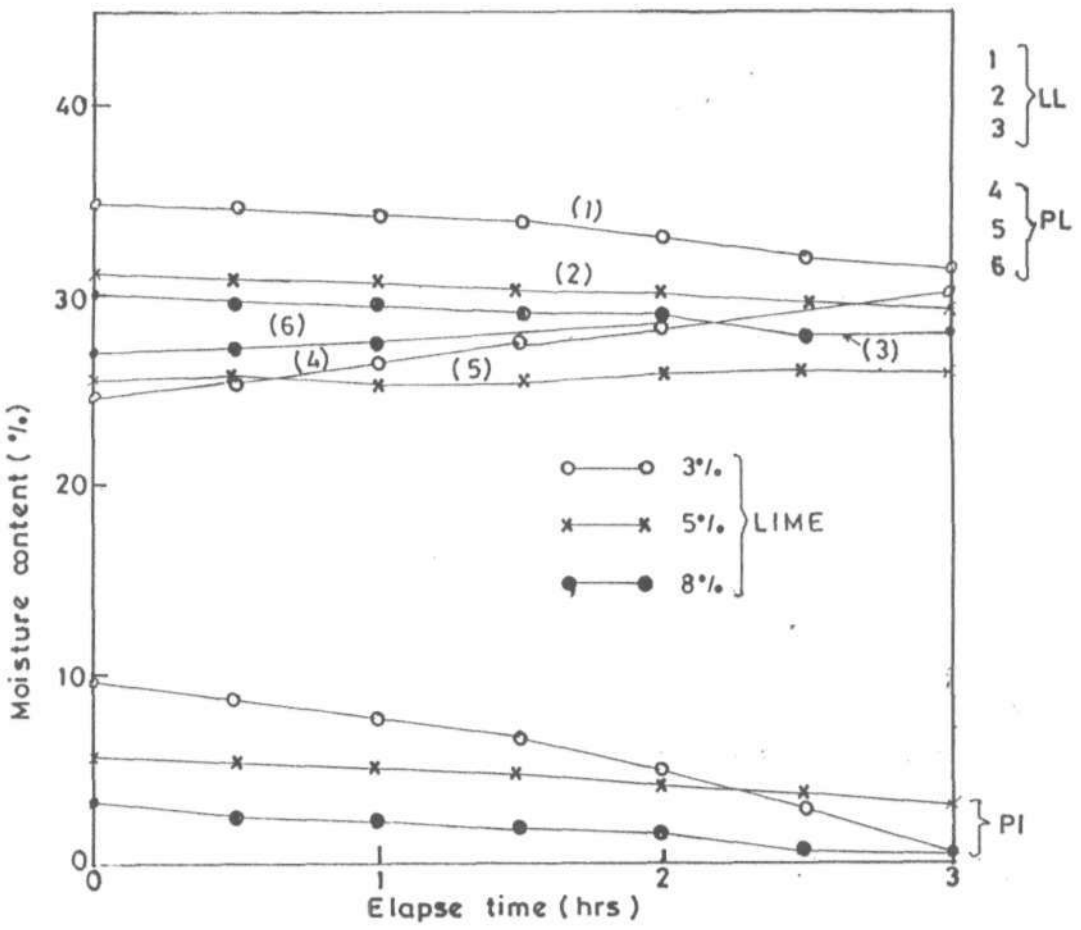



FIG.3-21 : VARIATION OF (LL), (PL) AND (PI) WITH ELAPSE TIME FOR LIME STABILIZED LATERITE (Proctor Compaction)

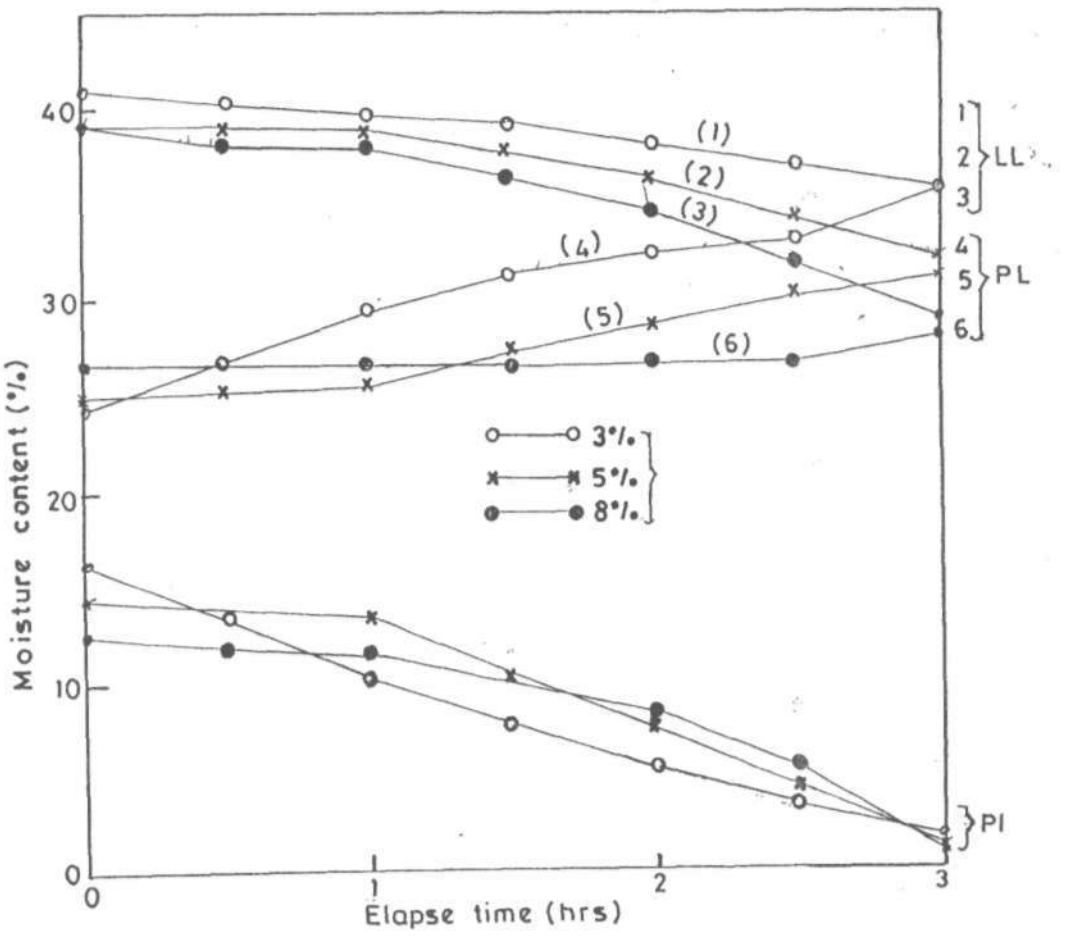



FIG. 3.22: VARIATION OF (LL), (PL) AND (PI) WITH ELAPSE TIME FOR LIME STABILIZED LATERITE (West Afrian Compaction )

The requirement for sub-base and base courses as specified by the Nigerian general specification for Roads and Bridges (1970) was not met by laterite stabilized with 3% and 5% lime content 0.0 hour after mixing. However soil treated with 8% lime content 3.0 hours after mixing passed the test.

A summary of the suitability of lime stabilized laterite for use in road construction with respect to the Highway Research Board (1943) requirement, Millard and O'Reilly (1965) criterion of free flow and the Nigerian specification at Roads and Bridges (1970) are shown in Tables 3.3 and 3.4.

TABLE 3.3 Summary Of Effect Of Elapse Time After Mixing On Grain Size And Atterberg Limits For Lime Stabilized Laterite For Proctor Compaction

| LIME CONTENT | ELAPSE TIME | PASSING BS NO 200 SIEVE | PASSING 425 m | LL | PI | HRB | MILLARD AND O'REILLY | NGSRB |
|---|---|---|---|---|---|---|---|---|
| 3 | 0.0 | 53.0 | 70.0 | 34.6 | 9.8 | x | v | x |
| | 0.5 | 53.0 | 69.0 | 34.4 | 8.7 | x | v | x |
| | 1.0 | 53.0 | 70.0 | 34.2 | 7.6 | x | v | x |
| | 1.5 | 51.0 | 69.0 | 34.0 | 6.5 | x | v | x |
| | 2.0 | 50.0 | 69.0 | 33.0 | 4.8 | v | v | x |
| | 2.5 | 50.0 | 69.0 | 32.0 | 2.8 | v | v | x |
| | 30 | 50.0 | 70.0 | 30.6 | 0.6 | v | v | x |
| 5 | 0.0 | 51.0 | 69.0 | 31.0 | 5.5 | x | v | x |
| | 0.5 | 51.0 | 70.0 | 30.0 | 5.1 | x | v | v |
| | 1.0 | 47.0 | 68.0 | 30.5 | 5.0 | v | v | v |
| | 1.5 | 48.0 | 69.0 | 30.0 | 4.5 | v | v | v |
| | 2.0 | 50.0 | 70.0 | 30.0 | 4.0 | v | v | v |
| | 2.5 | 50.0 | 72.0 | 29.5 | 3.5 | v | v | v |
| | 30 | 50.0 | 72.0 | 37.1 | 3.2 | v | v | v |
| 8 | 0.0 | 50.0 | 70.0 | 30.8 | 3.0 | v | v | v |
| | 0.5 | 50.0 | 71.0 | 29.0 | 2.3 | v | v | v |
| | 1.0 | 50.0 | 70.0 | 29.5 | 2.1 | v | v | v |
| | 1.5 | 50.0 | 70.0 | 29.0 | 1.6 | v | v | v |
| | 2.0 | 49.0 | 69.0 | 28.0 | 1.5 | v | v | v |
| | 2.5 | 49.0 | 69.0 | 28.0 | 0.5 | v | v | v |
| | 30 | 49.0 | 69.0 | 28.0 | 0.5 | v | v | v |

x Failed Test

v Passed Test

TABLE 3.4 Summary Of Effect Of Elapse Time After Mixing On Grain Size And Atterberg Limits For Lime Stabilized Laterite For West African Compaction

| LIME CONTENT | ELAPSE TIME | PASSING BS NO 200 SIEVE | PASSING 425 m $\mu$ | LL | PI | HRB | MILLARD AND O'REILLY | NGSRB |
|---|---|---|---|---|---|---|---|---|
| 3 | 0.0 | 53.0 | 70.0 | 40.6 | 16.1 | x | x | x |
| | 0.5 | 53.0 | 69.0 | 40.3 | 13.8 | x | v | x |
| | 1.0 | 53.0 | 70.0 | 39.7 | 10.2 | x | v | x |
| | 1.5 | 51.0 | 69.0 | 39.2 | 7.6 | x | v | x |
| | 2.0 | 50.0 | 69.0 | 38.2 | 5.6 | v | v | x |
| | 2.5 | 50.0 | 69.0 | 37.7 | 2.8 | v | v | x |
| | 30 | 50.0 | 70.0 | 35.8 | 1.8 | v | v | x |
| 5 | 0.0 | 51.0 | 69.0 | 39.2 | 14.1 | x | v | x |
| | 0.5 | 50.0 | 70.0 | 39.0 | 13.8 | v | v | x |
| | 1.0 | 47.0 | 68.0 | 34.0 | 13.6 | v | v | x |
| | 1.5 | 48.0 | 69.0 | 37.6 | 10.4 | v | v | x |
| | 2.0 | 50.0 | 70.0 | 36.4 | 7.8 | v | v | x |
| | 2.5 | 50.0 | 72.0 | 34.4 | 4.4 | v | v | x |
| | 3.0 | 50.0 | 72.0 | 33.2 | 1.5 | v | v | x |
| 8 | 0.0 | 48.0 | 66.0 | 39.0 | 12.5 | v | v | x |
| | 0.5 | 48.0 | 71.0 | 38.4 | 11.9 | v | v | x |
| | 1.0 | 48.0 | 70.0 | 38.0 | 11.5 | v | v | x |
| | 1.5 | 48.0 | 72.0 | 36.6 | 10.0 | v | v | x |
| | 2.0 | 48.0 | 70.0 | 34.7 | 8.1 | v | v | x |
| | 2.5 | 50.0 | 69.0 | 32.0 | 5.4 | v | v | x |
| | 3.0 | 50.0 | 70.0 | 29.0 | 1.0 | v | v | x |

x Failed Test

v Passed Test

### *3.2.3 Compaction Characteristics*

CEMENT STABILIZED LATERITE: The effects of cement content on the Maximum Dry density (MDD) and Optimum$_{\mu}$ moisture content (OMC) on Laterite 0.0 hour after mixing are shown in Figs 3.23 and 3.24 for Proctor and West African Compactions respectively. For Proctor Compaction 0.0 hour after mixing the MDD reduced from 1.84 Mg/m$^3$ at 0.% cement content to 1.797 Mg/m$^3$ at 5% cement content after which it increased to 1,518 Mg/m$^3$ at 8% cement content. For West African Compaction 0.0 hour after mixing the MDD reduced from 1.89 Mg/m$^3$ at 0% cement content to 1,866 Mg/m$^3$ and 1.861 Mg/m$^3$ at 3% cement contents respectively, and 5% after which it increased to 1.896 Mg/m$^3$ at 8% cement content.

The change in character of the MDD curve at 5% cement content is a result of the reaction between cement and the fine particles which formed larger aggregates. The quantity of cement available was enough to allow a reaction with the available silt and clay to form the coarser aggregates. The aggregates formed occupy larger spaces thus increasing the volume and consequently decreasing their maximum dry densities. Above 5% cement content, the coarse aggregates formed were firmly bonded to one another due to the excess cement available in the clay silt-cement reaction as a result of which the MDD increased.

The pattern of the OMC observed in Figs. 3.24 is irregular. The OMC for Proctor Compaction decreased from 19.1% at 0% cement content to 17% at 3% cement content then sharply increased to 19.2% at 5% cement content and finally dropped to 18.6% at 8% cement content. For West African Compaction, the OMC increased from 15.7% at 0% cement to 19.1% at 3% cement content and then decreased to 16.3% at 8% cement content.

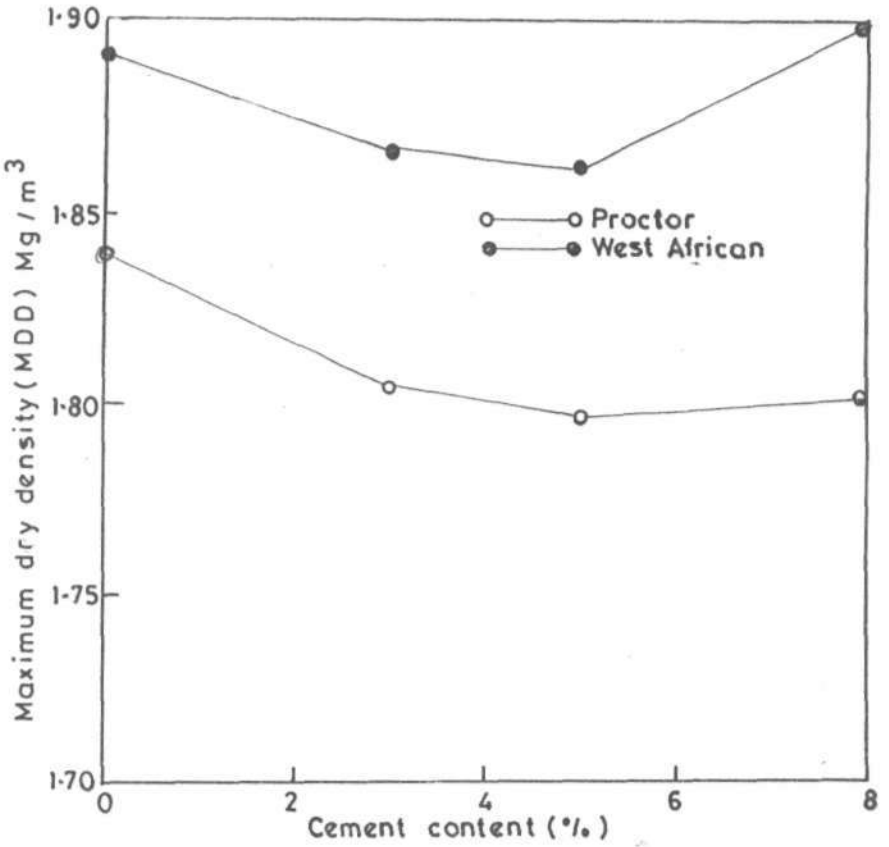
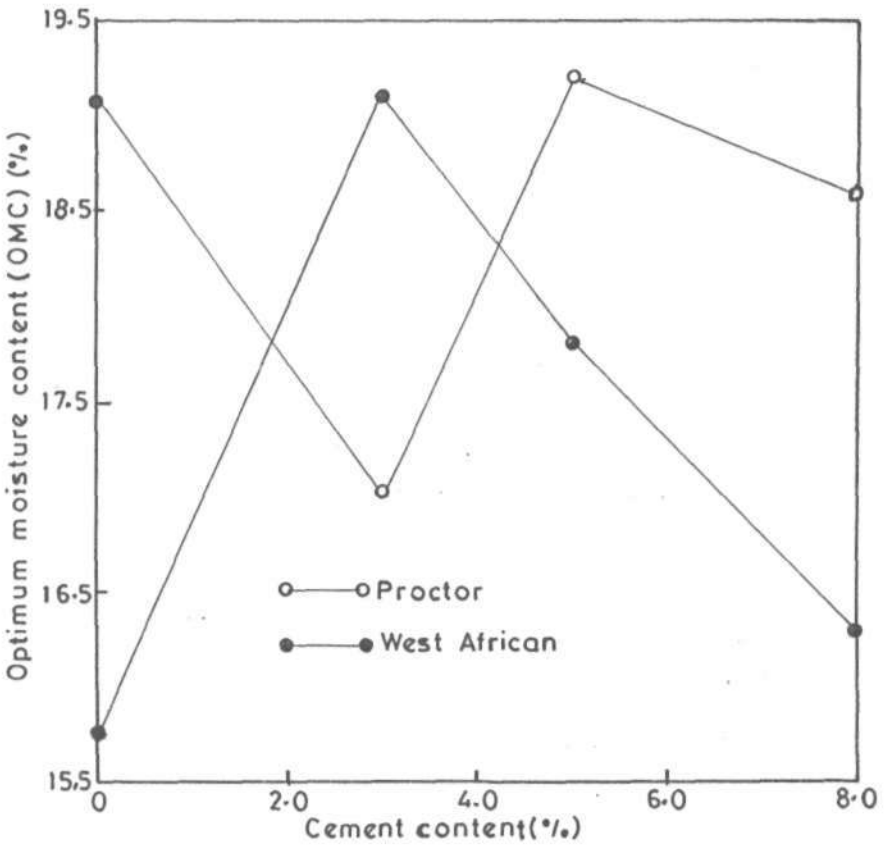



FIG.3.23 : VARIATION OF MDD WITH CEMENT CONTENT AT 0.0 HOUR

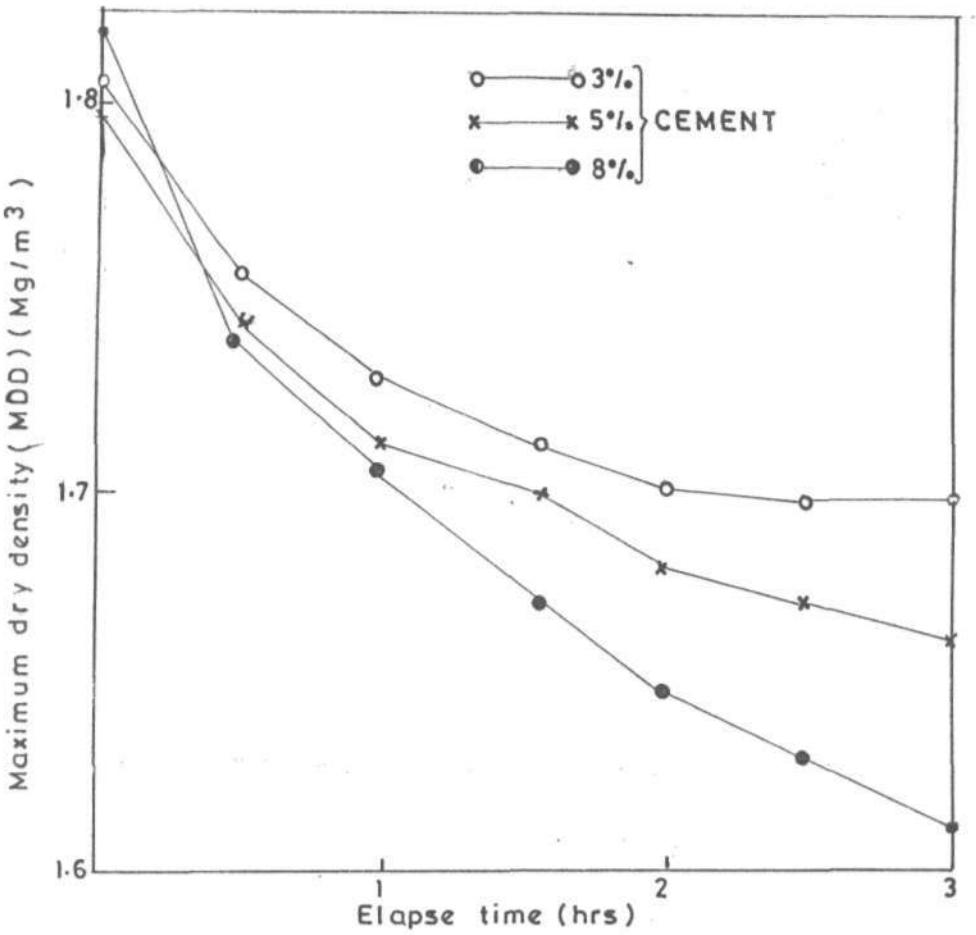



FIG·3·24: VARIATION OF OMC WITH CEMENT CONTENT AT 0·0 HOUR

The irregular pattern of variation of OMC with cement content for both Proctor and West African Compactions could be as a result of the OMC being dependent upon the MDD obtained, which implies that the reaction of cement affected the moisture content of the treated soil.

The variation of MDD for the various cement contents with elapse time after mixing for the Proctor and West African Compactions are shown in Figs. 3.25 and 3.26. There was a general decrease in MDD with increase in elapse time. The greatest drop in MDD was recorded at 8% cement content 3.0 hours after mixing. This was as a result of the effect of compaction on the clay-cement reaction. After mixing the soil and cement, a reaction between the clay fraction and cement took place forming coarser particles. However, during compaction these newly formed coarser particles were broken down thus disturbing the original reaction path. Due to the foregoing, the particle volume increased thus reducing the MDD.

The variation of OMC for the various cement contents with elapse time after mixing for Proctor and West African Compactions are shown in Figs 3.27 and 3.28. The OMC decreased with increase in elapse time as a result of water being continuously used up in the hydration reaction occurring in the cement stabilized soil.




FIG·3·25:VARIATION OF MDD WITH ELAPSE TIME FOR CEMENT STABILIZED LATERITE ( Proctor Compaction )

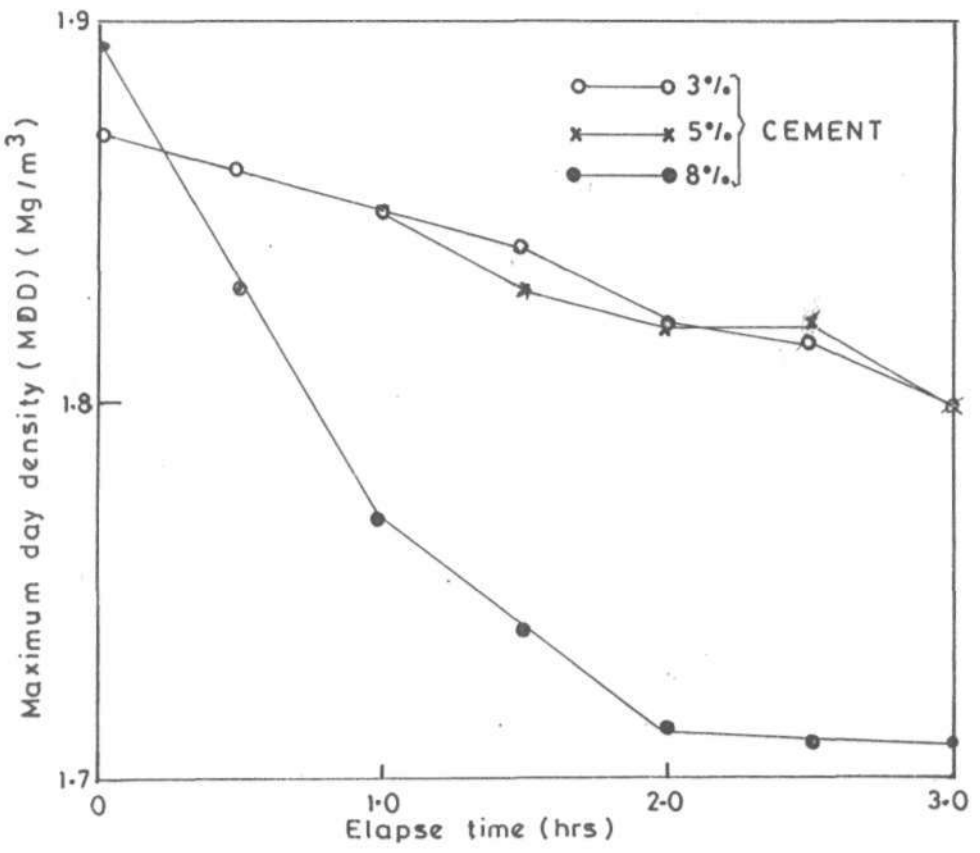
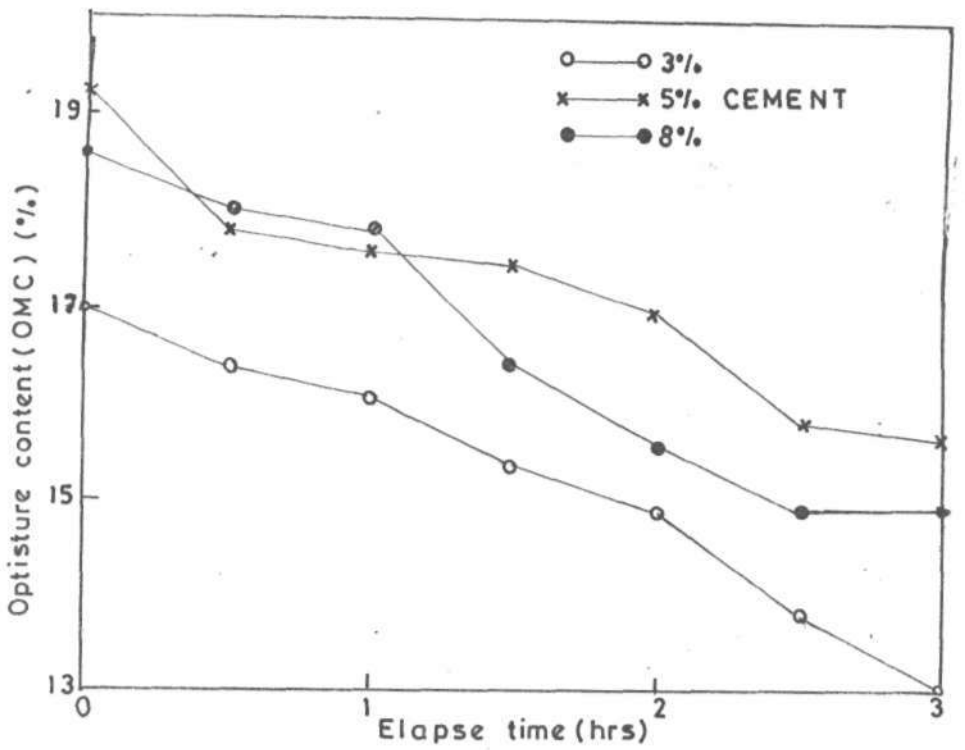
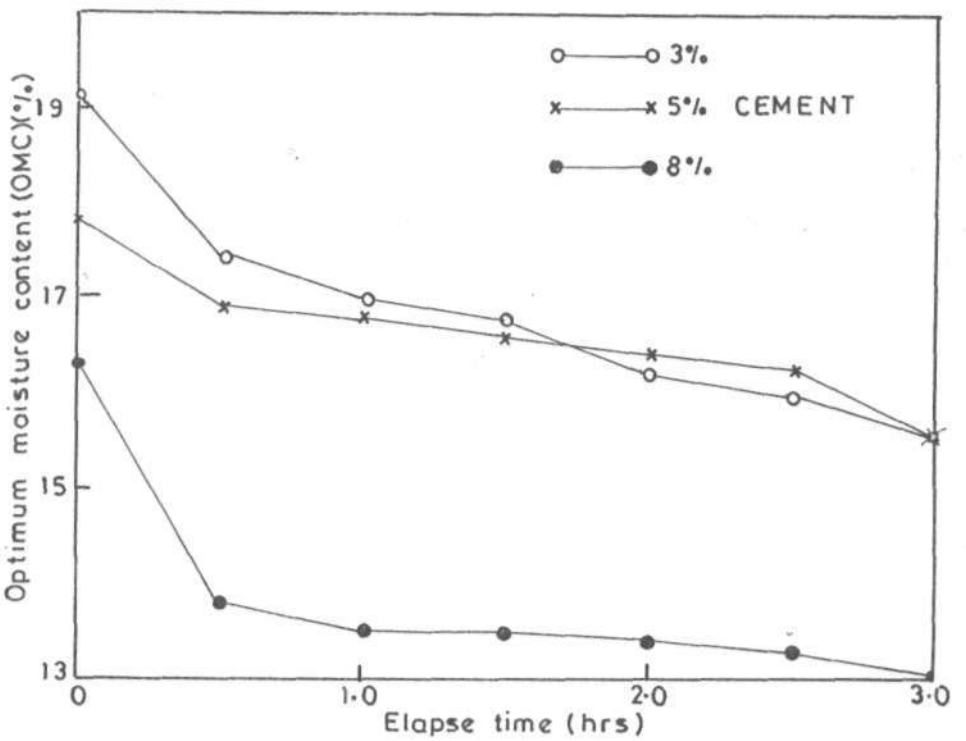



FIG. 3·26: VARIATION OF MDD WITH ELAPSE TIME FOR CEMENT STABILIZED LATERITE ( West African Compaction)




FIG·3·27: VARIATION OF OMC WITH ELAPSE TIME FOR CEMENT STABILIZED LATERITE (Proctor Compaction)




FIG·3·28: VARIATION OF OMC WITH ELAPSE TIME FOR CEMEN STABILIZED LATERITE (West African Compaction)

**LIME STABILIZED LATERITE:** The effects of lime content on the MDD and OMC of laterite 0.0 hour after mixing are shown in Figs. 3.29 and 3.30.

The patterns of the variation of MDD with lime content for the two compactive energy levels are similar. There is a decrease in MDD from a value of 1.840 $Mg/m^3$ (Proctor Compaction) and 1.890 $Mg/m^3$ (West African Compaction) at 0% lime content to 1.747 $Mg/m^3$ and 1.803 $Mg/m^3$ at 3% lime content then an increase to 1.789 $Mg/m^3$ (P Proctor Compaction) and 1.819 $Mg/m^3$ (West African Compaction) at 5% lime content and finally a decrease to 1.734 $Mg/m^3$ and 1.800 $Mg/m^3$ at 8% lime content respectively.

The initial drop in MDD was due to the flocculation and agglomeration of clay particles (caused by the cation exchange reaction) occupying larger spaces leading to a corresponding decrease in dry density (Ola 1977; Lees et al. 1982). The increase in density at 5% lime content is the result of molecular re-arrangement in the formation of "transitional compounds" which have a higher density than that at 3% lime content and this could be interpreted in the light of Brandl (1980) assumptions stated in paragraph 1.2.7 of the literature review.

Unlike the MDD, the variation of OMC, with lime content for the Proctor and West African compactions shown in fig 3.30 are not similar. The OMC increased with higher lime content with a tendency to flatten out for West African Compaction specimens while specimens compacted at the Proctor energy level gave OMC which decreased from 19.1% at 0% lime content to 17.7% at 3% lime content and thereafter rapidly increased with higher lime content. The increase in OMC with increasing lime content is due to the larger amount of water required in the dissociation of lime into $Ca^{2+}$ and $OH^-$ to supply more $Ca^{2+}$ for cation exchange (Osula, 1991).

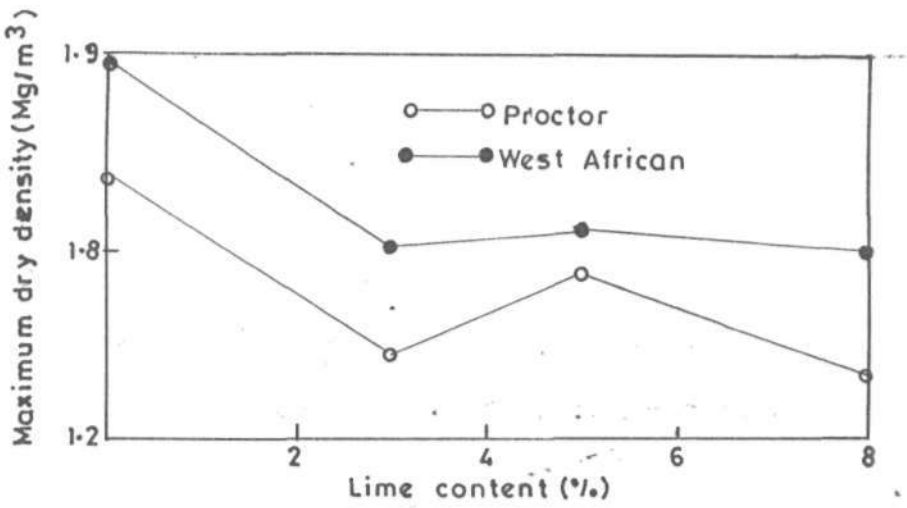
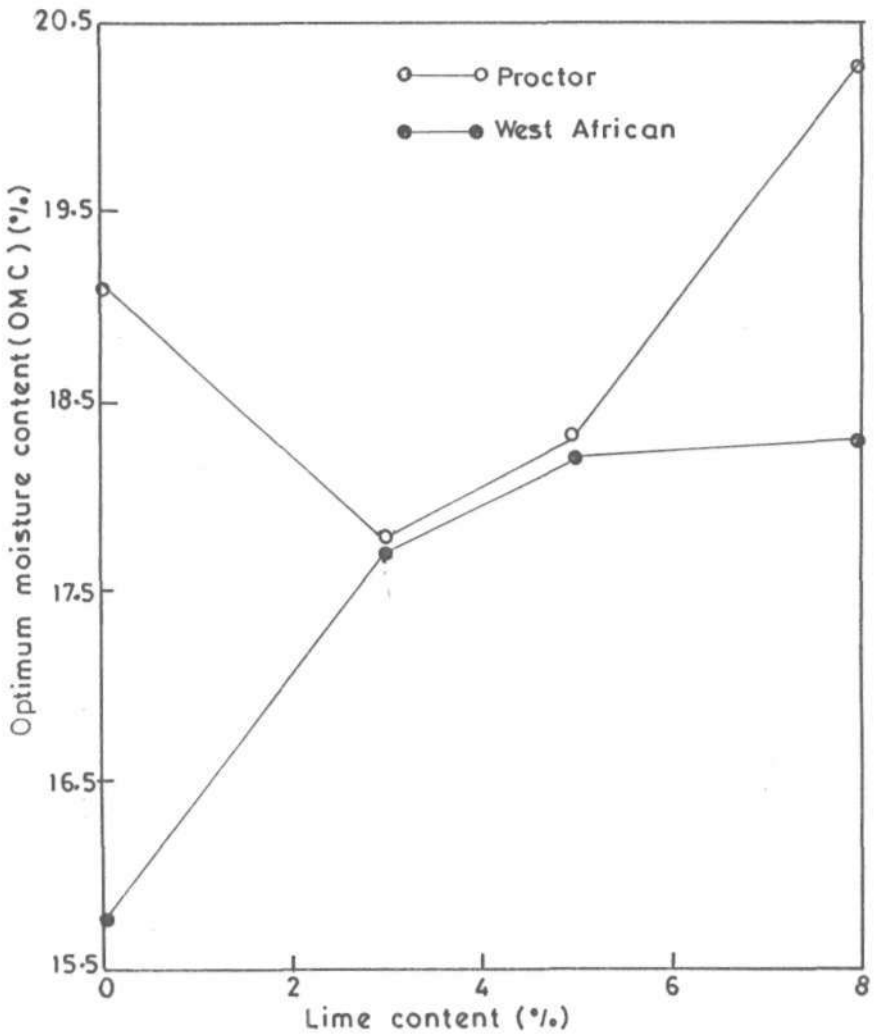


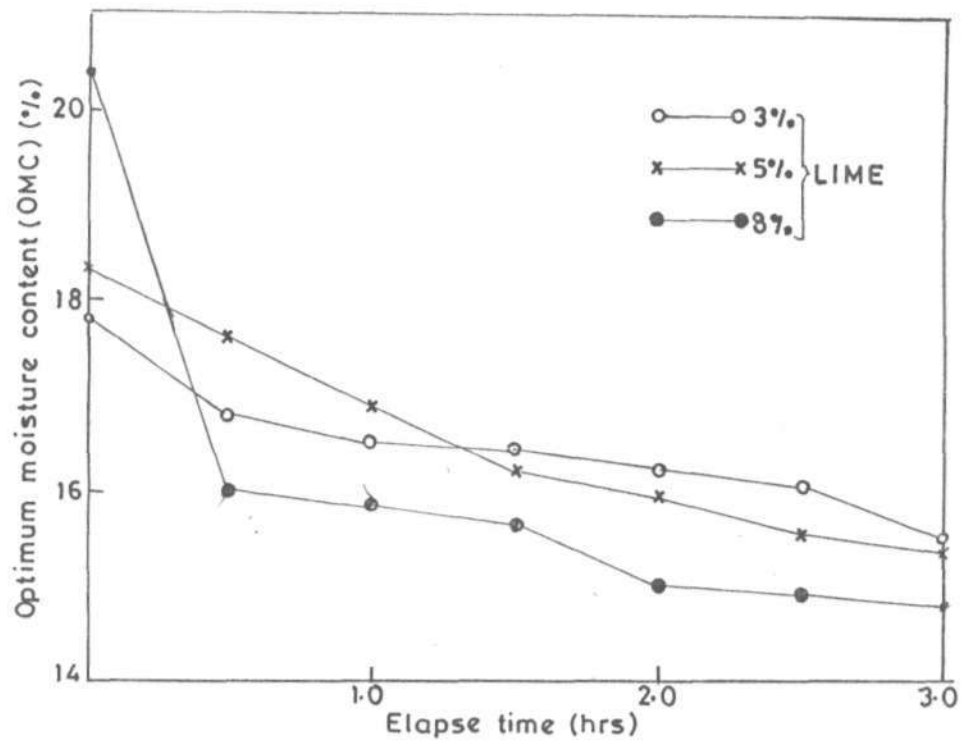

FIG. 3·29: VARIATION OF MDD WITH LIME CONTENT AT 0·0 HOUR



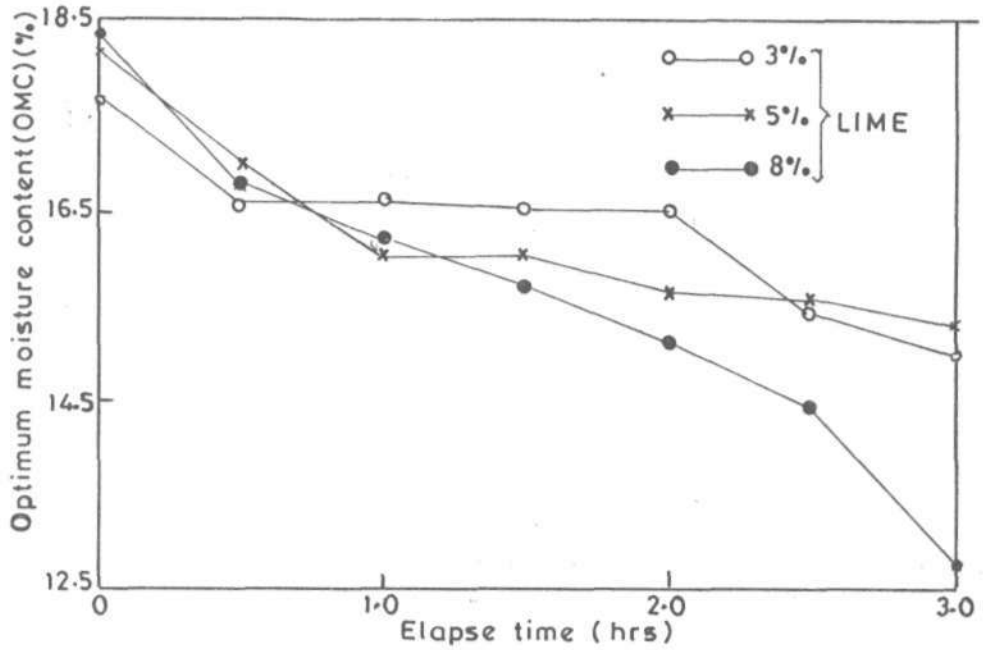

FIG·3·30: VARIATION OF OMC WITH LIME CONTENT AT 0·0 HOUR

The variation of the MDD for the various lime contents with elapse time after mixing for the Proctor and West African Compactions are shown in Figs 3.31 and 3.32. There was a general decrease in MDD with increase in elapse time. The greatest drop in MDD was recorded at the 8% lime content while the least drop in MDD was obtained at the 3% lime content, 3.0 hours after mixing. This was as a result of the flocculation and agglomeration reactions which took place in the lime stabilized soil forming coarser particles. These particles were loosely packed thus having an increased volume and consequently low MDD.

The variation of OMC for the various lime contents with elapse time after mixing for Proctor and West African Compactions are shown in Figs. 3.33 and 3.34. There was a decrease in OMC with increase in elapse time. Compaction delays allowed for flocculation and agglomeration reactions to proceed. This resulted in the reduction of water in the samples due to the exothermic nature of the reaction which facilitated evaporation of moisture.




FIG·3·33 : VARIATION OF OMC WITH ELAPSE TIME FOR LIME STABILIZED LATERITE (Proctor Compaction)




FIG·3·34 : VARIATION OF OMC WITH ELAPSE TIME FOR LIME STABILIZED LATERITE (West African Compaction)

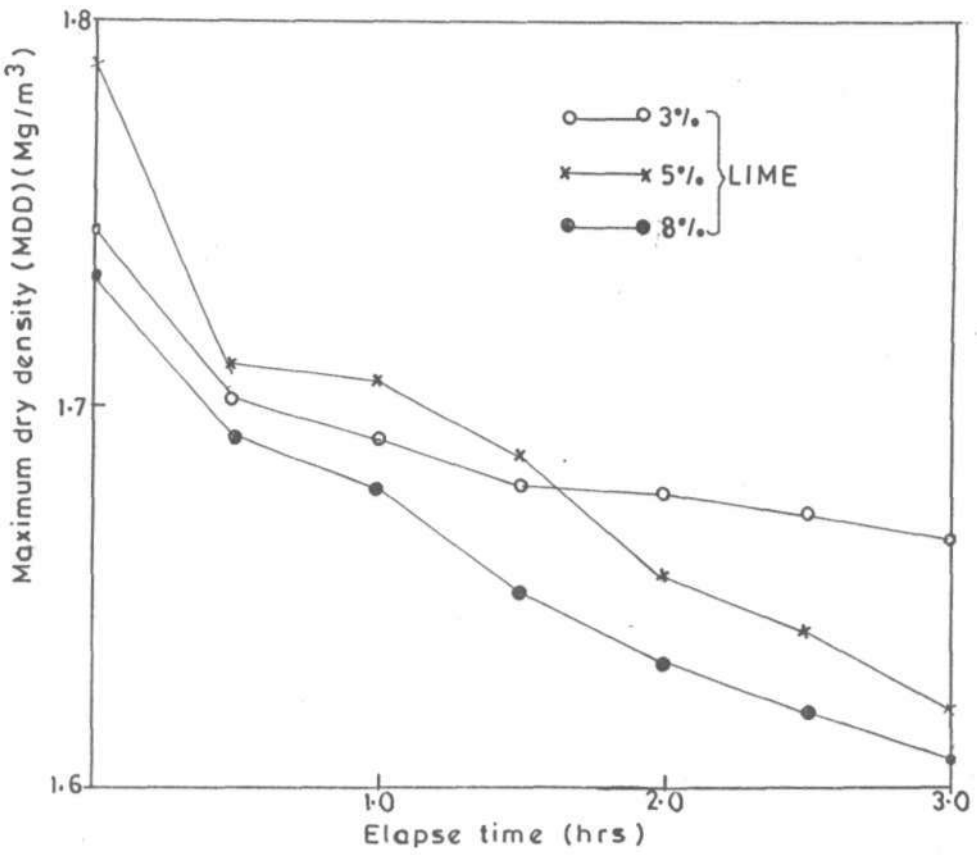
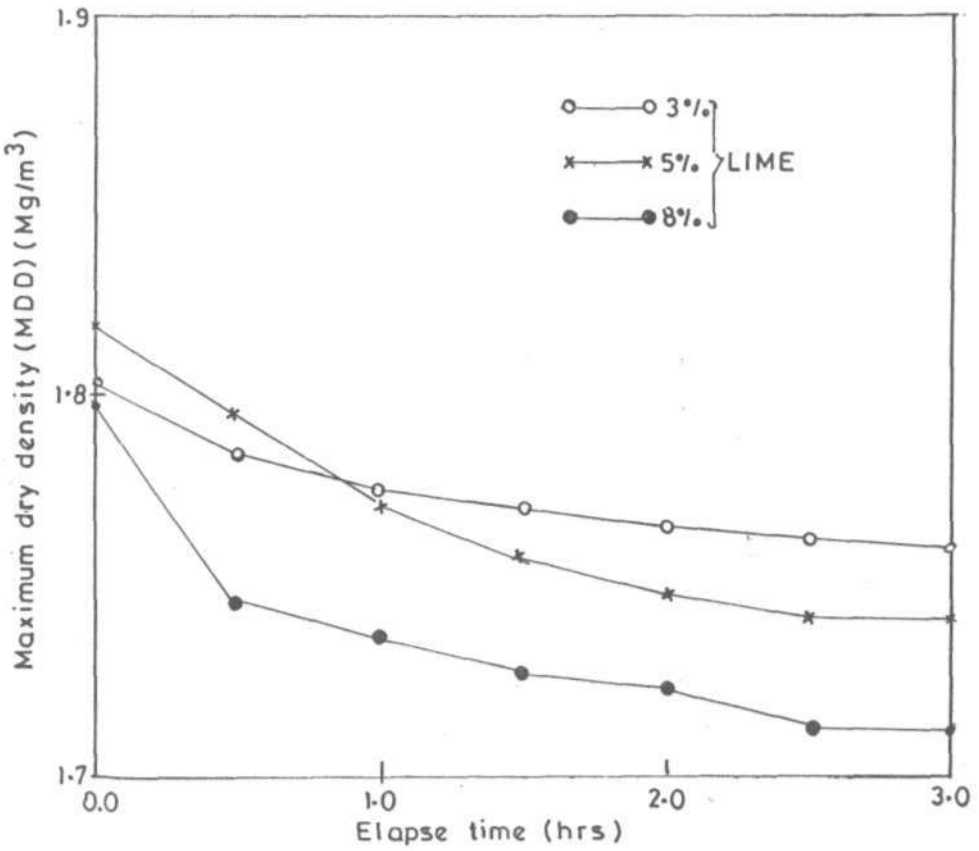



FIG.3·31: VARIATION OF MDD WITH ELAPSE TIME FOR LIME STABILIZED LATERITE (Proctor Compaction)




FIG·3·32: VARIATION OF MDD WITH ELAPSE TIME FOR LIME STABILIZED LATERITE (West African Compaction)

### *3.2.4 The Unconfined Compressive Strength (UCS)*

**CEMENT STABILIZED LATERITE:** The variations of the unconfined compressive strength with cement content are shown in Figs 3.35 and 3.36 for Proctor and West African Compactions respectively. The UCS of the specimens which were wax cured for 7 days, 14 days and those which were wax cured for 7 days and soaked for another 7 days increased with increase in cement content, for the compactive energy levels utilized. For the specimens compacted at the energy of the Proctor, the UCS at 7 days curing increased from 310 KN/m$^2$ at 0% cement content to 1025 KN/m$^2$, 1100 KN/m$^2$ and 1275 KN/m$^2$ at 3%, 5% and 8% cement contents respectively. At a curing age of 14 days, the UCS increased from 400 KN/m$^2$ at 0% cement content to 1325 KN/m$^2$, 1575 KN/m$^2$ and 1775 KN/m$^2$, at 3%, 5% and 8% cement contents respectively. However, the specimens crumbled in water after 72 hours giving a strength of 0 KN/m$^2$, while 450 KN/m$^2$, 475 KN/m$^2$ and 600 KN/m$^2$ were recorded against 3%, 5% and 8% cement contents respectively.

The specimens compacted using the West African energy level had the same trend as described above. At a curing age of 7 days, there was gain in strength from 450 KN/m$^2$ at 0% cement content to 1100 KN/m$^2$, 1425 KN/m$^2$ and 1650 KN/m$^2$ at 3%, 5% and 8% cement contents respectively. Similarly, at a curing age of 14 days the strength increased from 600 KN/m$^2$ at 0% cement content to 1475 KN/m$^2$, 1725 KN/m$^2$ and 2250 KN/m$^2$ at 3%, 5% and 8% cement contents respectively. The specimens which were wax cured for 7 days, dewaxed and immersed in water for another 7 days decreased in strength, relative to the 7 and 14 days strength respectively. However, the UCS increased with increasing cement content from 0KN/m$^2$ at 0% cement content to 500 KN/m$^2$, 600 KN/m$^2$ and 725 KN/m$^2$ at 3%, 5% and 8% cement contents respectively.

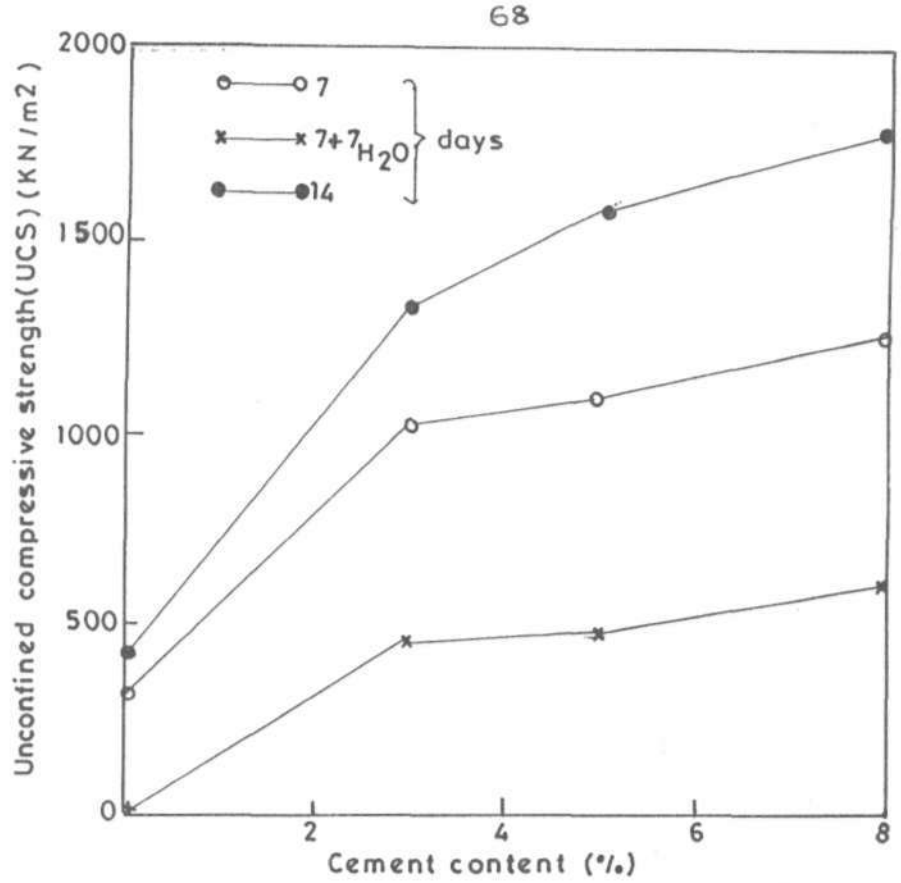



FIG. 3·35: VARIATION OF UCS WITH CEMENT CONTENT AT 0·0 HOUR
(Proctor Compaction)

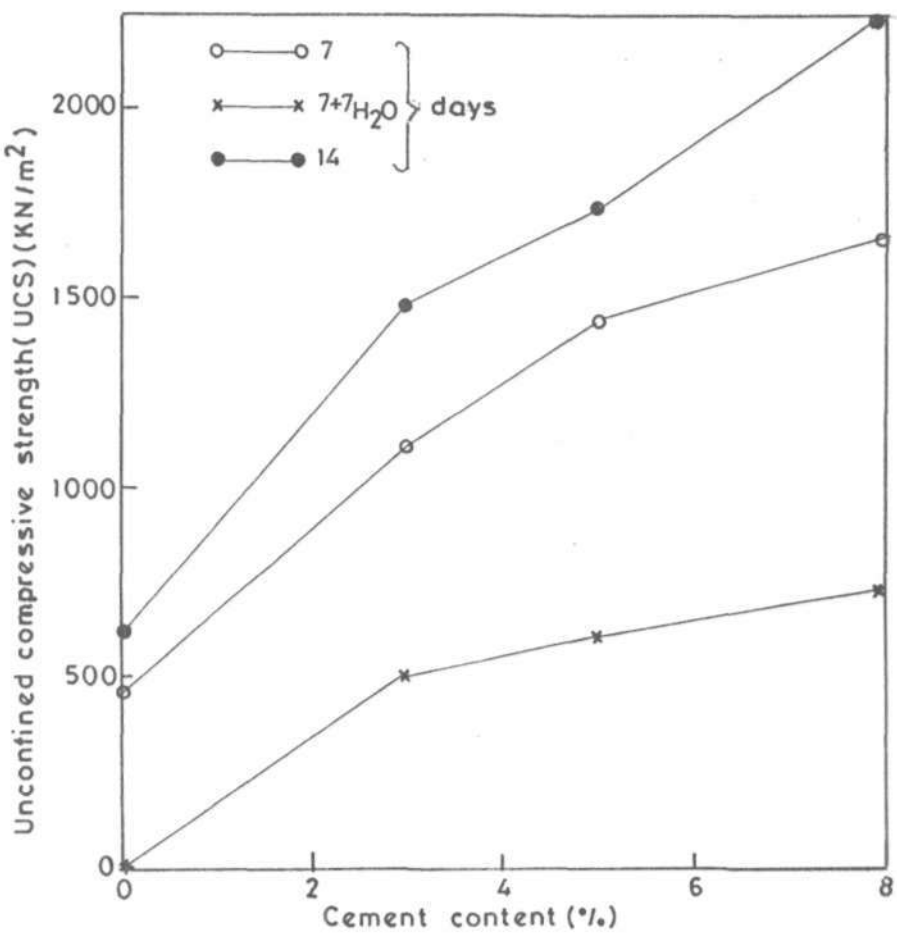



FIG-3·36: VARIATION OF UCS WITH CEMENT CONTENT AT 0·0 HOUR
(West African Compaction)

The increase in strength with increase in cement content was due to the increase in calcium silicate and calcium aluminate which hydrated and developed strength. These two compounds contributed to early strength gains and latter on lime was released which also contributed to strength gains.

The curing age affected the strength. Increasing the curing age caused the strength to increase because a longer period was allowed for the hydration reaction to proceed and then the pozzolanic reaction resulting from the release of lime was much more effective.

The soaked specimen decreased in strength because the water molecules surrounded the respective strength bonds making them liable to slide over one another. Hence the low strength recorded.

The variation of the UCS for the various cement contents with elapse time after mixing, for specimens compacted at the Proctor and West African energy levels are shown in Figs 3.37 and 3.38. There was a decrease in the UCS of both the unsoaked and soaked specimens with increasing elapse time.

At the energy level of the Proctor the curves were closer to each other at 1.5 hours after mixing. There was an overlap between the 8% cement stabilized laterite cured for 7 days and 3% cement stabilized laterite cured for 14 days at 2.5 hours. Immersing the specimen in water for 7 days drastically reduced the strength with increase in elapse time.

At the West African compaction energy level, there was an overlap at 2.0 hours after mixing between the 8% cement stabilized laterite cured for 7 days. Another overlap occurred at 2.5 hours between the 5% cement stabilized laterite cured for 7 days and 3% cement stabilized laterite

cured for 14 days. The specimens immersed in water for 7 days also had reduced strength with increase in elapse time.

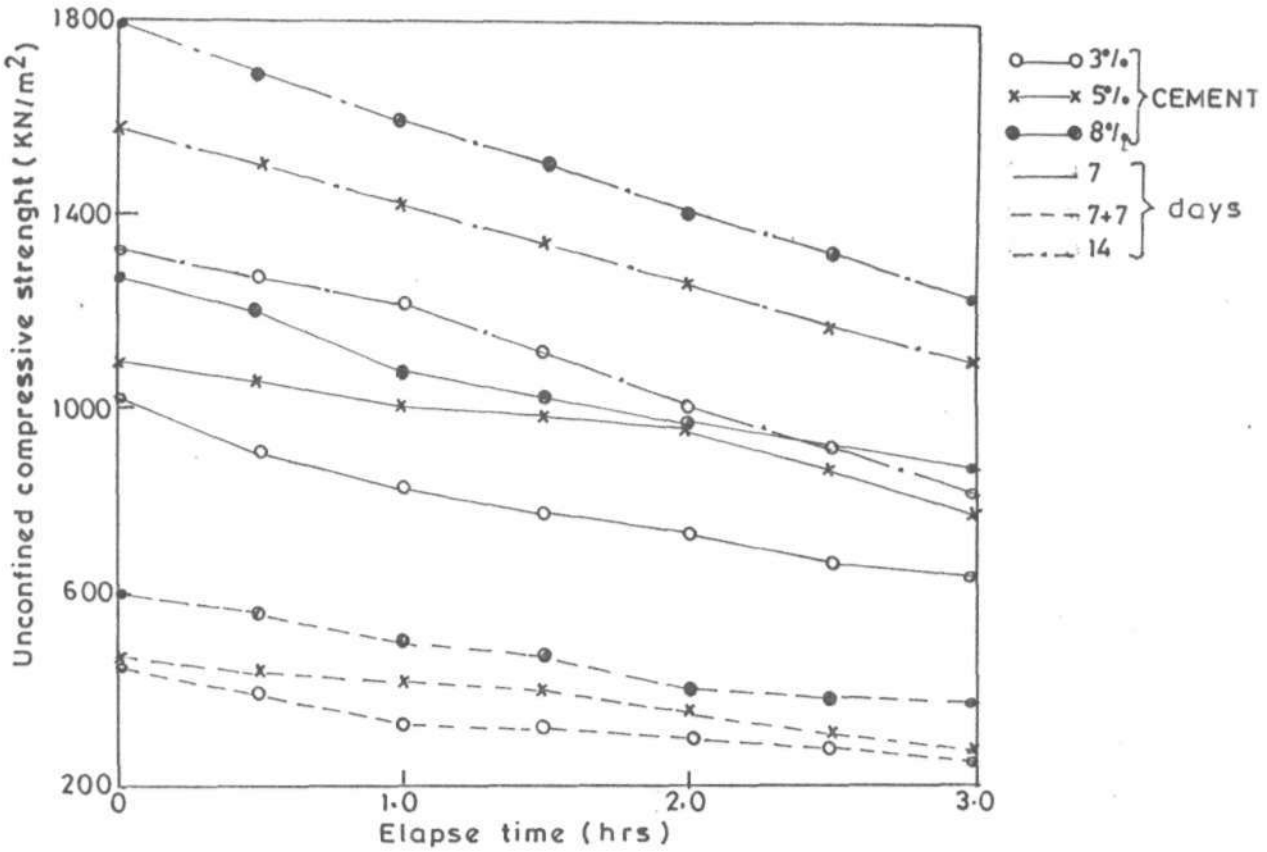
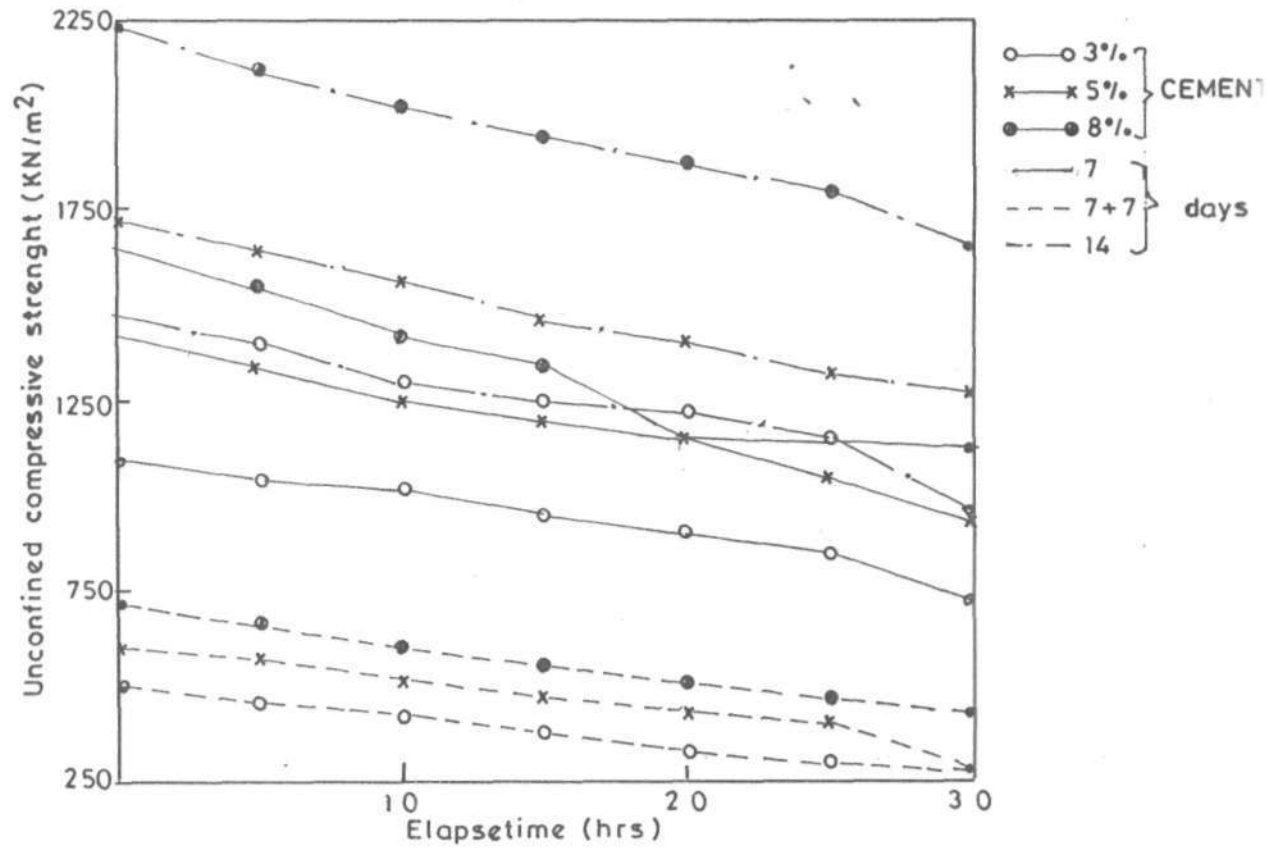



FIG. 3·37 : VARIATION OF UCS WITH ELAPSE TIME FOR CEMENT STABILIZED LATERITE (Proctor Compaction)




FIG·3·38 : VARIATION OF UCS WITH ELAPSE TIME FOR CEMENT STABILIZED LATERITE (West African Compaction)

An increase in the elapse time caused the hydration reaction to proceed forming coarser particles with the reacting surfaces far apart. Compaction of the mixture after the reaction had taken place resulted in a decrease in the strength development, whereas compaction of the mixture at 0.0 hour brought the reaction path closer resulting in higher strength.

**LIME STABILIZED LATERITE:** The variation of the unconfined compressive strength with lime content 0.0 hour after mixing for Proctor and West African Compactions are shown in Figs 3.39 and 3.40 respectively.

For the specimens compacted at the energy level of the Proctor and wax cured for 7 days, the UCS increased from 310 KN/$m^2$ at 0% lime content to 575 KN/$m^2$, 800 KN/$m^2$ and 875 KN/$m^2$ at 3%, 5% and 8% lime contents respectively. At a curing age of 14 days, the UCS increased from 400 KN/$m^2$ at 0% lime content to 850 KN/$m^2$, 1050 KN/$m^2$ and 1075 KN/$m^2$ at 3%, 5% and 8% lime contents respectively. However, the soaked specimen decreased in strength. The UCS increased with increasing lime content from 0 KN/$m^2$ at 0% lime content to 375 KN/$m^2$ at 3% lime content and 475 KN/$m^2$ at 5% lime content. It then slightly decreased to 450 KN/$m^2$ at 8% lime content.

There was a slight variation in the curve pattern for the specimens prepared at the West African compaction energy level. At 7 days curing the UCS increased from 450 KN/$m^2$ at 0% lime content to 725 KN/$m^2$, 825 KN/$m^2$ and 1025 KN/$m^2$ for 3%, 5%, and 8% lime contents respectively. At a curing age of 14 days, the UCS increased from 600 KN/$m^2$ at 0% lime content to 975 KN/$m^2$ at 3% lime content then to 1475 KN/$m^2$ at 5% lime content. There was then a slight decrease to 1275 KN/$m^2$ at 8% lime content. The specimens wax cured for 7 days and immersed in water for 7 days increased in strength from 0 KN/$m^2$ to 725 KN/$m^2$ at 5% lime contents, then slightly decreased to 600 KN/$m^2$ at 8% lime content.

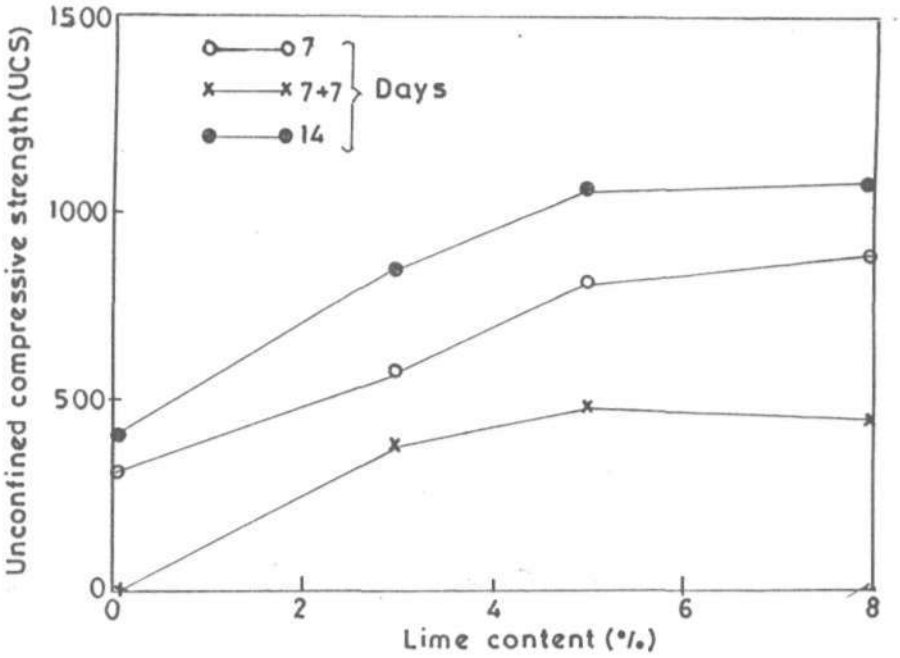



FIG.3.39: VARIATION OF UCS WITH LIME CONTENT AT 0.0 HOUR
(Proctor Compaction)

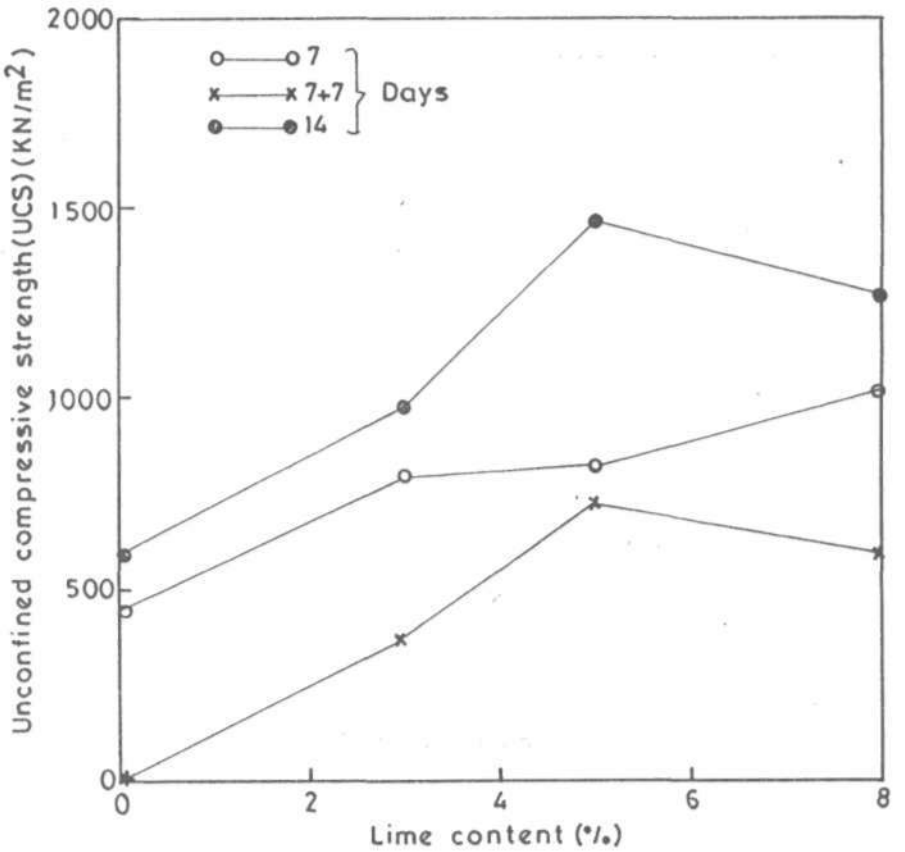



FIG.3.40: VARIATION OF UCS WITH LIME CONTENT AT 0.0 HOUR
(West African Compaction)

Increase in the lime content generally caused an increase in the UCS. There was increased flocculation and agglomeration reaction being the first stage, then an increase in the pozzolanic reaction being the second stage. The curing age also affected the extent of the pozzolanic reaction as evidenced by the increased UCS at 14 days curing period. The UCS of the soaked specimens decreased in strength because of the excess water molecules surrounding the strength bonds making them liable to slide over one another thus resulting in lower UCS values.

The variation of the UCS for the various lime contents with elapse time after mixing for Proctor and West African compacted specimens are shown in Figs 3.41 and 3.42 respectively. There was a decrease in the UCS with increase in elapse time for both compactive levels of either the unsoaked or soaked specimens.

At the energy level of the Proctor, the curves were closer to one another than for the West African Compaction curves indicating that the strength gain at each percent stabilizer content was not much. There were overlaps between the 3% lime stabilized laterite at 14 days curing age and 8% lime stabilized laterite at 7 days curing age occurring 0.5 hour and 1.0 hour after mixing. Another overlap occurred 3.0 hours after mixing between the 5% lime stabilized laterite at 7 days curing and 3.0% lime stabilized laterite at 14 days curing. There was an overlap at 2.0 hours in the soaked specimen between the 5% and 8% lime stabilized laterite respectively.

At the West African energy level, the curves were further apart as compared to the specimens compacted at the Proctor energy level. An overlap occurred at 3.0 hours after mixing between 3% and 8% lime stabilized laterite for the soaked specimens.

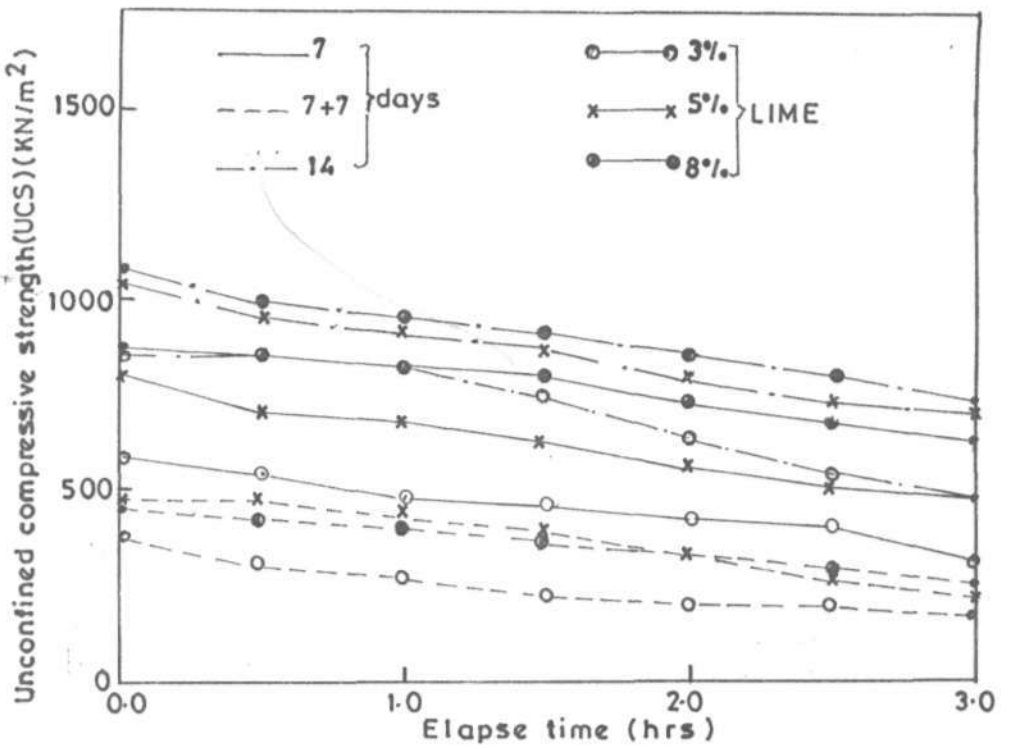



FIG-3-41 : VARIATION OF UCS WITH ELAPSE TIME FOR LIME STABILIZED LATERITE ( Proctor Compaction )

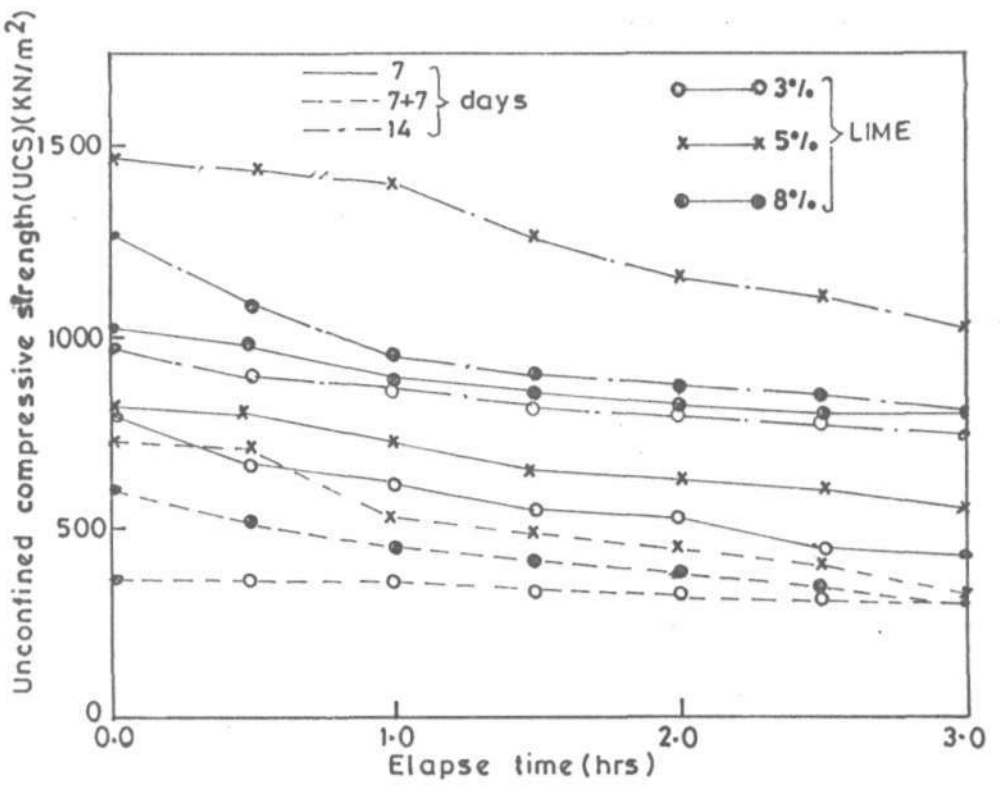



FIG-3-42 : VARIATION OF UCS WITH ELAPSE TIME FOR LIME STABILIZED LATERITE (West African Compaction )

Increase in the elapse time allowed the flocculation and agglomeration reaction to proceed before the particles surface were brought closer together by compaction. This situation is unlike the case of compacting 0.0 hour after mixing which brought the reaction particles closer together before a substantial part of the reaction process was attained.

The soaked specimen performed poorly due to the presence of excess water than that needed in strength development. The water molecules surrounded each layer of the lime-silica bond which are the strength developing bonds making them liable to slide over one another. Consequently the structure easily crumbled upon the application of load.

The results presented show that the strength developing process was more effective in the cement stabilized specimen than the lime stabilized specimen. The low curing temperature of 20 ± 2C and 100% relative humidity provided a better curing regime for the cement stabilized laterite, unlike the lime stabilized laterite whose strength development is enhanced by a much higher temperature. Increase in the curing age caused an increase in the strength development.

The summary of the suitability of stabilized laterite using the unconfined compressive strength UCS is shown in Table 4.1

TABLE 4.1 Summary of the suitability of stabilized laterite using the Unconfined Compresive Strength (UCS)

| ELAPSE TIME (HRS) | SUBBASE | | | | | | | | | | | | BASE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LIME | | | | | | CEMENT | | | | | | LIME | | | | | | CEMENT | | | | | |
| | PROC. | | | W. A | | | PROC | | | W.A | | | PROC. | | | W.A | | | PROC. | | | W.A | | |
| | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% |
| 0.0 | x | v | v | v | v | v | v | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | x | v |
| 0.5 | x | x | v | x | v | v | v | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | x | v |
| 1.0 | x | x | v | x | x | v | v | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | x | x |
| 1.5 | x | x | v | x | x | v | v | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | x | x |
| 2.0 | x | x | x | x | x | v | x | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | x | x |
| 2.5 | x | x | x | x | x | v | x | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | x | x |
| 3.0 | x | x | x | x | x | v | x | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | x | x |

x Failed Test v Passed Test

### *3.2.5. California Bearing Ratio (CBR)*

The variation of CBR with stabilizer content 0.0 hour after mixing for both Proctor and West African compaction specimens are shown in Figs. 3.43 and 3.44 respectively.

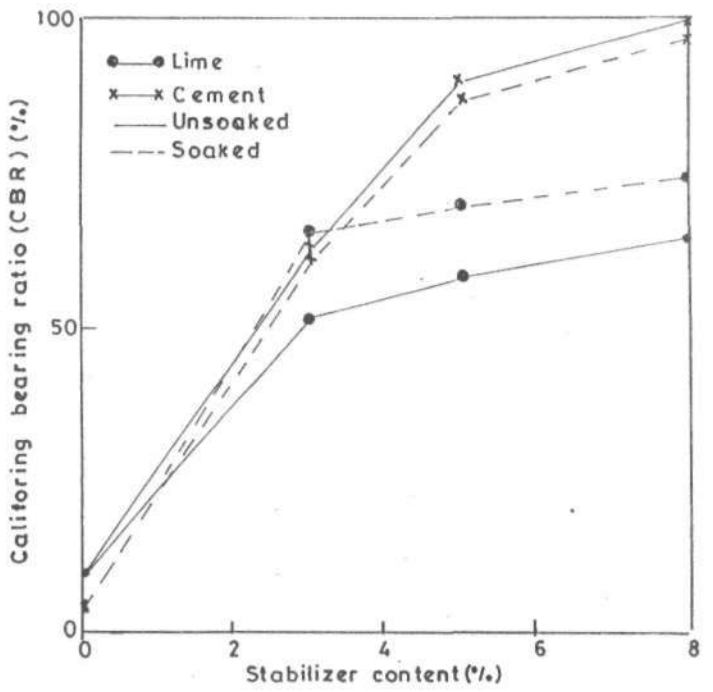



FIG-3-43: VARIATION OF CBR WITH STABITIZER CONTENT AT 0-0 HOUR FOR PROCTOR COMPACTION

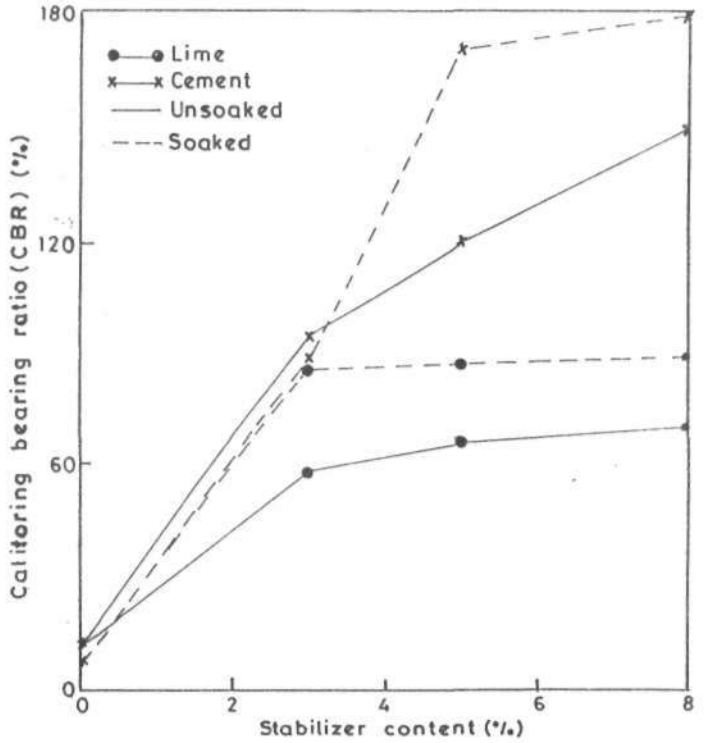



FIG-3-44: VARIATION OF CBR WITH STABILIZER CONTENT AT 00 HOUR FOR WEST AFRICAN . COMPACTION

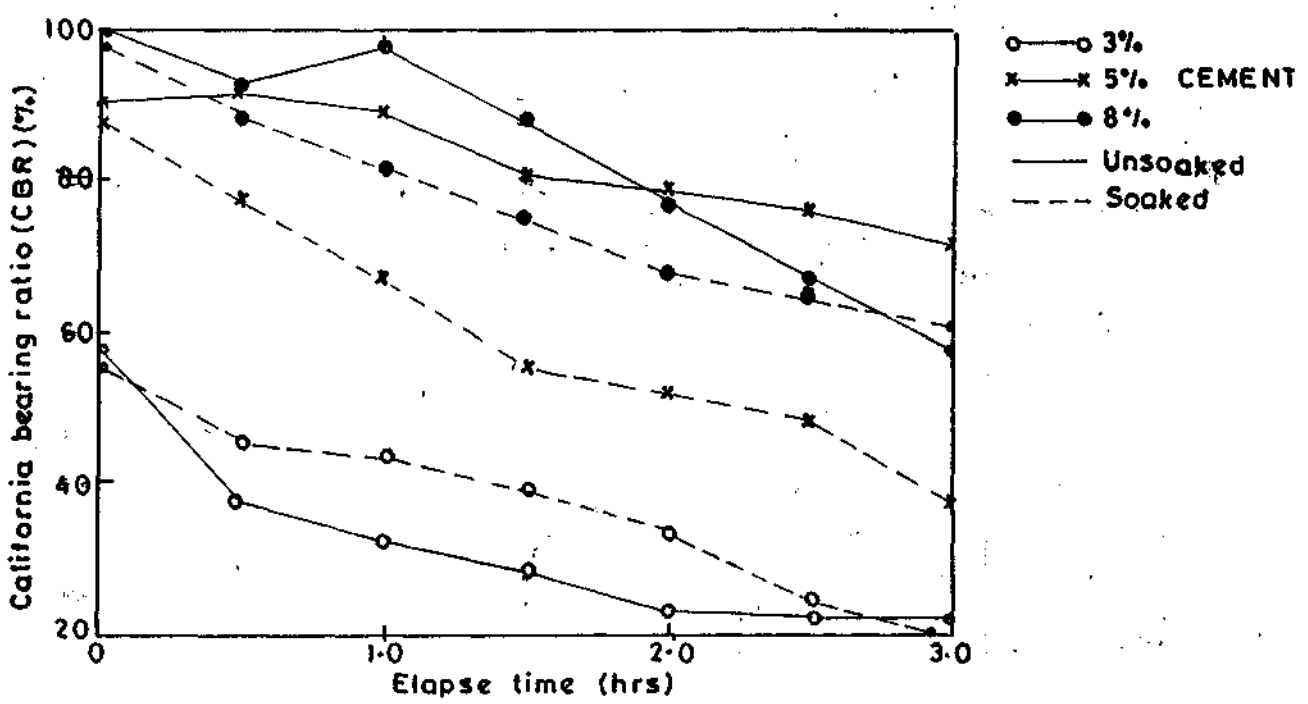
CEMENT STABILIZED LATERITE: There is an increase in the CBR values with increase in cement content for specimens prepared using Proctor and West African Compactive energies. Generally, higher CBR values were recorded for soaked cement stabilized specimens when compared with the unsoaked specimens. This may be attributed to a better curing effect produced when the specimens were immersed in water. Furthermore a better temperature regime was established and this enhanced strength development than the unsoaked condition.

With respect to elapse time after mixing for both Proctor and West African Compactions, there was a decrease in CBR values with increase in elapse time as shown in Figs 3.45 and 3.46. For the Proctor Compactive effort, the unsoaked specimens at 3% cement content, showed a 40% loss in CBR 3.0 hours after mixing. Similarly, 48% and 38% losses in CBR for 5% and 8% cement content respectively were recorded. The soaked specimens showed losses of 40%, 22% and 42% in CBR values for 3%, 5% and 8% cement content respectively, 3.0 hours after mixing. For the West African Compactive effort, the unsoaked specimens at 3% cement content showed a 30% loss in CBR 3.0 hour after mixing. Similarly, 73% and 120% losses in CBR for 5% and 8% cement content respectively were recorded. The soaked specimens showed losses of 45%, 25% and 60% CBR values for 3%, 5% and 8% cement contents respectively.

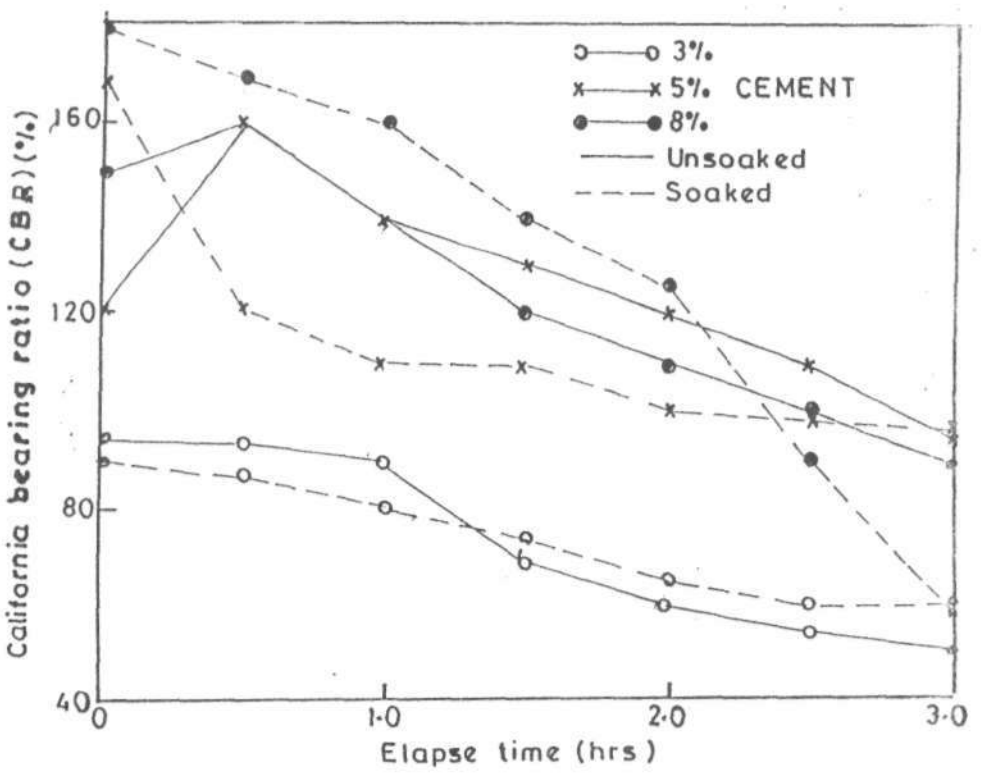
The Nigerian General Specification for Roads and Bridges (1970) clause 6228 prescribed a minimum strength of 80% CBR value for base coarse material determined at MDD and OMC with either West African Compaction or Modified AASHTO at the discretion of the engineer's representative. However, where he considers it necessary on account of perched Water tables or any other reasons, the engineer's representative may specify that a CBR value of 80% be obtained after at least 24 hours soaking.

The minimum strength of material for sub-base course shall not be less than 30% CBR after at least 24 hours soaking the CBR value being assessed in the same manner as for base coarse.

Using the above criteria, a minimum of 3% cement content is suitable for sub-base course even 3.0 hours after mixing. For base course material, 3% cement content is suitable with a maximum delay of 1.0 hour. However, 5% content is suitable with a maximum delay of 1.0 hour. However, 5% and 8% cement content are suitable for use with maximum delays of 3.0 hours and 2.5 hours respectively.




FIG·3·45: VARIATION OF CBR WITH ELAPSE TIME FOR CEMENT STABILIZED LATERITE ( Proctor Compaction )




FIG·3·46: VARIATION OF CBR WITH ELAPSE TIME FOR CEMENT STABILIZED LATERITE (West African Compaction)

**LIME STABILIZED LATERITE:** Figs 3.43 and 3.44 show that there is an increase in the CBR values with increase in lime content for specimens prepared 0.0 hour after mixing, using Proctor and West African Compactive energies. The increase in CBR values was as a result of the increased flocculation and agglomeration due to increasing lime content and an increase in the pozzolanic reaction due to the much available lime required for strength development in lime stabilization. The soaked specimens recorded lower CBR values. This was due to the effect of Water molecules surrounding the strength bonds which weakened them thus resulting in lower CBR values.

With respect to elapse time after mixing for both Proctor and West African Compactions, there was increase in CBR values with increase in elapse time as shown in Figs. 3.47 and 3.48. For Proctor compacted unsoaked specimens, there was a 19% loss in CBR for 3% lime

content at 3.0 hours elapse time. Similarly 28% and 45% losses in CBR for 5% and 8% lime content respectively were recorded. The soaked specimens showed losses of 10%, 28% and 35% in CBR values for 3% and 8% lime contents respectively. For the West African Compactive energy level, the unsoaked specimens at 3% lime content reported a 35% loss in CBR 3.0 hour after mixing. Similarly 30% and 26% losses in CBR for 5% and 8% lime contents respectively were recorded, 0.0 hour after mixing. The soaked specimens showed looses of 10%, 30% and 26% in CBR values for 3%, 5% and 8% lime content respectively.

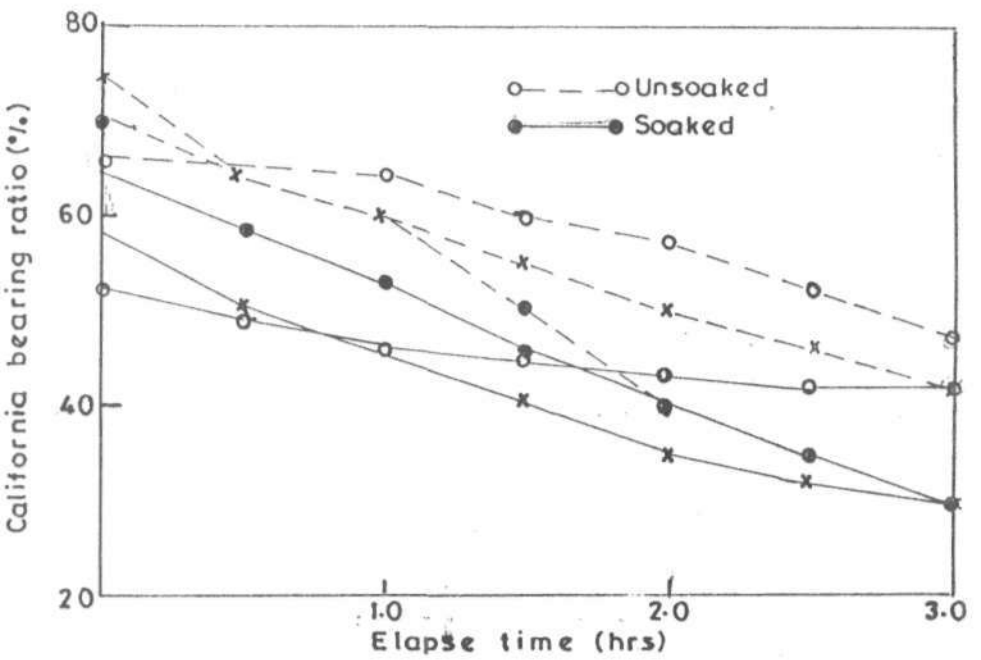
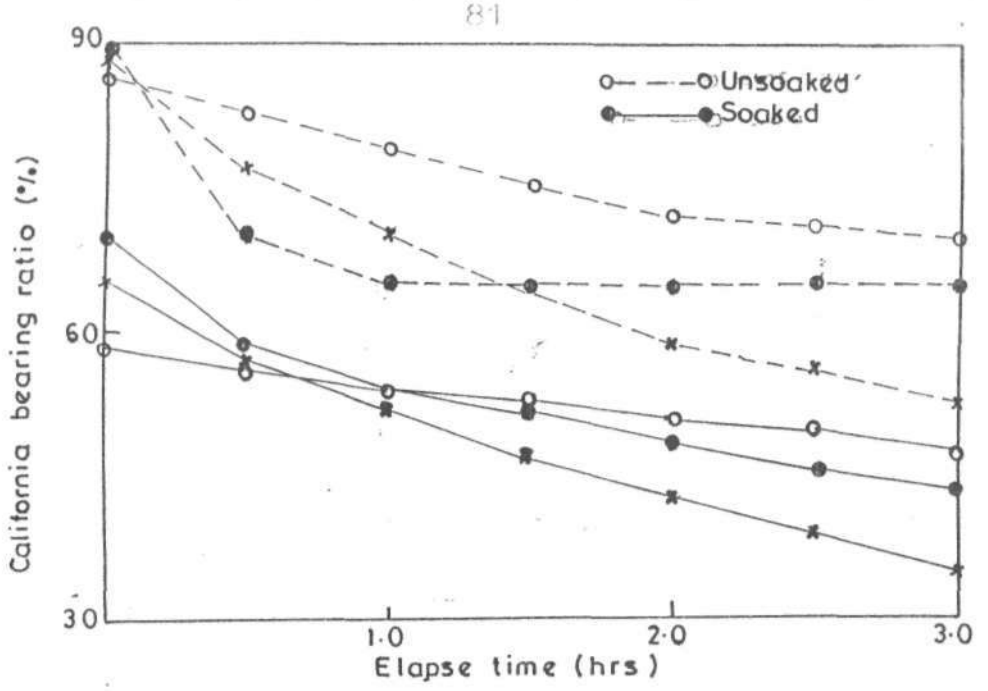



FIG.3.47 : VARIATION OF CBR WITH ELAPSE TIME FOR LIME STABILIZED LATERITE (Proctor Compaction)




FIG·3·48: VARIATION OF C B R WITH ELAPSE TIME FOR LIME STABILIZED LATERITE (West African Compaction)

Using the earlier stated criteria of the Nigerian General Specification for Roads and Bridges (1970), a minimum of 3% lime content is suitable for sub-base course even 3.0 hours after mixing. At 3% lime content, the materials suitable as a base course within a maximum delay of 30 minutes while for 5% and 8% lime constants it must be used immediately after mixing. The summary of the suitability of stabilized laterite using the California Bearing Ratio (CBR) is shown in Table 4.2.

TABLE 4.2. Summary of the suitability of stabilized laterite using the California Bearing Ratio (CBR)

| ELAPSE TIME (HRS) | SUBBASE | | | | | | | | | | | | BASE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LIME | | | | | | CEMENT | | | | | | LIME | | | | | | CEMENT | | | | | |
| | PROC. | | | W. A | | | PROC | | | W.A | | | PROC. | | | W.A | | | PROC. | | | W.A | | |
| | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% | 3% | 5% | 8% |
| 0.0 | v | v | v | v | v | v | v | v | v | v | v | v | x | x | x | x | x | x | x | v | v | v | v | v |
| 0.5 | v | v | v | v | v | v | v | v | v | v | v | v | x | x | x | x | x | x | x | v | v | v | v | v |
| 1.0 | v | v | v | v | v | v | v | v | v | v | v | v | x | x | x | x | x | x | x | v | v | v | v | v |
| 1.5 | v | v | v | v | v | v | x | v | v | v | v | v | x | x | x | x | x | x | x | v | v | x | v | v |
| 2.0 | v | v | v | v | v | v | x | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | v | v |
| 2.5 | v | v | v | v | v | v | x | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | v | v |
| 3.0 | v | v | v | v | v | v | x | v | v | v | v | v | x | x | x | x | x | x | x | x | x | x | v | v |

x Failed test v Passed test

# CHAPTER FOUR

# CONCLUSION AND RECOMMENDATION

## *4.1 CONCLUSION*

Based on the results of the investigation carried out, the following conclusion can be drawn;

1. The Soil was classified as an A-7-6 material according to the AASHTO Classification system and this agrees with an earlier classification carried out by (Ola, 1978)
2. From the results of the XRD and DTA Kaolinite was found to be the predominant clay mineral present in the Soil.
3. Cement and Lime altered the properties of the laterite and improved upon it. Cement improved the strength properties while lime improved the plasticity characteristics. Cement however proved to be a better stabilizer than lime.
4. The effect of elapse time after mixing caused a decrease in the properties analysed as shown in Figs 3.2, 3.3, 3.4, 3.6, 3.7, 3.8, 3.10, 3.11, 3.12, 3.14, 3.15, 3.16, 3.18, 3.19, 3.21, 3.22, 3.25, 3.26, 3.27, 3.28, 3.31, 3.32, 3.33, 3.34, 3.37, 3.38, 3.41, 3.42, 3.45, 3.46, 3.47 and 3.48. Furthermore, the effect of elapse time is more prominent in cement stabilized laterite.
5. The stabilized laterite could be used as a pavement material within the suitability limits summarized in Tables 3.1, 3.2, 3.3, 3.4, 4.1 and 4.2.

### *4.2 RECOMMENDATION*

It is recommended that a similar investigation be carried out on any laterite obtained within the confines of the Basic igneous rock and Ferruginous Tropical soil as shown in the Geological and Soil maps of Nigeria presented in Fig 2.1 and 2.2. The results thus obtained can be compared with the former and a general conclusion drawn on the effect of elapse time on the properties of stabilized laterite of the region described.

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