THE STABILIZATION POTENTIALS OF PULVERIZED COAL BOTTOM ASH (PCBA) AND SUPERPHOSPHATE FERTILIZER RESIDUE (SFPR)

BY

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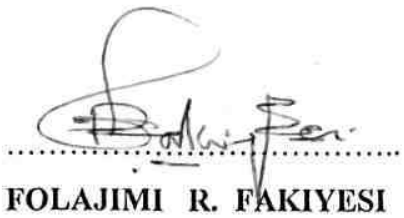
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JULY, 2000

DECLARATION

I hereby declare that this thesis is my own work, composed by me and it is record of my own research. It has not been accepted in any previous application for higher degree. All works, opinions and ideas other than mine have been fully acknowledged.



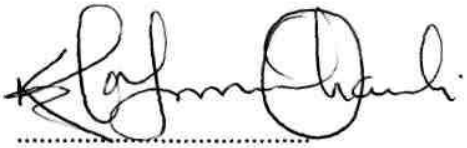
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CERTIFICATION

This thesis: THE STABILIZING POTENTIALS OF PULVERIZED COAL BOTTOM ASH (PCBA) AND SUPERPHOSPHATE FERTILIZER PROCESSING RESIDUE (SFPR), BY FOLAJIMI R. FAKIYESI meets the regulations govering the award of the degree of Master Science IN CIVIL ENGERRING of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.



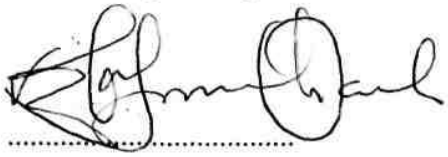
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DEDICATION

This work is dedicated to my daughter, Yejide and to the memories of my father Orisanmi, mother Olaniwun, and brother Olaniyi.

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The invaluable contributions in various forms made by the following people to the success of this project are highly appreciated.

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ABSTRACT

Pulverized Coal Bottom Ash (PCBA) and Superphosphate Fertilizer Processing Residue (SFPR) are capable of improving the stability of laterite soils. Varing admixture ratios of PCBA and SFPR severally with defective laterite soil from Shika area of Kaduna State produced substantial increase in the index and strength properties of the soil. The liquid limit, plasticity index and CBR of the soil were increased. Strength increase of up to 160 percent was obtained at mere 2 percent stochiometry for SFPR stabilized soil and 200 percent at 6 percent stochiometry for PCBA stabilized soil.

Curing improved the strengths of both SFPR and PCBA stabilized soils further by over 150 percent. Both SFPR and PCBA stabilized soils developed high early strength on curing, attaining peak strength within 14 days for low dose, low energy compacted admixtures. For high 'dose' admixtures, both SFPR and PCBA exhibited pozzolanic properties gaining strength gradually with ageing. Pozzolanic strength gains ranged from 20 to 60 percent. Unconfined compressive strength (UCS) for both SFPR and PCBA exceed 1.5 MPa and unsoaked and soaked CBR were 100 and 80 percent respectively, making both SFPR and PCBA suitable materials for subbase and base stabilization.

The results of the research can be applied to reduce incidence of distressed roads all over the country arising from lack or insufficient fund and high cost of inputs. The results. will particularly suit perenially neglected rural roads and small private roads that are outside regular orbit of public financing. The results of the research if utilized would also reduce environmental pollution constituted by phosphate residue and spent coal heaps. It will also add value to mining portfolios that depend on phosphate and carbon minerals.

ABBREVIATIONS

A	Al_2O_3
ADPO	Air Dried Preferred Orientation
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
C	CaO
C_2S	Dicalcium Silicate
C_3S	Tricalcium Silicate
C_3A	Tricalcium Aluminate
C_4AF	Tetracalcium Aluminoferrate
DTA	Differential Thermal Analysis
F	Fe_2O_3
LHPC	Low Heat Portland Cement
LL	Liquid Limit
LOI	Loss on Ignition
LS	Linear Shrinkage
LSF	Lime Saturation Factor
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PCBA	Pulverized Coal Bottom Ash
PFA	Pulverized Fuel Ash.
PI	Plasticity Index
PL	Plastic Limit
S	SiO_2
Gs	Specific Gravity
SFPR	Superphosphate Fertilizer Processing Residue
SRPC	Sulphate Resisting Portland Cement
SP	Standard Proctor (compaction)
SSV	Soil Stabilization Value
UCS	Unconfined Compressive Strength
WA	West African (compaction)

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CHAPTER ONE

INTRODUCTION

The present bad state of Nigerian roads is obvious from the deplorable conditions of inner city roads, even in the state capitals. The high cost of cement and lime, the two most common road stabilizing agents does not give cause for much hope of improvement in the near future. The conditions of rural roads are even far worse than those of city roads, and hope for their improvement, further remote. There is urgent need to find cheaper ways or materials of making good roads by making use of locally available raw material so that the hardship of rural inhabitants can be ameliorated.

Ola, (1974) and Akoto (1987) have identified the major problems of Nigerian roads as due to base and sub-base failures caused by the defective nature of laterite soils which are the commonly available local materials for base and sub-base constructions. They recommend the use of cement, lime and bitumen for soil improvement, but even when these materials are used, they often require one mineral additive or the other to fully develop cementitious and strength capabilities. For instance fly ash is used with lime and cement for this purpose.

Following developments in other lands, Akoto (1987) advocated the use of industrial wastes such as fly ash (PFA) to supplement cement, Fakiyesi and Osinubi (1995) investigated the feasibility of using wastes from superphosphate processing and found that it contains active ingredients found in many binding agents and deserve further investigation for stabilizing capability.

The use of an additive such as fly ash with lime or cement improves stabilization optimization. Fly-ash is derived from mineral and refuse sources. Nigeria is blessed with abundant mineral resources including fossil fuel, from which fly-ash derives. Even though these minerals have their primary uses, the solid wastes from their extraction and or processing is substantial, and solid wastes no longer connote materials to be gotten rid of; through research, they have become useful resource materials in their own right.

Pulverised coal bottom ash (PCBA) and superphosphate fertilizer processing residue (SFPR) are two such mineral waste- derived resources.

Fly-ash is a particulate matter consisting of ashes, cinders, mineral dust and partially burnt materials and soot resulting from the burning of fossil fuel e.g. coal, wood, etc (Pavoni et al. 1975). Ingredients of fly-ash are finely divided glassy spheres of silica and alumina with residual unburnt carbon, including fused glass, magnetic and non magnetic iron compounds, some alkalis and limited amount of water soluble material (O' Flaherty, 1974). The capability of natural fly-ash (volcanic ash) and calcined natural substances such as opaline shale, inert and diatomaceous earth as well as industrial chimney smoke in improving soil strength are well documented by Kryne and Judd (1957) and by Legget (1967). Also from various researches, pulverized fuel ash, otherwise known as fly-ash (of which pulverized coal bottom ash is a specie) can be used to improve pavement quality, cementation and soil stability (O' Flaherty, 1974; Wogrin, 1960 and Raymond 1960). Processed fly-ash is used in the production of concrete and pozzolanic cement, light weight aggregate (Lyat), bricks and blocks and the untreated ash as non load bearing fill (Knight, 1961). PFA produced from Arkansas coal in the United States of America has been used successfully with lime and cement to stabilize Arkansas soils (Parker et al. 1971). Aggregates deficient in A - 3 soils, slags and crushed stones have been successfully stabilized with fly-ash and cement with vastly improved strength and erosion resistance (Highway Research Board, 1959). Fly ash alone has also been used to stabilize soils and has been used in fills with good results (Anon, 1959). Research output on the use of PFA alone for soil improvement indicate that the practice is well advanced, but lagging behind the use of combined PFA-lime-cement. The use of PCBA for soil stabilization is even farther behind and has barely gotten off the ground as reflected in the conclusion to the Highway and Road Construction International Review (1977) that PFA has gained acceptance as a soil stabilizing agent, while PCBA has yet undetermined potential. Nigeria has over 1.5 million metric tons of proven and inferred coal reserve (UNO Symposium, 1979). The use to which Nigerian coal was put as railway locomotive fuel in the earlier days is well known; its present use (after

diesselization of the railways) is uncertain. The grading and residue characteristics of available Nigeria coal ash residue from railway locomotive fuel source are of bottom ash variety.

Superphosphate fertilizer processing residue (SFPR) is another mineral waste resource becoming available in Nigeria. SFPR is the waste/sludge residue from the processing of fertilizer minerals (e.g. phosphorite) into superphosphate fertilizer. Even though phosphorite is largely being imported into the country presently, Nigeria reportedly has large potential reserves of the mineral. As noted by Fakiyesi (1988), phosphorite occurs widely in the Sokoto basin and in most Cretaceous sedimentary basin/rocks in Nigeria. There are no available reports or literature on SFPR, but it is not a fuel derived residue. Preliminary tests by Fakiyesi and Osinubi (1995) indicate that SFPR contains similar active ingredients and are of approximate granulometry as PCBA.

1.1 LITERATURE REVIEW

Stabilization can be described as a refinement process by which the properties of a weak soil is improved to make it perform and sustain its planned engineering use, particularly with improved ability in strength and durability under periodic conditions of moisture content or repeated application of stresses at amplitudes less than the soils ultimate strength (Gillott, 1968). Stabilization was also described as stabilized fill, subgrade, road-subgrade or road base that will stay put (O' Flaherty, 1974); in order words, soil construction that will stay put.

The usual method of modifying the engineering properties of soil, or making it stay put is by compaction. When soil is compacted, desirable engineering properties are imparted to the soil. Soil response to compaction depends on the nature of the soil, and the physical, chemical, and mineralogical properties. It also depends on the genesis (or provenance) of the soil, its state of dessication, stratigraphic location, geological history and pre-test handling. In some cases, only soil cannot be readily stabilized without the addition of a catalyst or admixture to change its firmness. The stabilizer commonly used in Nigeria especially for road works are cement and lime,

which have become very scarce and expensive lately, leading to very sharp practices by construction workers and resulting in early deterioration of road constructions.

As noted above, the whole notion and purpose of stabilization is to make soil construction that will stay put and numerous ways of accomplishing this litter the pages of literature and can be summarised under the following heading (Gillott, 1968, O' Flaherty, 1974 and Tomlinson, 1976).

Mechanical stabilization
Chemical stabilization
Lime (Pozzolanic) stabilization
Bituminous stabilization
Cement stabilization
Electrokinetic stabilization
Stabilization with additive
Phosphate stabilization
Phosphorous stabilization
Slag stabilization
Sodium silicate stabilization
Sodium chloride stabilization
Calcium hydroxide stabilization.

However, from functional view point, the classification by Sewer and Sewer (1970) is preferred. They classified the methods of making a soil construction stay put under the following:-
Moisture holding stabilization
Moisture retaining stabilization
Cementation stabilization
Void filling stabilization
Mechanical stabilization Physico - chemical stabilization

A satisfactory stabilizing agent in addition to making soil construction stay must also be compatible with the soil material, permanent, easy to handle and process, and cheap. Soil - PCBA and soil-SFPR stabilization involve composite processes including

Compaction

Physico-chemical alteration

Thermal (curing) alteration

Compaction brings about artificial increase in soil unit weight thereby decreasing its void ratio. Increasing the state of compaction of a soil stabilizes it by increasing its strength and reducing possibility of settlements, caving in, and moisture content change. Curing has the same effect as heating and it has been widely practiced in the Guiana, Sudan, Australia, Romania and the USSR (O' Flaherty, 1974). The method causes clay to loose weight as a result of absorbed and intergranular moisture removal, and above certain temperature, structural alteration detectable in X - ray and dehydration curves. The resultant clay soil is a hard, relatively durable road construction material with lower plasticity and reduced attraction for water. Both soaked and unsoaked compressibility is reduced consequent on decrease in water sensitivity.

As has been noted, the stabilizing action of PCBA gets only sparse mentioning in the literatures while that of SFPR gets no mentioning yet at all. Some stabilizing capability can be expected in PCBA given its co-genesis with PFA of which it is a coarse equivalent, and also in SFPR due to its grading equivalency and similarity in composition to that of PCBA and hence to that of PFA. Ola, (1974) carried out work on the effect of lime stabilization on Nigerian soils and found that all categories from A-1 to A-7-6 improve their properties (LL, PL, and MDD) with liming. He also observed that in lime stabilization, there is hydration of lime to form cementitious compounds as in cement stabilization but that the physico-chemical reaction that occur are of cationic exchange with calcium replacing other ions present in base exchange. This is followed by flocculation into groups of coarse particles which produce immediate increase in strength. The addition of lime to the soil causes reduction in the moulding water due to partial

dissociation of calcium hydroxide. The calcium ions in turn combine with reactive silicate and/or aluminate, both of which harden on curing to stabilize the soil.

Mitchell (1976) demonstrated that in soils composed mainly of non - expansive clay minerals, the type of adsorbed cations are of greatest importance in influencing the behaviour of the material in suspension and the nature of an fabrics of the sediments formed. Thus mono-valent cations of Na^{+} and Li^{+} promote deflocculation while divalent and trivalent cations such as Ca^{+2}, Al^{+3} promote flocculation of the clay particles. Croft (1967) carried out microscopic examination of sections of soil-crete resulting from compacted, stabilizing agent-soil mixtures, after ageing. It was found that development and hardening of gelatinous reaction products and intergrowth of crystalline hydrous calcium silicates and aluminate are responsible for cementation in clay soils stabilized with lime, lime-fly-ash and cement. He concluded that chemical and physical properties do not uniquely characterize soil response to cementitious stabilizing agents and that the suitability of a soil for stabilization, the most suitable stabilizing agent, and the quantity of agent required, are jointly determined by the chemical, physical, mineralogical and textural characteristics of the soil as well as its origin.

Uppal and Chadda (1967) carried out mechanical analysis of clay lime stabilized mixtures and found that with small concentrations of lime, clay particles (less than 2 microns) only react to aggregate into larger flocks (2 to 5 microns) while with addition of more lime, particles previously aggregated react further with the stock to form larger flocs (7 microns); similar behaviour was observed in alkaline earth metals falling into Group 2A of the periodic classification table. Bell (1989) found that when lime is added to clay soil, calcium ions are initially combined with or adsorbed by clay minerals, leading to some improvement in soil workability, that is, to an increase in the plastic limit of the clay and generally to a decrease in its liquid limit. The optimal lime addition for maximum increase in the plastic limit of the soil is referred to as lime fixation point. Lime added in excess of fixation point requirement is utilized in the cementation process and gives rise to increase in the strength of the soil. The increase in strength is attributed to the formation of poorly ordered reaction products which surround the clay minerals.

Ejeh (1982) worked on laterite soil samples from Shika (near Zaria) and found that the predominant clay type is kaolinite, which he found has low specific surface area and moisture retention and also contained colloidal matter with high specific area thereby giving the soil high net moisture retentivity. The principal effect of this is in enhanced cementation and stabilization of the soil against internal swelling and improvement of its compressive strength.

Results of laterite soil stabilization studies carried out by Gidigasau (1976) have often been interpreted in terms of the following factors:-

(1) Genetic characteristics

(2) Compositional factors such as particle size and distribution, organic content, chemical, mineralogical composition, petrology, geological history and environmental factors such as weather, climate, rainfall, drought and ground water conditions etc.

(3) Method of sample handling and stabilization procedure. According to Gidigasau (1976), the various stabilization processes have considerable effect on plasticity, density, moisture relations, shrinkage, swelling, strength as well as durability and weathering characteristics.

1.2 EXPERIMENT WITH PCBA AND SFPR

A cheaper source of preferably locally- available and locally -source material is required to supplement or replace import-dependent lime and cement, the traditional stabilizers commonly used in the country. This can do a lot of good to the economy. In pursuance of this goal, two mineral derived industrial waste resource materials are examined in this research, namely: pulverized coal bottom ash (PCBA) and superphosphate fertilizer processing residue (SFPR), with the hope to determine if and to what extent the waste resources could improve soil stability and to determine the properties of the soil so stabilized and compare them with those of unstabilized (natural) soil. Properties of the stabilized soil to be examined include Atterberg limits, specific gravity, moisture content, dry density, unconfined compressive (UCS) strength and California bearing ratio (CBR).

1.2.1 Nature Of PCBA

PCBA belongs to the fly-ash family of particulate matter derived from divers waste sources, particularly the burning of fossil fuels including coal, wood, straw, industrial waste etc. The particulate matter making up fuel ash include fly ash, dust, partially burnt or fused materials and soot. Fly-ash is the lighter and finer component of fuel-ash and bottom ash is traction component composed of the heavy materials falling back into the furnace. The PCBA used in this research has the oxide composition given in Table 1.1.

Table 1.1 Percentage Oxide Composition of PCBA

Material	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	$Na_2O + K_2O$	SO_3	TiO_2	Mn_2O_3	P_2O_5	LOI	H_2O
PCBA	2.24	26.40	9.35	2.25	0.60	0.35	0.97	0.35	0.56	-	4.45	-

The capability of natural fly-ash (volcanic ash) and calcined natural substances such as opaline shale, inert and diatomaceous earth as well as industrial chimney smokes are well attested to and documented by Kryne and Judd (1957) as well as Legget (1967). From various research findings, pulverized fuel ash (PFA) can be used to improve pavement quality and soil stability (O'Flaherty, 1974; Worgin, 1960; and Raymond, 1960), and the difference between PFA and PCBA is mainly granulometry. PCBA could therefore be expected to have some of the properties of PFA and possibly be stabilizing like PFA.

1.2.1.1 Production of PCBA

When pulverized coal is injected into the furnace at high speed in streams of hot air, it is burnt in suspension in the temperature range of $1500.^{+}20\,C$, which is above the melting point of many of the constituent minerals in coal. (Akoto, 1987). Some ashes of the burning coal is carried out with the fume, this is fly ash. Some fall back into the

system and are sintered with coarser elements to form bottom ash. The fuel ash used in this project are of bottom variety and are derived from coal fired railway locomotive engines. The coal bottom ash was dried and pulverized (hence pulverized coal bottom ash) to improve its fineness and reactivity.

1.2.1.2 Stabilization with PCBA

The potential of PFA as road stabilizing agent has been examined by many workers that have ben cited earlier, but comparatively very little has been said or done on stabilizations with PCBA. According to the conclusion of the 1977 Highway and Road Construction International Review, "PFA has gained acceptance as soil stabilizing agent but PCBA as has yet undetermined potential" (Mates and Davisoa, 1962). The grading characteristics of PCBA and those of SFPR, and Shika laterite are shown in Table 1.2.

Table 1.2 Grain Size Distribution of Shika Laterite, SFPR and PCBA

Geo-material	Percentage Passing Sieve No.										
	5	6	10	12	16	22	36	44	60	80	120
Shika laterite		100	99.8	99.3	98.0	90	82	76	74	67	66
SFPR	-	-	-	-	76	65	60	55	45	36	27
PCBA	95	91	72	56	46	34	22	19	13	10	8

1.2.2 Nature of SFPR

Superphosphate fertilizer processing residue (SFPR) is the 'waste' (sludge) obtained from superphosphate extraction, when phosphorite rock/mineral is admitted into the processing plant already crushed and with oxide composition as shown on Table 1.3.

Table 1.3 Chemical Composition of Phosphorite and SFPR

Material	Oxide (%)											
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O K_2O	SO_3	TiO_2	Mn_2O_3	P_2O_5	Loi	H_2O
PCBA	28	35.24	27.44	2.40	0.12	0.53	1.31	0.80	1.0	4.0	9.61	-
Phosphorite	51.29	3.76	0.85	1.21	0.28	0.33	3.76	-	1.0	36.81	2.85	-

1.2.2.1 Production of SFPR

Phosphorite is reacted with 70 percent concentrated sulphuric acid. The flourine gas that is given off is scrubbed with caustic soda. The waste water (which is still highly basic) is treated with quicklime produced from limestone ($CaC0_3$) crushed at the plant. The following chemical sequence is obtained.

$Ca_9 (P0_4)_6 CaF_2 + 7H_2S0_4 + 3H_20 =$

$3CaH_4 (P0_4)_2 \quad H_20 + 7CaS0_4 + 2HF$.....(1)

$(HF + Si0_2 = SiF_4)$

$4HF + Si0_2 = SiF_4 + 2H_20 + 0_2$ ..... .(2)

$3SiF_4 + 4H_20 = 2H_2SiF_4 + Si(0H)_4$.....(3)

$SiF_4 + 4Na0H = 4NaF + Si(0H)_4$.....(4)

The residue is composed largely of NaF, $Si(0H)_4$ and $CaS0_4$. These are discharged into septic tanks. When the septic tanks are full, the sludge is evacuated and dumped in a heap beyond the factory walls, where it gets gradually flushed by rain into the drainage system, and during dry weather, it dries up and gets blown around by the wind. The SFPR thus for now is a pollutant of soil, ground and surface water and air.

1.2.2.2 **Stabilization with SFPR**

The main cementitious material in most inorganic particulate matters are $Si0_2$, Al_20_3 and Ca0, generally forming calcium silicates and aluminates. These cementatitious particles are greatly enhanced in SFPR over the original phosphorite. $Si0_2$, is increased by 90 percent, Al_20_3 by 3000 percent but Ca0 is reduced by over 180 percent in spite of the large quantities of $CaC0_3$ added to control the pH of the sludge water. (See Table 1.3). Like PCBA, SFPR has bottom ash granulometry (Table 1.2). There is phenomenal increase in some and depletion in other active ingredients on a scale that justifies enquiry into the cementitious nature of SFPR.

1.3 COMPARISON OF SFPR/PCBA WITH STANDARD CEMENTS

The chemical compositions of SFPR and PCBA are very close to one another and to the composition of cement which is the ultimate stabilizer (Table 1.4); some measure of binding capability should thus expected in SFPR or PCBA, only the extent was in doubt. Lime was much depleted by the reduction of phosphorite to SFPR (Table 1.4) but other chemical compounds normally found in cement are present to varying degrees as to approach the ASTM specification for Low Heat Portland Cement (LHPC) in both SFPR and PCBA (See Table 1.4).

No information on any previous work on soil SFPR has been documented. A successful soil SFPR stabilization could be beneficial in depolluting the environment of SFPR and could also be of benefit in the construction industries as stabilizer to laterize mud for block making and to the mining industries, as it will enhance the (market) value of phosphatic noddles or phosphorites

1.4 AIMS AND OBJECTIVES OF RESEARCH

The aim and objectives of the research are:-

Table 1.4 **Chemical Composition of Phosphorite, Admixtures, Laterite Soil, Andmixures and Standard Cements**

Material	Oxide (%)											
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O K_2O	SO_3	TiO_2	Mn_2O_3	P_2O_5	Loi	H_2O
Phosphorite *	51.29	3.76	0.95	1.21	0.28	0.33	0.76	-	1.0	36.81	2.85	
SFPR	0.28	35.24	27.44	2.40	0.12	0.53	1.31	0.80	1.0	4.0	9.61	
PCBA	2.24	26.40	9.35	2.25	0.60	0.35	0.97	0.35	0.56	-	4.45	
Shika Laterite	0.28	35.60	27.40	0.40	0.22	-	0.85	0.80	2.0	-	1.40	
OPC**	64.78	21.31	6.06	2.77	0.86	0.91	1.91	0.33	0.11	-	2.27	
LHPC**	61.90	25.44	4.57	2.07	2.64	0.90	2.22	0.24	0.08	-	2.10	
SRPC**	62.40	21.15	4.03	5.63	0.88	0.88	2.36	0.28	0.12	-	0.96	

* (National Superphosphate fertilizer file)

** (Chong, 1977)

(1) To improve the property of laterite soil with various admixture percentages of PCBA and SFPR using two compaction energy levels, namely, Proctor and West African.

(2) To compare the changes in properties of the improved soil through critical stages and conditions of stabilization, that is: admixture, compaction, curing and soaking.

(3) To produce experimental results to be used to establish the effects of PCBA and SFPR on laterite soil (Shika laterite), and correlate the effects of PCBA and SFPR as soil stabilizing admixtures.

1.5 SCOPE OF RESEARCH

Laterite soil that are defective from the point of view of pavement construction (base and sub-base stabilization) were collected from Shika area, near Samaru village and identification tests (chemical, physical, geotechnical and mineralogical) were performed on them in the laboratory. Increasing percentage (0-30) of PCBA of SFPR were then admixed to known weight of the soil and compacted, stabilized and cured in accordance with BS 1924: 1990. Unsoaked and soaked samples of the compacted natural and compacted stabilized soils were cured for up to 28 days. Among the properties that were examined are specific gravity, Atterberg limits and compactions characteristics at two levels of compaction energy. Strength was measured in terms of unconfined compressive strength (UCS), and California bearing ratio, CBR. The stability of the soil was then determined in terms of the strength of the stabilized to unstabilized (natural) soil. Correlation values were computed as soil stabilization values (SSV) which are the quotients of the unconfined compressive strength of stabilized to unstabilized soils. An SSV greater than unity indicate improvement due to stabilization. An SSV equal to unity indicates a no gain no loss situation in terms of stabilization. An SSV less than unity indicates loss in stabilization of the soil as a result of the mixture under that admixture situation.

CHAPTER TWO

MATERIALS AND METHODS

LOCATION PHYSIOGRAPHY AND GEOLOGY

2.1 LOCATION OF STUDY AREA:

The study area is located west of Zaria city about 5 km west of Samaru village on Zaria-Funtua road, around the meridians of longitudes 7°45" east and latitude 11°15" north. (Fig. 2.1).

2.2 PHYSIOGRAPHY:-

Shika occupies the Zaria plains, which is part of the gently undulating peneplain which extends from Sokoto eastward to the Lake Chad and southward to beyond Kaduna. This vast peneplain unites in a three in one geomorphic land mark (watershed) at Funtua as a result of gradual uplift of the crust during the Pleistocene. This watershed separates the vast peneplain into three parts, namely, Sokoto Garage, Chalawa and Galma-Tubo water shed, (Mc. Curry, 1973) respectively occupying the western, northwestern and southern portions of the drainage that indicate absence of influence of basement structure (Fig 2.2).

2.3 GEOLOGY

2.3.1 Surficial Geology

The surficial geology consists of alluvium, laterite soils and basement rock outcrops. Three varieties of laterite soils are found on the peneplain namely Older Laterites, Younger Laterites and Autochthonous Laterites.

2.3.2 Basement Geology

The Sokoto Garage is underlain by rocks of the Older Granite and Migmatite series while the Chalawa basin is underlain by Granite Gneiss (Fig 2.3). These basement rocks are greatly weathered and covered with thick mantles of soil overburden.

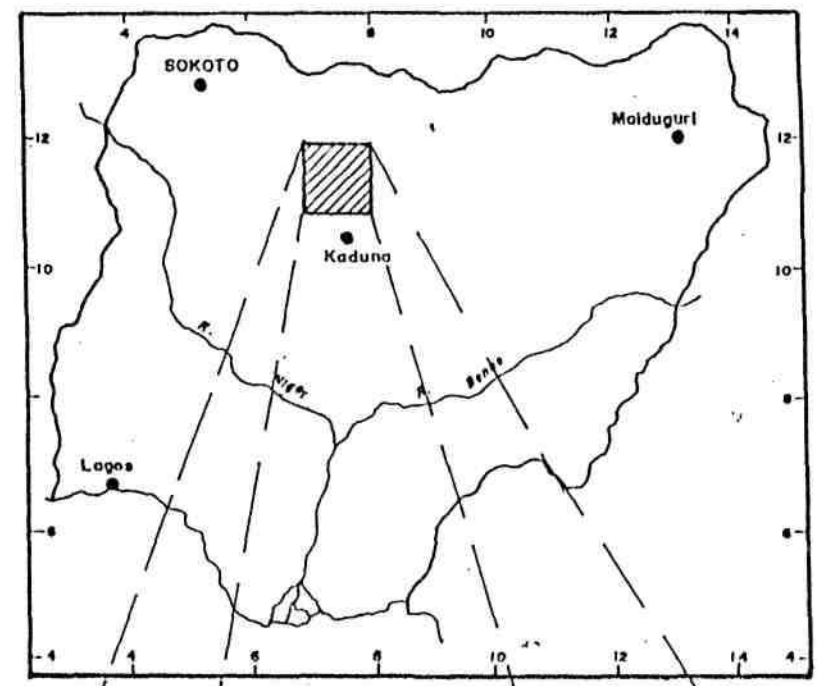


Fig 2.1 Location map of study area.

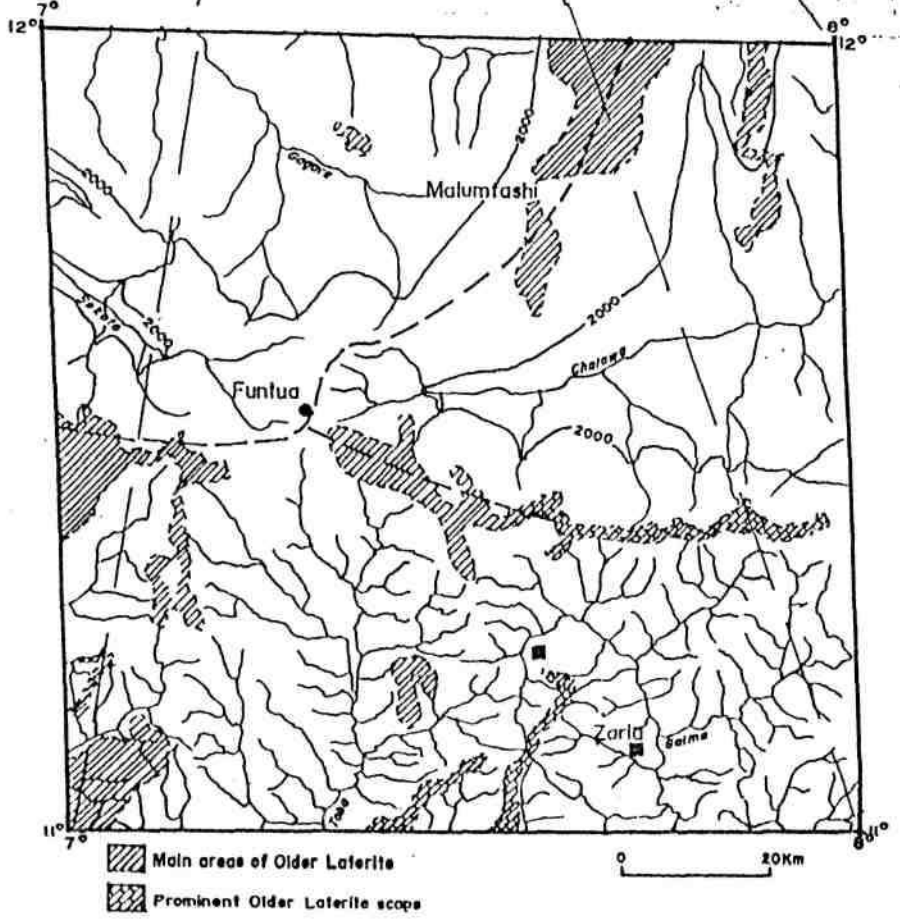


Fig 2.2 Drainage and Laterite distribution map of North Western Nigeria.

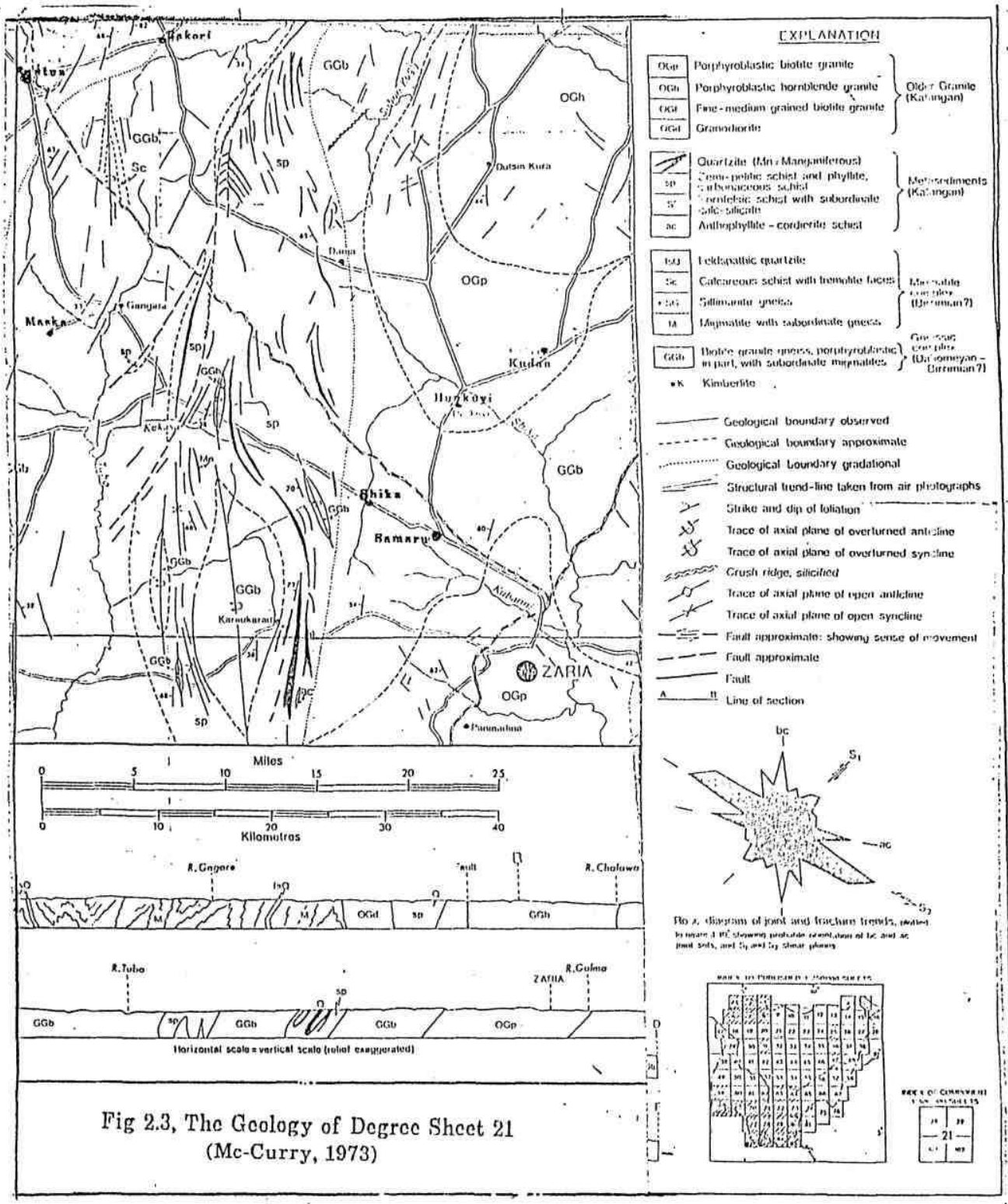


Fig 2.3, The Geology of Degree Sheet 21
(Mc-Curry, 1973)

2.3.3 Extent of Laterite Deposit

Laterite soils are not restricted to the study area, but are widespread through out Nigeria (Fig. 2.4) and vary in composition from place to place depending on the basement source rock, it texture and mineralogical composition and the geomorphic and chemical processes it had undergone during pedogenesis. Because of its wide spread occurrence, it is hardly practicable to execute any soil construction work in Nigeria without encountering and/or using laterite soil. Apart from its widespread occurence and hence availability within economic haulage distance from any construction site, laterite soils are easy to handle and work, easy to mould into any desired shape for a variety of engineering uses. Consequently the use of laterite soil for construction purposes nation-wide and Africa-wide is a matter of economic reality and necessity.

2.4 LABORATORY PREPARATIONS AND TESTING

2.4.1 Mechanical Grading Classification Tests

The natural soil as well as the SFPR and PCBA were air dried and thoroughly mixed, coned and quartered to obtain representative sample for grading classification which was carried out in stages: namely, coarse and fine.

2.4.1.1 Coarse Analysis

200 grams of the air dried soil samples were weighed and washed out on 200 sieve. The portion retained on No 200 sieve was dried weighed and sieved through the BS set of sieves. The weight of the fraction passing through successive sieves were expressed as a percentage of the total weight and plotted on logarithmic scale with abscissa representing particle size and ordinate representing percentage finer than corresponding particle size. The grading curves are shown (Fig. 2.5), in conjunction with those of SFPR and PCBA.

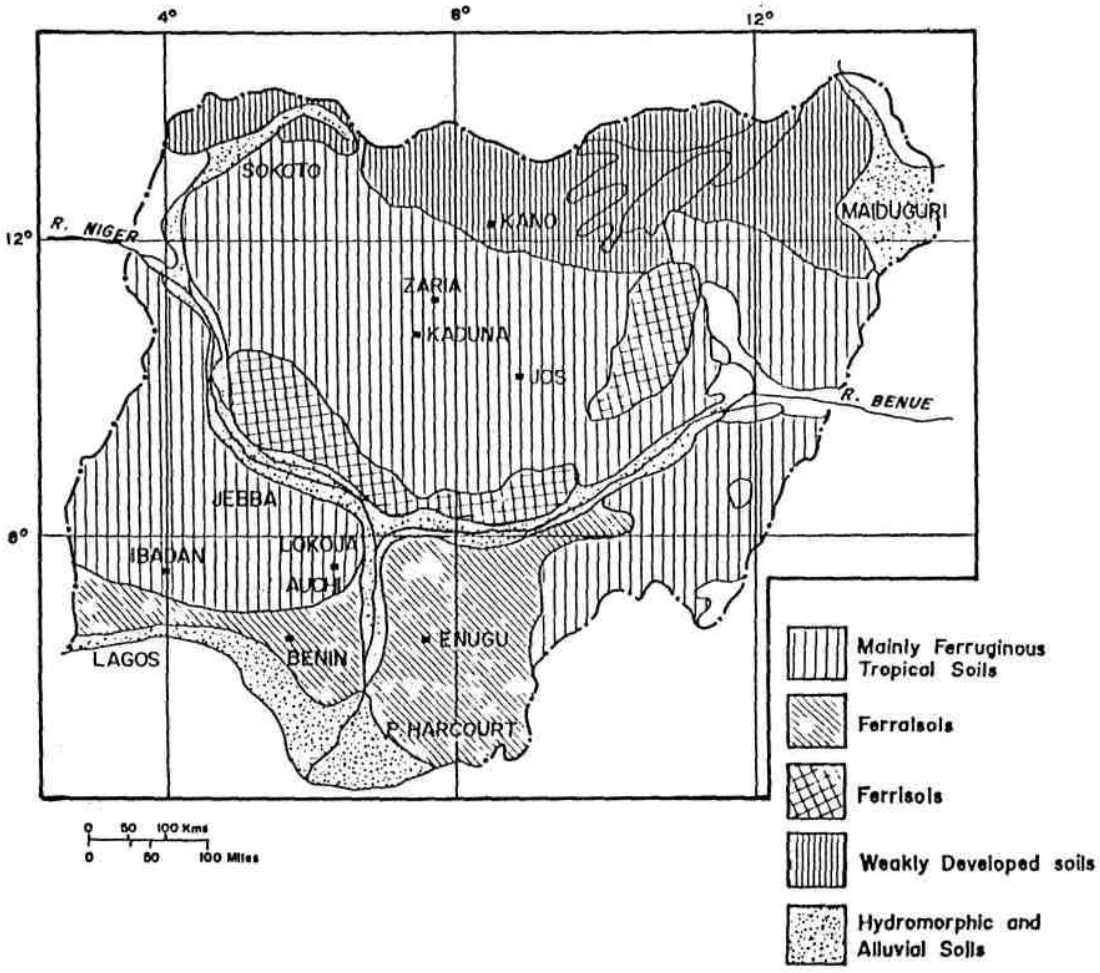


Fig. 24 Soil Map of Nigeria. (after Areola, 1982)

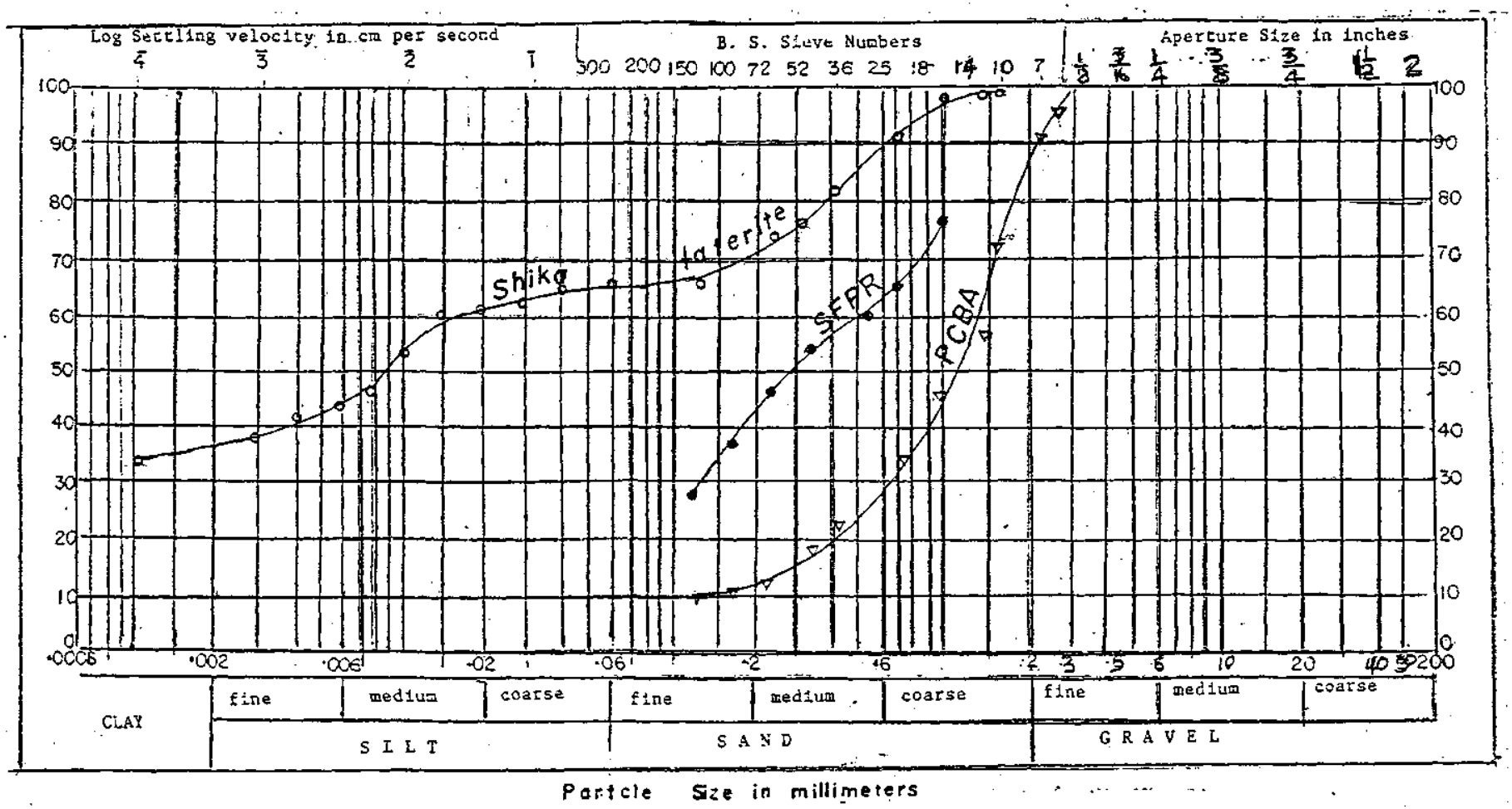


FIG 2.5 Shika laterite, SFPR, PCBA Particle Size Distribution

2.4.1.2 Fine Analysis

About 10 grams of the sample passing BS No 200 mesh was weight and pretreated with hydrogen peroxide, (H_20_2), sodium hexameta-phosphate [$Na(PH0_4)_6$] sodium carbonate ($NaCO_3$) and distilled water, to facilitate dispersion. The fine analysis is based on Stokes law according to which fine particles from suspension in liquid settle at different rates according to their sizes, the coarser particles settling faster than the finer particles of the same type. The specific gravity of the suspension was measured with a hydrometer with readings taken at 1/4, 1/2, 1, 2, 4, 8, 15, 30, 60, 120, 240 and 1440 minutes. Samples of the particles still in suspension after each of these periods were pipetted and placed in weighing bottles evaporated at 105-110EC, cooled, and the mass of soil determined and expressed as percentage of the original mass.

2.4.2 Consistency Limit Test

The moisture content at which soil passes from one state (liquid, plastic, semi solid and solid) to another was determined for Shika laterite, SFPR and PCBA using the Cassagrande apparatus. Samples of dried and pulverized samples were mixed with water to a stiff consistency and a cake of it placed in the Cassagrande dish and grooved. The cam dish was rotated at the rate of 2 blows per second on a hard rubber block through a height of 10cm until a 13cm groove inscribed in the dish was closed. Samples of the soil SFPR or soil PCBA were then taken for moisture content determination. The number of blows to achieve this, and the corresponding water content were determined and recorded. The test was repeated 5 times with addition of more water at each successive stage. A flow curve was drawn of moisture content against number of blows. These resulted in straight line graphs. The moisture content corresponding to 25 blows was obtained by interpolation from the graph and represents the liquid limit (LL).

The plastic limit (PL) was determined by wetting about 20 grams of the soil sample passing 425 mm sieve and rolling it into a thread of about 6 mm diameter on a glass plate, with the palm of the hand until the thread of soil began to crumble. The moisture content of the crumbled sample was determined as the plastic limit.

The plasticity index (PI) was calculated by substraction of the plastic limit from the liquid limit.

The linear shrinkage (LS) was determined at the moisture content at which further moisture loss caused no decrease in the volume of the soil. The rate of decrease in moisture content expressed as a percentage of the dry unit volume was determined as the linear shrinkage.

The above parameters were determined for the natural soil (see Table 2.1) as well as the stabilized soils (see Tables 2.2 to 2.5). and summarised in Table 2.6 for critical state conditions. A plot of plasticity against percentage finer than 2 micron for the soil (Fig 2.6) is juxtaposed with a plot of the plasticity of clay minerals of known mineral composition against percentage finer than 2 microns (Fig. 2.7)

Table 2.1: Geotechnical Proterties of Untreated Shika Laterite

Properties	Natural soil value
Colour	Reddish brown
Specific Gravity	2.66
Natural Moisture Content (%)	8. 50
Liquid Limit (%)	29
Plastic Limit (%)	15
Plasticity Index (%)	14
Linear Shrinkage (%)	7.14
Maximum Dry Density (Mg/m^3) (Proctor)	2.2
Maximum Dry Density (Mg/m^3) (West African)	2.4
Optimum Moisture Content (%)	4.5
CBR (Proctor, Unsoaked) (%)	65
CBR (W.A, Unsoaked) (%)	70
CBR (Proctor soaked) (%)	35
CBR (W.A, Soaked) (%)	40
UCS (Proctor) (kPa)	325
UCS (West African) (kPa)	425
Passing 200 mesh sieve (%)	66
Activity	0.38
Swell Index (%)	40
Group Index (%)	8
AASHTO Classification	A-7-6
Minerology Activity	Kaolinite-quartz
XRD	Kaolinite-quartz
DTA	Kaolinite-quartz

Table 2.2 Index Properties of Compacted Soil SFPR (Standard Proctor)

	Stabilizer %											Figure
Properties	0	1	2	4	6	8	10	15	20	25	30	
LL (%)	29	37	36	36	28	33	35	36	35	33	32	
PL (%)	15	19	18	20	20	17	24.3	29.5	17.5	17.7	29.8	3.1
PI (%)	14	18	18	16	19	16	13.1	10.3	17.0	16.0	11.2	
LS(%)	7.14	7.0	7.0	7.1	7.1	7.2	7.2	6.6	6.5	6.0	6.1	
Gs	2.66	2.62	2.63	-	2.61	2.62	2.34	2.48	2.52	2.38	2.40	
UCS (SP) (Kpa)	375	900	875	600	400	300	275	250	225	200	75	3.9.1
OMC (%)	4.0	17	12	28	29	16	22	22	20	20	20	3.7.1
MDD ($Mg/m^{3)}$	2.2	2.2	2.1	1.85	1.75	1.72	1.55	1.40	1.40	1.20	1.0	
CBR(%)unsoaked	65	95	100	85	75	70	55	25	20	10	10	3.8.1
CBR(%) soaked	35	70	80	60	60	40	30	15	15	15	5	

Table 2.3 Index Properties of Compacted Soil - SFPR (West African Standard)

	Stabilizer %											Figure
Properties	0	1	2	4	6	8	10	15	20	25	30	
LL (%)	29	37.9	38.6	39.6	38.7	39.4	36.9	36.9	36..1	34.9	32.7	
PL (%)	15	14.7	17.7	20	16.88	18.4	23.4	23.4	13.6	13.7	13.2	3.1
PI (%)	14	23.7	19.9	18.6	19.8	21	13.5	13.5	22.5	21.2	20.7	
LS (%)	7.14	7.2	7.1	7.2	7.2	7.45	7.35	6.8	6.6	6.3	6.2	
Gs	2.66	2.16	2.65	2.64	2.65	2.67	2.38	2.52	2.66	2.42	2.50	
UCS (SP) (kPa)	425	975	1050	650	450	400	375	2.40	2.30	225	100	3.9.2
OMC (%)	4.0	10.5	8.0	20	12	12.4	14.5	13.7	15	16	18.5	3.7.2
MDD $(Mg/m)^3$	2.2	2.08	2.07	2.02	2.01	2.01	1.48	1.96	1.82	1.80	1.74	
CBR(%) unsoaked	65	95	100	75	85	70	55	25	20	15	10	3.8.2
CBR(%) soaked	35	70	80	60	60	40	30	15	15	10	5	

Table 2.4 Index Properties of Compacted Soil –PCBA Standard Proctor

	Stabilizer %											
Properties	0	1	2	4	6	8	10	15	20	25	30	Figure
LL(%)	29	37.9	39.6	35	35	37	26.8	25.5	24.8	21.18	21.93	3.2
PL (%)	15	17	23	17	18	19	17.1	21.3	18.8	19.2	15	
PI (%)	14	16	16	18	17	18	9.7	5.13	6.3	7.98	6.93	
LS (%)	7.64	8.43	8.59	5.93	6.10	5.10	7.8	7.4	7.6	8.1	8.5	
Gs	2.60	2.73	2.71	2.65	2.63	2.62	2.52	2.73	2.74	2.70	2.55	
UCS (SP) (kPa)	375	500	550	825	1110	650	550	450	375	225	225	3.9.3
OMC (%)	4.9	15.0	11.8	16.9	16.9	20.0	20.5	22.1	25	29.8	32	3.7.3
MDD $(Mg/m)^3$	2.20	2.04	2.14	1.93	1.75	1.69	1.53	1.48	1.45	1.25	0.94	
CBR(%) unsoaked	65	95	95	95	70	90	55	20	20	15	10	3.8.3
CBR(%) soaked	35	70	65	70	55	60	25	15	15	10	5	

Table 2.5 Index Properties of Compacted Soil – PCBA (West African Standard)

	Stabilizer %											
Properties	0	1	2	4	6	8	10	15	20	25	30	Figure
LL%	29	38.6	37.1	38	38.7	39.1	31.38	29.85	29.06	27.74	25.66	3.2
LL%	15	15.9	18.5	16	14.5	18.6	16	19.96	17.6	18	13.13	
PI%	14	22.7	20.6	22	24.2	20.5	15.3	10.4	11.46	9.74	12.53	
LS%	7.14	7.0	7.4	7.3	7.3	7.3	6.5	5.9	6.3	6.7	7.1	
Gs%	2.60	2.65	2.67	2.66	2.67	2.64	2.45	2.65	2.66	2.62	2.48	
UCS (SP)kPa	425	550	800	900	1200	640	750	500	400	325	225	3.9.4
OMC %	4.5	10	8	14.3	12.8	17.8	19.6	22.5	30.2	29	35	3.7.4
MDD Mg/m^3	2.22	1.54	1.95	1.89	1.87	1.75	1.7	1.60	1.55	1.40	1.32	
CBR(%)unsoaked	65	95	95	95	70	90	55	20	20	15	10	3.8.4
CBR(%) soaked	35	70	65	70	55	60	25	15	15	10	5	

TABLE 2.6 GEOTECHNICAL INDEX PROPERTIES OF SFPR AND PCBA STABILIZED SHIKA LATERITE AT CRITICAL STATES OF COMPACTION AND STABILIZATION

Parameter	Natural Soil Value	Admixture			Compaction Level			
		Level	SFPR	PCBA	SOIL – SFPR		SOIL – PCBA	
		Low Optimum High	1% 2% >2%	1% 6% >6%	SPC	WAC	SPC	WAC
LL(%)	29	Low Optimum High			37.3 36 32	37.9 38.6 32.7	37.9 35.00 21.93	38.66 38.66 25.66
PL(%)	15	Low Optimum High			19 18 29.8	14.7 17.7 23.2	17 18.0 15.0	15.9 14.50 13.13
LI (%)	14	Low Optimum High			18 18 11.2	23.7 19.9 14.7	16 17 6.93	22..7 24.2 12.53
LS (%)	7.14	Low Optimum High			7.0 7.0 6.1	7.2 7.1 6.3	8.43 6.1 8.5	7.0 7.3 7.1
Gs	2.66	Low Optimum High			22.62 2.63 2.46	2.16 2.65 2.50	2.72 2.63 2.55	2.65 2.67 2.48
UCS (kPa)	375	Low Optimum High			900 875 75	975 1050 100	500 1110 250	550 1200 225
MDD (Mg/m^3)	2.2	Low Optimum High			2.20 2.09 1.13	1.95 1.96 1.40	2.04 1.93 1.100	2.07 2206 1.74
OMC (%)	4.0	Low Optimum High			12.0 10.5 24	10.5 8.0 18.5	15.0 16.9 30.00	100 122.8 35.0
CBR (%) (Unsoaked)	55	Low Optimum High			65 100 10	95 100 10	95 90 10	65 90 10
CBR (%) (Soaked)	35	Low Optimum High			70 80 5	70 80 5	70 70 5	70 70 5

2.4.3 Mineralogical Tests

Stabilization is highly sensitive to mineral composition, therefore a number of tests were carried out with the sole aim of ascertaining the mineral composition of the soil. These include:-

Free swell test

Activity test

X-Ray Diffraction and

DTA (Differential Thermal Analysis)

2.4.3.1 Free swell test:

The procedure for determining free swell used by NBRRI was adopted. 10cc of the dry soil passing BS 425 micron sieve was slowly poured into a 100cc water filled graduated cylinder and the volume of the swollen soil was noted after coming to rest at the bottom of the cylinder. The increase in volume over the original volume multiplied by 100 is the percentage swell. Mathematically,

$$S = \frac{V - V_0}{V_0} \times 100\%$$

where S = % Swell

V_0 = Original volume

V = Final volume

Shika laterite was found to have a free swell of 40 percent (see Table 2.1). This connotes preponderance of quartz minerals in the soil.

2.4.3.2 Soil Activity:

The activity of the soil was computed as the ratio of the plasticity index to the percentage clay size finer than 2 microns according to the formula.

$$A = \frac{PI}{\%<2\mu)}$$

where A = Activity, PI = plasticity index

Fig. 2.6 shows the activity plot for Shika laterite against that of natural clays (Fig. 2.7) for comparison. Shika laterite has activity of 0.38 (Table 2.1) which is indicative of abundance of Quartz and Kaolinite in the soil.

2.4.3.3 XRD (X-Ray Diffraction)

Inference of the mineral composition of the soil was also made from the XRD carried out by Ola (1974) on equivalent soil from same genetic source as the Shika soil under study and from the same (Shika) location. The characteristic peak in air dried preferred orientation (ADPO) and characteristic reflection were compared to standard results of known mineralogy (Fig. 2.8). It was found that all the diffraction peaks are due to Quartz or Kaolinite indicating the preponderance of these two minerals and confirming other tests.

2.4.3.4 DTA (Differential Thermal Analysis)

DTA was carried out on samples of Shika laterite. One gram of the soil material was carefully weighed into a crucible and fed into a high temperature furnace equiped with sensitive thermocouples and heated to 1000°C in stages through 50E, 110E, 125E, 250E, 750E and 1000E. The loss in weight at each stage was determined as a percentage of the original weight and plotted against temperature. The dehydration curve of the soil material was produced (Fig. 2.9) and placed side by side the diagram of the dehydration curve for pure kaolinite clay (Fig. 2.10)

The preceeding tests were first carried out on the natural soil samples. The natural soil was then admixed with varing (1-30) percentages of the admixtures (PCBA/SFPR). The index properties as well as the consistency limits for the varing admixtures were determined, and the following additional stabilization tests (section 2.2.4) were carried out.

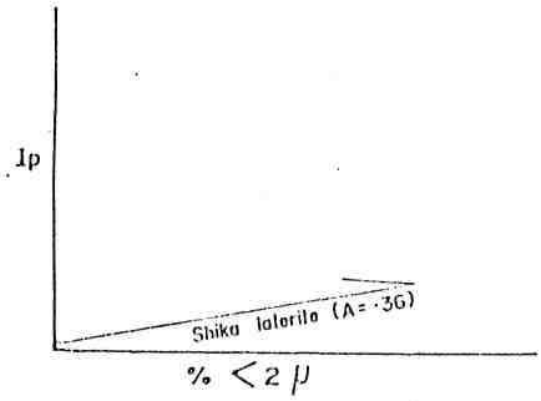


Fig. 2.6 Activity diagram for Shika laterite.

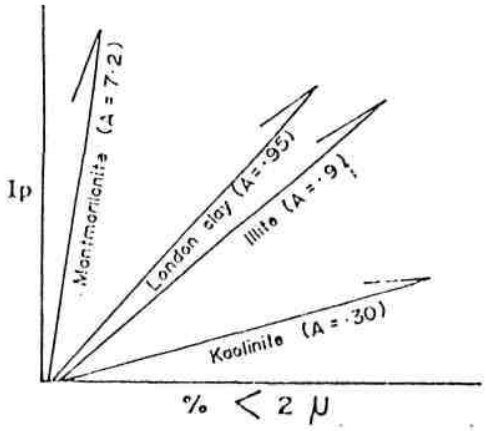


Fig. 2.7 Activity diagram for Clay minerals.

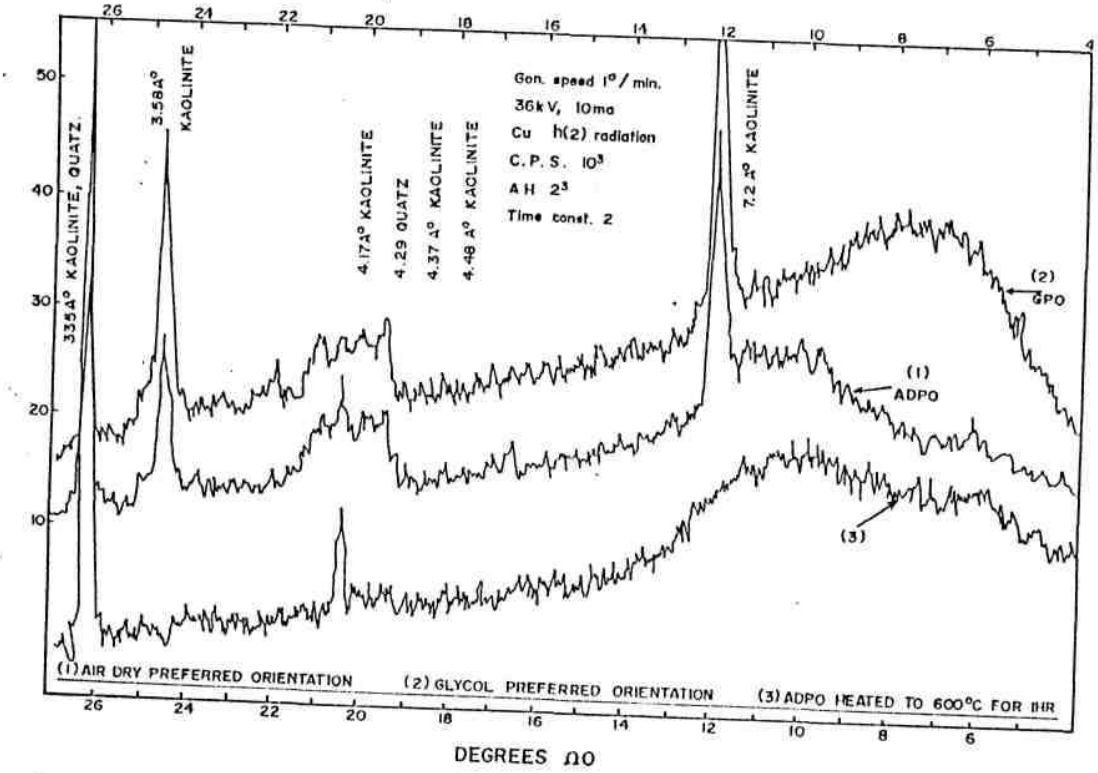


Fig. 2.8 XRD traces of minus 200 mesh faction of Shika laterite (After Ola, 1974)

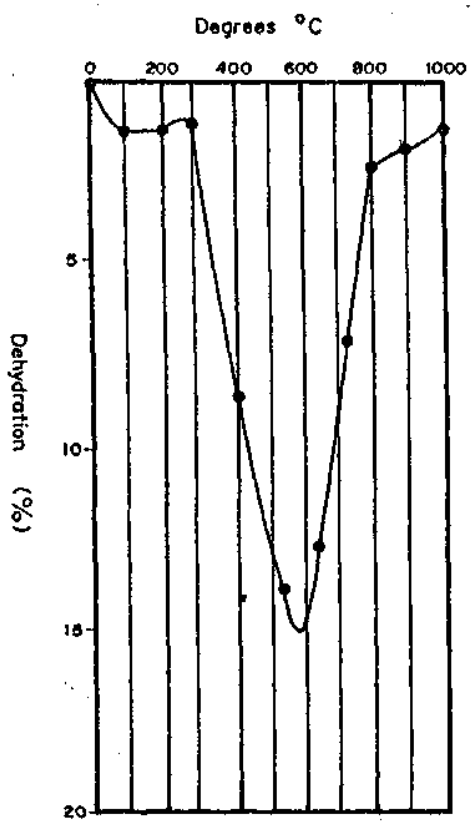


Fig. 2.9 DTA for Shika laterite

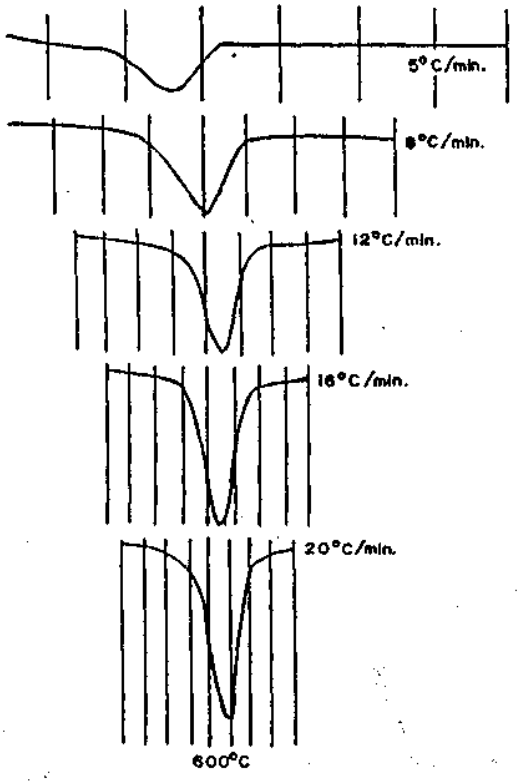


Fig. 2.10 DTA for Kaolinite (After Spiel et al, In Grim 1968).

2.4.4 Strength Tests

2.4.4.1 Compaction Test

Compaction test was performed on Shika laterite using standard Proctor compaction in accordance with BS 1924 (1990). Test (3) and the West African compaction in accordance with the Nigerian general specification for Road Works and Bridges (1970). 2.5kg samples of the air dried soil passing 20mm mesh sieve were admixed with zero or required amount of stabilizer and mixed with 3-4 percent water and compacted in 3 layers using BS mould of volume 1000cm^3 with 27 blows per layers. At a higher compaction level, 18 blows per layer were applied for 3 layers using the heavier 4.5kg rammer. The extension to the mould was then removed and the compacted soil trimmed level with the mould top with a straight edge and weighed.

Weight of mould plus soil was weighed.....(W_2)

Weight of empty mould.....(W_1)

An extruder was used to remove the soil sample from the mould. The soil was sampled for moisture content determination using the BS 1377, Test 1A method. The procedure was repeated, each time with increasing percentage of water added to the unit until 2 or 3 weighings record less than the maximum weight obtained from soil plus mould (W_2) weighing.

$$BD = W_2 - W_1$$

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

Where BD = Bulk density, DD = Dry density and W = moisture content.

The result of the compaction tests are set out in Tables 2.7 to 2.10 for Standard Proctor and West African compactions of both soil SFPR (Tables 2.7 and 2.8) and soil PCBA (Tables 2.9 and 2.10).

Table 2.7 Soil - SFPR Moisture - Density Data (Standard Proctor Compaction)

Parameter	Value										
MC(%)	2.3	5.6	3.8	3.20	2.02	2.99	6.40	5.89	4.63	5.08	12.09
DD(Mg/m)^3	1.96	1.89	1.90	1.46	1.37	1.30	1.22	0.93	1.14	0.90	0.79
MC(%)	4.0	8.13	7.45	7.10	5.91	7.24	9.75	8.20	1.32	7.14	20.32
DD(Mg/m^3)	2.20	2.05	2.09	1.67	1.48	1.47	1.33	1.03	1.24	0.93	0.94
MC(%)	9.2	12.21	13.49	11.50	14.00	12.23	13.01	14.10	21.21	22.08	24.00
DD(Mg/m^3)	2.10	2.20	2.10	1.89	1.80	.69	1.54	1.43	1.35	1.14	1.02
MC(%)	14.20	15.43	18.43	20.19	18.12	15.19	17.40	21.12	30.82	24.05	27.44
DD(Mg/m^3)	1.86	2.10	1.89	1.79	1.70	1.58	1.46	1.28	1.24	1.09	0.95
MC(%)	17.3	17.0	24.48	29.19	20.21	20.35	21.03	26.15	34.72	30.59	34.32
DD(Mg/m^3)	1.82	2.10	1.78	1.72	1.58	1.46	1.37	1.16	1.04	0.92	0.75
MC(%)	4	12	10.5	11.6	14	12.50	13	14	21	22	24
DD(Mg/m^3)	2.2	2.20	2.09	1.87	1.80	1.67	1.53	1.43	1.33	1.03	1.03

Table 2.8 Soil - SFPR Moisture - Density Data (West African Compaction)

Parameter	Value										
MC(%)	2.5	3.5	4.2	6.0	6.2	3.9	7.2	3.0	3.6	5.4	7.1
DD(Mg/m^3)	1.95	1.77	1.94	1.87	1.88	1.89	1.76	1.73	1.71	1.67	1.52
MC(%)	4.0	7.5	6.1	8.4	8.0	7.6	10.3	8.1	5.8	6.8	11.3
DD(Mg/m^3)	2.20	1.92	2.06	2.01	1.92	1.96	1.84	1.95	1.75	1.67	1.64
MC(%)	10.6	10.2	11.3	11.8	11.9	12.3	14.4	13.4	11.2	16.2	18.2
DD(Mg/m^3)	2.10	2.07	2.06	2.02	2.01	2.01	1.98	1.96	1.81	1.80	1.74
MC(%)	14.2	12.8	14.5	15.0	14.7	15.1	18.6	15.5	17.4	22.3	23.5
DD(Mg/m^3)	1.93	2.07	1.95	1.99	1.90	1.95	1.83	1.89	1.82	1.69	1.64
MC(%)	17.8	18.2	17.78	19.0	16.3	18.3	19.2	18.8	20.3	30.3	27.7
DD(Mg/m^3)	1.89	1.85	1.81	1.79	1.80	1.76	1.73	1.73	1.72	1.51	1.50
MC(%)	45	10	8	14.3	12.3	17.8	19.6	22.5	30.2	29	35
DD(Mg/m^3)	2.2	1.94	1.95	1.87	1.89	1.75	1.7	1.6	1.56	1.32	1.6

Table 2.9 Soil - PCBA Moisture - Density Data (Standard Proctor Compaction)

Parameter	Value										
MC(%)	2.4	8.16	5.11	7.22	8.10	10.81	12.08	12.79	16.82	18.15	20.93
DD(Mg/m³)	2.21	1.92	1.73	1.70	1.62	1.60	1.51	1.37	1.27	0.95	0.77
MC(%)	4.0	11.33	8.26	10.61	13.76	13.01	15.57	15.69	19.72	20.08	24.14
DD(Mg/m³)	2.49	2.04	1.82	1.98	1.76	1.64	1.58	1.49	1.41	0.98	0.97
MC(%)	10.6	16.85	12.78	15.54	17.05	20.67	20.89	22.14	26.74	30.73	32.47
DD(Mg/m³)	2.37	2.14	2.04	2.02	1.91	1.75	1.70	1.51	1.49	1.26	1.11
MC(%)	14.2	22.94	18.36	18.97	22.83	22.22	25.83	28.24	32.10	34.52	40.75
DD(Mg/m³)	2.26	2.00	1.96	1.93	1.76	1.68	1.61	1.32	1.31	1.08	0.98
MC(%)	17.8	26.45	22.81	23.27	25.34	26.23	32.96	36.51	36.69	42.09	48.88
DD(Mg/m³)	2.06	1.82	1.90	1.91	1.65	1.59	1.59	1.39	1.31	1.03	0.94
MC(%)	4.0	15.0	11.80	16.0	16.9	20.0	20.5	22.1	25.0	29.8	32.0
DD(Mg/m³)	2.20	2.04	2.04	2.14	1.93	1.75	1.69	1.53	1.48	1.25	1.10

Table 2.10 Soil - PCBA Moisture - Density Data (West African Standard Compaction)

Parameter	Value										
MC(%)	2.4	8.3	6.1	7.7	6.2	9.8	14.7	16.4	17.2	26.5	27.3
DD(Mg/m³)	2.21	1.86	1.93	1.77	1.86	1.63	1.55	1.52	1.39	1.33	1.33
MC(%)	4.0	9.6	8.0	12.2	9.6	11.6	16.1	19.1	23.1	28.3	31.5
DD(Mg/m³)	2.49	1.94	1.96	1.88	1.87	1.63	1.63	1.55	1.45	1.37	1.36
MC(%)	10.6	10.0	11.7	14.4	16.1	18.3	19.8	24.6	29.7	31.5	35.1
DD(Mg/m³)	2.37	1.95	1.89	1.87	1.81	1.75	1.71	1.62	1.56	1.53	1.40
MC(%)	14.2	13.2	13.4	15.1	17.3	19.8	20.5	27.8	31.2	33.9	38.2
DD(Mg/m³)	2.26	1.34	1.85	1.84	1.78	1.71	1.55	1.55	1.49	1.32	1.24
MC(%)	17.8	15.3	15.0	16.4	17.4	21.0	21.0	21.0	32.0	45.9	43.4
DD(Mg/m³)	2.06	1.78	1.79	1.81	1.77	1.46	1.46	1.46	1.31	1.14	1.19
MC(%)	4.5	10	8	14.3	12.3	17.8	19.6	19.6	30.2	29	35
DD(Mg/m³)	2.2	1.94	1.95	1.87	1.89	1.75	1.70	1.6	1.56	1.32	1.4

2.4.4.2 **Unconfined Compression Test**

Unconfined compression is a special case of the triaxial compression test in which uniaxial stress conditions are imposed on the test material and its strength measured in the unconfined state.

3 kilogram of the natural soil at OMC as obtained from compaction test results were mixed and compacted in a $1000cm^3$ cube mould using the same compactive efforts as in the compaction tests. The compacted specimens were then removed from the mould and placed on the platen of the uniaxial compression machine and crushed at the rate of 1723 kPa per minute until failure load attained for each specimen.

Unconfined compression tests were carried out on natural stabilized and cured specimens of the soil and their unconfined compressive strength (UCS) measured. The UCS for each sample is calculated from the following relationship

$$UCS = \frac{\text{Failure load (kN)}}{\text{Area of surface } (m^2)}$$

The results of the UCS measurements are set forth in Tables 2.11 to 2.14

Curing: Curing was carried out to allow hydration process to substantially complete its work which otherwise may go on for years. The stabilized and compacted soils as well as the natural soils were allowed to set or harden for up to 28 days under controlled humidity and temparature. Unconfined compression tests (UCS) were then carried out on samples of the stabilized and cured samples.

Table 2.11 UCS (kPa) of Soil - SFPR Mixtures (Standard Proctor Compaction)

MIX RATIO (%)	Curing time (days)					7 Curing	Figure
	0	7	14	21	28	7 Soaking	
0	375	450	675	775	1000	275	3.1
1	900	1000	1225	925	925	400	3.11
2	975	1300	1375	1100	800	425	3.12
4	600	625	800	700	775	325	3.13
6	400	525	625	668	770	200	
8	300	400	500	750	700	150	
10	275	350	475	575	650	140	
15	250	300	400	550	600	125	
20	225	250	375	475	500	115	
25	200	225	300	400	475	110	
30	75	150	250	300	400	50	
Figure	3.20	3.21	3.22	-	3.23	3.27	

Table 2.12 UCS (kPa) of Soil - SFPR Mixture West African Standard

MIX RATIO (%)	Curing time (days)					7 Curing	
	0	7	14	21	28	7 Soaking	Figure
0	425	575	750	875	1100	325	3.1
1	925	1125	1325	1025	1000	575	3.11
2	1050	1375	1475	1225	1025	700	3.12
4	650	725	900	800	926	400	3.14
6	450	600	700	825	925	275	
8	400	550	625	750	850	225	
10	375	450	550	625	775	175	
15	350	375	425	500	700	155	
20	325	350	400	450	550	100	
25	225	275	325	425	525	75	
30	100	175	260	450	500	65	
Figure	3.20	3.21	3.22	-	3.23	3.27	

Table 2.13 UCS (kPa) of Soil -PCBA Mixtures (Standard Proctor Compaction)

MIX RATIO (%)	Curing time (days)					7 Curing	Figure
	0	7	14	21	28	7 Soaking	
0	375	450	675	775	1000	275	3.1
1	500	625	825	975	1250	285	
2	550	725	1175	975	900	300	
4	825	1250	1125	975	950	375	3.15
6	1110	1275	1025	1075	1200	475	3.17
8	600	800	900	1100	1050	275	
10	550	725	825	975	1000	275	
15	450	600	625	800	850	225	
20	375	450	525	625	800	200	3.18
25	225	350	425	525	675	190	
30	220	275	400	550	600	100	
Figure	3.24	3.25	-	-	3.26	3.28	

Table 2.14 UCS (kPa) of Soil - PCBA Mixtures (West African Standard)

MIX RATIO (%)	Curing time (days)					7 - Curing	
	0	7	14	21	28	7 - Soaking	Figure
0	425	575	750	875	1100	325	3.1
1	550	675	900	1150	1325	425	
2	600	800	1250	1025	925	525	3.16
4	900	1325	1225	1050	900	573	
6	1200	1400	1150	1120	900	675	3.17
8	640	900	875	900	850	375	
10	600	850	825	850	900	275	
15	500	650	675	800	700	225	
20	400	500	650	750	600	175	3.19
25	325	450	525	650	600	150	
30	225	325	400	525	550	100	
Figure	3.24	3.25	-	-	3.26	3.28	

2.2.4.3 California Bearing Ratio (CBR) Test

The CBR test is essentially a penetrometer test used to determine the strength index of pavement subgrade surface. The test was carried out on both natural and stabilized soil samples as specified in BS 1924 (1990) using the standard Proctor, and as specified in the Nigerian General Specification for Road Works and Bridges (1970), clause 6228, using West African compaction.

5 kilogram of natural or stabilized soil (at desired stabilization ratio) was weighed and mixed at the OMC and compacted in 3 layers in a CBR mould with 62 blows of 2.5 kilogram rammer, for the Standard Proctor compaction; and in 5 layers with 25 blows of the 4.5 kilogram rammer, for the West African compaction. The compacted specimens were trimmed level with the mould sleeves, with a straight edge and then removed. Both faces of the samples to be cured were then waxed and placed in the curing chamber, while samples to be soaked were immersed in water immediately after trimming.

With the base plate of the CBR machine in position, the mould containing the specimen was placed on the lower plate of the CBR machine and surcharge rings carefully arranged on the exposed surface such that the plunger penetrated at uniform rate of 1.3 mm/minute in accordance with AASHTO specification until the specimen failed. The sample was then inverted and the same test carried out on the underside. A force penetration curve was then drawn with the value of the force as abscissa. A correction was made when the curve was concave upward by drawing a tangent to the curve at the point of maximum slope. The intersection of this tangent and the penetration axis was taken as the origin.

The force corresponding to penetration 2.5 mm and 5.0 mm were read and used to calculate the CBR as follows:-

$$\text{CBR} = \frac{\text{Measured force}}{\text{Standard force}} \times 100\%$$

The mean CBR values for the top and bottom was taken as sample CBR provided it fell within 10 percent of top and bottom values, otherwise the higher CBR value obtained at penetration 1.3 cm and 5 cm was recorded. Results of the CBR values for different stabilizers and varying admixture ratios are shown on Table 2.15.

Table 2.15 CBR of Soil-SFPR and Soil-PCBA Mixtures

Admixture	Compaction Energy	Stabilizer ratio (%)												Figure
		State	0	1	2	4	6	8	10	15	20	25	30	
SFPR	SP	Unsoaked	65	95	100	85	75	70	55	25	20	15	10	3.8.1
		Soaked	35	70	80	60	60	40	30	15	15	10	3	
PCBA		Unsoaked	65	90	95	90	80	75	55	20	20	15	10	3.8.2
		Soaked	35	65	70	65	60	50	25	15	15	10	5	
SFPR	WA	Unsoaked	70	100	105	85	80	75	60	30	25	20	15	3.8.3
		Soaked	40	80	85	70	65	45	40	20	20	15	10	
PCBA		Unsoaked	70	95	105	100	90	85	60	30	25	20	15	3.8.4
		Soaked	45	75	80	75	70	60	40	20	15	15	10	

CHAPTER THREE
DISCUSSION

3.1 ANALYTICAL CONCEPT

A multi-stage analytical model is presented whose effects are cummulative, taking advantage of the special effects of individual parameters and stages, including

(a) Mineral admixturing (chemical effects)
(b) Compaction (mechanical and energy effect)
(c) Curing (thermal effect).

Individual and group effects were measured in terms of changes in soil-consistency or Atterbrgo limits, soil-moisture and density relationship, California Bearing Ratio (CBR) soil stabilization value (SSV).

The stabilization effect were examined at 4 critical levels of admixture

(i) Zero Admixture level. (Natural Soil), 0% SFPR 0% PCBA
(ii) Low Admixture level (SFPR < PCBA < 6%)
(iii) Optimum Admixture level or Stochiometric Admixture level (2% SFPR and 6% PCBA)
(iv) High Admixture level. (SFPR > 2%, PCBA > 6%)

Compaction was carried out at 2 energy levels

(i) Low energy compaction level (Standard Proctor)
(ii) Medium energy compaction level (West African)

Samples were subjected to soaking treatment

(i) Soaked
(ii) Unsoaked

Finally samples were age cured for 28 days and classified into stages

(i) Uncurred natural soil stage

(ii) Low curing stage (<< 7days)

(iii) Optimum curing stage (7-14days)

(iv) Long curing stage (> 7 to 14 < 30 days)

3.2 NEED FOR STABILIZATION

From classification into A-7-6 (AASHTO) and CL group of the unified for classification system (Cassagrande), and its Low Activity (A=0.36) and Group Index (GI) of 8, Shika Laterite, like similar soils in this grouping has medium compressibility with unconfined compressive strengh just around 375 kPa (Standard Proctor Compaction) and 425 kPa (West African Compaction), California Bearing Ratio (CBR) of 35 and 65 respectively for soaked and unsoaked samples. Shika laterite falls short of the quality requirement for base/sub-base material (see Table 3.1) and therefore needs to be improved.

Table 3.1 Some pavement design standards and Shika laterite values

	Africa wide	Ghana	FMW	Natural soil (Shika Laterite)
LL (%)	25.54	25	25	29
PI (%)	6-25	6	15.0	15
Passing 200 mesh (%)	10-40	20	15.0	65
Soaked CBR (%)	-	-	-	35
Unsoaked CBR (%)	-	80	80	65
UCS (kPa)	1000-2000	-	-	375 - 425

3.2.1 Improvement By Traditional Stabilization Method

The usual (traditional) method of soil improvement i.e. Mechanical compaction was carried out at 2 energy levels, low and medium energy levels this resulted in 13 percent improvement in the strength of the soil and raised the UCS from 375 kPa to 425 kPa still far below pavement design standard. This led to carring out age curing of the natural soil. Curing resulted in substantial improvement in the UCS of Shika Laterite. With curing, progressive daily gain in UCS of 22 and 26 kPa or about 6 and 6 percent per curing day for SP and WA compacted soils were obtained. At the end of the full (28 days) curing period, strength improvement at 167 and 158 percent over the UCS of the uncured natural soil were obtained which raised the UCS of Shika Laterite to 1000 and 1100 kPa are within the lower limit of pavement design standard (table 3.1) but which is obtainable after curing for 28days, a time consuming and expensive proposition. Consequently a stabilizer additive is required with specification of cheapness, low dosage, fast acting. An admixture like cement but without the high cost or the bulk of cement. These qualities were substantially found in SFPR and PCBA

3.3. EFFECTS OF SFPR/PCBA STABILIZATION ON THE GEOTECHNICAL INDEX PROPERTIES OF SHIKA LATERITE

In all cases of soil-SFPR and soil-PCDA stabilizations at their stochiometries, improvements were noticed in the geotechnical index properties of Shika Laterite (see figures 3.1 & 3.2) the exceptions being the PL (Plastic Limit), LS (Linear Shrinkage) and as (Specific gravity). In the case of PL, the value where enhanced for both soil-SFPR and soil-PCBA at the low (Standard Proctor) compaction energy level over the natural soil value and was further enhanced when compacted at higher (West African) compaction energy level. The value of the PL dropped from high values in the natural state to lower, from high values for both stochiometric soil-SFPR and soil-PCBA compacted at both low and medium energy levels dropped to lower values from high natural soil values._3.4.

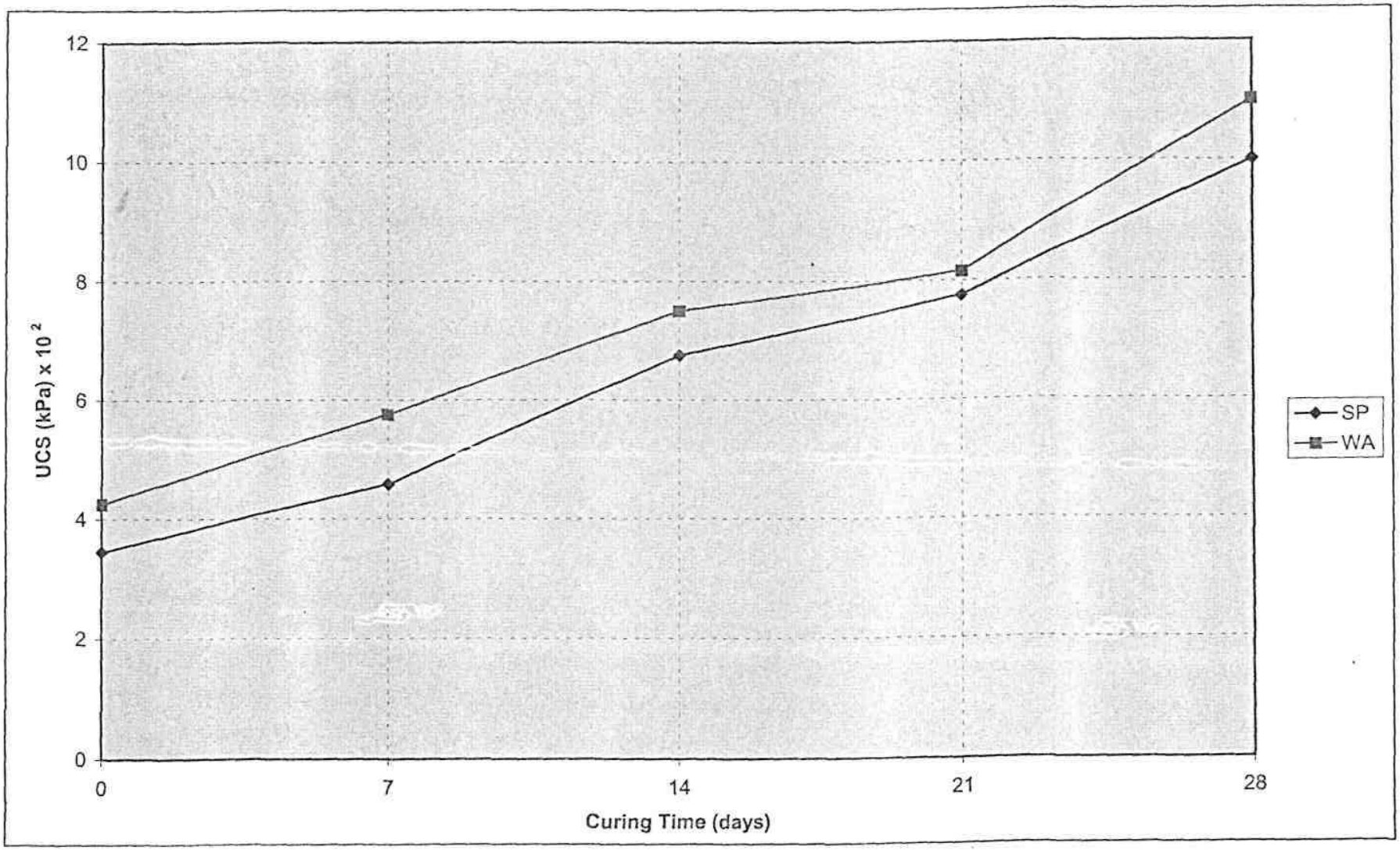


FIG 3.1. Variation in the UCS of unstabilized and unsoaked Shilka laterite with curing (days) and compaction energy (Table 2.11 & 2.14)

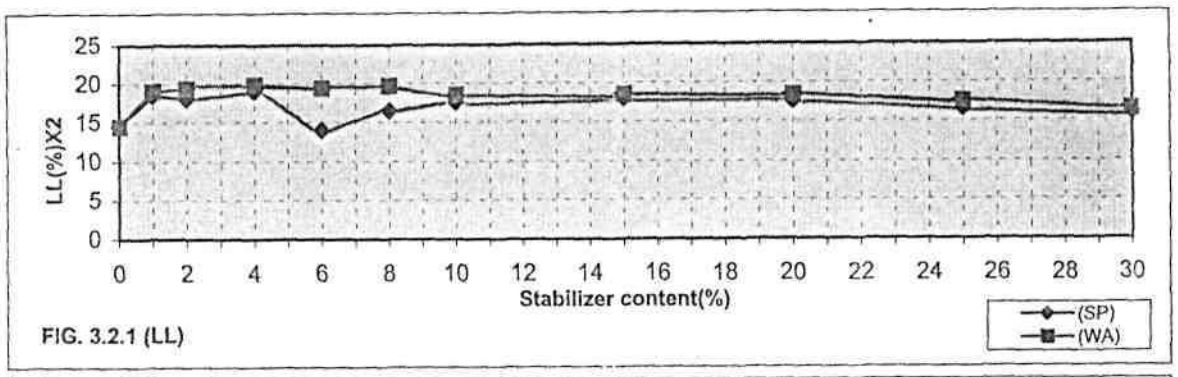


FIG. 3.2.1 (LL)

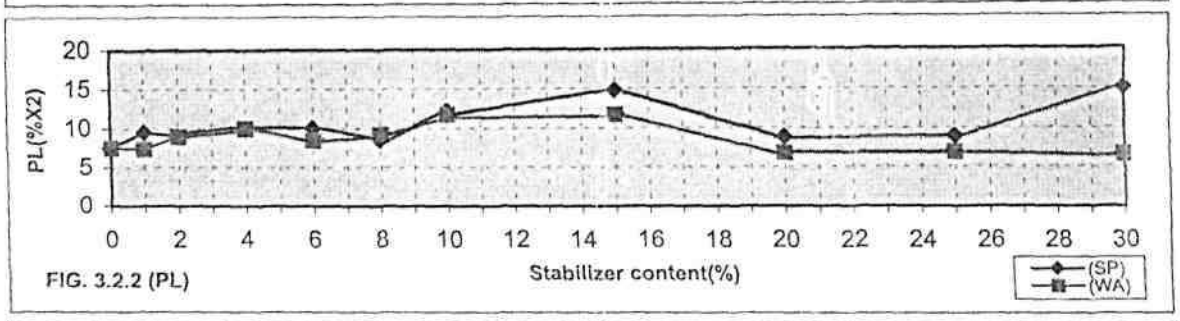


FIG. 3.2.2 (PL)

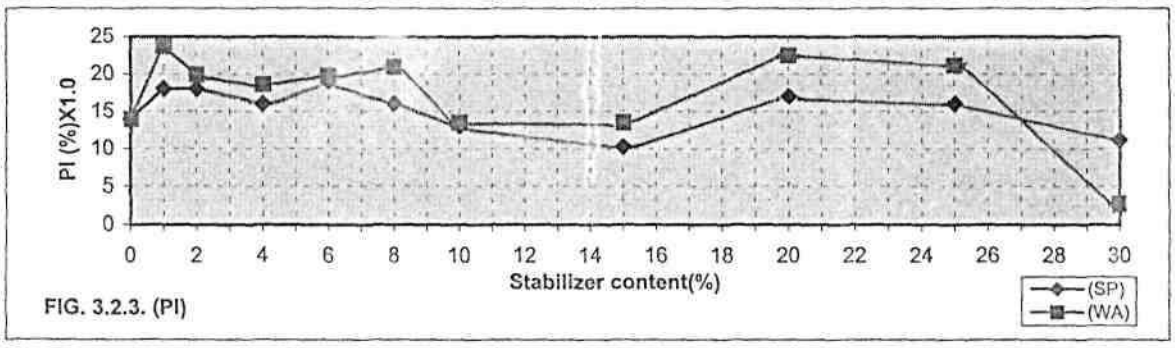


FIG. 3.2.3. (PI)

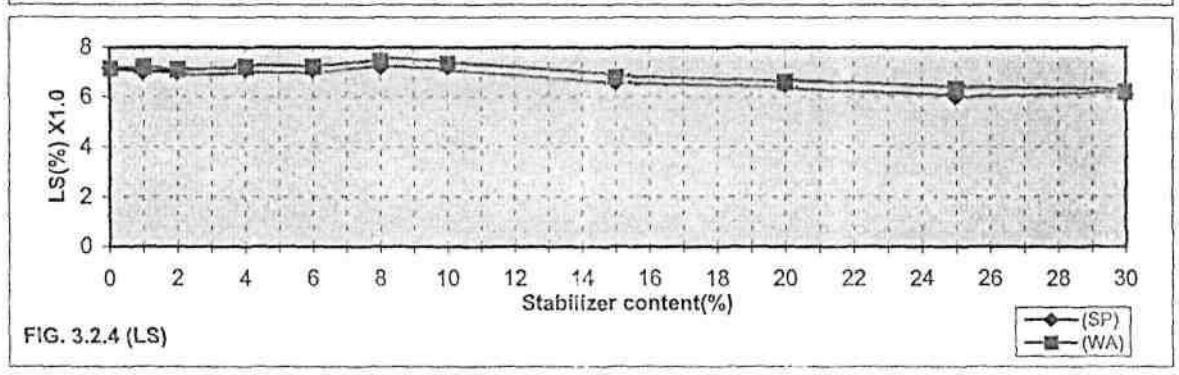


FIG. 3.2.4 (LS)

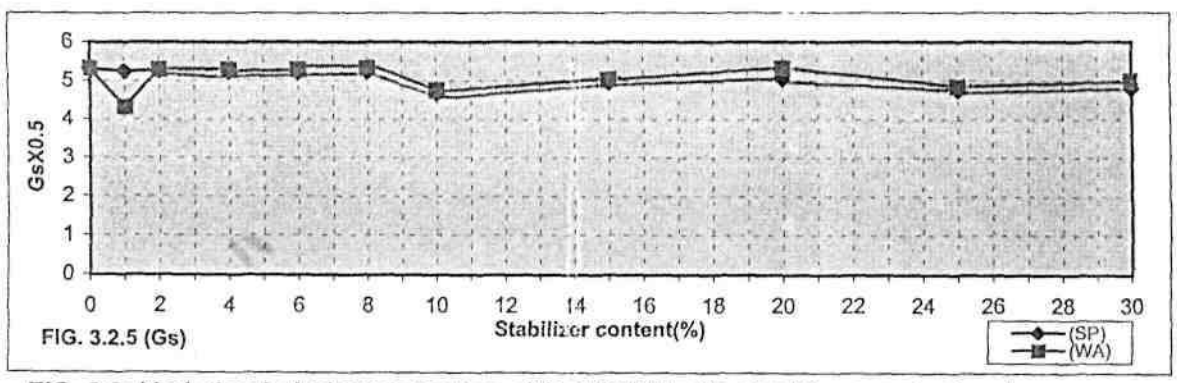


FIG. 3.2.5 (Gs)

FIG. 3.2: Variation in Index properties of Soil-SFPR with stabilizer content and compaction energ (Tables 2.4 & 2.5)

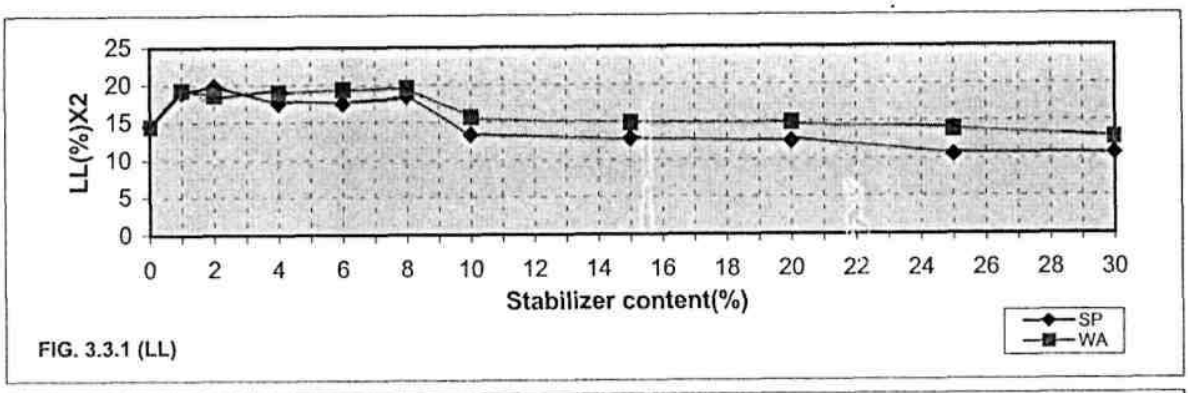


FIG. 3.3.1 (LL)

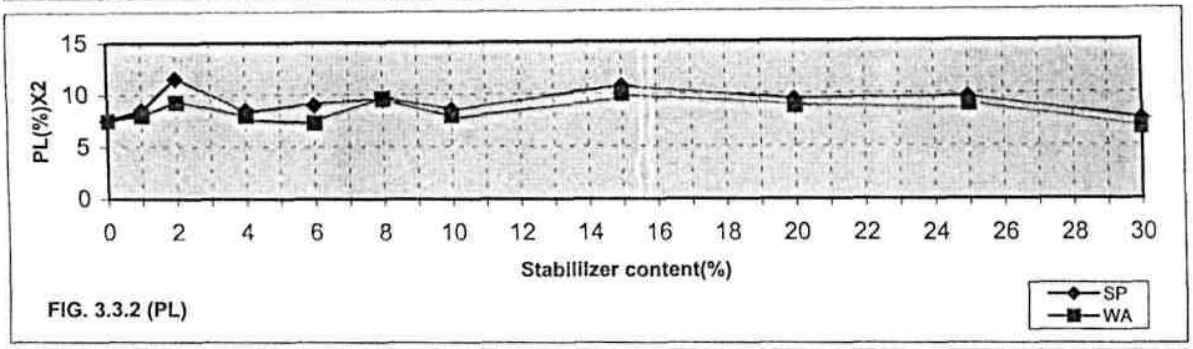


FIG. 3.3.2 (PL)

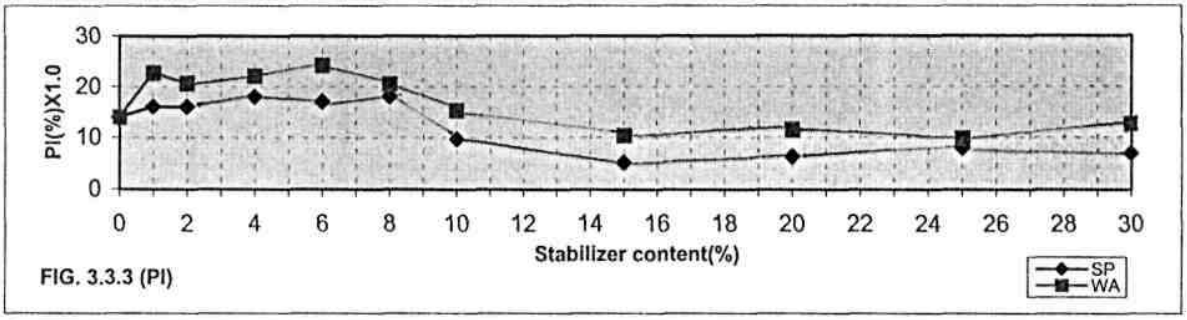


FIG. 3.3.3 (PI)

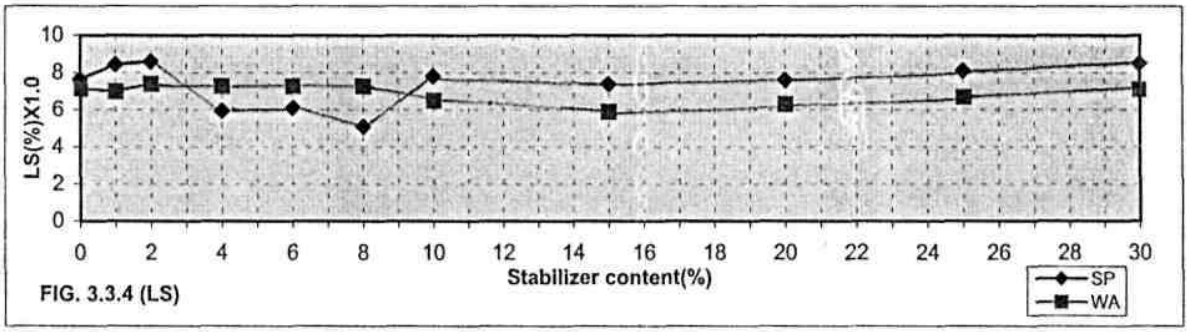


FIG. 3.3.4 (LS)

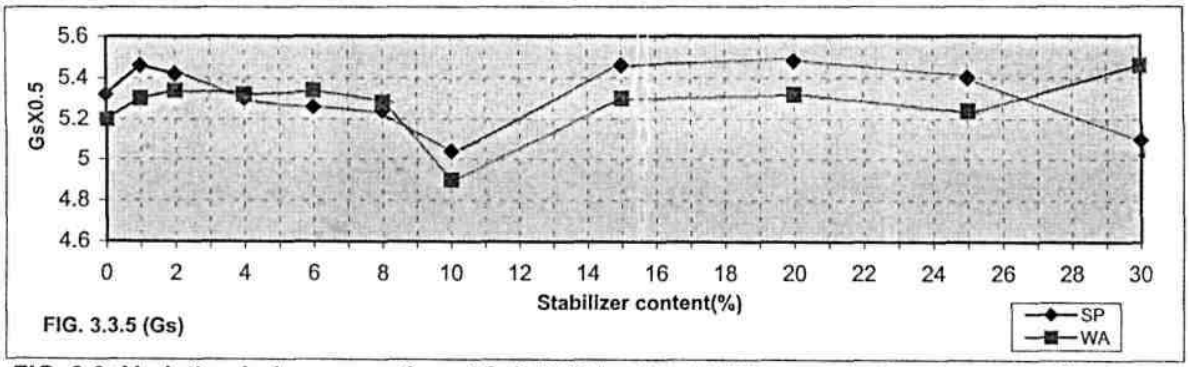


FIG. 3.3.5 (Gs)

FIG. 3.3: Variation Index properties of Soil-PCBA with stabilizer content and compaction energy (Tables 2.4 & 2.5)

3.4 EFFECTS OF SFPR/PCBA STABILIZATION ON MAJOR ENGINEERING CHARACTERISTICS OF SHIKA LATERITE

3.4.1 Effects On Moisture-Density Relationship

Both SFPR and PCBA are sensitive to moisture/density changes in either **soil-SFPR** or soil-PCBA compacted at Standard Proctor (Fig. 3.3 & 3.4) and West African (Fig 3.5 and 3.6). The dry densities first increase with increasing moisture content up to a point where the moisture/density curve undergoes downward inversion and then decreases with further increase in moisture application. The peaks of the curves define the maximum dry densities and the corresponding moistures, the optimum moistures.

3.4.2. Effects On Compaction

In both soil-SFPR and soil-PCBA, the compaction curves for the West African are flatter than the compaction curves for the Standard Proctor that is, the medium energy of the West African compaction is responsible for flatter curves than produced by the low energy of the Standard Proctor compaction.

The Standard Proctor compaction curves regress more steeply than the West African compaction curves for both soil-SFPR and soil-PCBA.

In both soil-SFPR and soil-PCBA at all levels of compaction, the maximum dry densities decrease, while the optimum moisture content increase with increasing stabilizer content (Fig. 3.8)

3.4.3 Effects On The California Bearing Ratio (CBR).

3.4.3.1 Effect Of Un-Soaking On CBR

The CBR of unsoaked Shika Laterite increased by 54 and 42 percent for SP and WA compacted samples when stabilized with stochiometric amount of SFPR. The CBR of unstabilized soil are 65 and 70 percent (SP and WA), there was an average CBR gain of 18 and 15 percent per percentage increase in stabilizer content below optimum. At optimum (2% SFPR) stabilization, CBR attained its peak values which are 154 and 143 percent the CBR value of the natural soil. Beyond 2 percent (SFPR) stochiometry, there was gradual decline of 3.20 and 3.04 percent per percentage increase in stabilizer ratio at (30% SFPR) full overstabilization, CBR values dropped to 15 and 21 percent of natural

soil, or 10 and 15 percent of optimum values, for SP and WA compacted samples.(Fig.3.9.1 and 3.9.2)

Similarly for soil-PCBA ,there was a gain of 4 and 6 percent in CBR over natural soil values per percentage increase in PCBA content below stochiometry. At (6% PCBA) stochiometry soil-PCBA essentially attained its highest CBR which is 146 and 142 percentage the CBR value of the natural soil. Beyond 6 percent PCBA stochiometry, a decline of 3.5 and 3.5 percent in CBR values were observed for every percentage increase in stabilizer content. At (30% PCBA) full stabilization CBR of soil-SFPR dropped to 15 and 21 percent of natural soil values or 11 and 15 percent of optimally stabilized soil-PCBA values. (Fig.3.9.3 and 3.9.4)

3.4.3.2 **Effect Of Soaking On CBR**

The unsoaked CBR values for the natural soil, optimally stabilized soil, and peak (fully) overstabilized soils were lowered on soaking by 46, 20 and 70 percent respectively for SP compacted soil-SFPR and by 43, 20 and 33 percent for WA compacted soil-SFPR. In the case of soil-PCBA, the reduction for SP compaction were 46, 16 and 50, and for WA compaction, 35, 25 and 33.

The CBR of soaked soil-SFPR increased by 35 and 30 percent per percentage rise in stabilizer content below stochiometry while those of soaked soil-PCBA increased by 6.7 and 9.2 percent per percentage increase in stabilizer content below stochiometry. At the optimum stabilization stages CBR values for soaked soil-SFPR was 121 and 206 percent the CBR values of the soaked natural soil while those of soil-PCBA were 214 and 155 percent for SP and WA compactions respectively.

Beyond stochiometric points, both SP and WA compacted soaked soil-SFPR and soil-PCBA declined gradually in value with increasing SFPR and PCBA content. The rate of reduction for soil-SFPR is 2.5 and 2.5 percent SP and WA compactions while for soil-PCBA the reduction was 2.9 and 2.7 percent per percentage increase in stabilizer content. At the full (30%) overstabilization, the value of the CBR had reduced to 8.5 and 3.8 percent of natural and optimally stabilized SP compacted, soil-SFPR and 25 and 13 percent for WA compacted soil-SFPR for soil-PCBA in similar situation, the values of the reduction are 14 and 7, and 22 and 13 percent. (Fig.3.9.3 and 3.9.4)

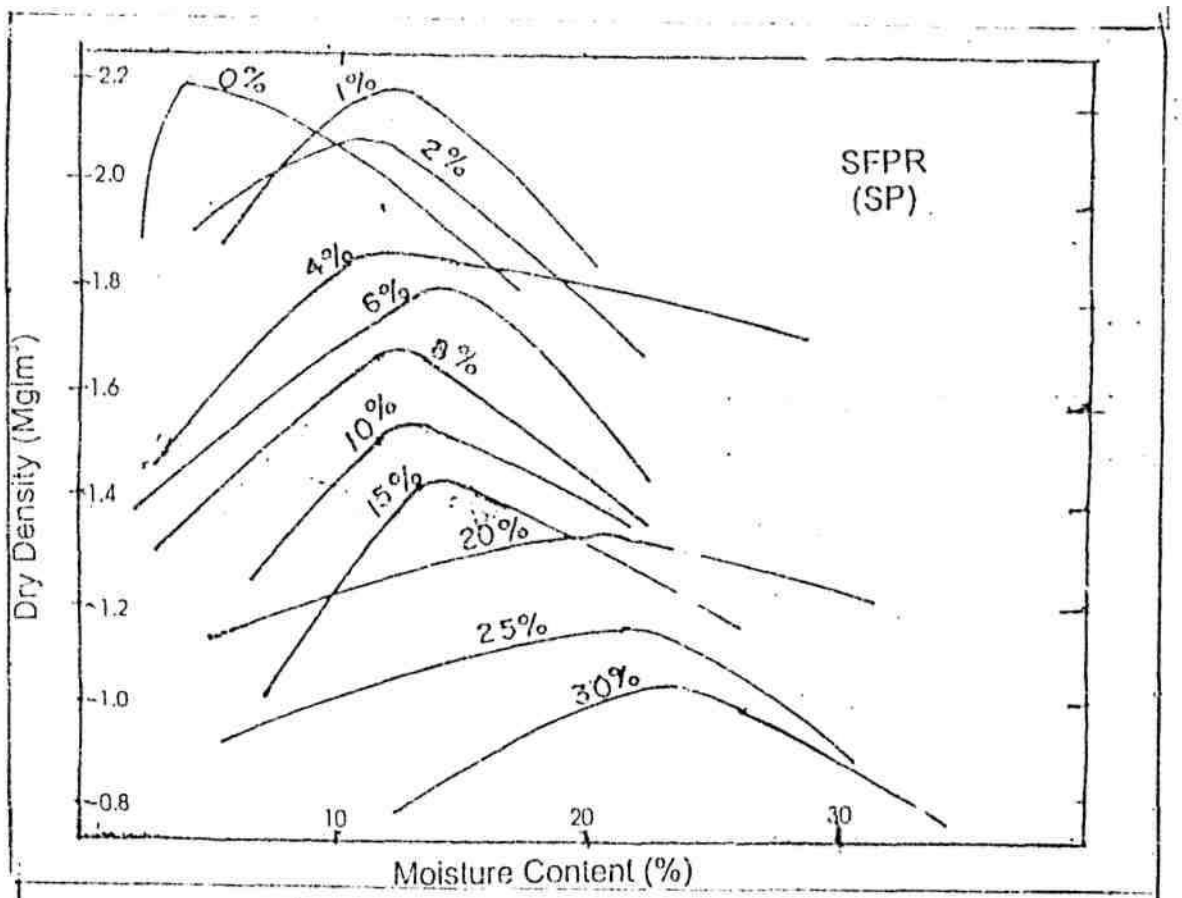


FIG 3.4 Soil - SFPR (SP) COMPACTION CURVES

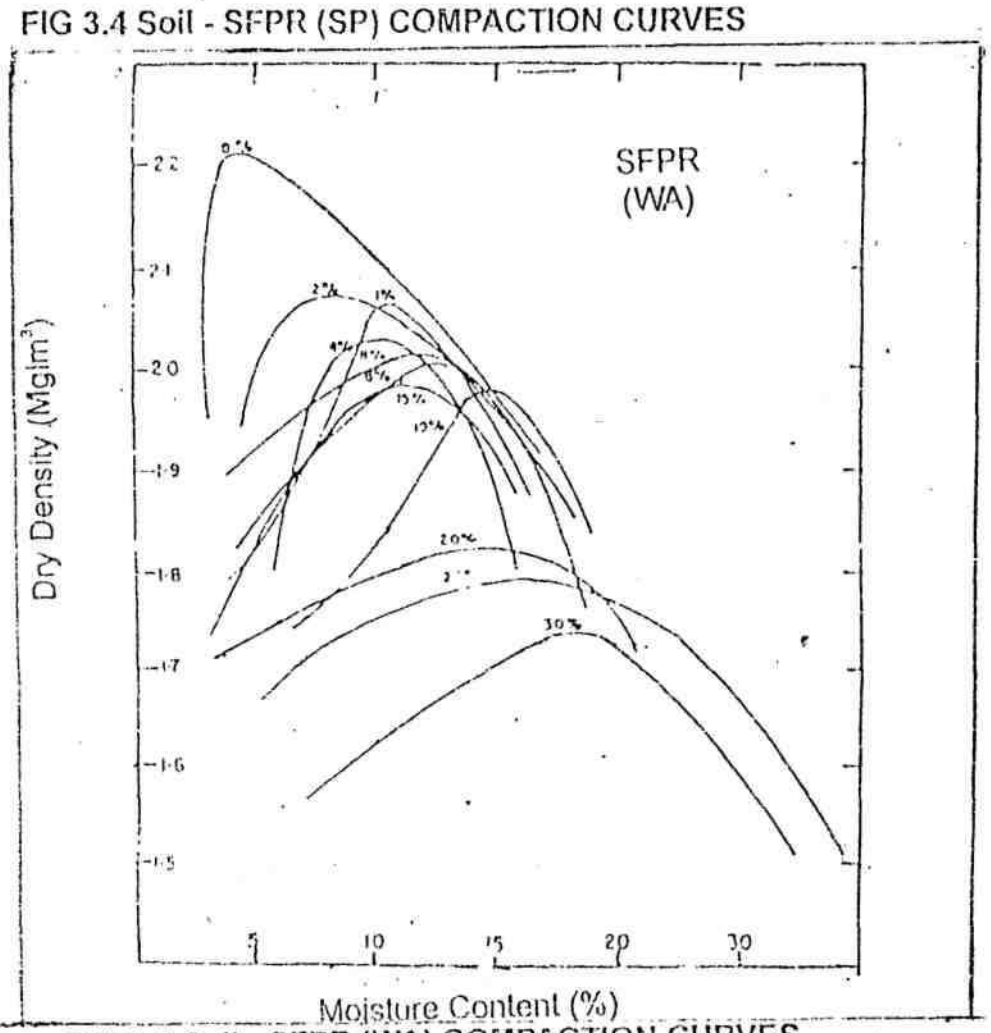


FIG 3.5 Soil - SFPR (WA) COMPACTION CURVES

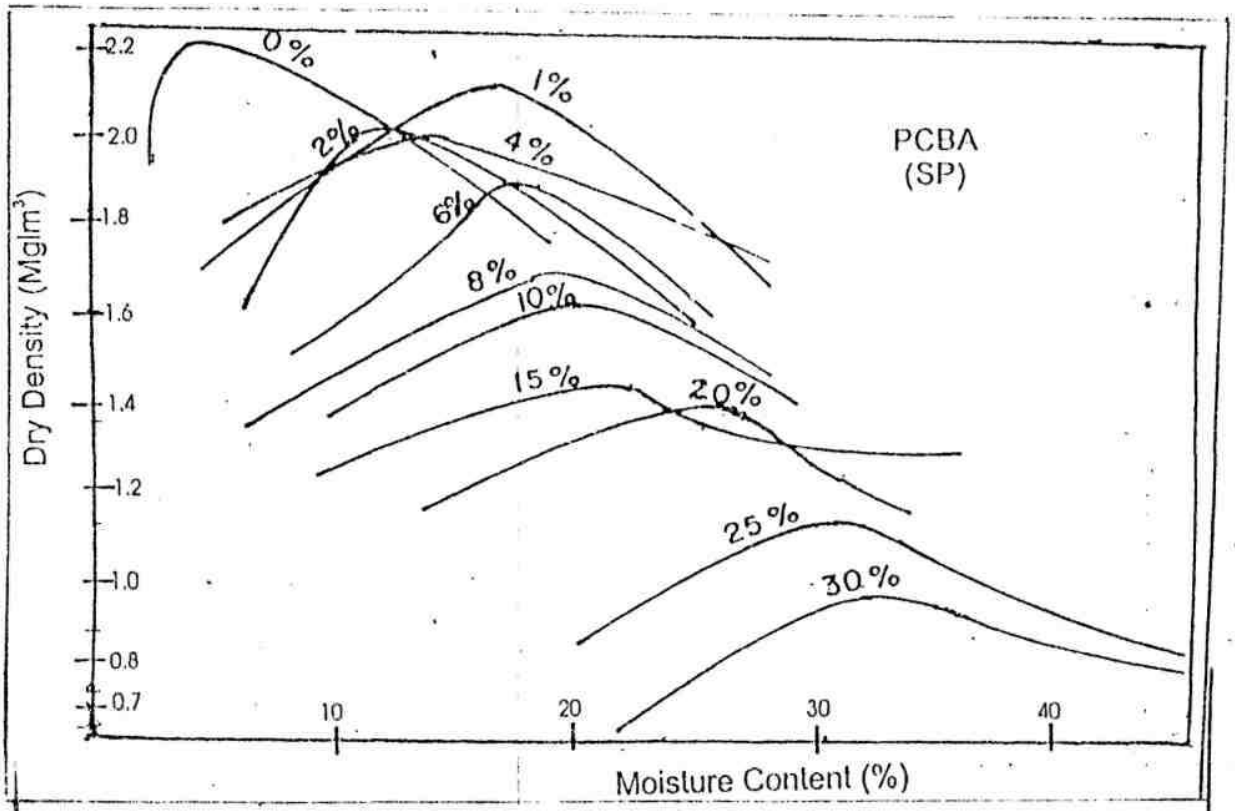


FIG 3.6 Soil - PCBA (SP) COMPACTION CURVES

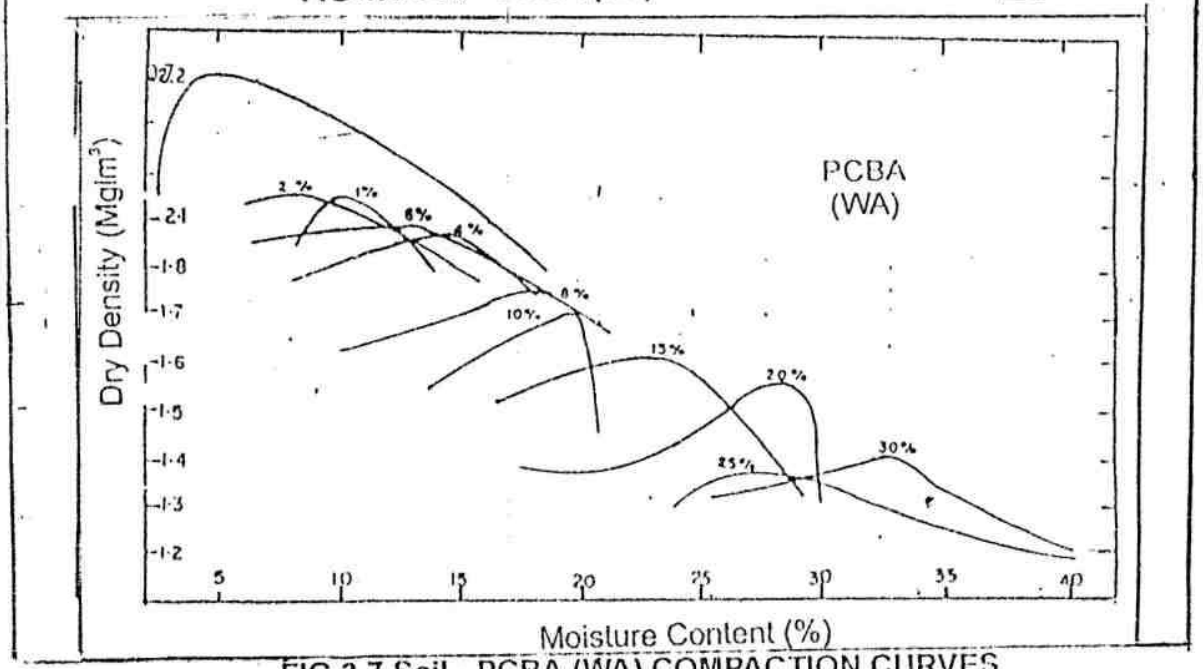


FIG 3.7 Soil - PCBA (WA) COMPACTION CURVES

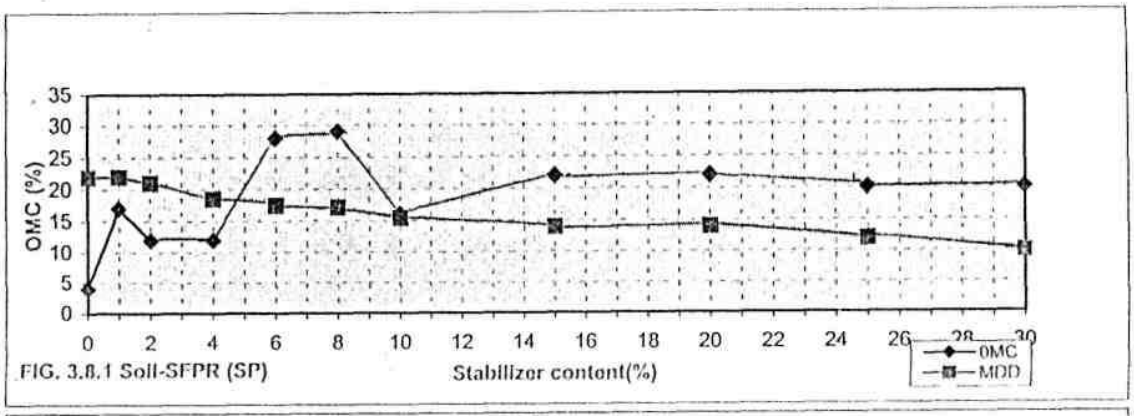


FIG. 3.8.1 Soil-SFPR (SP)

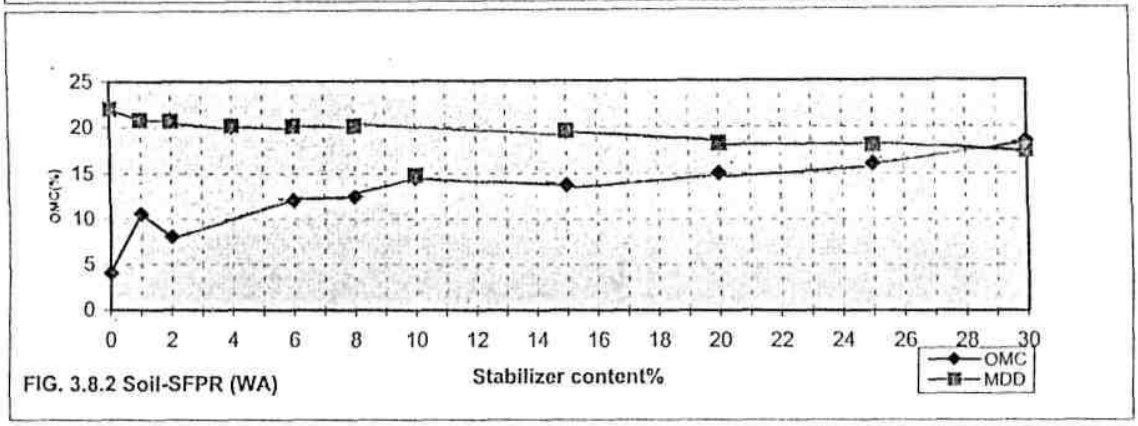


FIG. 3.8.2 Soil-SFPR (WA)

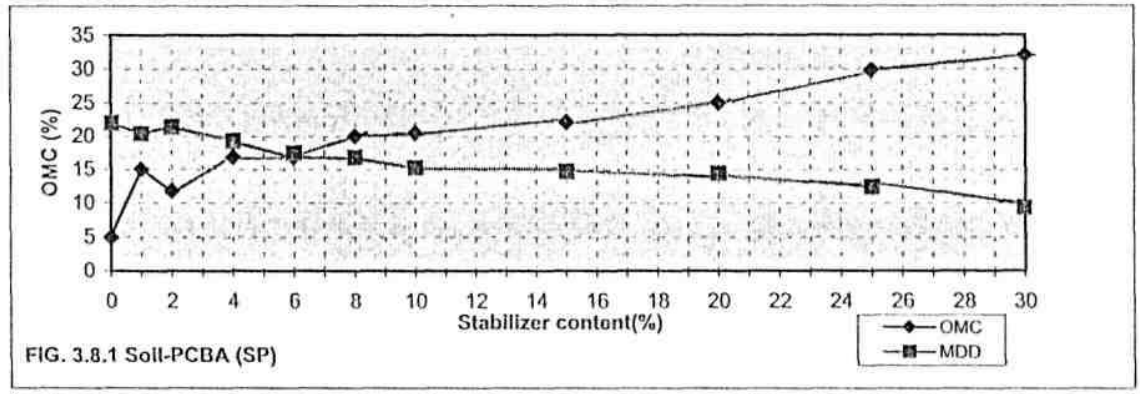


FIG. 3.8.1 Soil-PCBA (SP)

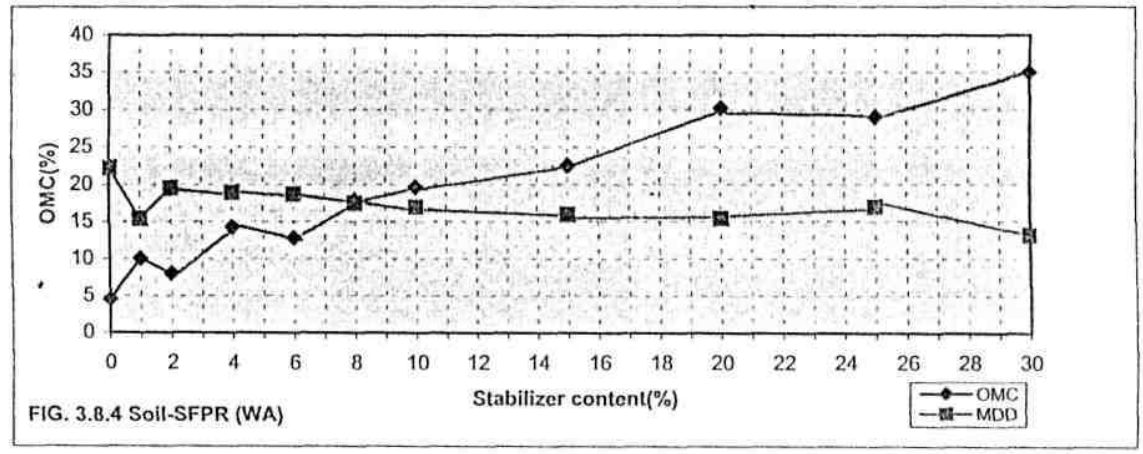


FIG. 3.8.4 Soil-SFPR (WA)

FIG. 3.8: Variation in optimum moisture content and maxium dry density with stabilizer content and compaction energy for Soil- SFPR (Fig 3.8.1 & 3.8.2) and Soil - PCBA (Fig. 3.8.3 & 3.8.4) (Tables 2.2 to 2.5)

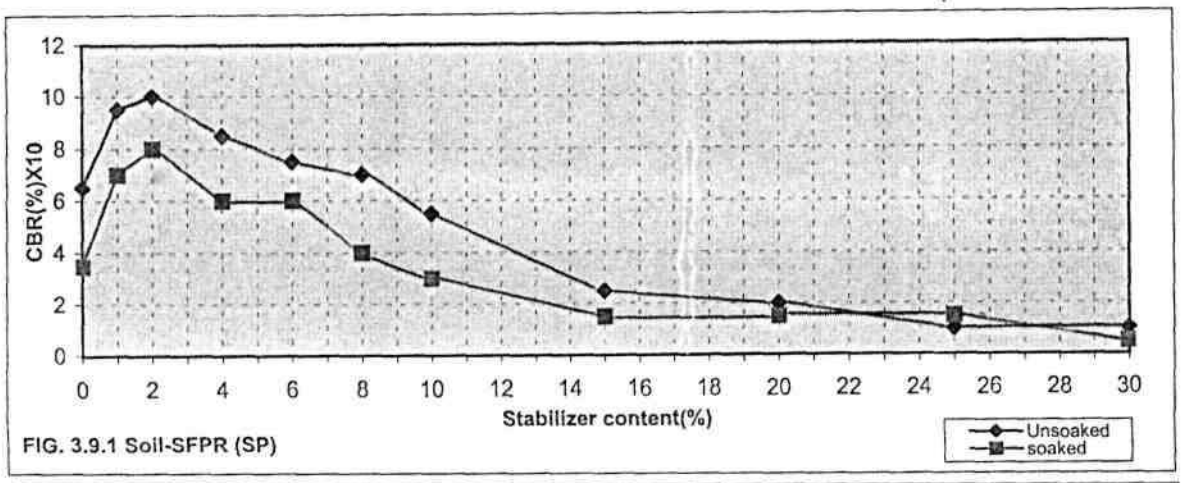


FIG. 3.9.1 Soil-SFPR (SP)

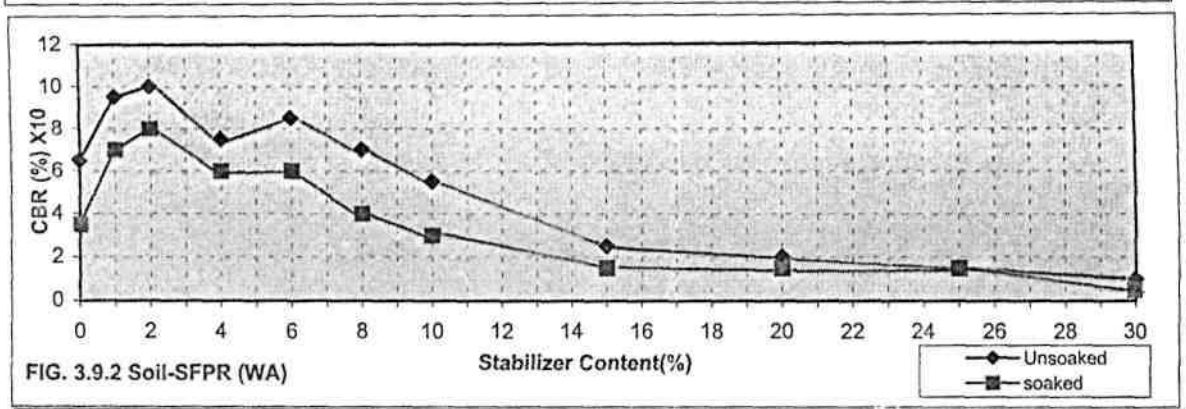


FIG. 3.9.2 Soil-SFPR (WA)

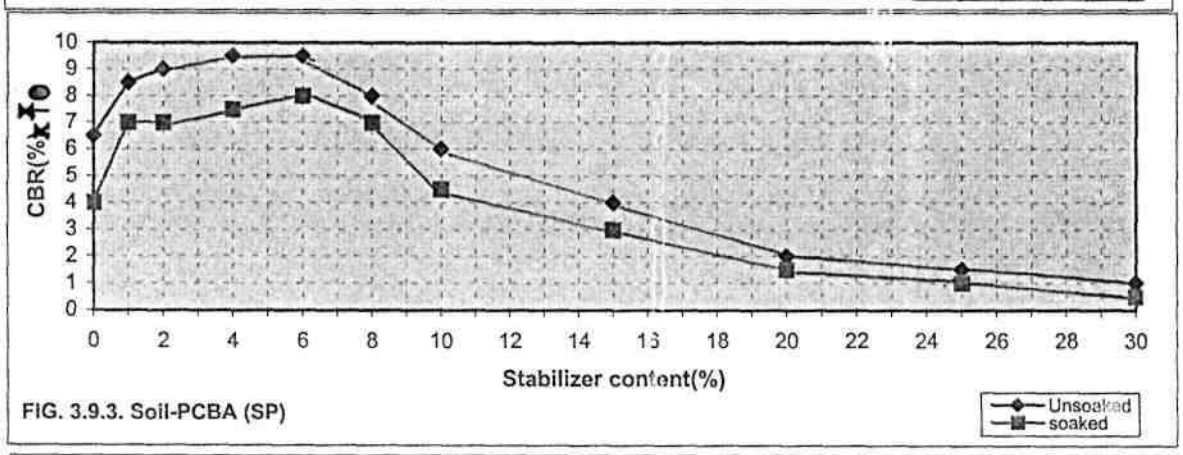


FIG. 3.9.3. Soil-PCBA (SP)

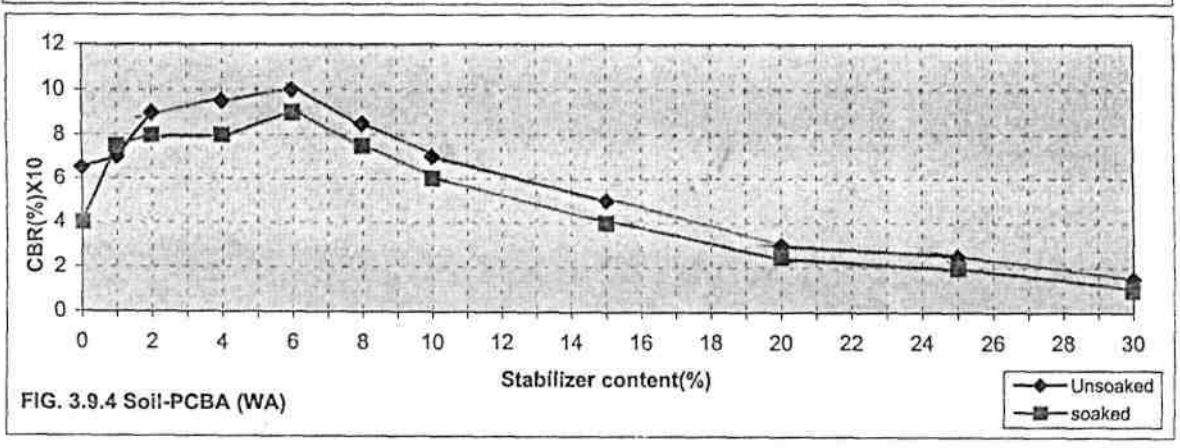


FIG. 3.9.4 Soil-PCBA (WA)

FIG. 3.9: Variation in CBR with stabilizer content and Compaction energy for Soil - SFPR (Fig. 3.9.1 & 3.9.2) and Soil - PCBA (fig 3.9.3 and 3.9.4) (Table 2.15)

3.4.4 Effect Of Stabilization On Unconfined Compressive Strenth (UCS)

3.4.4.1 UCS Of Unsoaked Samples.

The highest UCS of 1050 kPa for uncured samples was attained at SFPR stochiometry of 2 percent, and at medium (WA) compaction energy level (Fig. 310). This is about 8 percent higher than the UCS of the SP compacted equivalent which is itself 160 percent higher than the unstabilized and uncured low energy compacted natural soil. The optimum strength of uncured SFPR stabilized soil declined from the 1050 kPa peak at the rate of 32 kPa(or 9 percent) per percentage increase in stabilizer content beyond stochiometry.

Ditto for soil-PCBA which attained experimentally highest strength at PCBA stochiometry of 6 percent West African Compaction. (Fig. 310.3 and 3.10.4). This peak UCS value is 8 percent higher than the SP compacted.

Uncured soil-SFPR attained UCS value of 1200 kPa. This is 14 percent higher than the highest UCS attained with soil-SFPR, and 8 percent higher than obtained with SP compacted PCBA stabilized sample, and this was achieved at PCBA stochiometry of 6 percent WA compaction. The UCS of SP and WA compacted soil-PCBA declined at the rate of 37 and 41 kPa per percentage increase in PCBA dose above 6 percent (stochiometry) until at full overstabililzation (30% PCBA) the UCS of soil-PCBA reduced to 50 and 52 percent of natural soil values for SP and WA compactions or 20 and 19 percent of peak (stochiometric) strengths.

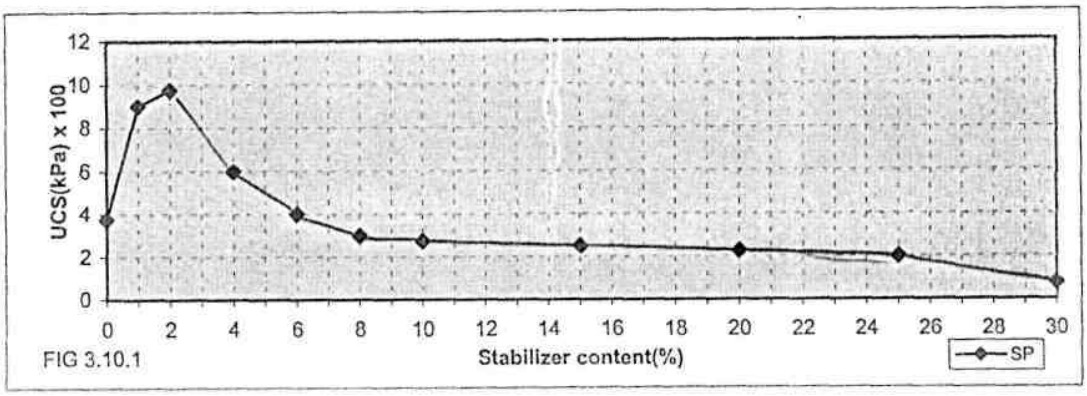


FIG 3.10.1

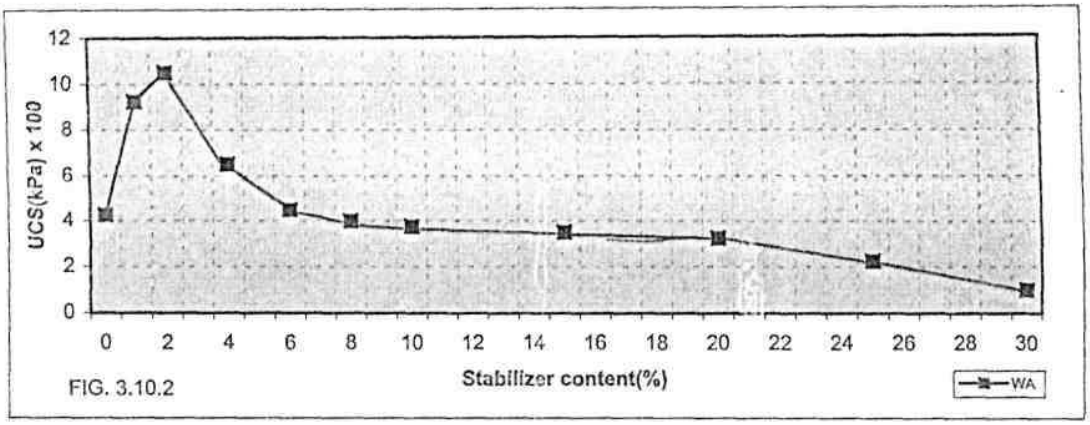


FIG. 3.10.2

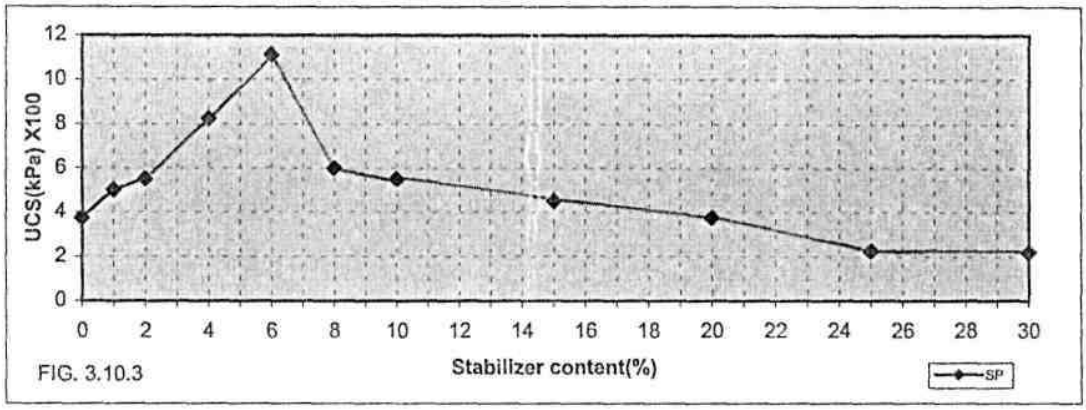


FIG. 3.10.3

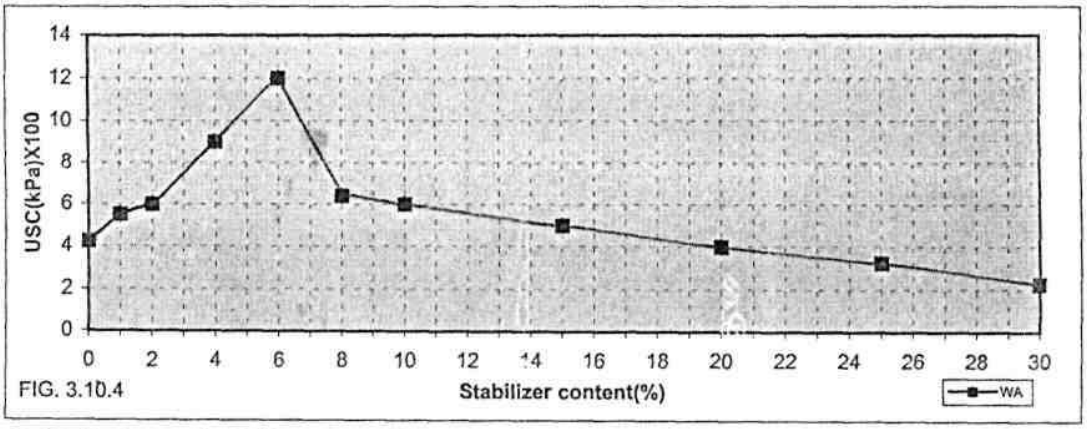


FIG. 3.10.4

Fig 3.10: Variation in UCS with stablizer content and compaction energy of soil-SFPR (Fig. 3.10.1 & 3.10.2) and Soil-PCBA (Fig. 3.10.3 & 3.10.4) (Tables 2.2 to 2.5)

3.5.0. EFFECT OF CHANGING STABILIZATION AND CURING STAGES AND LEVEL

3.5.1 SOIL SFPR STABILIZATION

3.5.1.1 SOIL-SFPR UNDERSTABILIZATION(<2% SFPR)

a. Soil-SFPR Understabilization At Low (7 Days) Curing

Uncured, compacted soil only samples of Shika laterite has unconfined compressive strength of 375 and 425 kPa at low and medium energy levels. On introduction of very little (1%) dose of SFPR, the strength of the admixture increased by 140 and 118 percent, which brought the UCS of the admixture to 900 and 925 kPa. With low curing, increase of about 23 and 30 kPa per curing day were observed, representing curing gain of 23.2 and 28.6kPa or 2.6 and 3.1 percent per curing day below optimum for low and medium energy compacted understabilized (1%) soil-SFPR. (Fig. 3.11, Tables 2.11 and 2.12)

b. Soil-SRPR Understabilization At Optimum (14 Days) Curing

Optimum curing duration for soil-SFPR was found to be 14 days. At this curing stage, the UCS of only soil had increased by 80 and 76 percent from percent form375 and 425 kPa. With the addition of 1 percent SFPR to optimally cured soil-only sample, strength gains of 550 and 575 kPa were observed, representing increment of 81 and 76 percent.

c. Soil-SFPR Understabilization At Long (14-28 Days) Curing

The UCS of long cured soil only increased by 23 and 25 kPa or 3.4 and 3.3 percent per curing day above optimum (14 days) curing.

With stabilization at 1 percent (understabilization) and overcuring, an over all drop of 17.9 and 17.9 kPa was observed per day of overcuring of understabilized (1%) soil-SFPR. At full curing, understabilized (1% SFPR-soil) attained 246, 92.5 and 76 kPa and 235, 90 and 75 percent of uncured natural soil, fully cured soil and optimally stabilized undercured soil-SFPR. For low and medium energy compaction levels respectivlly.

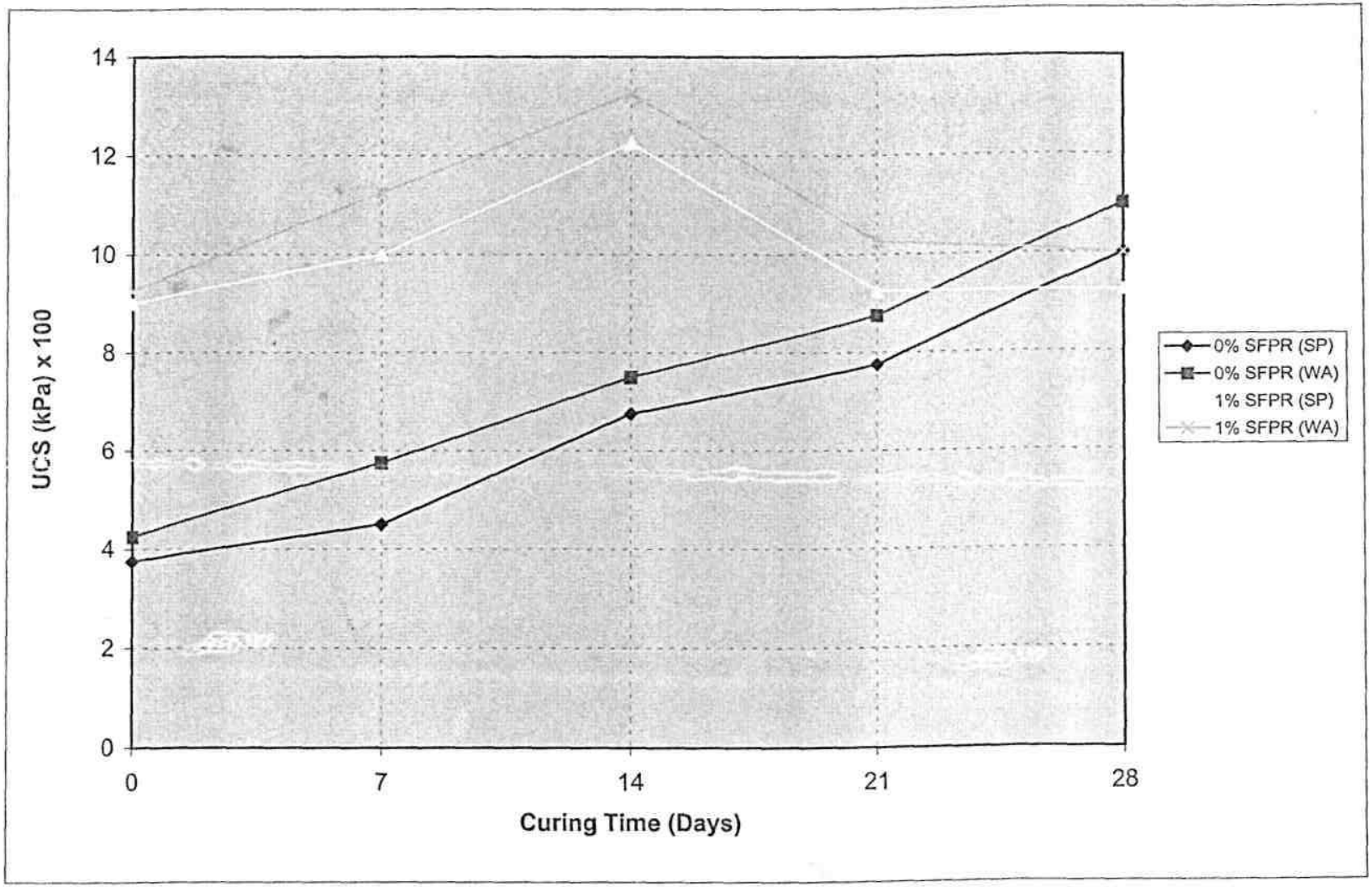


FIG. 3.11: SOIL SFPR Understabilization diiagram

3.5.1.2 SOIL-SFPR OPTIMUM STABILIZATION (2% SFPR) STAGES

a. Soil-SFPR Optimum Stabilization (2% SFPR) STAGES

The USC of unstabilized natural soil is 375 and 425 kPa. When optimally stabilized with 2 percent SFPR, the UCS of the admixture rose to 975 and 1050 kPa, representing an increase of 80 and 74 percent per percentage increase in stabilizer content below stochiometric. With curing below optimum (14 days), daily improvement in UCS of 28.6 and 30.4 kPa was observed.

b. Soil-SFPR Optimum Stabilization (2% SFPR) At Optimum (14 Days) Curing.

Optimally (14 days) cured, unstabilized soil attained UCS of 675 and 750 kPa or 180 and 176 percent the UCS of the natural soil, while soil-SFPR optimally stabilized at 2 percent gained 28.6 and 30.4 kPa or 7.6 and 7.2 percent per curing day up to optimum (14 days). The peak optimally stabilized optimally cured values attained of 1375 and 1475 kPa represent 367, 181 and 141 percent and 347, 147 and 140 percent the values of uncured natural, optimally (14 days) cured soil, and uncured optimally stabilized soil-SFPR at 2 percent SFPR.

c. Soil-SFPR Optimum Stabilizaton (2% SFPR) At full 928 Days Curing

The peak optimally stabilized and optimally cured soil-SFPR UCS values of 1375 and 1475 kPa or 3 and 2.2. percent per curing day above 14 days (over curing). At the full curing (28 days) period, the ultimate strength of the optimally stabilized, fully cured Soil-SFPR had reduced to 800 and 1045 kPa, that is, 213, 80, 82 and 58 percent and 241, 93, 98 and 69 percent the UCS values of unstabilized uncured soil, fully (28 Days) cured unstabilized soil, optimally stabilized uncured soil-SFPR and optimally stabilized and optimally cured soil-SFPR and optimally stabilized optimally cured (14 Days) soil-SFPR.

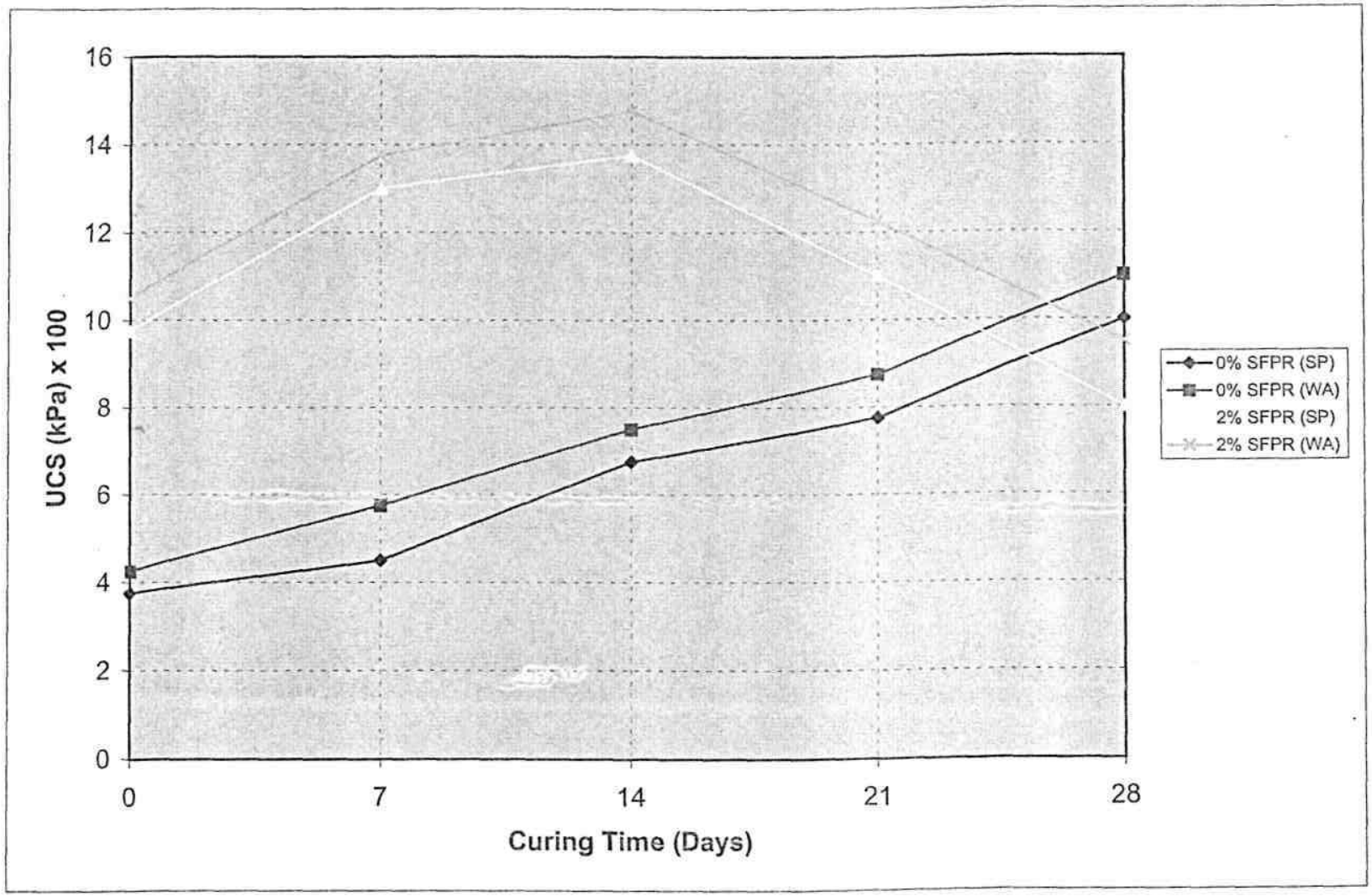


FIG. 3.12 Soil -SFPR optimum stabilization diagram

3.5.1.3. SOIL-SFPR OVERSTABILIZATION(>2% SFPR) STAGE

a. Soil-SFPR Overstabilization At Low (<14 Days) Curing

Overstabilization of soil-SFPR commenced from above 2% SFPR dose. When the SFPR content of 0 Day cured optimally (2% SFPR) stabilized admixture is raised marginally to 4 percent, a drop in UCS of 185 and 200 kPa is observed. This represents a drop of 19.2 and 19 percent in the peak UCS of optimally stabilized 0 Day cured adimxture. Overall for 0 Day cured overstabilized soil-SFPR, an average stepwise drop of 32 and 34 kPa or 3.9 and 3.2 percent per percentage increase in stabilizer dose above optimum were noticed. The same trend was observed for 7 days cured overstabilized soil –SFPR with an initial drop of 338 and 325 kPa or 26 and 24 percent per percentage overdose and overall step-wise drop of 41 and 43 kPa or 3.2 and 3.1 percent per percentage increase in stabilizer content above stochiometry. For all levels of overstabilization, a mean strength increase ingradient of 60 percent was observed for curing days below optimum.

b. Soil-SFPR Overstabilization At Optimum (14 Days) Curing

At optimum (14 Days) curing period, marginal increase in stabilizer content form optimum (2%) to 4% SFPR produced a drop in UCS of 288 and 288 kPa or 21 and 20 percent per percentage increase in stabilizer content, and an overall stepwise drop in peak (stochiometric) strength of 40 and 43kPa or 2.9 and 2.9 percent per percentage increase in stabilizer content above stochiometric.

c. Soil-SFPR Overstabilized At Full (28 Days) Curing.

At full (28 Days) curing , the UCS of marginally overstabilized soil-SFPR from 2-4% resulted in drop in peak strength of 2.5 and 50 kPa or 0.3 and 5 percent per percentage increase in stabilizer content above stochiometric. The overall step-wise drop in strength for fully (28 Days) cured. Samples were 14.3 and 18.9 kPa or 1.9 and 1.8 percent per percentage overstabilization. The ultimate strength of fully cured and fully overstabilized soil-SFPR is 106, 40 and 533 percent and 118, 45 and 500 percent the UCS of the natural soil, fully cured unstabilized soil and fully stabilized 0 Day cured samples.

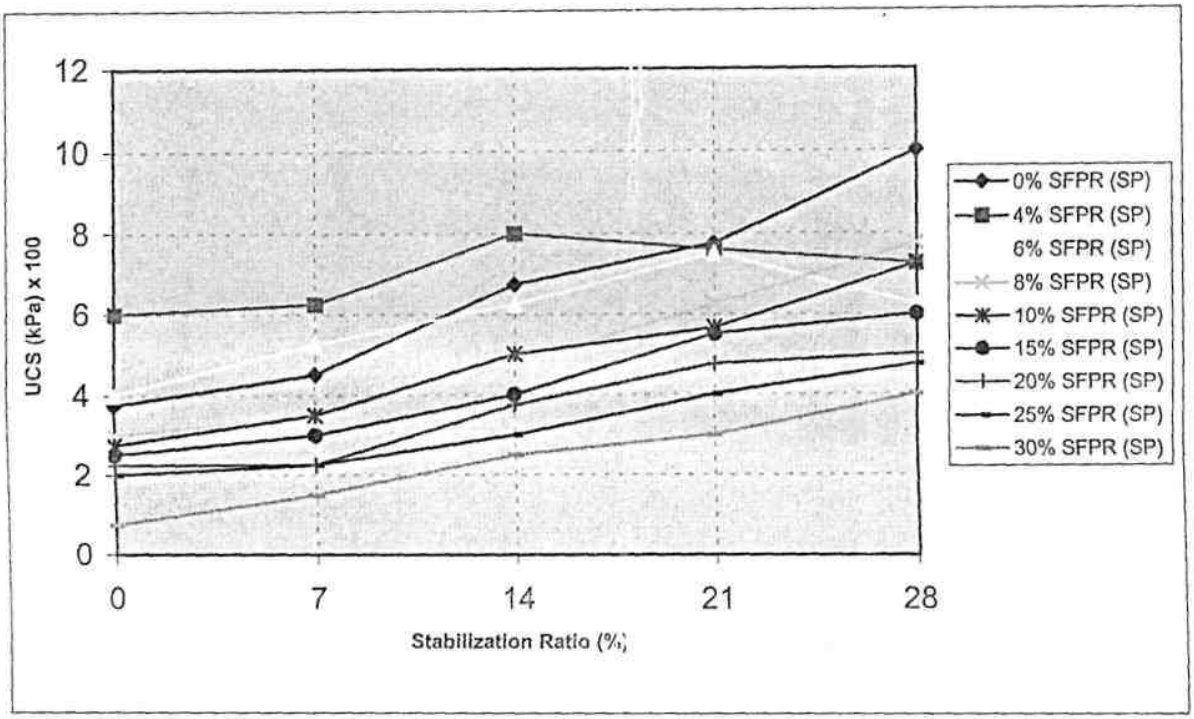


FIG. 3.13 Soil - SFPR (SP) Overstabilization Diagram

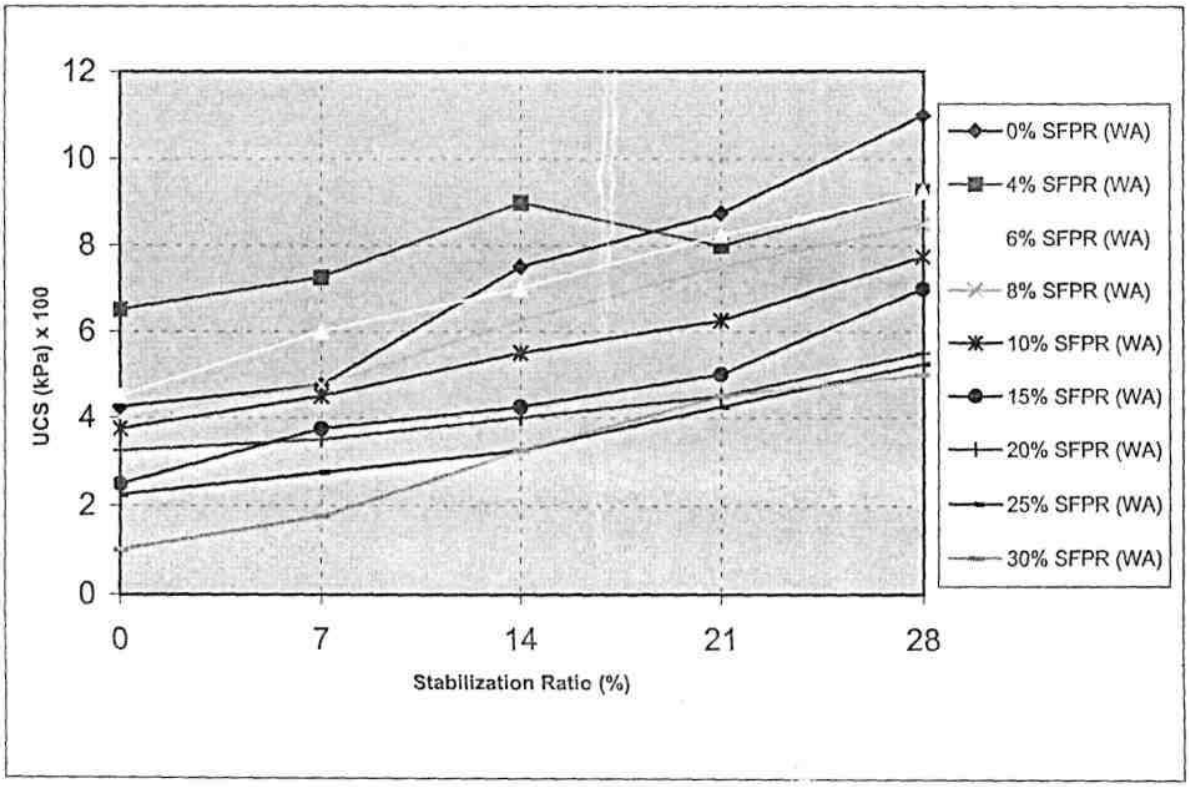


FIG. 3.14 Soil - SFPR (WA) Overstabilization Diagram

3.5.2 SOIL PCBA STABILIZATION

3.5.2.1 Soil-PCBA Understabilization (<6% PCBA)

a. Soil-PCBA Understabilization At low (< 7 Days) Curing

The uncurred unstabilised natural compacted soil sample of Shika laterite has UCS of 375 and 425 kPa low and medium energy. This increased to 500 and 550 kPa, an increase of 33 and 29% over unstabilised uncurred soil sample. With progressive percentage increase in stabilisation below 6% stochiometry, stepwise increase in UCS of 123 and 129 kPa or 35 and 30% were observed

b. **Soil-PCBA Understabilisation at Optimum (7 Days) Curing**

The (7 Days) optimum curing strength (UCS) of soil only sample are 450 and 575 kPa which are 120 and 135 percent of the UCS of soil only samples. On introduction of 1 percent PCBA, strength increase of 175 and 100 kPa or 39 and 10% were observed. An overall average stepwise increase in UCS of 138 and 138 kPa or 39 and 32% per percentage increase in stabiliser content below stochiometric were observed.

c. **Soil-PCBA Understabilisation At Long (< 7 Days) Curing**

For 14 Days curing, an initial increase of 150 and 150 kPa or 22 and 20 percent were observed for 1 percent PCBA addition. Increasing PCBA dosage stepwise below stochiometry gave rise to progressive increase of 58 and 67 kPa or 8.6 and 8.9 per percentage increase in stabiliser content. Similarly for 21 Days curing, initial increase of 200 and 275 kPa or 26 and 31 percent were observed on introduction of 1 percent PCBA dose. A general progressive increase in stabiliser dosage below stochiometry also attracted average stepwise increase of 50 and 41 kPa or 6.5 and 4.7 percent per percentage stabiliser dose increase. It was generally observed that the rate of increase in UCS per percentage increase in stabiliser dose declined as the curing age of nsamples increased.

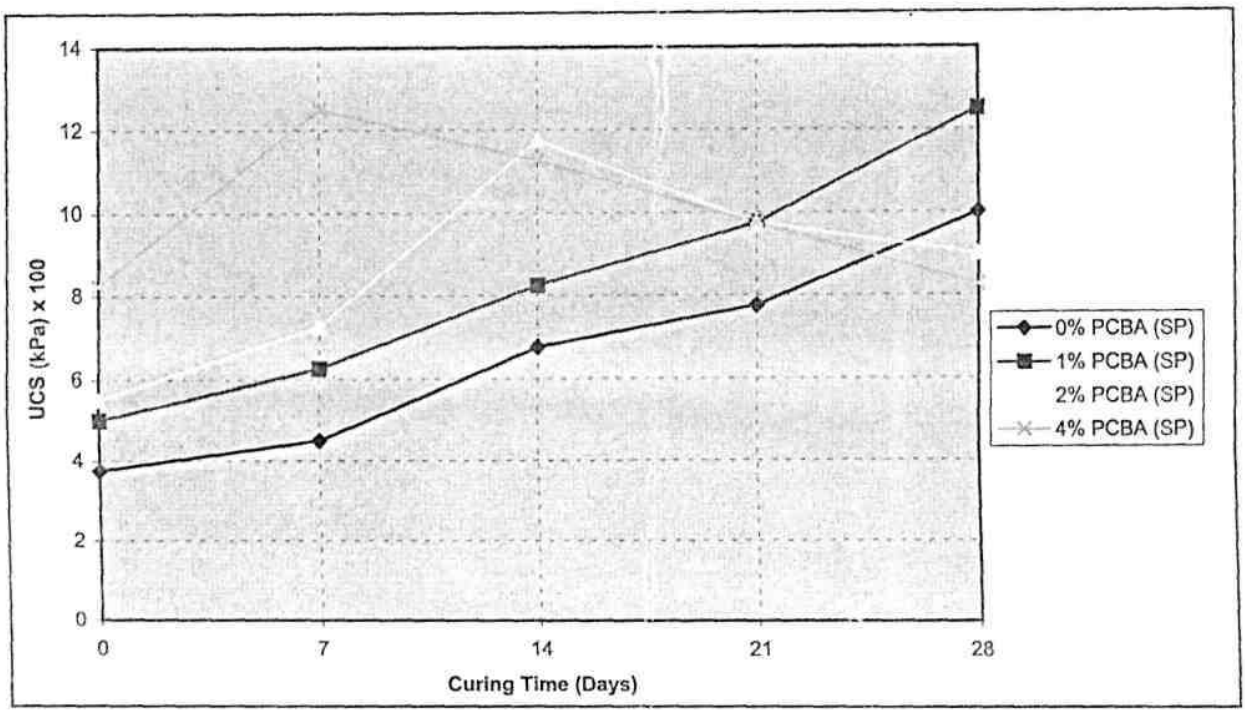


FIG. 3.15 Soil - PCBA (SP) understabilization diagram

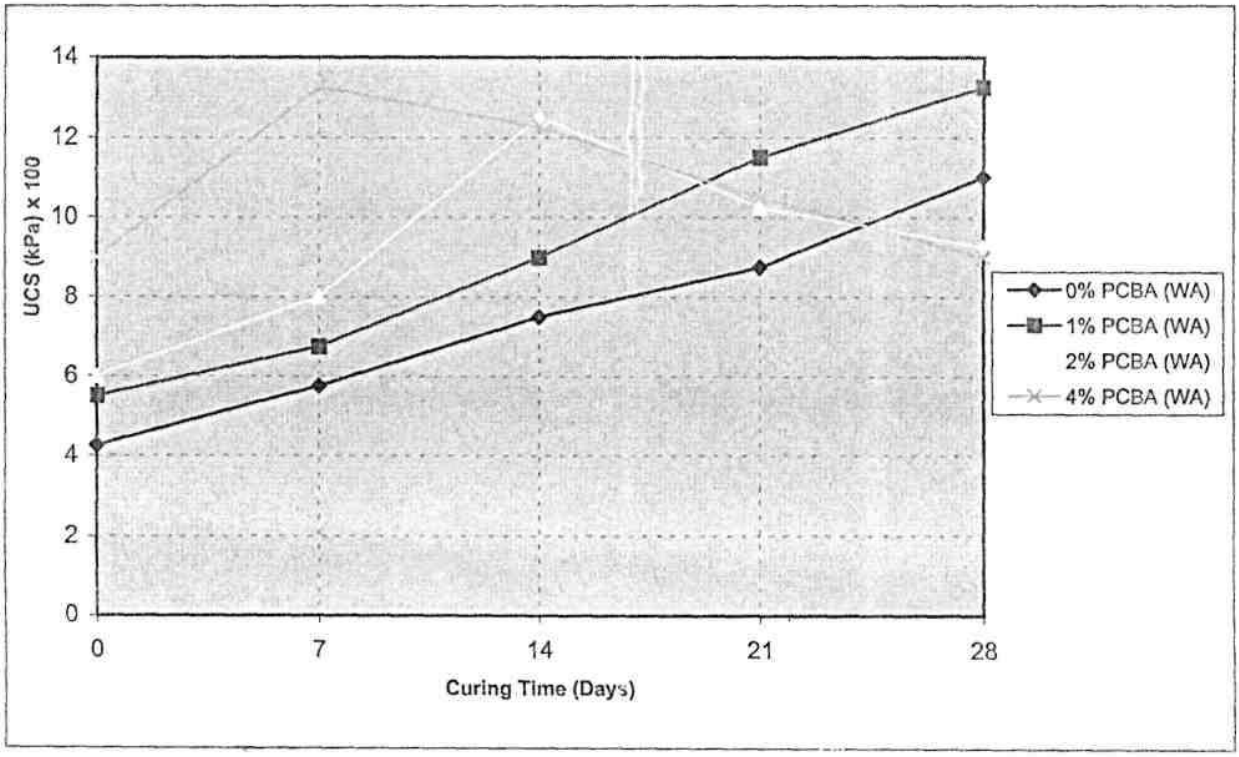


FIG. 3.16 Soil - PCBA (WA) understabilization diagram

3.5.2.2. Soil-PCBA OPTIMUM STABILIZATION (6% PCBA)

a. Soil-PCBA Optimum Stabilizaton At Low Optimum (<7 Days) Curing

At 1110 and 1200 kPa, the UCS of optimally stabilized soil-PCBA are 296 and 282 percent the UCS of unstabilized and uncured natural soil. With low curing, progressive strength increase of 24 and 29 kPa or 2.2 and 2.4 percent per curing day below optimum (<7 Days) were observed for low and medium energy compactions

b. Soil-PCBA Optimum Stabilizaton At optimum (7 Days) Curing

1275 and 1400 kPa represent the 7 Days (optimum) curing strength of soil-PCBA. This is 337 and 329, 283 and 187, and, 115 and 117 percent the values of unstabilized uncured natural soil, optimally 7 Days cured unstabilized soil and optimally stabilized 0 Day cured soil-PCBA at low and medium compaction energy.

c. Soil-PCBA Optimum Stabilization At Full (28 Days)

From the peak optimally stabilized optimally cured UCS of 1275 and 1400, further curing of soil-PCBA resulted in 3.4 and 24 kPa or 0.2 and 1.7 percent stepwise drop in the UCS of optimally stabilized optimally cured samples.

The ultimate UCS of optimally stabilized and optimally cured samples of 1200 and 900 kPa represent 320, 120, 108 and 94 percent and 212, 82, 75 and 64 percent of uncured and unstabilized natural soil, fully cured unstabilized soil, optimally stabilized 0 Day cured and optimally stabilized 7 Days (optimally) cured low and medium energy compacted samples. Generally the average rate of decline in peak UCS of both low and medium energy compacted samples per day of overcuring is about 41 percent the rate gain per curing day below 7 days optimum for optimally stabilized soil-PCBA.

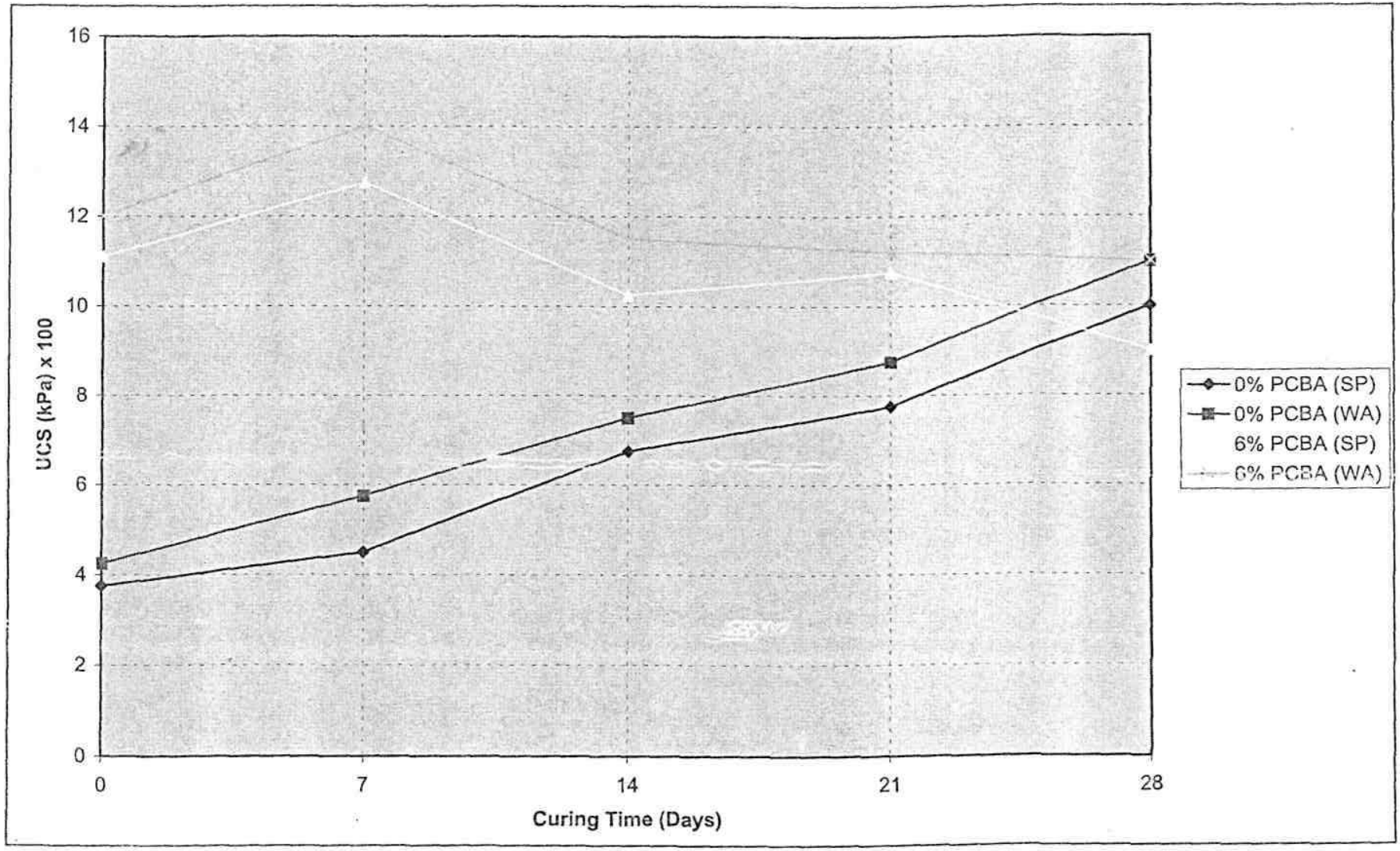


FIG. 3.17 SOIL - PCBA Optimum Stabilization Diagram

3.5.2.3 SOIL-PCBA OVERSTABILIZATION (6%>PCBA) STAGE

a. Soil-PCBA Overstabilization Low (<7 Days) Curing

Overstabilization of soil-PCBA commenced at 6% PCBA dose. On marginal increase of PCBA dose form 6 to 8% at 0 Day curing, a drop in UCS of 255 and 280 kPa or 23 percent per percentage increase in stabilizer content beyond optimum was observed. Overall, 0 Day cured overstabilized soil-PCBA showed a stepwise average drop of 37 and 41 kPa or 3.3 and 3.4 percent per percentage increase in stabilizer content. The ultimate strength (UCS) of fully overstabilized 0 Day cured soil-PCBA of 220 and 225 kPa are 59 and 20 percent of uncured natural soil and 0 Day cured optimally stabilized soil-PCBA for low and medium compaction energy levels respectively.

b. Soil-PCBA Overstabilization At Optimum (7 Days) Curing

At the optimum (7 Days) curing period, marginal increase in stabilizer content from 6% optimum to 8%, resulted in 238 and 250 kPa or 18.7 and 17.9 percent per percentage increase in stabilizer content beyond 6% PCBA optimum. On the whole, average stepwise drop of 42 and 45 kPa or 3.3 and 3.2 percent per percentage increase in stabilizer content beyond stochiomeric for 0 Day cured overstabilized soil-PCBA. was observed. The ultimate strength of 275 and 325 kPa for optimally stabilized fully cured soil-PCBA represent 73, 61 and 125 percent and 76,57 and 144 percent the UCS values of unstabilized uncured natural soil, unstabilized optimally (7 Days) stabilized soil and fully overstabilized 0 Day cured soil-PCBA.

c. Soil-PCBA Overstabilization At Full (28 Days) Curing

At full (28 Days) curing, the UCS of marginally overstabilized (6 – 8%) soil-PCBA resulted in 75 and 25 kPa or 6.3 and 2.8% drop per percentage overstabilization. The overall stepwise drop in peak stochiometric strength per percentage overstabilization was observed to be 25 and 2.3 kPa or 2.1 and 2%. At full (28 Days) curing, the UCS of fully overstabilized soil-PCBA of 600 and 550 kPa represent 100, 60, and 272% and 129, 50 and 244% the UCS of unstabilized uncured soil, fully cured unstabilized soil and fully stabilized 0 Day cured soil-PCBA.

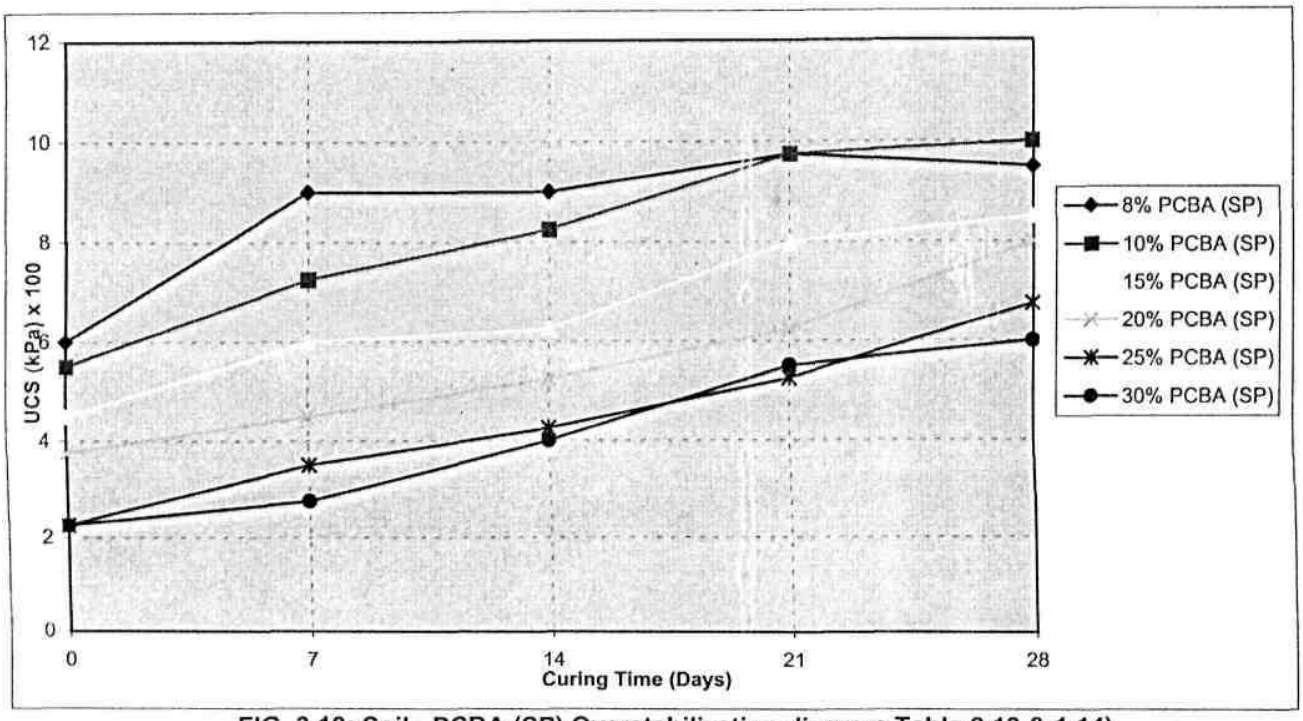


FIG. 3.18: Soil - PCBA (SP) Overstabilization diagram Table 2.13 & 1.14)

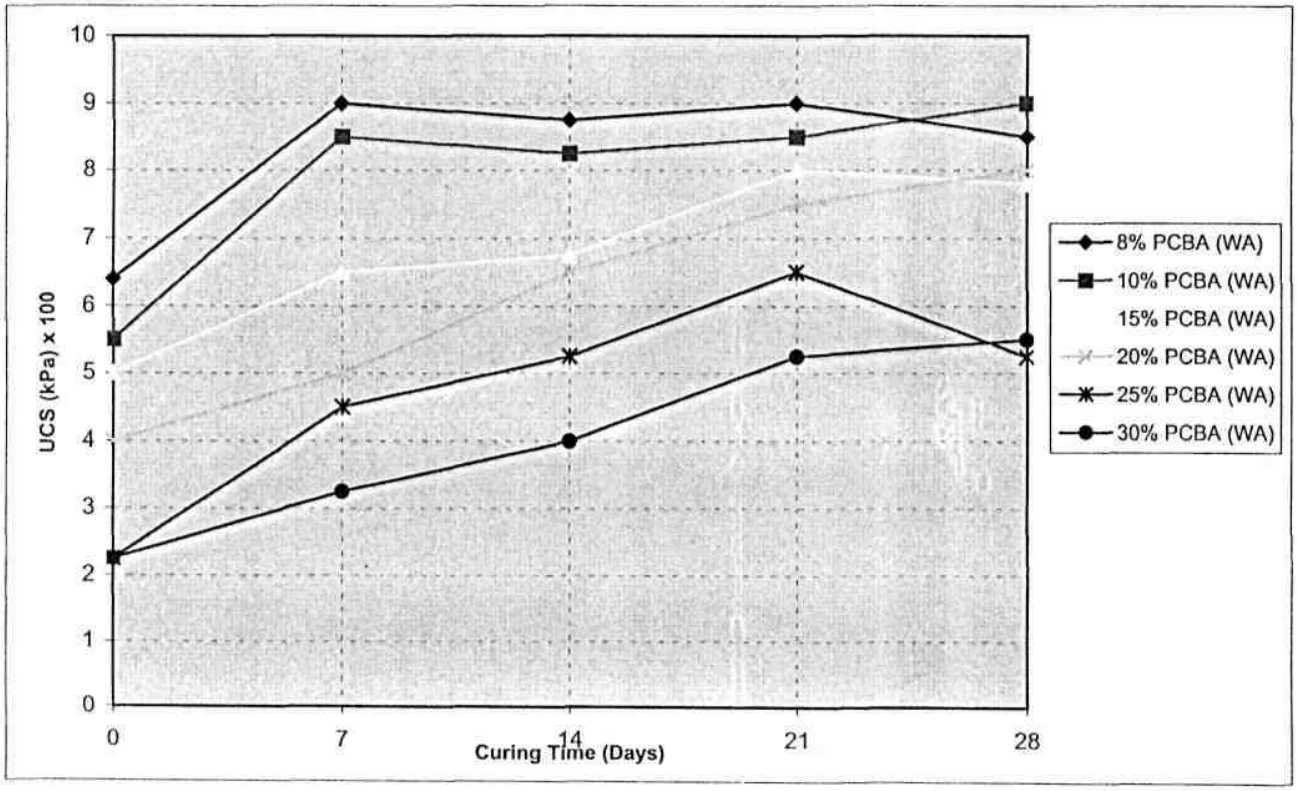


FIG. 3.19: Soil - PCBA (WA) Overstabilization diagram Table 2.13 & 2.14)

3.5.3 SOIL-SFPR CURING

3.5.3.1 Soil-SFPR Undercuring(< 14 Days)

a. **Soil-SFPR Undercuring At Low (<2% SFPR) Stabilization**

The UCS of unstabilized natural low and medium energy compacted uncured soil is 375 and 425 kPa. At low stabilization and undercuring (0 Day curing) UCS of soil-SFPR increased by 525 and 500 kPa or 140 and 118 percent to 900 and 925 kPa. There was a high rate of increase of 300 and 313 kPa or 80 and 74 percent per percentage increase in stabilizer content below stochiometry for low and medium undercured soil-SFPR similarly for undercuring at 7 Days the uncured understabilized values are 1000 and 1125 kPa and the general increase in per percentage increase in stabilizer content are 425 and 400 kPa or 94 and 70 percent.

b. **Soil-PCBA Under-Curing At Optimum (2%SFPR) Stabilization.**

At optimum stabilization and undercuring, the UCS of the previously uncured unstabilized natural soil, low optimally stabilized at 0 Day curing is 975 and 1050 kPa which represent 160 and 148 percent increase over the natural low and medium energy compacted values of 375 and 425 kPa. Undercuring for seven days increased the UCS of optimally stabilized undercured soil-SFPR by 46.4 and 46.4 or 4.8 and 10.9 percent per curing day.

c. **Soil-SFPR Under-Curing At Full (30% SFPR) Stabilizaton**

With increasing stabilization beyond optimum and undercuring of soil-SFPR, step-wise drop in UCS values form optimum were observed with increasing overstabilization. Average drop in strength of 72 and 77 kPa or 3.1 and 3.1 percent were observed up to full soil-SFPR overstabilization and undercuring. The ultimate overstabilized uncured soil-SFPR values of 250 and 260kPa represent 78, 233, and 18 percent and, 61 260 and 18 percent of uncured natural soil, 0 Day cured fully overstabilized and optimally cured, optimally stabilized soil-SFPR.

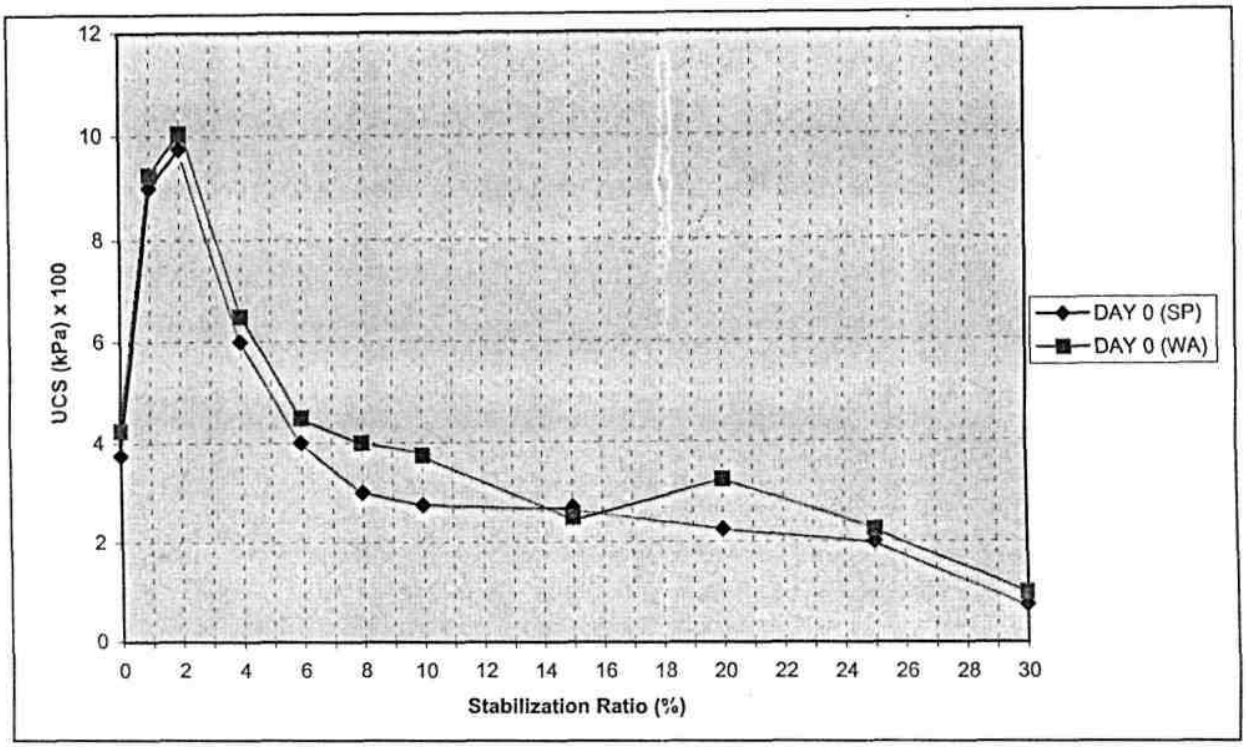


FIG. 3.20 Soil - SFPR Very Low (0 - 1 days) Curing diagram (Table 2.11 & 2.12)

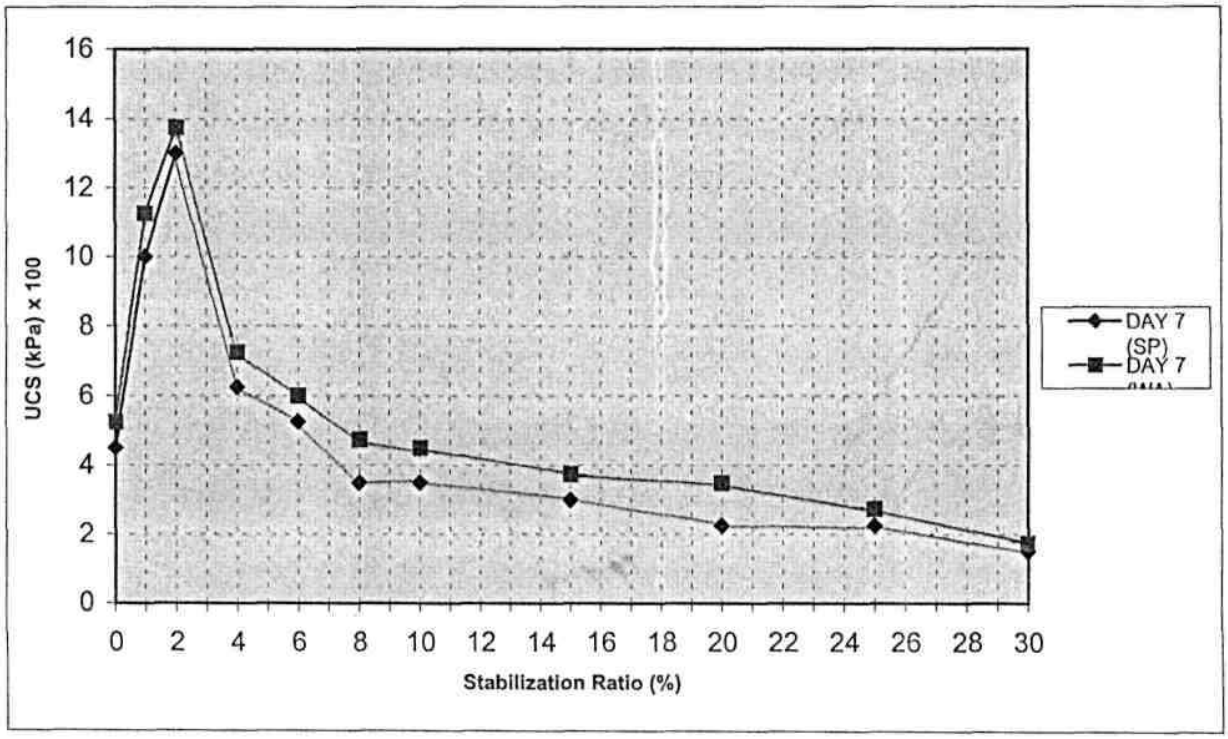


FIG. 3.21 Soil - SFPR Low (7 days) Curing diagram (Tables 2.11 & 2.12)

3.5.3.2 SOIL-SFPR OPTIMUM CURING AT LOW (14 DAYS) STAGE.

a. **Soil-SFPR Optimum Curing At Low (1% SFPR) Stabilization**

The UCS of natural soil compacted at SP and WA in the uncured state was 375 and 425 kPa. When cured for optimum duration (14 days) it increased by 80 and 76 percent to 675 and 750 kPa . With addition of 1% dose of SFPR the UCS of the optimally cured understabilized admixture increased by 81 and 77 percent to 1225 and 1325kPa, which is 327 amd 312 percent and 136 and 143 percent the UCS of uncured natural soil and uncured under-stabilized (1% SFPR) soil.

b. **Soil-SFPR Optimum Curing At Optimum (2% SFPR) Stabilization**

At optimum curing time of 14 days the effect of additional dose at SFPR was to raise the UCS by 9 and 12 percent form 1225 and 1325 kPa to the peak (stochiometric) values of 1375 and 1475 kPa which is 36 and 347 and 347 percent, 141 and 140 percent and 203 and 197 percent the UCS values of uncured natural soil, uncured optimally stabilized soil, and optimum duration cured natural soil compacted at SP and WA compaction energy levels.

c. **Soil-SFPR Optimum Curing At Peak (30% SFPR) Stabilization**

From the peak (stochiometric) UCS values of 1375 and 1475 kPa attained at optimum curing duration, increasing SFPR dose beyond 2% resulted in 21 and 19 percent drop in UCS per percentage increase in stabilizer content up to 4% SFPR. Beyond 4% SFPR there was a step-wise drop of 2.6 and 2.8 percent in UCS until at peak (30% SFPR) overstabilization, the UCS of optimally cured overstabilized soi-SFPR dropped to 250 and 260 kPa or 67 and 61 percent, and 18 and 18 percent the UCS values of unstabilized uncured natural and optimally stabilized optimally cured soil-SFPR.

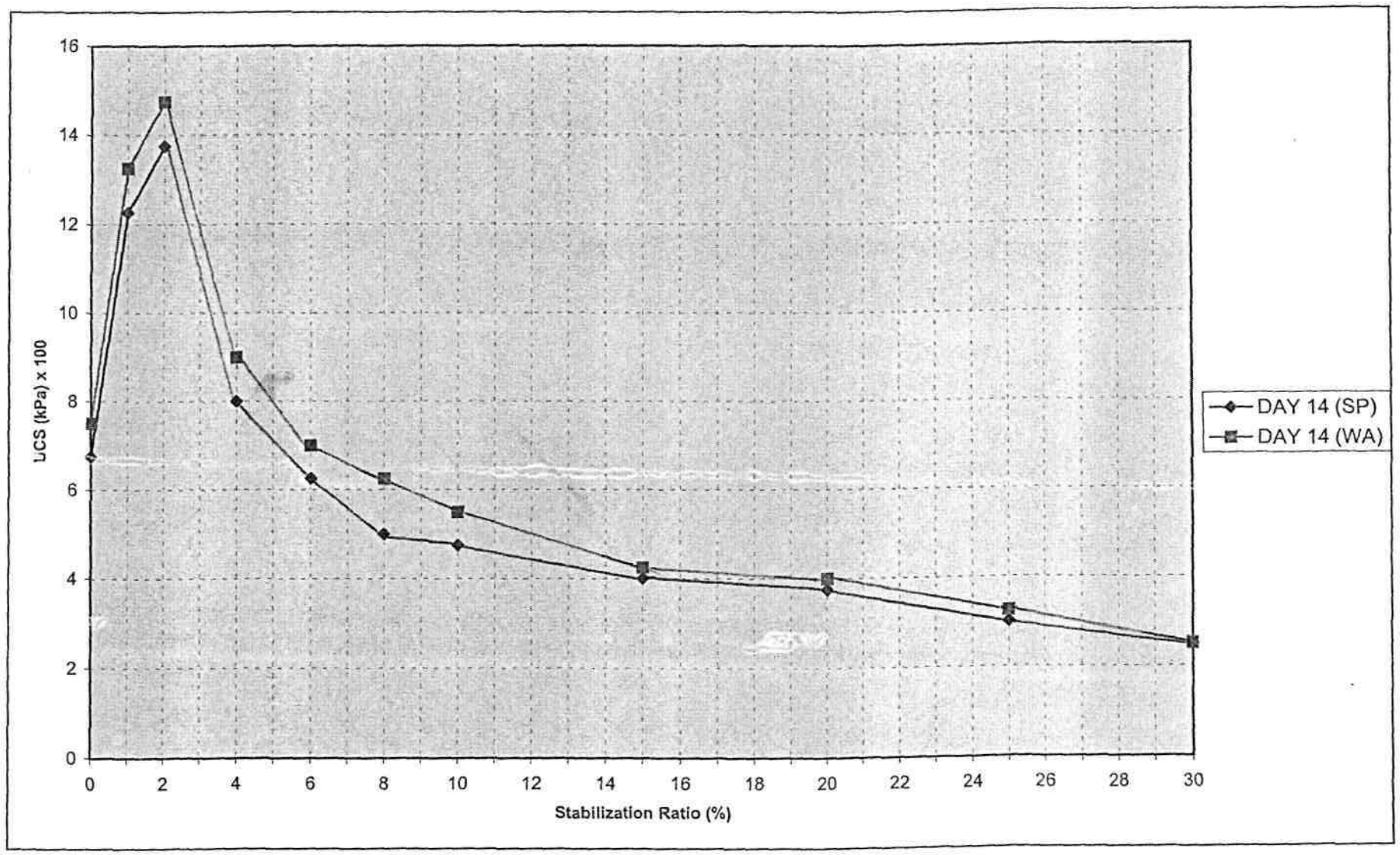


FIG. 3.22 Soil - SFPR Optimum (14 Days) Curing Diagram (*Table* 2.11 & 2.12)

3.5.3.3 SOIL-SFPR (28 DAYS) FULL CURING STAGE (Fig. 3.23)

a. **Soil-SFPR Full Curing At Low (<2% SFPR) Stabilization**

Unstabilized fully cured SP and WA compacted natural soil sample had UCS values of 1000 and 1100 kPa or 267 and 259 percent the UCS of unstabilized and uncured natural soil sample. Addition of 1 percent dose of SFPR and givwen full (28 days) curing treatment resulted in decline of 75 and 100 kPa in the UCS of fully cured unstabilized SP and WA compacted natural soil values to 925 and 1000 kPa which is 247 and 235 percent and 93 and 91 percent and 103 and 105 percent the UCS of uncured natural soil, fully cured natural soil. And uncured understabilized soil at 1 percent SFPR.

b. **Soil-SFPR Full Curing At Optimum (2% SFPR) Stabilization**

The UCS of fully cured 2% SFPR stabilized soil is 800 and 1025 kPa this did not represent a unique but a transitional value between fully cured unstabilized natural soil and fully stabilized and fully cured soil-SFPR, and represents a drop of 20 and 7 percent from the value of fully cured natural soil but 213 and 241 percent the value of fully stabilized and fully cured soil-SFPR.

c. **Soil-SFPR Full Curing At Peak (30% SFPR) Stabilization**

Fully cured unstabilized soil developed UCS of 1000 and 1100 kPa (SP and WA). These declined to 925 and 1000 kPa on stabilizaton with 1 percent dose of SFPR and thereafter declined at the rate of 18 and 17 kPa per percentage increase in stabilizer content until at peak dosage of 30% SFPR (i.e overstabilization) when the UCS of the fully cured overstabilized soil-SFPR dropped to 400 and 500 kPa which are 107 and 118 percent natural soil values, and 40 45 percent UCS values of fully cured unstailized soil, 533 and 500 percent of peak stabilized but uncured and 29 and 34 percent of optimally cured and optimally stabilized soil-SFPR.

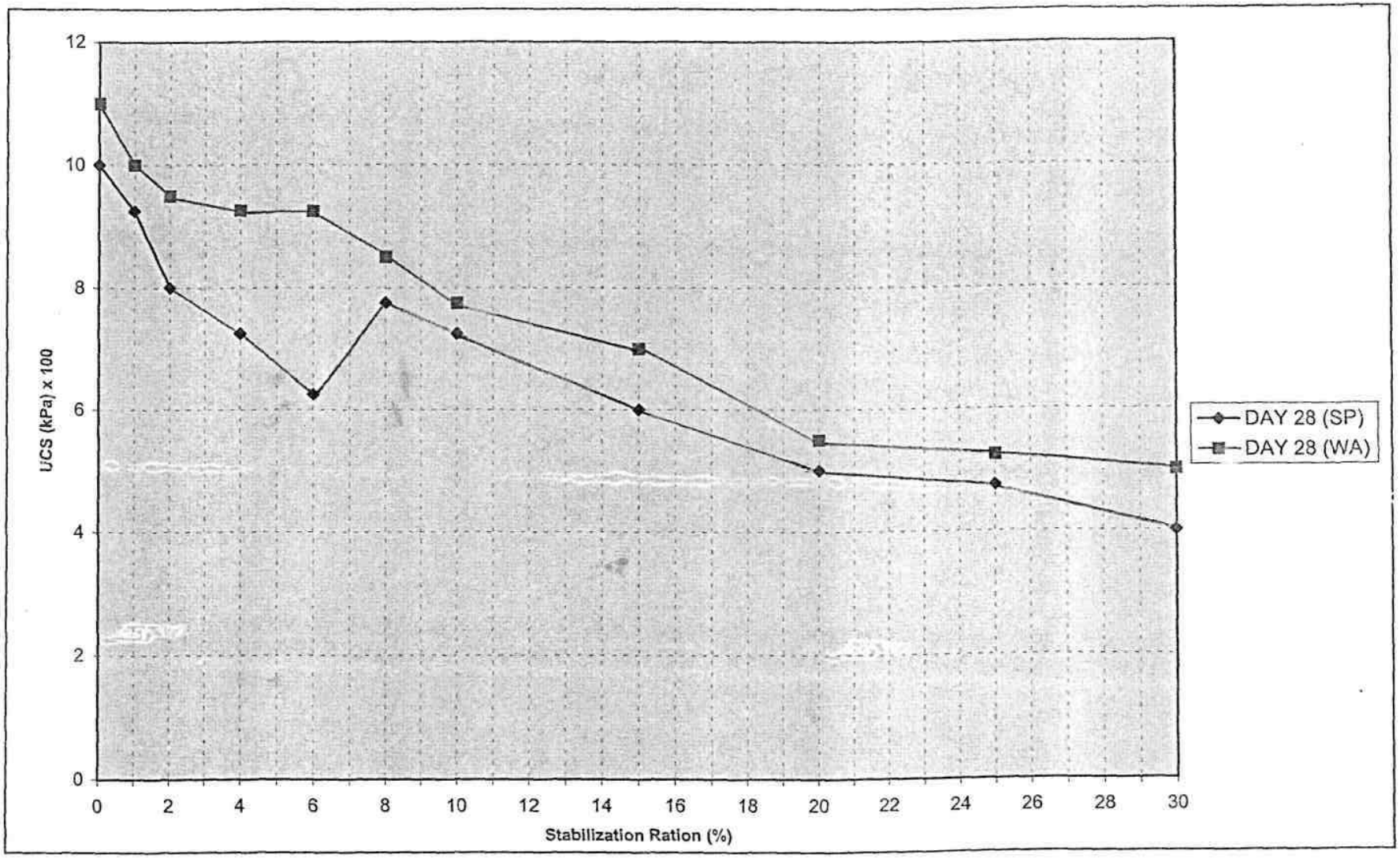


FIG. 3.23 Soil - SFPR full Curing (28 Days) Diagram (Table 2.11 & 2.13)

3.5.4 SOIL-PCBA CURING

3.5.4.1 SOIL-PCBA (7 DAYS) STAGE. (FIG. 3.24; (TABLE 2.13 & 2.14)

a. **Soil-PCBA Undercuring At Low (<6% PCBA) Stabilization**

At low curing, the UCS of unstabilized soil increased by 11 and 22 kPa per cuirng day under 7 days curing, while uncured stabilized soil improved by 123 and 129 kPa. In general, there was an increase of 21.4 and 24.4 kPa per percentage increase in stabilizer content (below stochiometric) per curing day (below optimum).

b. **Soil-PCBA Undercuring At Optimum (6% PCBA) Stabilization**

At optimum stabilization and undercured the UCS of soil PCBA is 1180 and 1263 Kpa which represent increase of 28 and 31 kPa per percentage increase in stabilizer content The peak optimum stabilization value at low curing represents 106 and 105 percent, 205 and 220 percent and 315 and 297 percent the values of optimally stabilized undercured, natural soil samples.

c. **Soil-PCBA Undercuring At High (>6 < 30% PCBA) Stabilization**

At optimum stabilization and undercuring the UCS of soli PCBA improved by 25.6 and 28.7 kPa per curing day form 375 and 425 kPa to 1275 and 1400 kPa. Increasing stabilization dose above optimum values at undercured stage, the optimum values of 1275 and 1400 kPa decline in value step-wise by 5 and 5.2 kPa per percentage increase in stabilization dose above stochiometric, at full overstabilization (30% PCBA) and undercuring (< 7 days) the UCS of soil-PCBA had reduced to 285 and 338 kPa which replresent 130 and 150 percent, 63 and 59 percent, and 76 and 59 percent at the values of fully stabilized uncured, optimally cured unstabilized and unstabilized uncured natural soil.

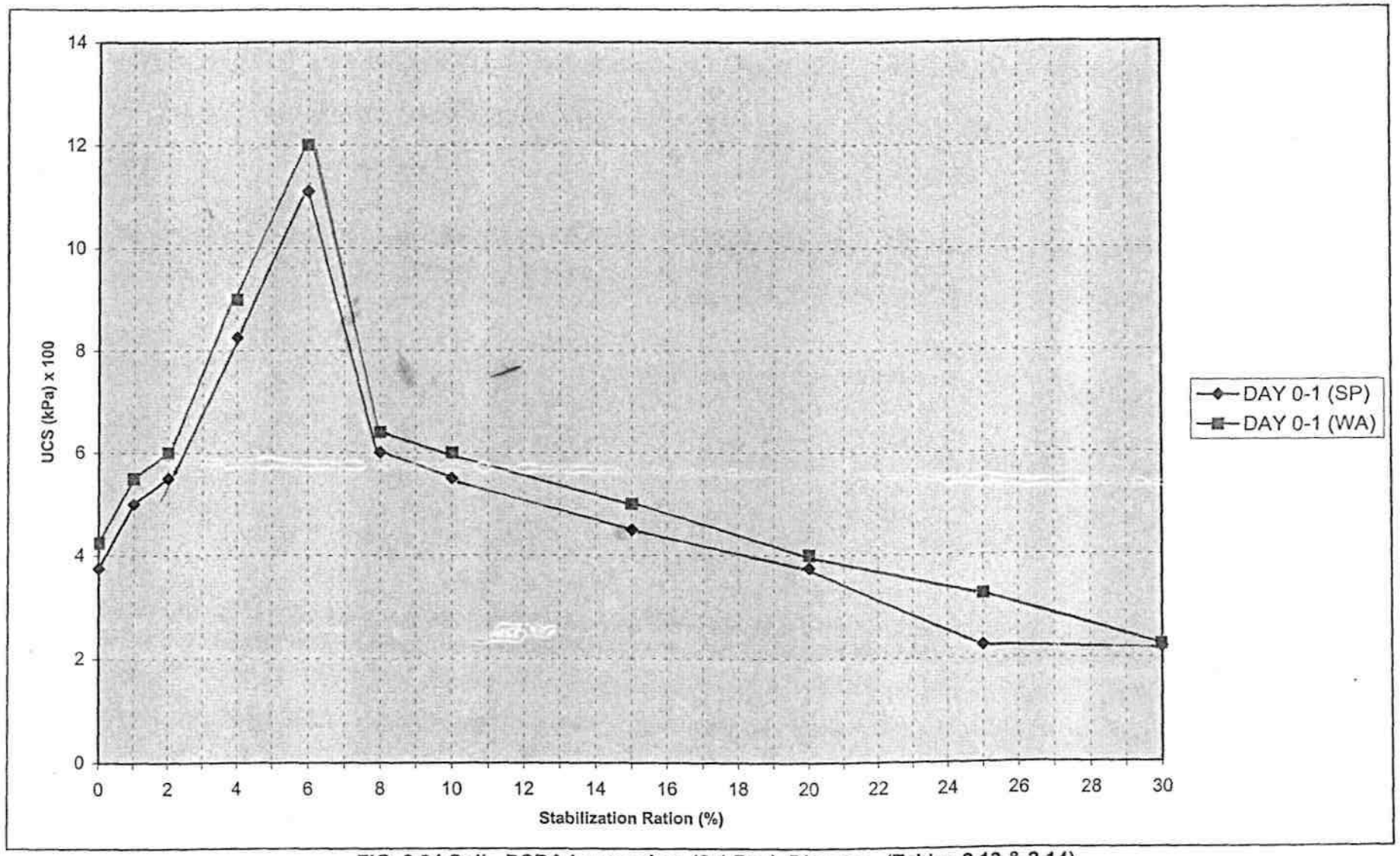


FIG. 3.24 Soil - PCBA Low curing (0-1 Day) Diagram (Tables 2.13 & 2.14)

3.5.4.2 SOIL-PCBA OPTIMUM CURING (7 DAYS) STAGE & 2.14)

a. **Soil-PCBA Optimum Curing At Low (<6% PCBA) Stabilization**

The UCS values of unstabilized optimum duration (7 days) curd SP and WA compacted natural soil are 450 and 575 kPa, representing 120 and 135 percent of the UCS of natrual soil. When 1 percent PCBA was admixture there was a sharp incresase in UCS values to 625 and 675 kPa representing 167 and 155 percent and 139 and 117 percent the UCS f natural soil and unstabilized optimally cured SP and WA compactged soil. There was a gradual increase of 28 and 30 kPa in UXCS values per percentage increase in stablizer content below (6% PCBA) stochiometire, per curing day below optimum.

b. **Soil-PCBA Optimum Curing At Optimum (6% PCBA) Stabilization**

The UCS values for optimally stabilied and optimally cured soil-PCBA were 1275 and 1400 kPa occurring at 6% PCBA stochiometry.

There are 340 and 329, 283 and 243 and 115 and 117 percent of the UCS values for natrual unstabilized, optimally cured and optimally stabilized soil samples.

c. **Soil-PCBA Optimum Curing At Iligh (>6 <30% PCBA) Stabilization**

Overstabilization of optimally cured soil-PCBA commenced at 6% stochiometry on day 7 on the curing schedule to 30% PCBA and the same day 7. Overstabilizaton gave rise to total reduction of 1000 and 10 75 kPa in the peak UCS.

The 1275 and 1400 kPa optimally cured and optimally stabilized soil-PCBA values reduced step-wise in by 42 and 45 kPa per percentage increase in stabilizer content of optimally cured sample, to 275 and 325 kPa representing 22 and 23 percent, 123 and 144 percent and 73 and 76 percent of optimally cured stochiometric, overstabilized uncured and unstabilized and uncured samples.

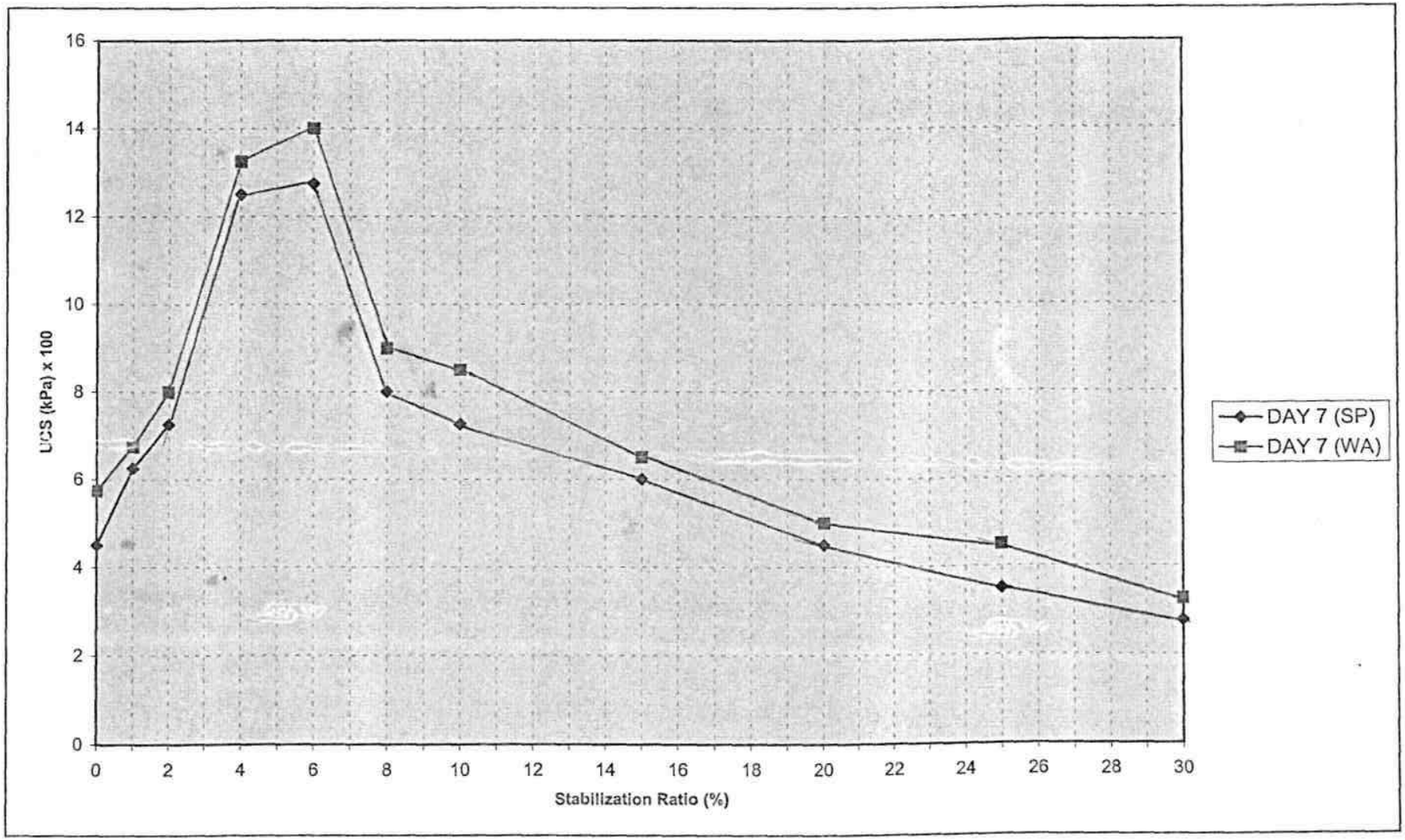


FIG. 3.25, Soil - PCBA Optimum (7 - Days) Curing Diagram (Table 2.13 & 2.14)

3.5.4.3 SOIL-PCBA FULL (28 DAYS) CURING STAGE

2.14

a **Soil-PCBA Full Curing At Low (<6% PCBA) Stabilization**

Fully cured unstabilized natural soil has ultimate UCS test values of 1000 and 1100 kPa. With the addition of 1 percent PCBA dose, early peak strength of 1250 kPa was attained with SP compacted samples. This reduced to a low of 900 kPa at 2 percent PCBA dose and reduced step-wise thereafter by 8.3 percent per percentage increase in stabilizer content below optimum.

The WA compacted samples developed an early peak of 1325 kPa at 1% PCBA dose which is 6 percent higher than the UCS generated by the SP compacted sample of the same stabilizer dosage. This reduced step-wise by 5.3% per percentage increase in stabilizer content at the understabilization stage.

b. **Soil-PCBA Full Curing At Optimum (6% PCBA) Stabilization**

SP and WA compacted samples showed peak ultimate UCS of 1250 and 1325 kPa at 1% PCBA dose. These are 233 and 212 percent, 25 and 20 percent, and 150 and 140 above the UCS values of uncured natural, fully cured unstabilized and understabilized (1% PCBA) uncured samples. Another peak strength was attained by SP compacted samples at 8% PCBA dose.

c. **Soil-PCBA Full Curing At High (>6 <30% PCBA) Stabilization.**

The maximum UCS value 1275 and 1400 kPa observed at stochiometric (6% PCBA) and optimum (7 days) curing declined step-wise gradual overstiblization and overcuring. The resulted in a drop of 1.3 and 1.7 kPa per percentage overstailization per diem overcuirng. At full (28 days) curing and 30% PCBA stabilization the ultimate UCS of soil-PCBA had dropped to 600 and 550 kPa representing 160 and 129, percent 60 and 50 percent 272 and 244 percent and, 47 and 39 percent of unstabilized, uncured natural soil, fully cured unstabilized soil, fully overstabilized uncured and optimally stabilized and optimally cured sample. (Fig. 3.26)

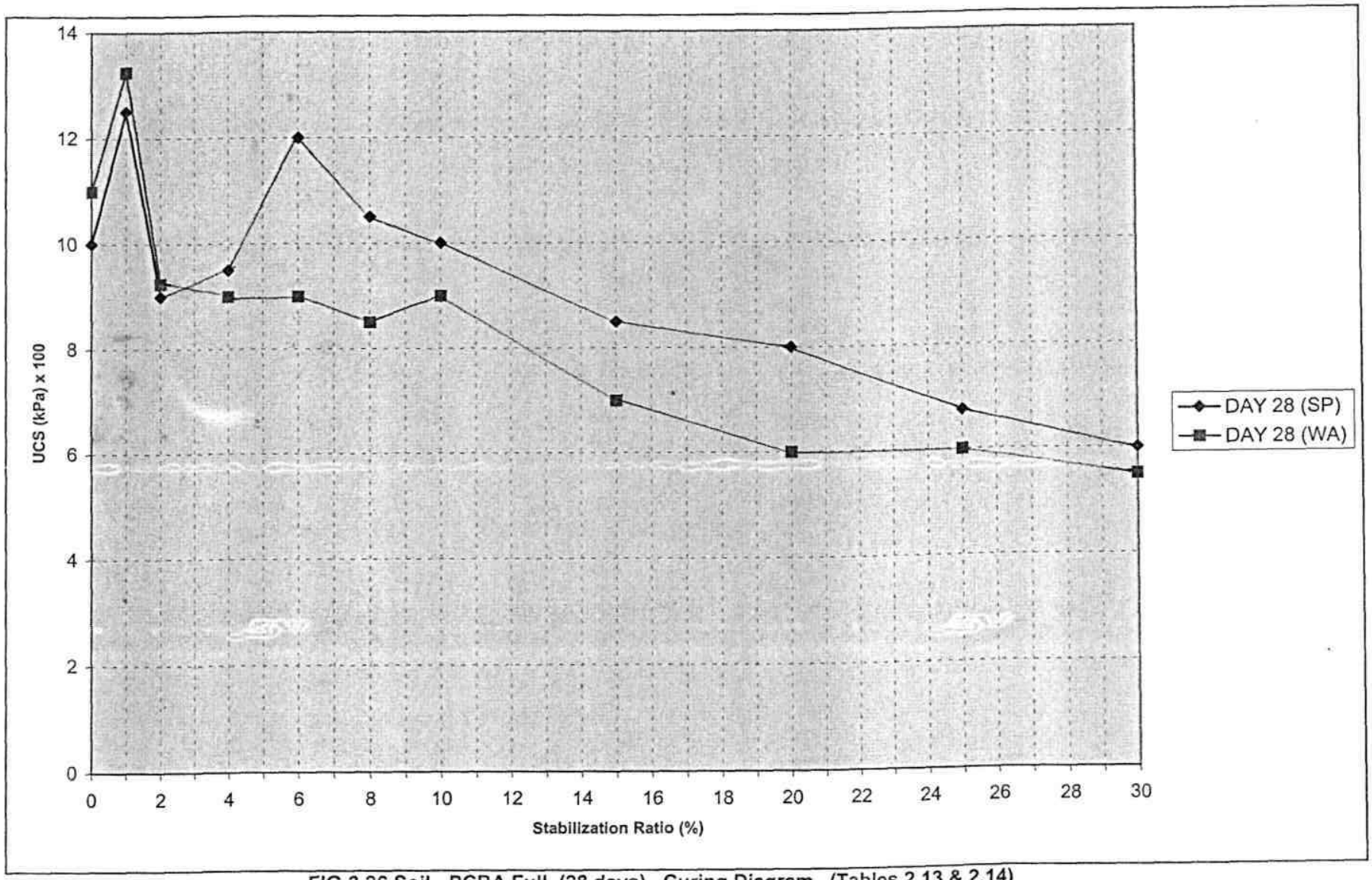


FIG 3.26 Soil - PCBA Full (28 days) Curing Diagram (Tables 2.13 & 2.14)

3.5.5. SOAKED SOIL – SFPR CURING

a. Soaked Soil-SFPR Understabilization

At the natural condition the UCS of Shika Laterite was 375 and 425 kPa at UCS and WA compaction. These reduced by 27 and 23 percent on soaking and curing for 7 days. On 1% SFPR, there was immediate improvement of 6 and 115 percent over unsoaked natural soil values and 45 and 77 percent over soaked and cured natural soil values. There was rapid gain of 75 and 188 kPa per percentage rise SFPR content below stochiometry. (Tables 2.11 and 2.12)

b. Soaked Soil-SFPR Optimum Stabilization

At (2% SFPR) stochiometry, was attained in soil-SFPR admixture with peak UCS at 425 and 700 kPa (SP and WA). These were 113 and 165 percent, 155 and 215 percent and 44 and 67 percent the UCS values of unsoaked natural, soaked natural and optimally stabilized unsoaked soil-SFPR.

c. Soaked Soil-SFPR Overstabilization

Continued soil-SFPR admixture beyond 2% SFPR resulted in gradual loss in the peak UCS attained at 2% SFPR. A step-wise decline of 3.2 and 3 percent in peak stochiometric strenght per percentage increase in SFPR admixture beyond 2% SFPR was observed. At full stabilization (maximum overstabilization) point of 30% SFPR, the UCS of soil-SFPR had reduced to 50 and 65 kPa representing 13 percent, 12 and 9.3 percent, and 67 and 65 percent of unsoaked natural soil, peak stochiometric and maximum overstabilization and uncured UCS values.

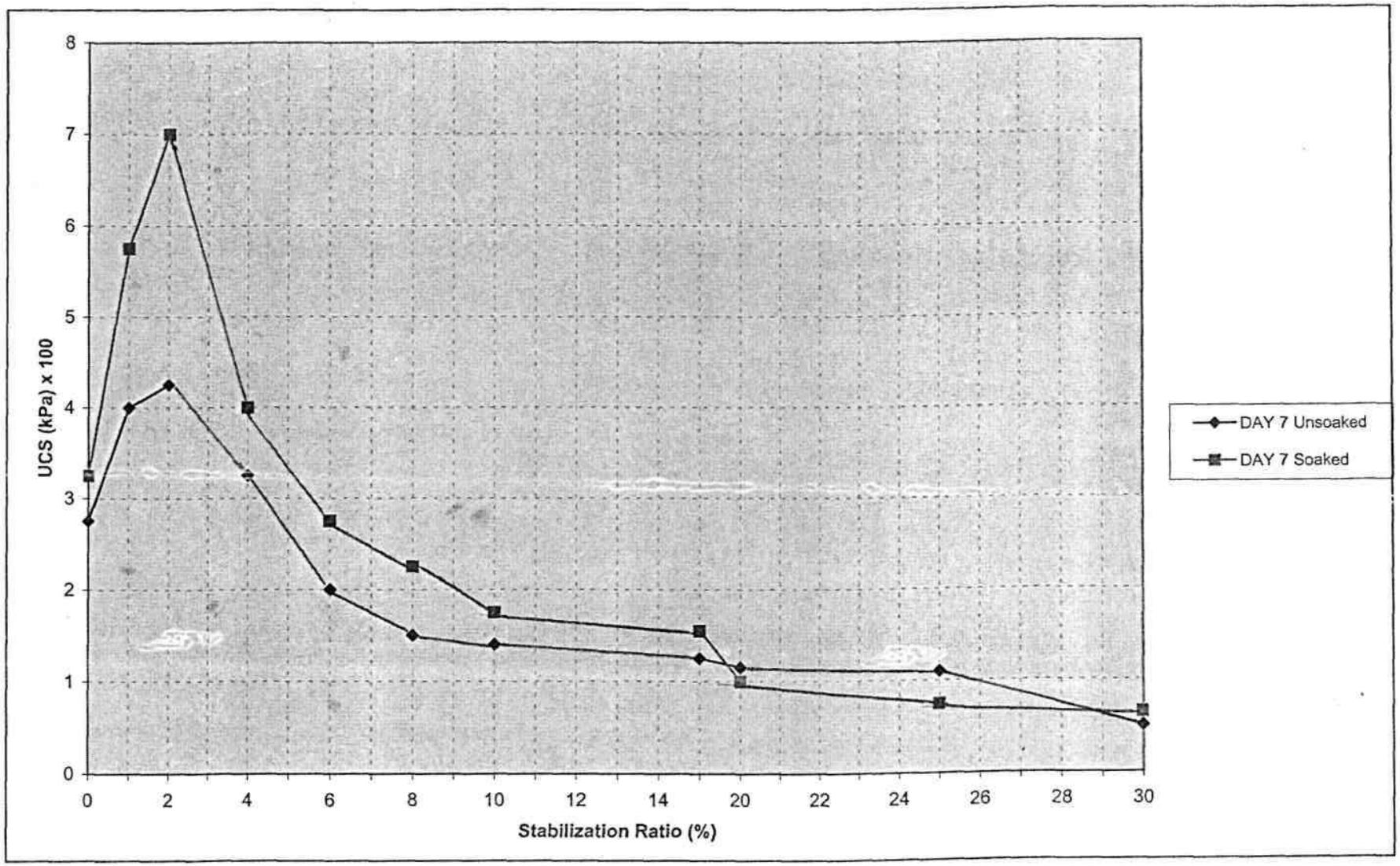


FIG. 3.27, Soil - SFPR (7 - Days) Soaked Curing Diagram

3.5.6. SOAKED SOIL – PCBA CURING

a. **Soaked Soil-PCBA Understabilization**

The UCS values for the soaked natural soil are 275 and 325 kPa (SP and WA) which are 27 and 24 percent below the UCS of unsoaked natural soil. With the admixture of 1% PCBA, immediate improvement of 3.6 and 3.1 percent in strength was observed and the understabilized soaked soil-PCBA attained 70 and 100 percent the UCS of the unstabilized and unsoaked natural soil. Continued admixture of PCBA beyond 1% level gave rise to step-wise increase in UCS with stabilizer content below stochiometric point. In general, increase in UCS by 12 and 18 percent per percentage increasee in stabilizer content were observed.

b. **Soaked Soil-PCBA Optimum Stabilization**

At 6% PCBA stochiometry was attained in soil-PCBA admixture with the development of UCS of 475 and 675 kPa (SP and WA) representing 27 and 59 percent improvement on the UCS of unstabilized and uncured natural soil, 43 and 56 percent of optimally stabilized uncured soil-PCBA and 73 and 207 percent of 2 days soaked and cured natural soil.

c. **Soaked Soil-PCBA Overstabilization**

Beyond stochiometric point, the UCS of soaked soil-PCBA decline steadily by 3.3 and 3.5 percent of stochiometric values per percentage increase in stabilized content above stochiometric. At peak stabilization (full overstabilization) point of 30% PCBA admixture, the UCS of overstabilized soil-PCBA had reduced to 100 and 100 kPa which are 27 and 24 percent, 21 and 15 percent and 45 and 44 percent of unstabilized and uncured (natural) soil, soaked and cured stochiometric soil-PCBA, and fully overstabilized uncured soil-PCBA UCS values.

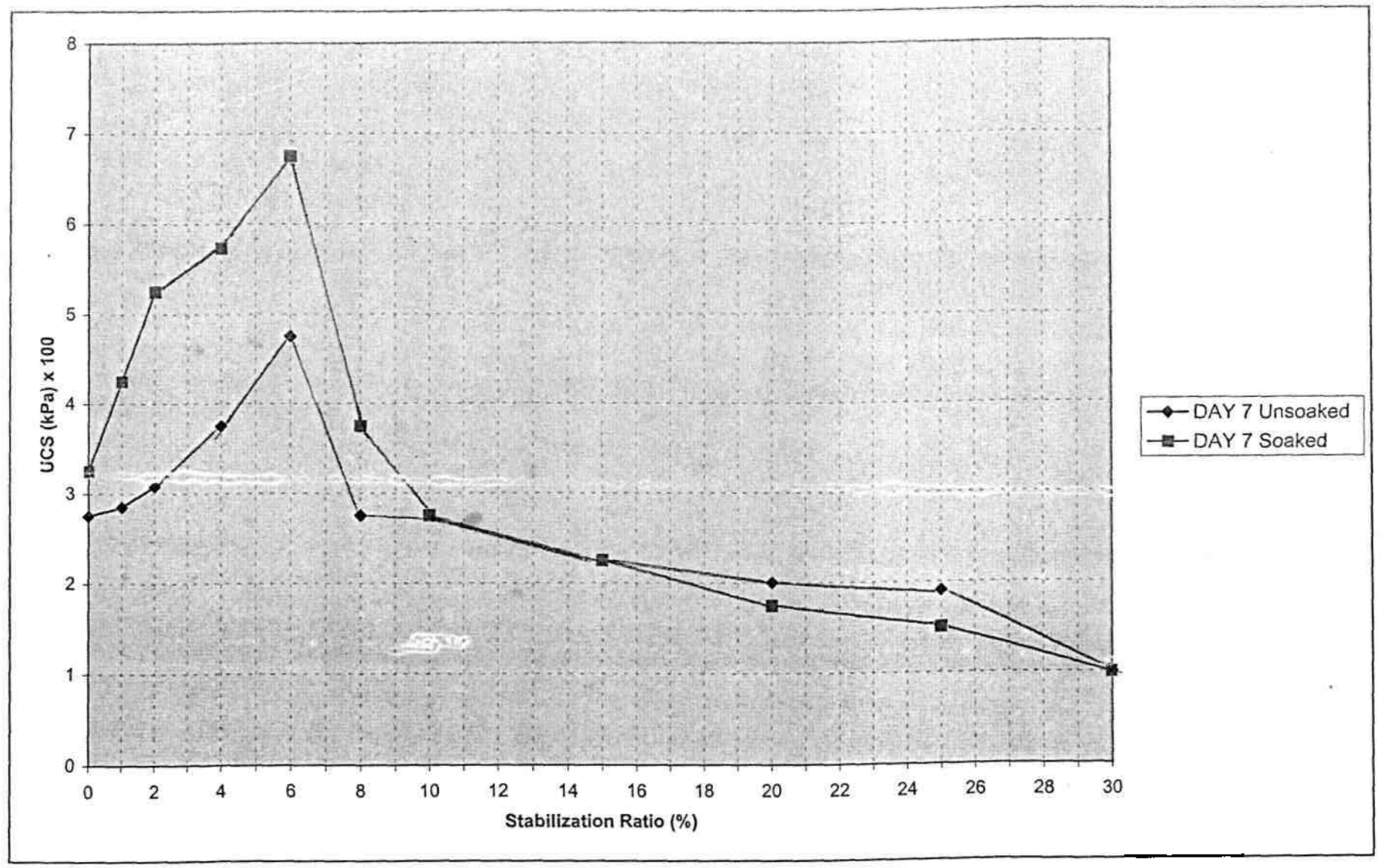


FIG. 3.28 Soil - PCBA (7 Days) Soaked Curing Diagram

3.6 PROBABLE CAUSES OF VARIABILITY IN RESULTS.

SFPR and PCBA contain predominantly high valency cations of Si^{4+} Al^{3+}, Fe^{2+}, Ti^{2+}, Ca^{2+}, and P^{2+} (Fakiyesi and Osinubi, 1995). These are high on the Hofmeister scale of cationic reactive elements (Clews, 1969), with sequence H^{+}, Al^{3+}, Ba^{2+}, Sr^{2+} Mg^{2+}, K^{+}, Na^{+}, and Li^{+}, which regularly take part in base exchange reactions with lower valency rare earth radicals such as K^{+}, Na^{+}, and Li^{+} in the soil and which actively produce deflocuculations. The commonest exchangable cations in clay minerals are Ca^{2+}, Mg^{2+}, H^{+}, K^{+}, Li^{+} and NH_4^{+}.

The magnitude of uniformity or variation in soil-SFPR and soil-PCBA stabilization results are due to a variety of factors, major of which are:-

(a) Fluctuation in cationic exchange activity
(b) Magnitude of cationic exchange activity
(c) Quality, quantity, uniformity and purity of stabilizer
(d) Degree of processing and
(e) Stabilizer source.

Fluctuations in cation exchange activity leads to variation in stabilizing capacity of the admixtures and are generally caused by:-

(i) Broken bonds at the edges of silica and alumina units, together with charge defects
(ii) Ionic substitution within the lattice structure of trivalent and ions of lower valency, namely Mg^{2+}, and Al^{3+}, octahedral sheets, resulting in charge defects
(iii) Hydrogen of exposed hydroxyls that are being replaced by exchangable cations.
(iv) Position of exchangable cation which vary from clay mineral to clay mineral and which in the case of kaolinite, is always located on the basal oxygen surface of the silica tetrahedron unit (Weiser, 1969).

A comparison of cementitious chemical compounds in OPC, SFPR, PCBA is carried out on Table 3.2

Table 3.2 Cementitious Chemical Compounds in OPC, SFPR, PCBA and Shika laterite.

	C_3S	C_2S	C_3A	C_4AF	Na_20+K_20	SO_3	LSF	Si Ratio	Al-Fe Ratio
OPC	56.2	18.24	11.38	8.42	0.25	1.91	66.102	1.5-4.5	1.4-3.5
SFPR	0	101.14	68.66	7.30	N.A.	0.85	4.5	1.18	11.42
PCBA	0	75.17	20.98	6.84	0.35	0.35	2.28	2.28	4.16

It indicates that tricalcium silicate (C_3S) the principal active hydraulic component in cement, is present in OPC to the tune of 56 percent but is lacking in SFPR and PCBA. On the other hand, dicalcium silicate (C_2S) a less hydraulic component of cement present in OPC to the tune of 18.24 percent, form more copious components of SFPR, and PCBA, to the tunes of 5.5 and 4.2 times the presence in OPC. Bonding (cementitious properties such as strength, shrinkage, permeability etc) are also due to the finess and low specific area (300 m^2/g), while the calcium hydroxide provide alkaline medium beneficial as protection against corrosion (Chong 1977).

Tricalcium aluminate (C_3A) and tetracalcium aluminoferrate (C_4AF) are copious in SFPR and PCBA but their presence is not healthy because they promote susceptibility to sulphate attack in high salinity areas, near the sea and in areas where sulphate is significant in the ground water regime. C_4AF in SFPR (7.30%) and PCBA (6.84%) are of the some order of magnitude as in OPC (8.12%) and even on the lower side of it, but C_3A in SFPR and PCBA are six fold and two fold OPC content and should be the major source of worry. If a choice is to be made for application in saline environment, PCBA is the logical choice. It contains 3 times less of the deleterious compound (C_3A) than SFPR.

Holding the silica ratio at a constant level while increasing the L.S.F and reducing the Al-Fe ratio will greatly enhance the stabilization potentials of both SFPR and PCBA on Shika laterite or other laterites with the same properties. The lime stabilization factors (LSF) of SFPR and PCBA are 0.22 and 0.17 that of OPC. There is therefore room for raising the LSF and consequently improving their binding and hence stabilizing capabilities. Lime, like SFPR and PCBA can be obtained also as waste resource in the form of the calcium carbide (CaC_2) from acetylene production plants. This is suggested for further research, that is, to determine the effect of the addition of lime or cement to soil SFPR and soil PCBA stabilizations.

3.7 APPLICATION OF RESEARCH RESULTS TO ENGINEERING AND GEOLOGY

Road Construction

PCBA or SFPR can be admixed with laterite soil and compacted to improve the strength and durability of the natural soil as material for road base and sub base construction.

Harzard and Pollution abatement

The utilization of PCBA or SFPR would reduce the level of potentially toxic and hazardous wastes from the environment.

Mining and Mineral explorations

Utilization of PCBA or SFPR in any way will raise the value of the parent minerals, coal and phosphorite. This would encourage geological exploration and mining of these minerals, with positive multiplier effects on the economy and on the standard of living of Nigerians.

Geological correlation

One of the fundamental activities in geology is the mapping of rock/soil variability. Reliable maps are sine-qua-non for sites of important engineering construction works. Good mapping requires ability to identify similar rocks and soil units even if separated in time and space. It also requires ability to differentiate between formations that apparently look the same, into their fundamental units. This task is achieved in geology by correlation. Correlation is

done by using fossil, lithology, texture, mineralogy, chemistry and environmental criteria. Geological mapping of engineering materials and sites rely mainly on correlation. Correlation is also applied in measuring/comparing (correlate) the ages and strengths of rock/soil units. This later operation can be facilitated using the concept of soil stabilization value (SSV) developed in this research. Table 3.3 show correlation values (soil stabilization values) for Shika laterite for different conditions/stages of stabilization, compaction, soaking and curing. Table 3.4 shows a summary of the correlation pitting natural, understabilized, optimally stabilized soil conditions against natural (uncured) normal curing, long curing and soaked stages. The bar diagram (Fig. 3.25) depict the correlation of Shika laterite under six distinct stages of stabilization:-

(i) Soil only (compaction)

(ii) Soil and admixture

(iii) Soil and admixture (compacted)

(iv) Soil and admixture (compacted and cured)

(v) i-iv compacted at low energy

(vi) i-iv compacted at medium energy.

For 2 rock/soil units that are the same or similar in every respect, the stabilization capacity of SFPR or PCBA against the rock/soil would be the same and the SSV of the rock/soil would also be the same. Conversely, for different rock/soil units that are different in whatever degree, the stabilization potentials of SFPR or PCBA against the rock/soil would be different and the SSV of the rock/soil would also be different.

Table 3.3 **SOIL STABILIZATION VALUES FOR STANDARD PROCTOR AND WEST AFRICAN COMPACTED SOIL – SFPR AND SOIL – PCBA**

Standard Proctor Compacted Soil – SFPR							Standard Proctor Compacted Soil – PCBA					
Admixture ratio (%)	CURING DAYS						CURING DAYS					
	0	7	14	21	28	7+7	0	7	14	21	28	7+7
0	1	1.5	2.7	2.1	2.7	0.73	1	1.2	1.8	2.1	2.4	0.46
1	2.4	2.7	3.3	2.5	2.2	1.06	1.3	1.7	2.2	2.6	3.3	0.60
2	2.6	3.7	3.7	2.9	2.9	1.13	1.5	1.9	3.1	2.6	2.3	0.73
4	1.6	1.7	2.1	1.9	1.9	0.87	2.2	3.3	3.0	2.6	2.2	1.0
6	1.1	1.4	1.7	2.2	2.2	0.53	3.0	3.4	2.7	2.1	1.7	1.27
8	0.8	0.9	1.3	1.1	1.1	0.40	1.6	2.4	2.4	2.9	3.5	0.73
10	0.7	0.9	1.3	1.5	1.5	0.37	1.5	1.9	2.2	2.1	2.7	0.73
15	0.7	0.8	1.1	1.5	1.6	0.30	1.2	1.6	1.7	2.1	2.5	0.60
20	0.6	0.7	1.0	1.3	1.3	0.31	1.0	1.2	1.4	1.7	2.2	0.53
25	0.5	0.6	0.8	1.1	1.3	0.29	0.6	0.9	1.1	1.4	1.8	0.51
30	0.2	0.4	0.7	0.8	1.1	0.13	0.6	0.7	1.1	1.1	1.4	0.27
West African Compacted Soil – SFPR							West African Compacted Soil – PCBA					
Admixture ratio (%)	CURING DAYS						CURING DAYS					
	0	7	14	21	28	7+7	0	7	14	21	28	7+7
0	1.13	1.5	1.9	3.0	2.1	1.73	1.13	1.5	2.0	2.3	3.0	0.6
1	2.6	3.0	3.5	2.7	2.3	1.63	1.5	1.8	2.4	3.1	3.5	1.13
2	2.8	3.7	3.9	3.3	2.7	1.0	1.6	2.1	3.3	2.7	2.5	1.53
4	1.7	1.9	2.4	2.1	2.7	1.06	2.4	3.5	3.3	2.8	2.4	1.8
6	1.2	1.6	1.9	2.2	2.5	0.73	3.2	3.7	3.1	2.5	2.0	1.53
8	1.1	1.3	1.7	2.0	2.5	0.60	1.7	2.4	2.3	3.33	1.9	1.6
10	1.0	1.2	1.5	1.7	2.3	0.47	1.5	2.3	2.2	2.7	1.7	0.73
15	0.9	1.0	1.1	1.3	2.1	0.41	1.3	1.7	1.9	2.2	1.3	0.6
20	0.9	0.9	1.1	1.2	1.9	0.32	1.1	1.3	1.7	2.0	1.2	0.47
25	0.6	0.7	0.9	1.1	1.5	0.20	0.9	1.2	1.4	1.7	1.0	0.40
30	0.3	0.5	0.7	0.9	1.0	0.17	0.6	0.7	1.1	1.7	0.7	0.27

Table 3.4 **SOIL STABILIZATION VALUES (SSV) AT CRITICAL CONDITIONS, STAGES AND LEVELS OF ADMIXTURE, COMPACTION, CURING AND SOAKING.**

STABILIZED CONDITION		STABILIZED STAGE							
		UNCURED		NORMAL URING		LONG CURING		SOAKED	
Natural Soil		SPC	WAC	SPC	WAC	SPC	WAC	SPC	WAC
		1.0	1.13	2.7	3.1	2.7	3.1	0.73	0.93
Under stabilized	1% SFPR	2.4	2.6	3.3	3.5	2.2	2.7	1.13	1.53
	1% PCBA	1.3	1.3	1.3	1.5	3.3	3.5	1.30	1.50
Optimally stabilized	2% SFPR	2.6	2.8	3.7	3.9	2.5	2.7	1.06	1.86
	6% PCBA	3.0	3.2	3.4	3.7	1.7	2.0	1.27	1.59
Over stabilized	30% SFPR	0.2	0.3	1.1	1.0	1.1	1.0	0.13	0.17
	30% PCBA	0.6	0.6	1.4	0.7	1.4	0.7	0.27	0.27

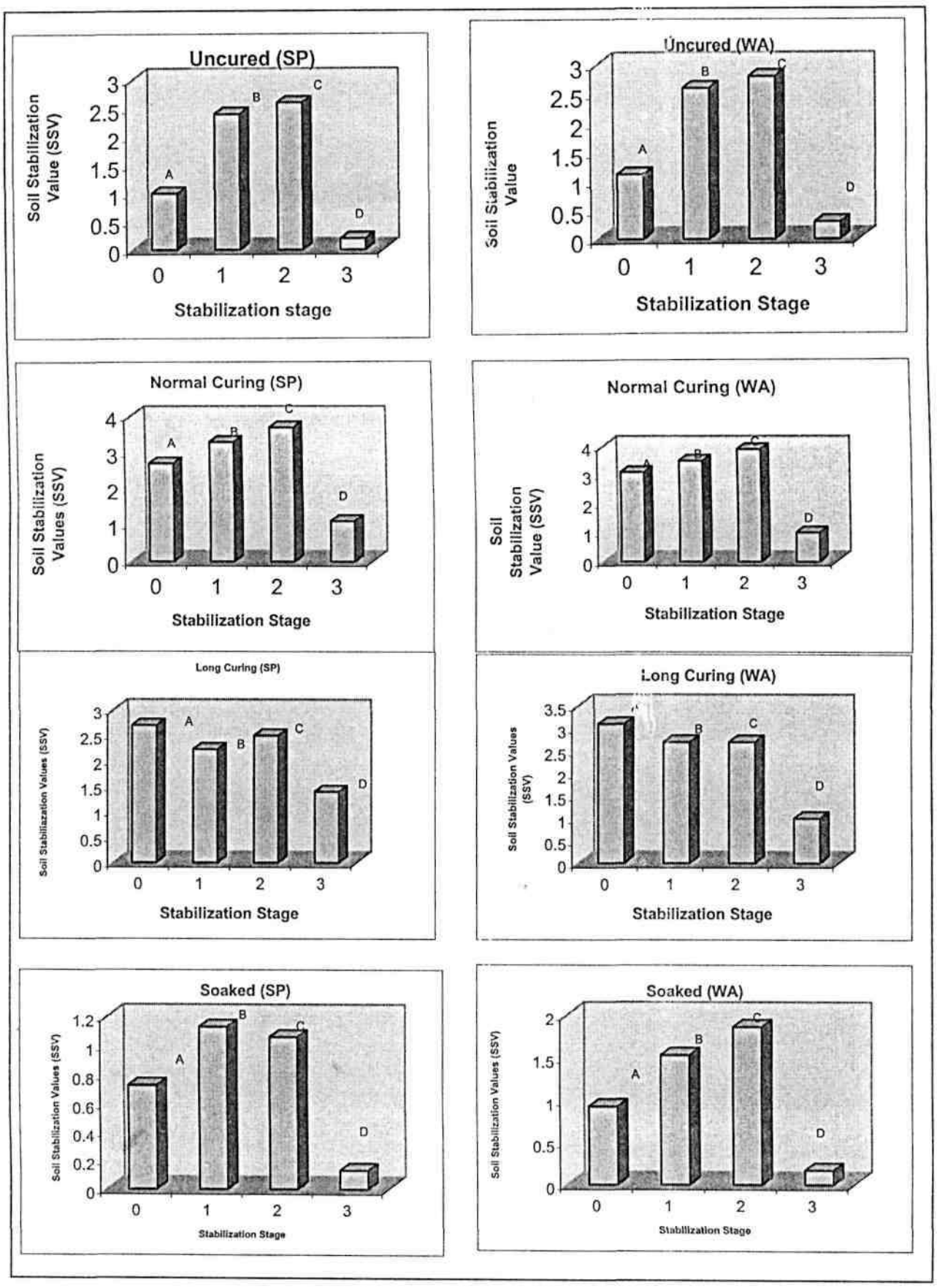


FIG: 3.29 SSV Block diagrams for different stages of soil SFPR Compaction & Curing (A: Unstabilized) (B: Understabilized) (C. Optimally Stabilized, D: Overstabilized

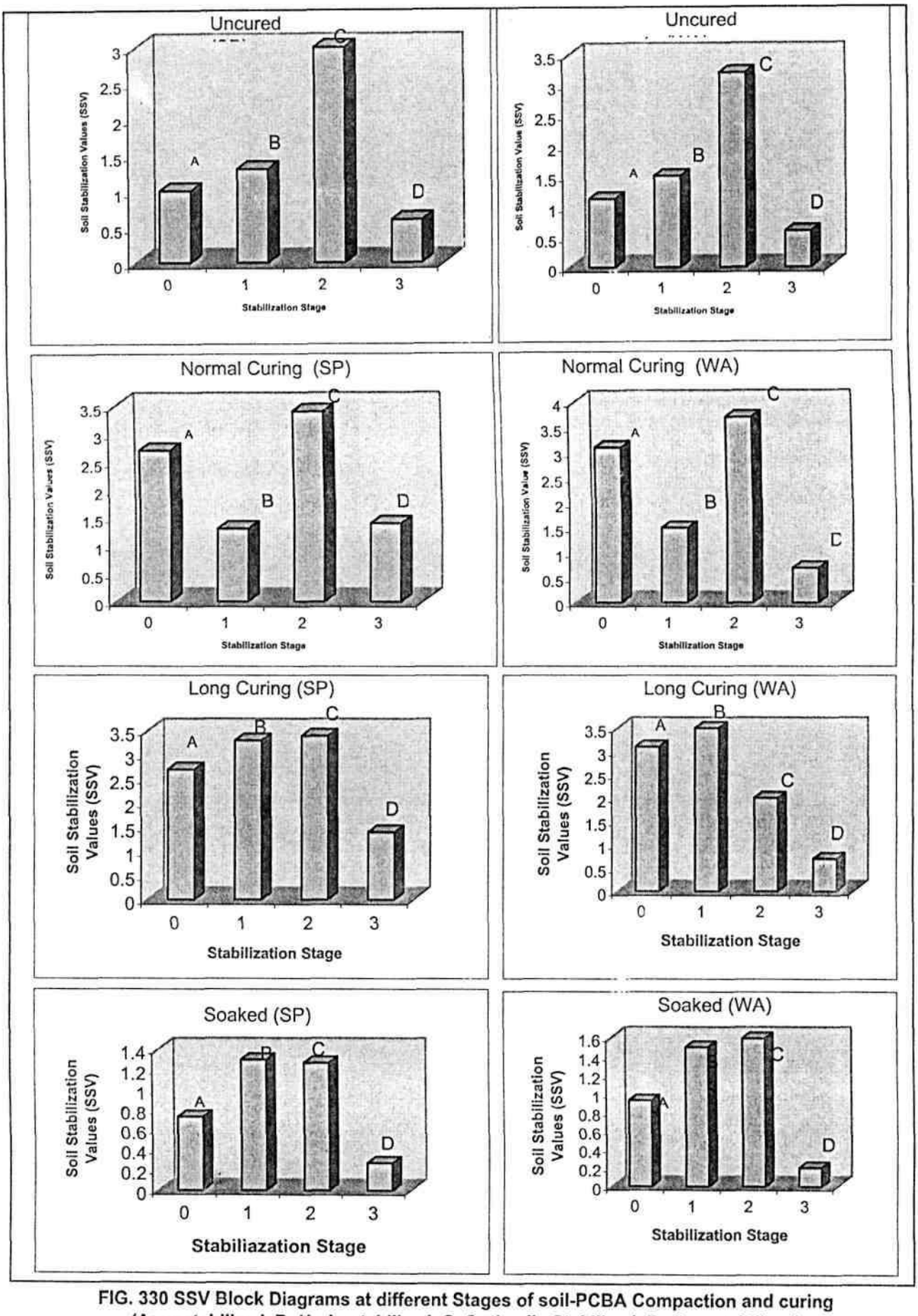


FIG. 330 SSV Block Diagrams at different Stages of soil-PCBA Compaction and curing
(A: unstabilized, B: Understabilized, C, Optimally Stabilized D: Overstabilized)

CHAPTER FOUR

CONCLUSION AND RECOMMENDATION

As a result of the stabilization tests carried out on Shika laterite with pulverized coal bottom ash PCBA and superphosphate fertilizer processing residue SFPR, the following conclusions can be drawn:

1. Shika laterite falls into group A-7-6 of AASHTO and CL group of the Unified Soil Classification System.
2. XRD, DTA, Swell and Activity tests all prescribe that Shika laterite contains predominantly kaolinite and quartz minerals.

3(i) SFPR and PCBA altered and improved upon the proportion of Shika laterite.

(ii) Optimum improvements were obtained at SFPR and PCBA stochiometrics of 2 percent and 6 percent.

4. The following properties attained critical values at 2% or 6% SFPR or PCBA stochiometries, namely:-

   (i) Unsoaked unconfined compressive strength of soil-SFPR attained peak values of 972 kPa (Standard Proctor Compaction) and 1050 kPa (West African compaction) for uncured samples, from the low value of 375 kPa of the unstabilized (natural) soil. The corresponding values attained by soil-PCBA are 1110 kPa and 1200 kPa.

   (ii) Soaked unconfined compressive strength values of 425 kPa (Standard Proctor compaction) and 700 kPa (West African compaction), and values of 475 kPa (Standard Proctor Compaction) and 675 kPa (West African compaction) were attained by soil-SFPR and soil-PCBA from low soaked values of 275 and 375 kPa respectively.

   (iii) Peak unconfined compressive strength values of 1375 and 1475 kPa were obtained (on curing) of Standard Proctor compaction and West African compacted soil-SFPR, while values of 1275 and 1400 kpa were obtained for Standard Proctor and West African compacted soil-PCBA.

   (iv) Compacting at higher (West African) has greater effect (10% increase) on the UCS of soil-PCBA than on soil-SFPR (with only 7% increase).

(v) Equally high early strengths of 1400 kPa and 1475 kPa were developed in 7 days curing of soil-PCBA and 14 days of soil-SFPR curing. The early strength in soil-PCBA declined rapidly after seven days while the strength developed in soil-SFPR made further gain of 7% (from 1375 to 1475 kPa) between 7 and 14 days curing before declining in value after the 14^{th} day.

5(i). SFPR stabilization accounts for higher (by 5%) of the absolute strength than PCBA.

(ii) SFPR is also 15 percent more curing sensitive than PCBA

(iii) But PCBA is 12 percent more stabilizer only effective than SFPR.

(iv) 62 percent of total strength of only soil is due to pozzolanic reaction

6. The peak strengths of 1375 and 1475 kPa obtained for Standard Proctor and West African compacted optimum soil-SFPR and the peak strengths of 1275 and 1400 kPa obtained for optimum soil-PCBA are within the range of 1000 and 2000 kPa considered adequate for either base or sub-base construction (Clutterbuck, 1982).

   The peak strengths are also within the specification limits of 689 and 1379 kPa for class 1 and 2 load bearing bricks (Fisher, 1964).

7. The CBR improved from 65% (in natural unstabilized soil) to 100% and 75% in soil-SFPR and soil-PCBA at Standard Proctor compaction and to 100% and 75% for West African Compaction.

   The CBR of natural soaked samples also improved from 35 to 80 and 75% for soil-SFPR and soil-PCBA at Standard Proctor compaction and 8.5% and 80% at West African compaction.

8. The dominant chemical reaction for stochiometric admixtures of both soil-SFPR and soil-PCBA is cationic while for natural soil and non stochiometric admixtures, the dominant chemical reaction is pozzolanic.

9. Soil stabilization values (SSV) nearly quadrupled from only soil value of unity, to SSV of 3.9 soil-SFPR and SSV of 3.7 soil-PCBA.

10. Peak attainable strengths can be raised by adding free lime. Free lime can be obtained from CaC_2, a waste resource from acetylene production. This

is recommended for further investigation that is, to determine the effect of adding lime or cement to soil-SFPR and soil-PCBA stabilization.

11. Due to the effectiveness of curing only in raising the UCS of only soil to within specification limits for load bearing bricks, Shika laterite could be a good source of load bearing burnt brick. This is also recommended for further investigation.

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