CHARACTERISTICS OF CEMENT-MODIFIED ASPHALT-EMULSION LATERITE MIXES

BY

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CERTIFICATION

This is to certify that this research work was carried out and written by Oluyemi-Ayibiowu Bamitale Dorcas.

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Signature and Date.

DEDICATION

With a deep sense of appreciation, this thesis is dedicated to my husband, Mr. Olatokunbo Oluyemi-Ayibiowu for his moral and financial support and my children Olayinka, Olanrewaju and Olawumi for their co-operation throughout the period of carrying out this research work.

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May God Bless You All.

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A B S T R A C T

The influence of the physical characteristics and composition of three selected laterite samples on their engineering behaviour in the natural untreated state and on their responsiveness to treatment with chemical additives was determined in the laboratory.

The additives used are cement; asphalt-emulsion; and mixtures of cement with asphalt-emulsion in various proportions. The percentages of cement and asphalt emulsion used are 2,4,6 and 8% for soil cement and soil-asphalt emulsion. For cement modification of asphalt-emulsion mixtures, the percentages of cement used are ½, 1 and 2% with each percentage of asphalt-emulsion.

Adding chemical stabilizers to the samples generally increase their strength, the rate of increase depending on the type of soil. Sample A increased from its natural CBR value of 20% to 120% using 4% cement; sample B gave a CBR value of 88% with 4% cement from its 18% CBR value and at 6% cement it gave a CBR value of 150% while sample C increased from its natural CBR value of 8% to 102% using 8% cement content.

Using asphalt-emulsion to treat the samples gave CBR values of 110% and 80% with 6% emulsion for samples A and B respectively. Sample C gave a CBR value of 60% using 8% emulsion.

Beneficial results were obtained using 1 - 2% cement with asphalt-emulsion for treating all the samples especially the highly plastic and organic soil types such as soil sample C which is often detrimental to successful stabilization with the use of only cement or asphalt-emulsion thus bringing to enlightenment a new technology of

improving the strength of locally available weak soils by pretreating the soil with small amount of cement before the addition of asphalt-emulsion for required strength characteristics. For the modified samples, the proportions of cement to asphalt emulsion are 1:2, 2:2 and 2:6 for samples A, B and C respectively.

The cost comparison of using cement; asphalt emulsion and combinations of cement with asphalt-emulsion was carried out and results show that the soils can be stabilized economically with well designed mixes of asphalt-emulsion and cement.

CHAPTER ONE

INTRODUCTION

1.1 PREAMBLE

In practice, the soil engineer has many diverse and important encounters with soil. Every work of construction in civil engineering is built on soil and in many instances, soils are also the raw materials of construction. Soil exist in a great variety, and are the accumulated result of many separate factors and processes such as weathering of the parent rocks, weathering of the soil itself at various stages of formation, means of transporting the soil to its present location, the manner of deposition, drainage, wetting, drying and many other factors.

Laterites are residual soils which result when some materials from weathered igneous, metamorphic or sedimentary rocks are leached out in tropical and semi tropical climates with heavy rains, high temperature and good drainage leaving behind soils with high iron and alumina contents. For years now, laterites have been used for construction purposes such as in road works and in the rural areas of Nigeria as building materials. The abundance and cheapness of laterite and their use have reduced construction costs. Construction costs have increased largely because of the ever increasing cost of petroleum products which has in turn caused tremendous increases in prices of all other materials.

However, not all the laterite soils encountered on a site can be used directly for construction purposes due to poor workability or poor strength characteristics of the soil. In some cases, potential soil problems can be avoided by choosing another site or by removing unwanted soil and replacing with desirable soil or by adapting the design to the conditions on site. In addition, attempts are made to alter the properties of the existing soil in order to create a new material capable of meeting the requirement of the task at hand. Some engineering properties such as stiffness, strength, shear strength, compressibility, permeability, workability, swelling potentials, sensitivity to changes in moisture contents and many others may be altered by treatments ranging from simple compaction to expensive techniques of grouting, drainage, water proofing, strengthening by thermal means or by the application of stabilizing agents to the natural soil.

Over the years, the last approach has become more feasible and attractive and is called soil stabilization. The stabilizing agents may be classified as cementing agents, modifiers or water-proofers. The most commonly used are portland cement, lime and bitumen. Before a soil is stabilized with chemical additives, the following questions must be answered viz;

i. can the stabilizing agent be mixed easily through the soil due to its high moisture content or high plasticity?

ii. can the stabilizing agent be uniformly distributed through the soil?

iii is the needed amount and cost of stabilizing material economically feasible?

iv. is the curing time such that it does not have a negative effect on construction time?

v. can the stabilizer be used without any safety problems?

vi. is the stabilizer easily available and effective?

After considering all these facts, stabilizing agents are chosen according to the type of soil, the problem at hand and the economics in their use. Stabilized soils have been used in the construction of roads, airports, car parks, earth dams, building foundation and in various other construction works and have been found to be effective for enhancing the quality of problem soils. It is against this background that there is the need to evaluate the use of cement in conjunction with asphalt-emulsion to improve weak locally available materials for construction purposes

1.2 Background Information To Proposed Study

The use of chemical additives to soil for construction purposes dates back to the beginning of man's recorded history. Mixtures of lime and clay were used in the construction of the pyramids of Shensi on the Tibetan - Mongolian Plateau and in ancient China for the construction of bridges and dams. Studies on the mixing of soil and cement were undertaken by several states in the U.S.A. during the 1920s, but it was not until 1935 that the South Carolina Highway Department demonstrated that soil and cement were compatible materials and could be mixed together to provide a usable pavement base (Draft TRH 13: Cementitious stabilizers in Road Construction, Technical Recommendations for Highways, 1986). The use of cement in the treatment of road construction materials in South Africa was first recorded in the early 1940s, and since then, there has been a steady increase in their use.

Bituminous stabilization has also been used successfully for construction works in Nigeria. It has been used particularly in the North-Eastern part due to lack of naturally available road stone that meets the acceptance standards. The first sand-bitumen stabilized based road was constructed in 1960 on the Maiduguri-Burma road and was followed in 1972 by the construction of a 150mm soil-sand bituminous stabilized base on the then existing cement base of the road in 1970. Also, on the Damaturu-Beni-Sheik road, sand bitumen stabilized base was used, (Ayodele Ibrahim, 1977).

The Kenyan government is currently carrying out some tests on a chemical solution, Con Aid, which is expected to revolutionise road building and maintenance in the country (Ogweno Bonyo, 1997). A process has been developed for use in U.K. in which asphalt emulsion has been used in conjunction with cement (Information Note: Introduction to soil stabilization, Overseas Unit, Transport and Road Research Laboratory, 1987) and which is the basis of this project. Although, the use of this mixture has been investigated before as earlier mentioned, the effectiveness of the addition has not been thoroughly explained or recorded. This present research is an attempt to fill this gap.

1.3 Objectives

The objectives of this study are:

a. to examine the general engineering properties of 3 selected laterite soil samples in their natural state.

b. to determine the mineralogical composition of these samples for establishing a correlation between composition and successful chemical stabilization.

c. to determine the effects of the chemical additives on the strength of the soils.

d. to determine the feasibility of using cement and asphalt-emulsion, to stabilize the three samples.

e. to investigate the possible use of asphalt-emulsion mixed with cement as a stabilization technique using the 3 samples.

f. to examine the response of these soils to varied percentages of the mixtures and

g. to determine whether the use of cement in conjunction with asphalt-emulsion can be optimally designed.

1.4 Justification For The Study

Naturally occurring and crushed materials have certain inherent limitations which can have far reaching effects on the performance of the pavement. Laterites, though abundant in many countries have varied properties from place to place and their performance is diverse and unpredictable. This has brought about limitations on their use in some construction sites. Many of these limitations have been overcomed by the addition of a stabilizing agent to improve their properties or by various other means of improvement. The economics of stabilization and of compaction provide challenges to highway technology. Stabilization techniques in common use involve the addition of cement, lime or bitumen to the soil. Almost all soils respond to treatment with cement; however, chemical conditions of some soils (by interfering in the hydration of cement) and high plasticity of others (by preventing intimate mixtures) which can either inhibit the normal hardening of cement or lead ultimately to a loss of durability of the hardened material have limited the use of portland cement.

Previous studies have pointed out beneficial results of simultaneous use of lime and cement but the use of cement in conjunction with asphalt-emulsion has not been thoroughly investigated. It is therefore necessary to investigate the use of this mixture and determine their engineering properties for utility as road foundation and construction material. Laterite soils when stabilized with mixtures of cement and asphalt-emulsion will have properties intermediate between those of soil cement and soil-bitumen in that they possess some rigidity and are also fairly waterproofed and thus potentially constitute a good method for improving some of the properties of soils.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Laterites and lateritic soils have over the years been given an increased attention by soil engineers because of their wide-spread distribution and engineering application. The word 'Laterite' was originally suggested by Buchanan (1807) as a name for a highly ferruginous deposit first observed in Malabar during his journey through the countries of Mysore, Canava and Malabar in 1800-1801. Laterites have been described as soils which were developed together with red and yellow soils under optimal moisture contents. They result from changes which occur in zones of permanent and intermittent saturation in the vicinity of a water table. Martin and Doyne (1930) works on the chemical composition of lateritic soils defined laterite soils in terms of the silica-alumina ratio (S_iO_2: Al_2O_3) as:

i. true laterites (those with silica - alumina ratio less than 1.33),

ii. Lateritic soils (those with ratio between 1.33 and 2.0) and

iii. Non lateritic with a ratio greater than 2.00

The British Association for the Advancement of science in their glossary of Geographical terms (1961) defined laterite as a porous layer of reddish material formed by weathering from the breakdown of rocks, chiefly under humid tropical conditions. The material is heavily leached of silica and alkalis leaving a concentration of hydrated form of aluminium oxide. Overseas unit, Transport and Road Research Laboratory (1952) defined laterite as a tropical soil in which the weathering processes have resulted in an accumulation of sesqui oxides particularly iron. Laterite is a granular type of earth of a strong red colour, generally well cemented together and with a high density in the natural state, but which can easily be disintegrated by mechanical equipment, Giuseppe (1969).

Also in 1969, Little defined laterites as in-situ products of tropically weathered Igneous rock which has decomposed partially or totally with a concentration of iron or aluminium sesqui oxides at the expense of silica. Vallerge et al (1969) gave what seems the most generally accepted definition of laterite as a hardened material formed by the primary weathering of residual soil in which sesquioxides are present in parent rock or by the secondary leaching cementation of transported or residual soil in which the sesquioxides are supplied by lateral ground water movement.

The dictionary of Earth science defines laterite as a layer of deposit formed from weathering of rocks in humid tropical conditions and consisting mostly of iron and aluminum oxide. Furthermore, a number of studies by several researchers revealed that laterite is a weathered product of various materials including crystalline igneous rock sediments and volcanic ash. From the various definitions above, there is the consensus opinion that laterite contains aluminium, iron and silica in varied proportions and based on the constituent components of laterite, each definition follows the type of laterite formation available.

2.2 Laterites

2.1.1 Origin And Formation of Laterites

Laterites are products of weathered rocks which accumulate in place mostly in very warm humid regions. Some theories were put forward to account for the origin and formation of laterites and these theories vary in concept and view. Basically, laterite is formed by weathering under conditions that lead to the removal of silica, alkalis, and alkaline earths. The resulting concentration of iron and aluminium oxides sharply differentiate laterization from temperate climate weathering in which the end product is largely clay minerals. As a result of heavy rainfall during the wet season, followed by the dry seasonal high temperature and rapid evaporation in the tropics, plants draw water far below the ground to replenish the ones lost to the atmosphere, as long as the supply holds. The weak solution produced by leaching of the rocks during the wet season thus become concentrated by evaporation and dissolved minerals are deposited which leads to the accumulation of iron and aluminium hydroxides which are insoluble and are not re-dissolved during the raining season and are therefore left at or near the surface where they form a thick red to blackish soil called laterite, from the latin word "later" which means brick.

Besides, studies conducted with various samples of the soil in tropical regions revealed that because laterites originate from Precambrian basement complex, they exist in a great variety and their characteristics depend on the parent rock or the geology of the area. Mohr and Mazhar (1969) gave four basic conditions were given for laterization, namely:

a. Availability of iron rich mineral in the parent bed rock

b. High soil permeability and ample ground water movement through the soil

c. Presence of ample oxygen in the ground water in order to form iron oxide and

d. Presence of a primary neutral or acidic geochemical environment.

Gidigasu, (1976) also expressed the opinion that laterite is composed essentially of secondary oxides of iron and alumina or both and contains large amounts of quartz and kaolinite. Levinson (1974) noted that for the formation of laterite, the optimum conditions appear during the high seasonal rainfall, high temperature, intense leaching, strong oxidising environment, subdued topography, a long duration of weathering and a chemically unstable rock. Therefore, laterite originates from tropical weathering of some rocks which include micaceous schists and dolerites.

2.2.2 Distribution and Morphology of Laterites

Laterites are found all over the world especially in inter-tropical regions of Africa, Australia, South-East Asia, India and South-Africa. Their extension show that their formation is favoured by some conditions at one time or the other in the history of the world but not necessarily simultaneous at all points. Prescot and Pendleton (1952) concluded that Laterites are widely distributed in the semi-humid and humid inter-tropical regions of the world, and laterites in fossil states are found in dried climates and sometimes in temperate climates. Also as hardened occurrences, laterite extends beyond sub-humid tropical climate to desert regions where there are indications of humidity in the past.

Abundance of laterite gravels and soils are located in the precambrian basement complex area in the northern part of Nigeria. They are found in large quantities in the southern parts of Nigeria and constitute about 50-70 percent of their total soil. Laterites can be associated with a characteristic profile forming the following level in descending order as shown in fig.2.1

1. A surface zone with ferruginous incrustation and concretion
2. A lateritic bed
3. A zone of primary alteration to Kaolinite
4. A fresh zone of unaltered rock.

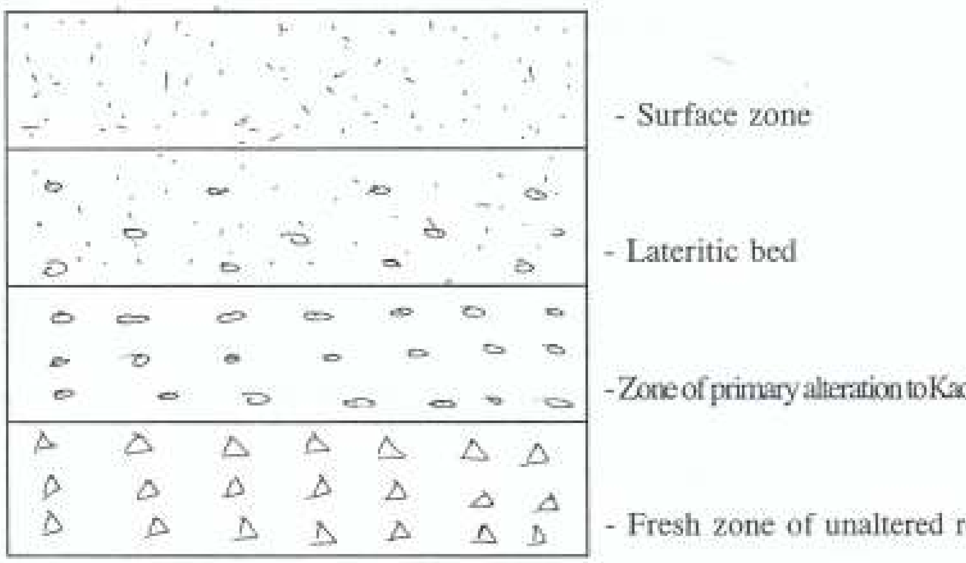


Fig. 2.1: Typical laterite soil profile.

2.2.3 Properties and Composition of Laterite Soil

The physical properties of laterite depend on the properties inherited by the soil from the parent rock material, environmental factors and characteristics of the locality in which the soil has been in the course of its geologic history (Gidigasu, 1976). In permanent moist condition, laterite is soft but when it is exposed to the atmosphere or by fall of water table, the material hardens irreversibly by dehydration to hard lateritic forms. The colour of laterites vary from one source to the other, but the most common ones are red, reddish brown or yellowish brown, pink and reddish shades of other colours.

According to De.Graft-Johnson (1969), the specific gravity of laterite falls within a wide range of 2.2 to 2.8. He also observed that the higher the degree of laterization, the greater the specific gravity. Moreover, the specific gravity for the coarser fraction is generally higher than that of the finer fraction. Also their specific gravities vary in relation to their chemical composition, increasing with iron content and decreasing with alumina. The specific gravity of oxidized forms is higher than that of hydrated forms. Also the looser the structure of the soil, the lower is the specific gravity of the same composition.

Laterite is incompressible and does not swell under severe conditions of water and this reduces differential expansion and strength changes. It is easily compacted which ensures higher dry density and strength under a given amount of compaction. At low water contents, laterite is characterized by excellent values of angle of internal friction due to the high percentage of quartz in it. Alexander and Cady (1962) viewed laterites under a microscope and noted useful details on the arrangement of the elements present in their microstructure. In a section of laterites, they observed spheroidal or elongated particles that are dense or spongy. The round elements completely fused may be separated or highly clustered. The outline varied from specimen to specimen. A specimen may be homogenous in appearance without may distinguishing features or may exhibit regular patterns. Newill and Dowling, 1970 pointed out the difference between laterites in western Malaysia and those in northern Nigeria. He noted that nodular laterite is more common in Malaysia while in Nigeria, it exists in the form of laterite crust overlying sandstone, granite and gneiss.

However, from the analysis of the properties of laterite around the world, it could be observed that these properties depend on the parent rock from which they were formed. Furthermore, from chemical composition, laterite is formed when the ratio of silica to sesquioxides (S_10_2: (Fe_20_3+$A1_2$ 0_3) is less than 1.33 and we have non lateritic soil if the ratio is greater than 2.00 (Martin and Doyne, 1930).

Conclusively, it has been observed that laterite soils have some mineralogical composition such as silica, Kaolinite, Geothite, Gibbsite, Heamatite, Micro cline and Quartz.

2.2.4 Economic Importance of Laterite

Laterite are traditional road building materials available in most parts of West Africa and several other countries. They are extensively used for various construction works all over the world. Indiscriminate use of laterites without fully appreciating their limitations has resulted in the failure of a large number of road pavement in this country. Based on the engineering properties of laterite, they are used in the following ways:

i. For roofing local buildings.

ii. Construction of earth structures, such as earth dams.

iii. For brick making.

iv. For structural foundations as in dams and irrigation works.

v. For the construction of local silos for storage purposes in the Northern part of Nigeria and

vi. For making local ovens for baking.

Considering the natural strength of laterite, they are good as subgrade for airfield and highway pavements. The softer types are good subbase courses while the harder materials are good for subgrade courses. They can be used for earth roads, compacted at required moisture content and are capable of supporting heavy traffic. However when the road is exposed to weather, it becomes dusty during the dry season and pot holes develop when traffic passes during and after rainfall but this can be prevented by adequate maintenance of the road.

2.3 Soil Stabilization

Soil stabilization is the process by which natural soils and aggregates are improved for engineering use. It is a technique used in the construction of road bases and sub-bases and for the treatment of subgrade soils. The simplest and most cost-effective forms include improvements in soil by compaction and drainage. Another method (known as mechanical stabilization), involves the blending of different natural materials to obtain a mixture with the desired engineering properties in terms of grading and plasticity. More commonly, soil stabilization is recognised as the improvement of natural materials by the addition of a small proportion, usually less than 10 per cent, of a stabilizing agent. This may involve the addition of additives such as cement, lime (usually hydrated lime), bitumen or a chemical stabilizer such as sodium silicate, calcium chloride, or industrial wastes and resins depending on the nature of soil to be stabilized. The improvements which can result from stabilization include the following:

i. Increase in strength

ii. increased resistance to the effects of water

iii. drying of wet soils

iv. volumetric stability

v. improved workability and

vi. improved durability.

Cement, lime and bitumen stabilization are used either to improve strength or to improve workability or for waterproofing (Cementitions stabilizers in roadworks, Draft TR H13). Portland cement has been used with great success to improve existing gravel roads, as well as to stabilize natural soils. It can be used in granular soils, silty soils, and lean clays, but it cannot be used in organic materials. Another cementing agent, which is often used is hydrated lime. Lime increases soil strength primarily by pozzolanic action, which is the formation of cementatious silicates and aluminates. This material is most efficient when used in granular materials and lean clays; the quantity required for proper hydration generally is relatively low. Flyash is generally high in silica and alumina. Therefore, the addition of flyash to lime stabilized soil speeds the pozzolanic action but the quantity of flyash required for adequate stabilization is relatively high, restricting its

2.3.1.1 Soil And Cement Reaction

The primary and most important reactions are the hydration reactions of the cement with water in the soil. These lead to the formation of cementitious materials, (calcium silicate and aluminate hydrates as in concrete). The reactions occur almost independently of the nature of the soil and it is for this reason that cement can be used to stabilize materials ranging from cohesionless sands and gravels, to silts and plastic clays. The hydration reactions release hydrated lime (about 30 per cent by mass of added cement) which can cause secondary reactions with any reactive elements (e.g. clays, flyash, etc.) within the soil. The secondary reactions produce cementitious products similar to those of the primary reactions. Hydration reaction starts immediately on contact of the cement with water and proceeds rapidly with very significant strength gains within the first day. The secondary reactions are similar to those that occur in lime stabilization and proceed slowly with time. However, it is essentially the characteristic bonding of particles by the cement that provides early and long-term strength and thus determines the engineering properties of cement-treated materials. The differing properties imparted by varying cement content produce materials for different usages. Hence for practical reasons, two categories of cement stabilized materials have been identified. These are cement "modified" materials and cement "bound" materials Bulman, (1972).

Cement modified materials are used and evaluated in the same manner as conventional unbound flexible pavement materials. Small cement contents are used primarily to reduce the moisture susceptibility of soils and to increase shear strength and CBR, without endowing the material with a significant modulus and tensile strength. The modified material is assumed to have a very close spaced network of fine, benign cracks and does not develop the open systematic network of widely spaced open cracks of some bound materials. Fine-grained gravels, very clayey gravels, silty sands and other materials without significant particle interlock are not suitable for cement modified products as they deteriorate rapidly with use. If used for cement stabilized bases they should be designed as "bound" materials.

Cement "bound" materials have a sufficiently enhanced elastic modulus and tensile strength to have practical application in stiffening the pavement. Bound materials have high moduli in the range 2,000 to 20,000 Mpa and their use in some situations can lead to reduced pavement thickness. To obtain the full value of a bound material, it is necessary to resort to elastic methods in pavement design and use fatigue performance criteria.

2.3.1.2 Strength Parameters

The strength parameters stabilization are

i. Age

After rapid strength gain in the first one to two days, cement stabilized materials continue to gain strength slowly, provided curing is sustained (Fig. 2.2). Elastic modulus also increases with age.

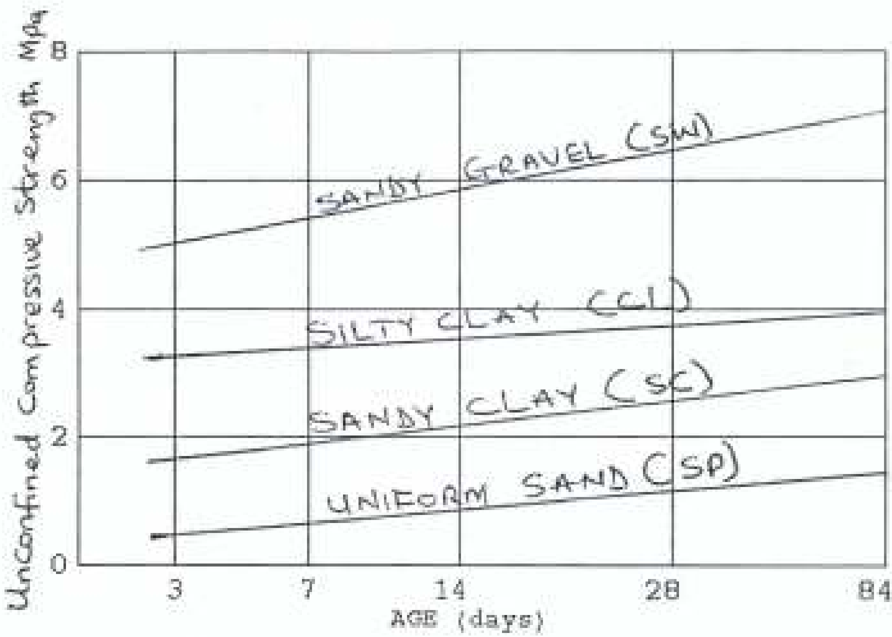


Fig. 2.2 Effect of Age on strength of various soils stabilized with 5% cement (after Met - calf, 1973).

ii. Unconfined compressive strength

The unconfined compressive strength has been extensively used to determine the response of materials to cement stabilization, but it has little direct application to pavement design. It is better to use some form of tensile strength testing which has direct bearing on the design.

iii. CBR And Texas Triaxial Tests

These test methods have application to modified materials but not to bound materials. However, there are limitations to their use in modified materials. Small additions of cement to well-graded granular materials will commonly lead to large increases in measured CBR's. Such CBR's may grossly over-estimate the strength of the material in service due in part to weak cementation bonds which may be destroyed in service. The CBR measured at high strains, when such bonds are likely to be broken (e.g. at 5mm pen) is probably more representative of in-service strength. As with all strength considerations, the principal variables are particles size distribution, density, and cement content. Increasing cement content lead to increased strengths in both the soaked and unsoaked conditions.

iv. Tensile strength and Strain.

These properties are of particular significance in the design of cement bound layers which are relatively brittle, with a high modulus and very low tensile strain at fracture. Their behaviour under triaxial compression does not fit the Mohr-coulomb theories but fits better the Griffith crack theory. Tensile strength is influenced by particle size distribution, moisture content, cement content and density. Maximum tensile strength would usually occur for materials compacted close to optimum moisture content.

Cement bound materials fail in tension under low strain. The critical strain usually decreases with increasing modulus.

v. Elastic Modulus

When a cemented material is loaded beyond a certain limit, micro cracking first develops at the inter-face between the coarse particles and the matrix and increases upon subsequent loading, and eventually the microcracks join up, the matrix disintegrates, and the treated material no longer behaves like a cemented material. From laboratory flexural and compressive test results, micro cracking starts at about 35 per cent of the ultimate strength and at about 25 per cent of the strain at break during initial loading; the strength versus deformation is linear-elastic up to the onset of microcraking and thereafter becomes non-linear and non-elastic (Introduction to soil stabilization, 1987).

2.3.1.3 Condition Appropriate For Cement Stabilization

Overseas unit (1987) gave two main factors for cement stabilization:

1. Soil factors, dealing with the composition of the untreated soil and its response to cement
2. Production factors concerned with the quality of the cement, and water and the methods used to construct the stabilized materials.

1. Soil Factors

It was observed that cement is particularly effective in stabilizing medium to low plasticity materials for use as pavement layers. Although it is possible to treat almost any soil with cement to improve its properties, in practice it is difficult to treat fine, clayed materials with cement owing to the high cement content required and the difficulty of pulverizing the soil and mixing-in the cement; hence lime is a better stabilizing agent for this type of soil. Natural soils with low volume of voids when compacted require only small cement content for a specified strength gain. Also well-graded materials

(GW, GC) require relatively small cement contents compared to poorly-graded high-void materials (Guide to stabilization in road works, 1986). Table 2.1 shows the property limits for effective cement stabilization.

Table 2.1: Guide to Property Limits For Effective Cement Stabilization

(a) Property limit	Particle size
Maximum size	75mm
Passing 4.75 mm	>50%
Passing 425 -μm sieve	>15%
Passing 75-μm sieve	<50%
Finer than 2-μm	<30%
(b) Plasticity	
Liquid Limit	<40%
Plasticity Index	<20%

2. Production Factors

The quality of the stabilized soil according to Anwar and Rurik (1964) is very dependent on the production processes which include the following:

i. **Breakdown and Mixing**

It was observed that an even distribution of cement ensures its most economic use and increasing the laboratory selected cement content reduces mixing inefficiencies. Plant mixing leads to high quality modified and bound materials because there is even distribution of cement throughout the full design depth. Cohesive materials are properly broken down to enhance mixing well with cement and Plastic soils pre-conditioned with a small percentage of hydrated lime or quicklime or cement for efficient break down thus enhancing the stabilization (Coyne and Ripple, 1975).

ii. Water Quality

Previous works and stabilization have pointed out that water suitable for making concrete is also suitable for use in cement stabilization. Water having organic matter or a high sulphate content (i.e above 0.05 per cent) is unsuitable so as to prevent sulphate attack on the stabilized material and the quantity of water added depends on the desired maximum dry density.

iii. Compaction

The addition of a stabilizing agent to a soil usually has various effects on optimum moisture content and maximum dry density depending on the type of soil and stabilizer used. It is usual practice to complete compaction within hours of the addition of cement depending on weather conditions and laboratory density tests carried out with care. It is important to replicate likely field moisture conditions in the laboratory.

iv. Curing

Cement stabilized materials are cured to:

a. ensure that there is always adequate water for complete hydration reactions

b. Limit drying shrinkage while hydration proceeds and the material is strengthened. A curing membrane are applied in some cases to prevent the dryout of stabilized materials due to continual loss of water to the atmosphere or alternatively frequent surface watering may be applied to keep the stabilized material damp. For laboratory prepared specimens, it is usual to keep samples in sealed, air-tight bags at constant temperature. Some samples are also soaked after curing by complete immersion in water (Anwar and Rurik, 1964).

2.3.2 Bituminous Stabilization

Bituminous stabilization of a soil-aggregate mixture is usually intended either to introduce some cohesion into non-plastic materials or make a cohesive soil less sensitive to loss of stability with increased moisture content. Both effects stem partly from the formation of films around the soil particles, which stick together and prevent the absorption of water, and partly from simple blocking of the pores, preventing water from entering the soil mass.

2.3.2.1 Bituminous Material

The bituminous materials that are used for stabilization works are mostly:

i. Hot Bitumen

ii. Liquid bituminous products in the form of cut-back bitumen or the lower grades of tar.

iii. Bitumen Emulsion either as anionic or cationic emulsion. Stabilization with hot bitumen involves a temporary change of state of the stabilizing material by significantly increasing its surface area at the point of mixing. Bitumen emulsions and cutbacks are usually used in stabilization works. Basically a cutback is a bitumen + a solvent. Three designation are used RC, MC and SC meaning:

RC (rapid curing) = AC (80 pen) + gasoline

MC (medium curing) = (120-250 pen) + kerosine

SC (slow curing) = AC + slowly volatile oil (e.g. diesel oil)

Since the solvent in the SC cutbacks remains to a large extent in the mix, SC cutbacks are called Road oil. In a rapid curing cutback, the solvent evaporates within a few hours and in a medium curing cutback it will take a few days while in the slow curing cutbacks, it will take a number of months. A designation in number is also used (e.g Rc-250) to indicate the viscosity.

Asphalt emulsions are liquid mixtures that contain asphalt cement, water and an emulsifying agent. They are graded according to the time it takes for them to break or come out of suspension, and are referred to as rapid setting (RS), medium setting (MS) and slow setting (SS). Also a number (1 or 2) is used after the letter (e.g. Ms-2). The lower numbered grades are the most fluid (i.e. a Ms-1 emulsions is more fluid than a MS-2). Sometimes a small letter h is used after the number (MS-2 h) meaning that the base asphalt is a harder grade.

There are two types of emulsions, anionic and cationic. In the latter case a C is used in front of the grade indication as C Ms - 2 where the particles of bitumen are negatively and positively charged respectively. The types of cutback bitumen most commonly used for soil stabilization are the medium - curing types - Mc-1, Mc-2 grade.

However, both rapid curing and slow curing cut back bitumens of similar viscosity have also frequently been used. The characteristics of the cutback bitumen will depend on the particle size distribution of the sand, the temperature of application and the type of mixing plant. Bitumen emulsions are generally only suitable for soil stabilization in climates where rapid drying conditions occur, since this is equivalent to adding water to the soil as well as a bituminous binder. In the British Isles, this tends to make cohesive soils plastic since in the natural state they often have a relatively high moisture content. In dry conditions however, such as in the middle East and part of Africa and India, the water in the emulsion may be an advantage since it helps to provide part of the optimum fluids content to the compaction thereby reducing the amount of water necessary for this purpose (Guide to stabilization in roadworks, 1969).

2.3.2.2 Soil Types And Conditions of Mixing

The most suitable types of soil for stabilization with cut back bitumen or tar, are slightly moderately plastic sands and gravels provided the clays present are such that the soil agglomerations may readily be granulated in the moist condition and intimately mixed with the stabilizer and mixing should be carried out near optimum fluid content. Care must be taken not to bring the fluid content too high, the stabilizing material acting as a liquid for compaction purposes. Bitumen can be incorporated into cohesive soils to waterproof them as a means to maintain low moisture contents and high bearing capacities.

The most suitable soils for emulsion stabilization are well-graded non-cohesive to slightly cohesive soils (sands) with plasticity index less than 6. The distribution of emulsion throughout the soils is influenced by the moisture content of the soil. Dry soil causes the emulsion to break prematurely resulting in the bitumen forming into "blobs" and not spreading evenly. At increased moisture content, the tendency for the emulsion to break prematurely is reduced and the time of mixing can be prolonged with a better distribution. If the moisture content becomes too high, aeration of the soil to remove excess moisture may be necessary before rolling starts.

CHAPTER THREE

METHODOLOGY

3.1 Materials

Three laterite soil samples designated as samples A, B and C were used for this investigation. The samples are borrow pit materials used on Ado-Ekiti - Ikare road rehabilitation project. The three samples were chosen as representative samples after tests had been carried out on various samples around the locality.

Sample A was taken at km 9+500 along Ado-Ikare road, sample B at km 58+700, Ogbagi town while sample C was collected at km 53+550, Irun Akoko town. After collection, samples were stored in polythene bags immediately prior to their use to prevent loss of moisture.

Portlant cement type 1 was used for soil-cement mixtures because it is the type mostly used in soil stabilization due to its availability. The Asphalt-emulsion used is colax. A obtained from Ondo State Asphalt company, Akure and water for mixing was clean stream water.

3.2 Testing Procedures

A. Natural Soil Samples

The following tests were carried out on each of the three samples used viz:

i. identification and classification tests which include particle size distribution, atterberg limits and specific gravity.

ii. Mineralogical composition to determine the clay minerals of the soils.

iii. Compaction tests to determine moisture - density relations for each sample

iv. California Bearing Ratio Test (CBR) and

v. Unconfined compressive strength test.

The procedures used in carrying out these tests were according to standard methods as mentioned later.

B. Treated Samples

The chemical additives used for treating the soils are cement, Asphalt-emusion and a mixture of Asphalt-emulsion with cement as modifier. Varying proportions of the additives were used. The following tests were carried out on each treated sample:

i. Compaction tests using modified AASHTO T180-70 method

ii. California Bearing Ratio using AASHTO T193-63

iii. Unconfined compression strength tests using BS 1377.

3.3 Pre-Treatment of Samples

Samples at their natural water content as collected from the sites were stored in polythene bags to prevent loss of moisture. Prior to their use, deleterious materials such as roots were removed. The samples were air-dried, broken down with mortar and pestle and passed through a No 10 sieve to remove large particles.

To compare relative effects of the additives on performance of samples, varying proportions of each additive were used to prepare mixtures. The amounts of additives used are expressed as percentages of the dry weight of the samples.

Cement and Asphalt-emulsion contents used were 2,4,6, and 8 percent and for the combination of asphalt-emulsion with cement, 0.5, 1 and 2 percent of cement were used to modify each asphalt-emulsion mixture.

Mixing of samples with additives was done manually at the optimum moisture content of natural samples as obtained from compaction tests. For soil-cement mixtures, cement was hand-mixed into the soil prior to the mixing in of water while for the soil asphalt-emulsion mixtures, the emulsion was mixed into the soil with water for proper mixing in of emulsion. For the combination of cement and asphalt-emulsion, cement was first mixed with the soil and then the asphalt-emulsion with water was added and mixed into the soil.

Moulding of tests specimens was started as soon as possible after completion of mixing. Specimens were molded in CBR mould using the modified AASHO compaction method for moisture - density relations and CBR values. The unconfined compression test mould was used for compressive strength determination.

For each percentage of additive, an average of four specimens were used to obtain each point on the moisture - density relation and CBR curves. Nine specimens were used for UCS, three each for 7, 14 and 28 - day strength tests. The strength values reported are averages of the results of three test specimens for each mixture. After casting of specimens, they were wrapped in nylon bags and placed in a humidity room for curing to reduce loss of moisture.

Testing of specimens for relevant characteristics were then carried out using standard methods as previously stated. The results are discussed in chapter four with the following relations shown:

i. Moisture-density relations for natural and treated samples with varying percentages.

ii. Maximum dry density versus chemical content.

iii. Optimum moisture content versus chemical content.

iv. CBR versus chemical content.

v. Unconfined compressive strength (UCS) versus chemical content and

vi. UCS with Age of curing.

CHAPTER FOUR

LABORATORY RESULTS AND ANALYSIS OF NATURAL AND TREATED SOIL SAMPLES

4.1 CHARACTERISTICS OF NATURAL SAMPLES

After the samples had been collected and treated as described in chapter three, their properties were determined to ensure that when their response to additives was studied, all relevant factors would be available for establishing a correlation between composition and chemical stabilization of the soils.

Results of tests performed on the three samples are as recorded below:

A. Identification and Classification Tests

The particle size distributions of the samples are as shown in Table 4.1. The average distributions were:

Sample A:

Gravel	3.4%
Sand	62.4%
Fine	34.2%

Sample B:

Gravel	5.8%
Sand	62.2%
Fine	32.% and

Sample C

Gravel	0.5%
Sand	44%
Fine	55.5%

The grain size distribution curves are shown in Fig. 4.1.

The results of the Atterberg Limits tests are shown in Table 4.2. and fig 4.2. Soil A comprises 65.8% coarse material and 34.2% fines with a liquid limit, plastic limit and plasticity index of 31%, 22% and 9% respectively. The soil is classified as very clayed sand, SCl (Clay of Low Plasticity) according to British Soil Classification System (BSC) and as A-2-5 according to AASHO classification. Soil B contains 68% coarse material and 32% fines with a liquid limit of 46%, plastic limit of 31% and plasticity index of 15. The classification is CIS (Sandy Clay of Intermediate plasticity) according to BSC and A-2-7 according to AASHO classification.

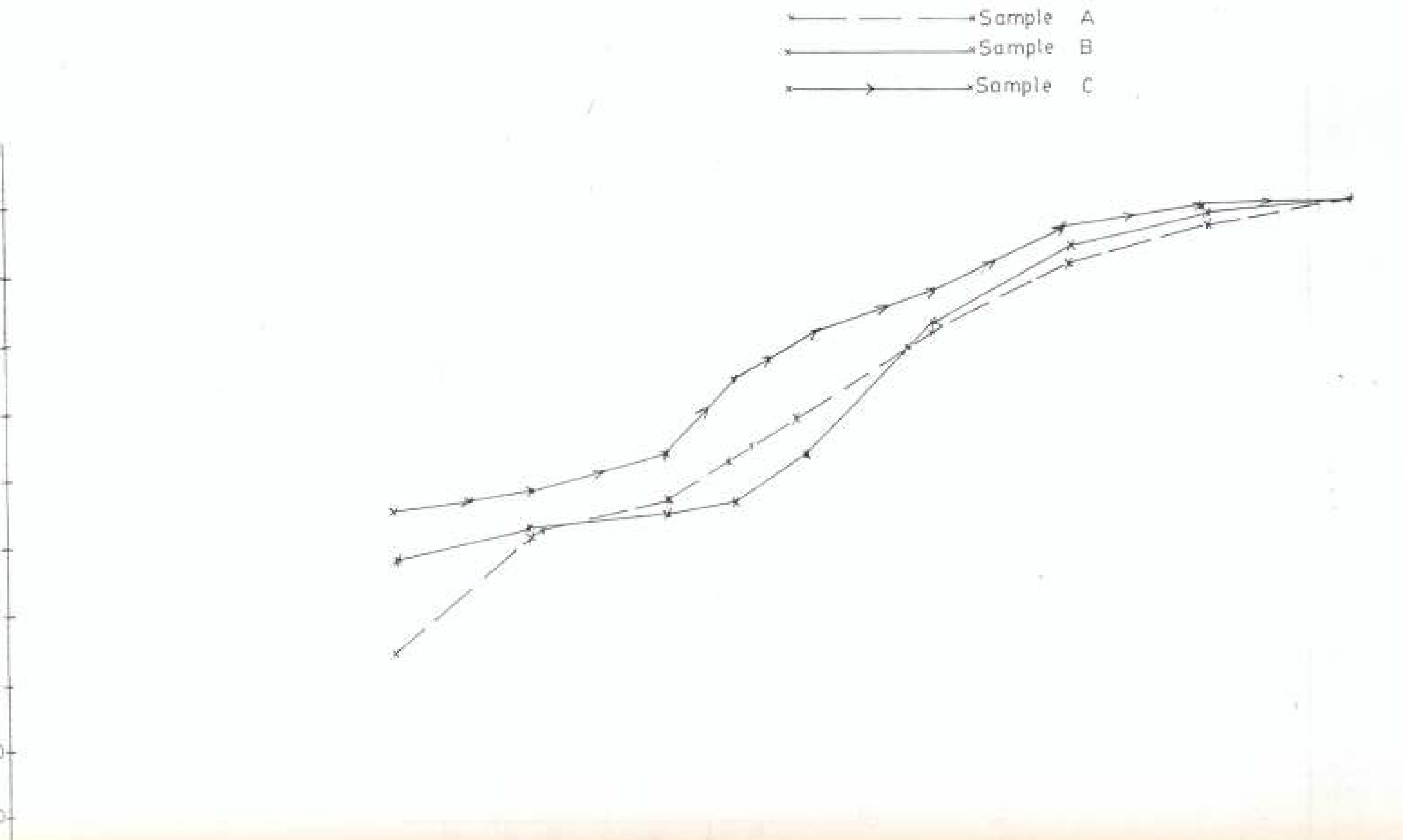
Soil C consists of 44.5% coarse material and 55.5% fines. It has a liquid limit of 55%, plastic limit of 29% and plasticity index of 26. It is thus classified as CH (Clay of high Plasticity).

Table 4.1: **Particle Size Distribution of Samples A, B and C.**

Sieve Opening	Wt. Retained (g)	% Cumm. Retained	% Passing
9.5	-		
4.76	17	-	
2.30	46.2	3.4	100.0
1.18	97.1	9.2	96.6
0.60	153.0	19.4	90.8
0.425	180.6	30.6	80.6
0.300	218.2	36.1	69.4
0.150	241.1	43.6	63.9
0.075	241.1	48.2	56.4
	329.0	65.8	51.8
Sample B			34.2
9.5	-		
4.76	37.5	-	100.0
2.30	94.0	5.8	94.2
1.18	183.0	7.5	92.5
0.60	217.5	18.8	81.2
0.425	226.0	36.6	63.4
0.300	236.5	43.5	56.5
0.150	260.0	45.2	54.8
0.075		47.3	52.7
		68.0	32.0
Sample C	-		
	2.5		
9.5	34.0	-	100.0
4.76	64.0	0.5	99.9
2.30	99.0	6.8	93.2
1.18	127.5	12.8	87.2
0.60	182.5	19.8	80.2
0.425	209.0	25.5	74.5
0.300	222.5	36.5	63.5
0.150		41.8	58.2
0.075		44.5	55.5

Weight of Sample Used = 500g

Fig 4: Particle Size Distribution Curve



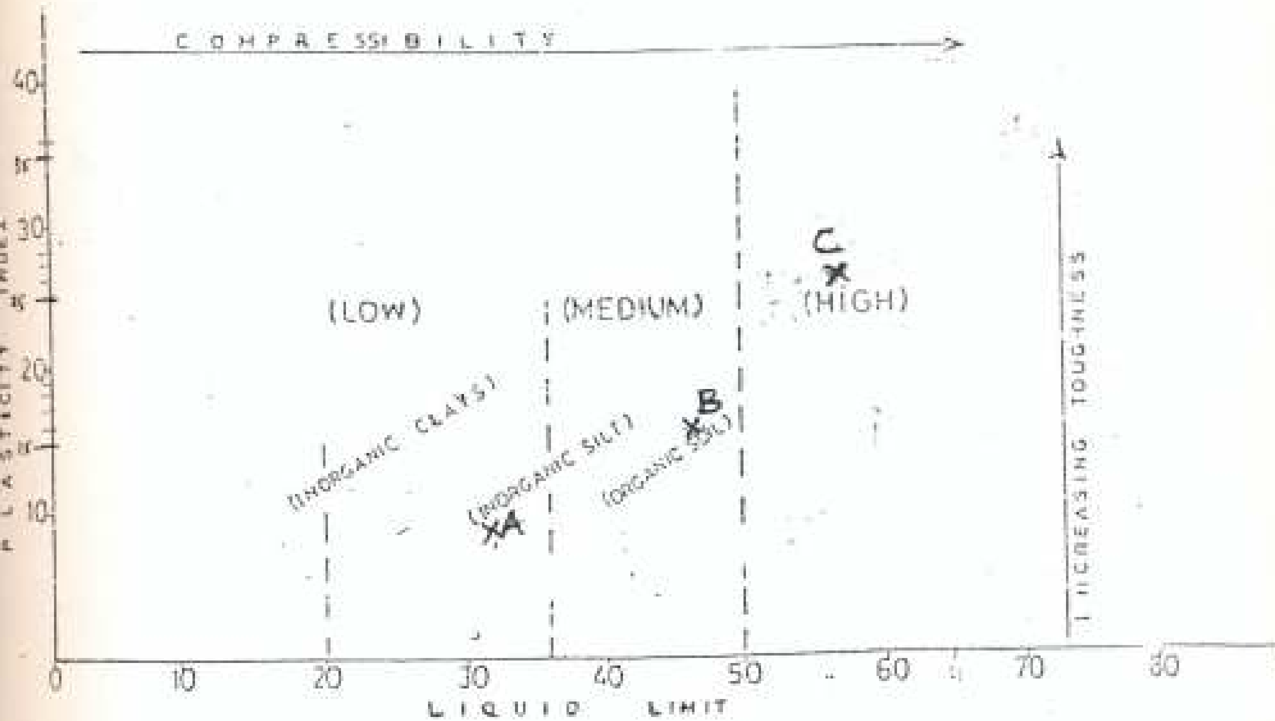


Fig. 4.2: Casangrande Chart for classifying Samples A, B, and C.

B. Chemical And Mineralogical Composition

In order to establish correlation between composition and chemical stabilization, the chemical and mineralogical composition of the samples were determined using the procedures as given in BS 1377. The results are as shown in Table 4.3.

For the three samples, the silica-alumina ratio are about 2, thus they are lateritic soils with no presence of sulphates and carbonates. The pH of samples A, B and C are 5.6, 5.4 and 4.8 respectively, thus the soils are acidic with soil sample C having substantial amount of organic matter.

The results of the mineralogical composition (fig 4.3) show that samples A and B consisted mainly of kaolinite.

Table 4.2: Atterberg Limits of Sample

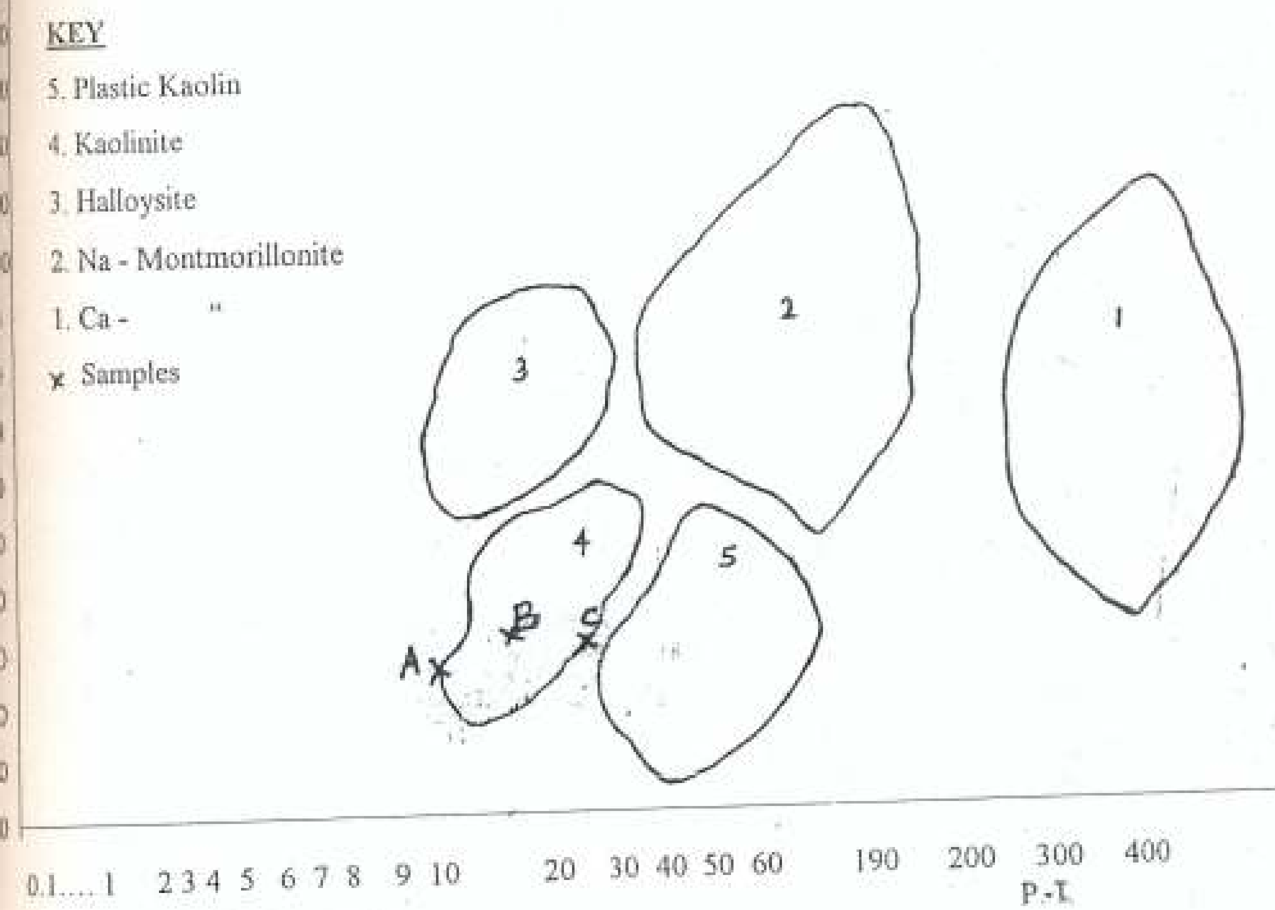
Limits	Sample A %	Sample B %	Sample B %
Liquid limit	31	46	55
Plastic limit	22	31	29
Plasticity Index	9	15	26

Table 4.3: Chemical Analysis Result

SAMPLE	S_iO_2	Al_2O_3	Fe_2O_3	CaO	MgO	LOI	Na_2O	K_2O	PH
A	56.81	26.22	0.88	2.71	3.06	11.10	Bd	Bd	5.6
B	56.00	26.11	0.10	2.73	3.46	11.13	Bd	Bd	5.4
C	50.50	30.93	0.11	2.40	3.01	12.50	Bd	Bd	4.8

LOI - Loss on Ignition

S_iO_2 - Silica content



F.g 4.3: Clay identification Chart using plastic limit and plasticity index.

C. Compaction Test

Results of compaction tests on the natural samples are shown in figure 1 in appendix II for sample C as representative of the Laboratory procedures. Samples A and B both have a maximum dry density of 1.80g/cc with optimum moisture contents of 12.3% and 15.3% respectively. The M.D.D and O.M.C for soil C are 1.70g/cc and 16.3% respectively. From the results, the samples show low dry densities which will lead to low strength of the samples if used naturally as construction materials. Therefore the need arises to improve their properties.

D. California Bearing Ratio (CBR)

The suitability of the samples in their natural forms for use as highway materials was investigated using the CBR test. The results gave CBR values of 20% , 18% and 8% for samples A, B and C respectively. From the results, the samples are rated as fair subbase material which normally have CBR values between 8-20% and thus needed to be improved for base material which have a minimum standard CBR value of 100%.

E. Unconfined Compressive Strength, UCS

Unconfined compressive strength of the three natural samples were determined using remoulded samples. The Tests were carried out at 7, 14 and 28 - days and as specified in BS 1377.

The remoulded samples had strengths that increased with age of curing from 0.85 MN/m^2 7-day strength to 1.20 MN/m^2 28-day strength for sample A and from a 7-day strength of 0.50 MN/m^2 to 0.85 MN/m^2 at 28 days for sample B with sample C increasing from a 7-day strength of 0.41 MN/m^2 to a 28-day strength of 0.68 MN/m^2.

The low results of the unconfined compressive strength tests of the three samples indicate that the samples are unsuitable for use directly as highway materials; hence the need for their improvement.

4.2 Characteristics of Stabilized Materials

Each of the three samples was treated with different chemicals to improve the engineering properties. The additives used are cement, asphalt-emulsion and asphalt-emulsion modified with cement. For proper investigation and comparison of results, varying proportions of the additives were used as previously discussed. The following tests were carried out on the treated samples:

a. Compaction test

b. California Bearing Ratio (C.B.R.) test.

c. Unconfined Compressive Strength test.

4.2.1 Compaction Characteristics

Compaction tests were carried out on treated samples to establish relationships between strength and density for treated soil mixtures compacted at different moisture contents and using varying proportions of the additives.

4.2.1.1 Cement Treated Samples

Results of compaction test on samples treated with cement are as shown on Table 4.4. The variations of dry density and moisture content are shown in Figures 2 to 5 in

Appendix II for sample C treated with 2, 4, 6 and 8% cement contents. The results show that adding cement to the samples increased the optimum moisture content and decreased the maximum dry densities.

For soil sample A, the O.M.C and M.D.D change from 12.3% and 1.80 g/cc at 0% cement content to 14.5% and 1.73 g/cc at 8% cement content. Soil B has a maximum dry density and optimum moisture content of 15.3% and 1.80g/cc at 0% cement and 16.5% and 1.74 g/cc at 8% cement content while soil C increased in O.M.C from 16.3% at 0% cement to 16.8% at 8% cement with M.D.D. of 1.70g/cc and 1.62g/cc respectively.

Sample A and B have the highest M.D.D in all percentages of cement content because of the presence of high coarse materials in the samples which resulted into high compacted strength while soil C has the lowest M.D.D. due to its high plasticity which caused low compaction.

The increase in optimum moisture content as cement content increases is caused by the increase in amount of water needed for full hydration of cement to take place within the soil while the reduction in maximum dry densities is as a result of flocculation of soil fines and creation of loosely bonded aggregations in treated samples caused by the added cement.

The variations of M.D.D and O.M.C with cement content are shown in Figures 4.4 to 4.6 for samples A, B and C respectively.

Table 4.4: Summary of Test Results For Cement-Treated Samples

Samples

CEMENT CONTENT %	OMC %	MDD g/cc	CBR %	UCS 7days	UCS 14days	UCS 28days
SAMPLE A						
0	12.3	1.80	20	0.85	1.00	1.20
2	13.2	1.78	94	1.98	2.01	2.20
4	13.9	1.77	120	3.50	3.62	3.72
6	14.2	1.75	180	4.65	4.78	4.95
8	14.5	1.72	220	5.20	5.48	5.61
SAMPLE B						
0	15.3	1.80	18	0.50	0.72	0.85
2	15.6	1.79	58	1.25	1.38	1.50
4	15.8	1.78	88	3.39	3.65	3.76
6	16.1	1.76	150	4.42	4.65	4.80
8	16.5	1.74	199	4.85	4.95	4.98
SAMPLE C						
0	16.3	1.70	8	0.41	0.50	0.68
2	16.0	1.68	22	0.68	0.73	0.90
4	16.5	1.65	40	0.99	1.26	1.16
6	16.7	1.64	80	1.21	1.35	1.47
8	16.8	1.62	102	2.00	2.15	2.21

TABLE 4.5 SUMMARY OF TEST RESULTS FOR SAMPLES TREATED WITH ASPHALT-EMULSION

Asphalt-Emulsion Content %	OMC %	MDD g/cc	CBR %	UCS 7days	UCS 14days	UCS 28days
SAMPLE A						
0	12.3	1.80	20	0.85	1.00	1.20
2	15.8	1.80	76	1.61	1.72	1.80
4	15.4	1.86	110	2.20	2.30	2.50
6	16.0	1.76	140	3.00	3.60	4.10
8	16.5	1.74	91	2.00	2.20	2.25
SAMPLE B						
0	15.3	1.80	18	0.50	0.72	0.85
2	15.5	1.78	45	0.85	0.92	1.20
4	15.8	1.76	70	2.09	2.35	2.45
6	16.0	1.75	80	2.59	2.68	2.82
8	16.1	1.72	60	1.95	2.10	2.35
SAMPLE C						
0	16.3	1.70	8	0.41	0.50	0.68
2	16.1	1.63	12	0.50	0.56	0.69
4	16.0	1.60	33	1.00	1.20	1.45
6	16.2	1.59	40	1.50	1.60	1.80
8	15.7	1.53	60	1.80	2.00	2.44

4.2.1.2 Asphalt -Emulsion Treated Samples

The results of compaction tests on sample treated with asphalt-emulsion and the relationship between dry density and moisture content at different percentages of emulsion are shown in Figures 6 to 9 in Appendix II. For samples A, B and C, the results are shown on Table 4.5.

From the results, the optimum moisture content of sample A increased with increase in asphalt-emulsion content from 12.3% at 0% emulsion to 16.5% at 8% emulsion content while maximum dry density decreased from 1.80 g/cc at 0% emulsion to 1.74g/cc at 8% emulsion.

The O.M.C of sample B also increased from 15.3% at 0% asphalt-emulsion to 16.1% at 8% asphalt-emulsion content but decreased in M.D.D as emulsion content increases from 1.80 g/cc at 0% emulsion to 1.72 g/cc at 8% emulsion content.

For soil sample C, there is reduction in O.M.C and M.D.D as asphalt-emulsion content increases. At 0% emulsion, result gave an O.M.C of 16.3% which decreased to 15.7% at 8% emulsion content. The M.D.D also reduced from 1.70g/cc to 1.53g/cc at 8% emulsion content. Variations of M.D.D and O.M.C with asphalt-emulsion contents for samples A, B and C are shown in Figures 4.7 to 4.9.

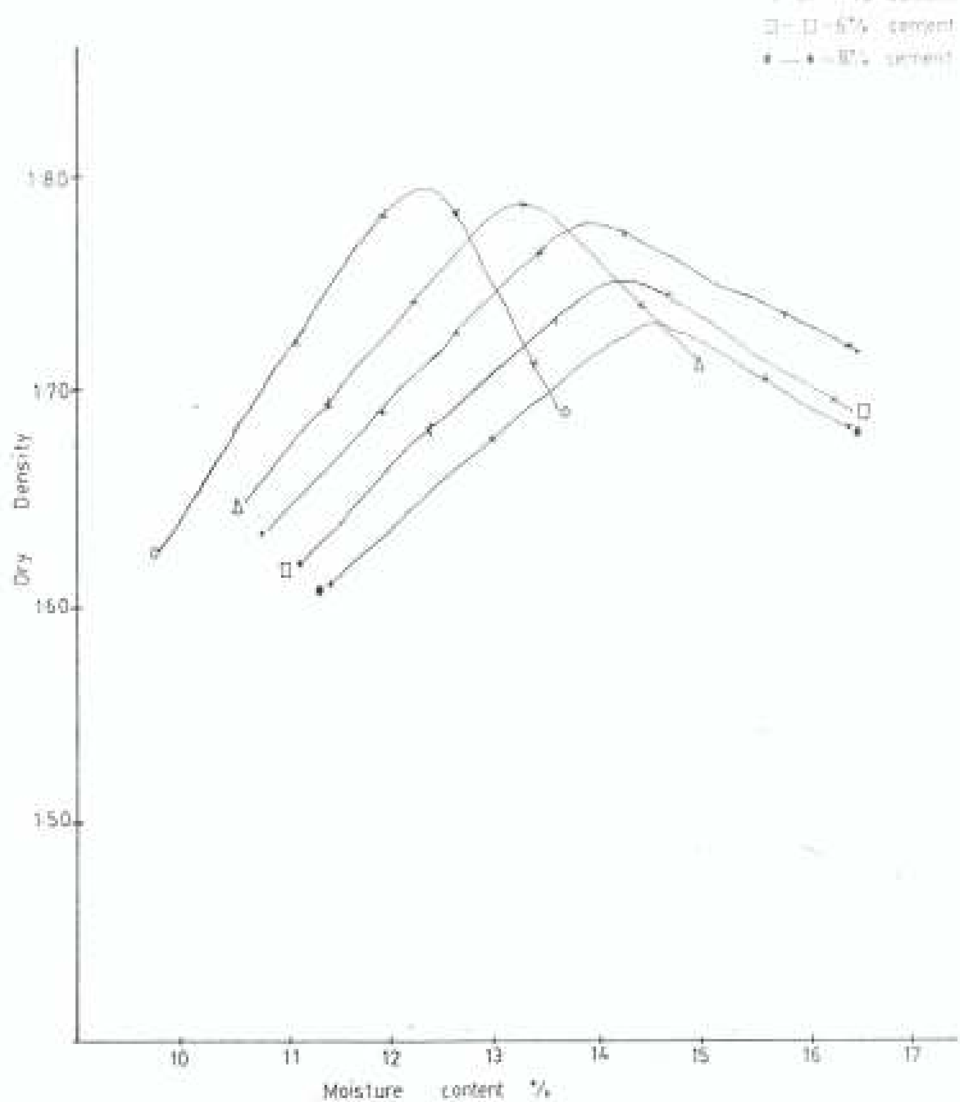


Fig4.4: Variation of Dry Density and Moisture content with cement content
(sample A)

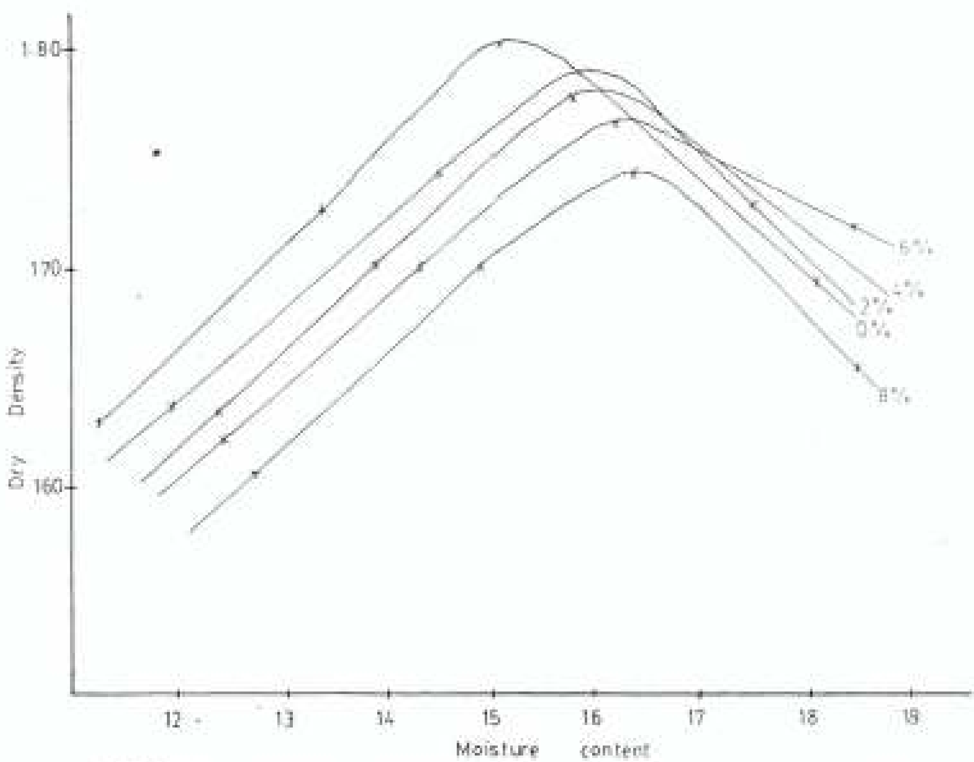


Fig4.5: Variation of Dry Density and Moisture content with Cement content
(sample B)

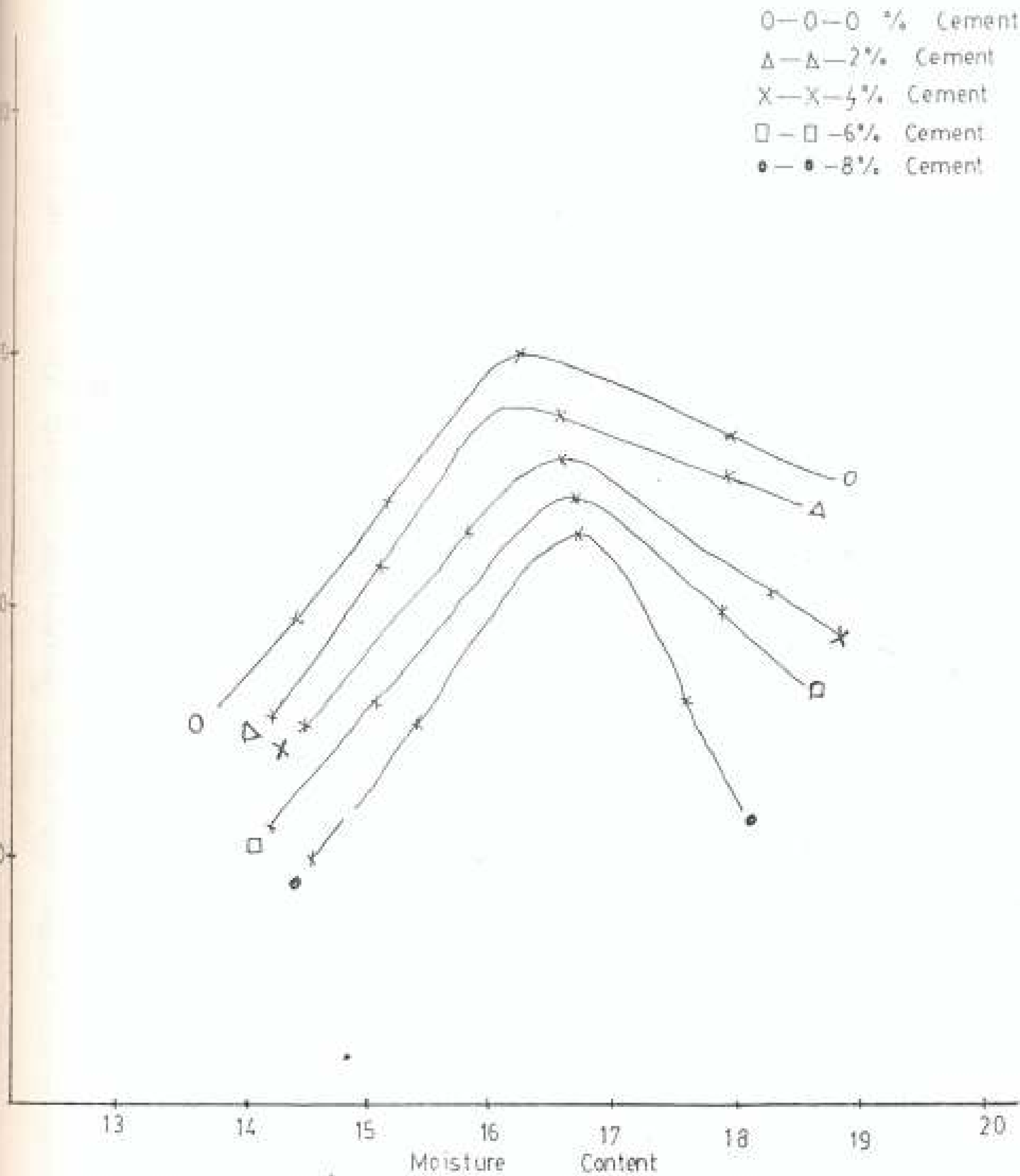


Fig4.6: variation of Dry Density and Moisture content with cement content [sample C]

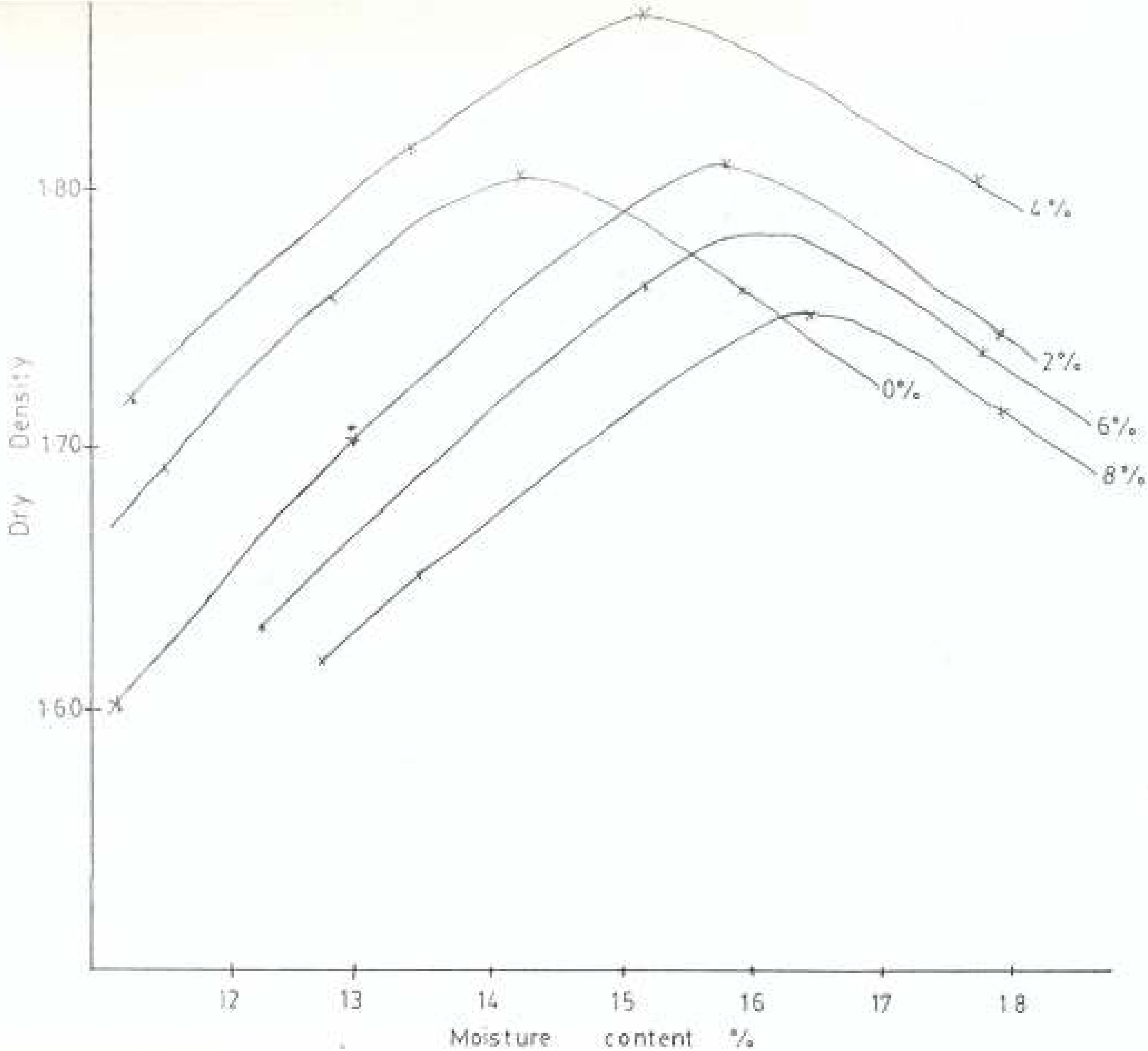


Fig 4.7: variation of Dry Density and Moisture Content with Asphalt-Emulsion content
(Sample A)

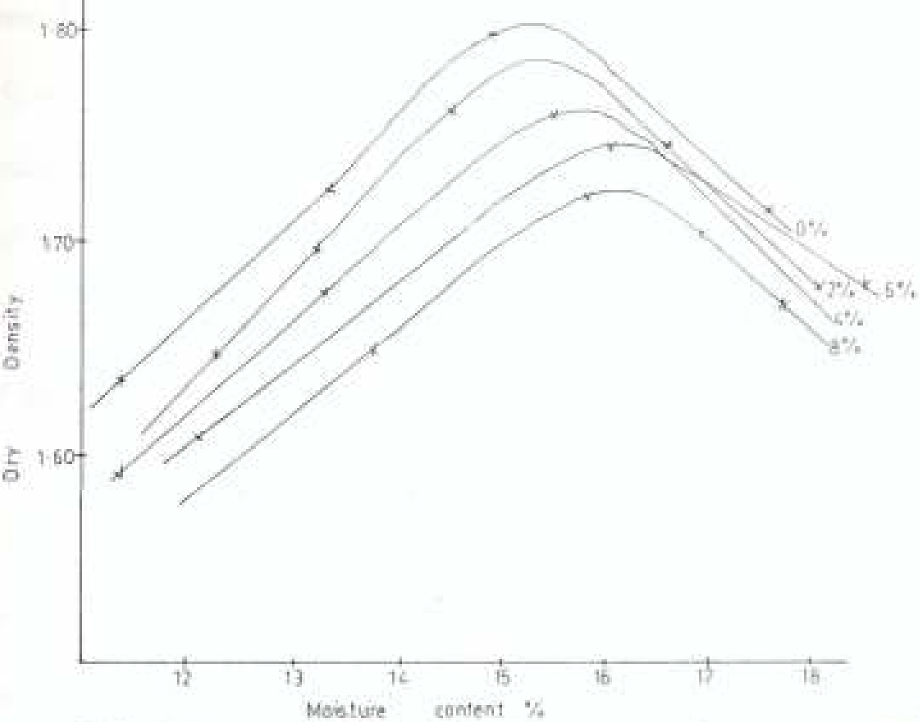


Fig48:variation of Dry Density and Moisture content with Asphalt-Emulsion content (sample B)

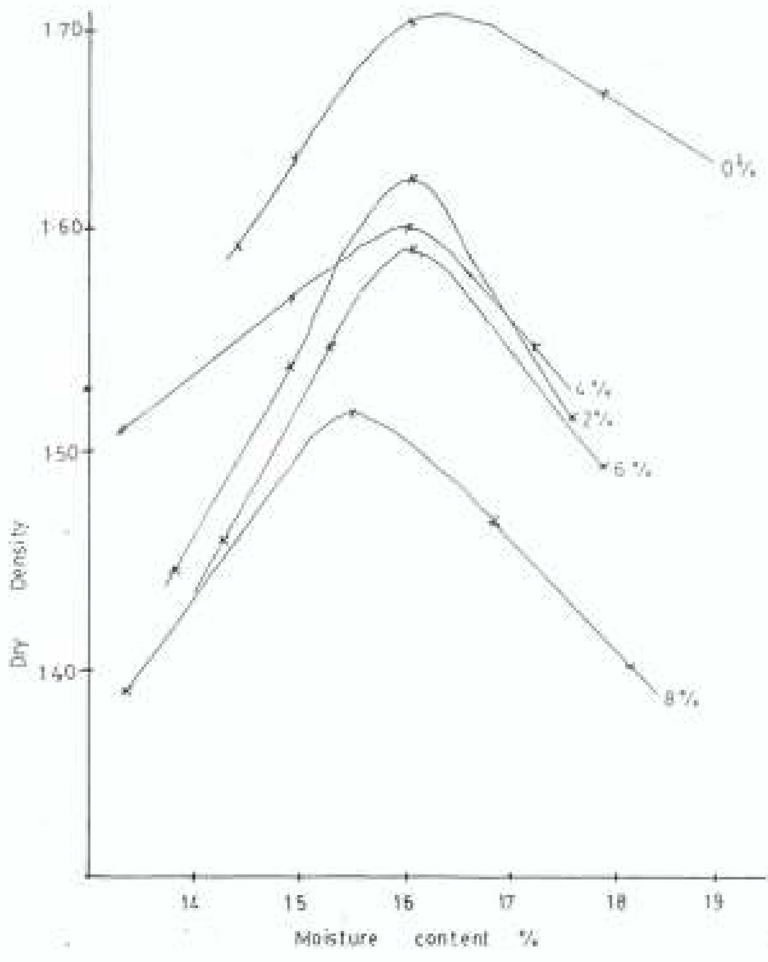


Fig49:variation of Dry Density and Moisture content with Asphalt-Emulsion content [sample C]

4.2.1.3 Cement-Modified Asphalt-Emulsion Mixtures

Samples A, B and C were treated with mixtures of asphalt-emulsion and cement. The proportions of asphalt-emulsion used were 2-8% with each percentage mixed with 0.5 - 2% cement to modify the samples.

Results of compaction tests carried out on the samples so treated are shown in Tables 4.6 to 4.8 for samples A, B and C respectively, with the relationship between dry density and mositure content at each variation of additives for sample C shown in Figures 10 to 21 in Appendix II.

Results show an increase in O.M.C and M.D.D of soil - cement - asphalt-emulsion combination of sample A. There is an increase in the O.M.C from 12.3% at 0% additives to 16.3% with 8% asphalt-emulsion combined with 2% cement. The M.D.D also increased from 1.80g/cc at 0% additive to 1.89g/cc using 2% emulsion and 2% cement content. Further increase in the quantity of additive led to reduction in the M.D.D to 1.78 g/cc at 8% emulsion and 2% cement content.

The O.M.C of sample B decreases from 15.3% at 0% emulsion to 13.2% at 8% emulsion combined with 0.5% cement and increased as the amount of cement added for modification increases. Using 8% emulsion and 2% cement gave an O.M.C of 16.3% with increase in additive content from 1.80g/cc at 0% emulsion to 1.64g/cc at 8% emulsion and 2% cement.

Table 4.6: SUMMARY OF TEST RESULTS FOR SAMPLE A TREATED WITH ASPHALT-EMULSION AND CEMENT

EMULSION :CEMENT	OMC %	MDD g/cc	CBR %	UCS 7days	UCS 14days	UCS 28days
2:0.5	14.8	1.86	85	1.02	1.20	1.34
4:0.5	15.0	1.84	120	3.96	4.19	4.32
6:0.5	15.2	1.82	145	3.00	3.25	3.60
8:0.5	15.4	1.79	100	2.20	2.41	2.53
2:1	15.0	1.83	105	2.81	3.00	3.25
4:1	15.4	1.81	125	4.00	4.25	4.66
6:1	15.8	1.77	150	3.50	3.72	3.80
8:1	16.1	1.76	120	2.70	2.81	2.88
2:2	14.8	1.89	120	3.56	3.73	3.90
4:2	15.6	1.83	200	4.85	5.00	5.12
6:2	15.8	1.82	150	3.80	3.98	4.21
8:2	16.3	1.78	125	2.86	2.90	2.98

TABLE 4.7 SUMMARY OF TEST RESULTS FOR SAMPLE B TREATED WITH ASPHALT-EMULSION AND CEMENT

EMULSION: CEMENT	OMC %	MDD g/cc	CBR %	UCS 7days	UCS 14days	UCS 28days
2:0.5	13.4	1.74	50	0.87	0.95	1.02
4:0.5	13.8	1.73	85	2.35	2.79	2.85
6:0.5	13.1	1.72	95	2.70	2.87	3.01
8:0.5	13.2	1.70	80	2.00	2.36	2.41
2:1	13.6	1.72	75	0.96	1.02	1.16
4:1	15.4	1.70	98	3.19	3.30	3.46
6:1	14.2	1.63	119	2.80	2.93	3.01
8:1	15.0	1.60	80	2.50	2.61	2.75
2:2	14.4	1.70	100	2.90	3.00	3.34
4:2	15.3	1.68	140	3.50	3.65	3.80
6:2	15.8	1.66	125	3.01	3.30	3.38
8:2	16.3	1.64	115	2.60	2.72	2.80

TABLE 4.8: SUMMARY OF TEST RESULTS FOR SAMPLE C TREATED WITH ASPHALT-EMULSION AND CEMENT

EMULSION: CEMENT	OMC %	MDD g/cc	CBR %	UCS 7days	UCS 14days	UCS 28days
2:0.5	15.2	1.63	25	0.58	0.95	1.20
4:0.5	16.3	1.69	45	0.90	1.16	1.28
6:0.5	16.6	1.63	50	1.50	1.65	1.80
8:0.5	16.3	1.54	80	1.60	1.80	1.87
2:1	15.6	1.61	30	0.75	1.00	1.18
4:1	15.6	1.60	50	0.95	1.07	1.29
6:1	16.1	1.58	70	1.20	1.38	1.50
8:1	16.5	1.55	90	1.70	1.83	1.95
2:2	15.8	1.65	40	1.86	2.00	2.54
4:2	15.9	1.63	90	2.80	3.15	3.40
6:2	16.3	1.59	105	3.05	3.20	3.50
8:2	16.6	1.56	120	3.70	4.00	4.21

For soil sample C, using 4% asphalt-emulsion mixed with 0.5% cement gave the highest M.D.D result of 1.69g/cc at an O.M.C of 16.3% but adding more emulsion and cement led to reduction in the M.D.D. With 2% emulsion and 1% cement, result show a M.D.D. of 1.61g/cc which reduced to 1.56 g/cc and an increased O.M.C of 16.6% at 8% emulsion with 2% cement content.

Figures 4.10 to 4.18 show relationship between M.D.D and O.M.C for varied percentages of asphalt-emulsion modified with different proportions of cement for the three samples.

4.2.2 California Bearing Ratio (CBR)

California Bearing Ratio tests were carried out on samples A, B and C, using cement asphalt-emulsion and combinations of asphalt-emulsion and cement for treatment in varied proportions at varying moisture contents. Values of CBR at the optimum moisture contents were taken and recorded for the three samples. Shown in Figures 1 to 21 in Appendix II are the laboratory results for sample C.

4.2.2.1 Cement Treated Samples

California Bearing Ratio test was carried out on samples A,B and C treated with cement. The test results are as shown in Figures 1 to 5 in Appendix II for sample C.

For all samples tested, results show a general increase in C.B.R values with increasing amount of additives. The C.B.R of sample A increased tremendously from 20% at 0% cement to 220% at 8% cement content while sample B C.B.R value increases from 18% at 0% cement to 199% at 8% cement contents.

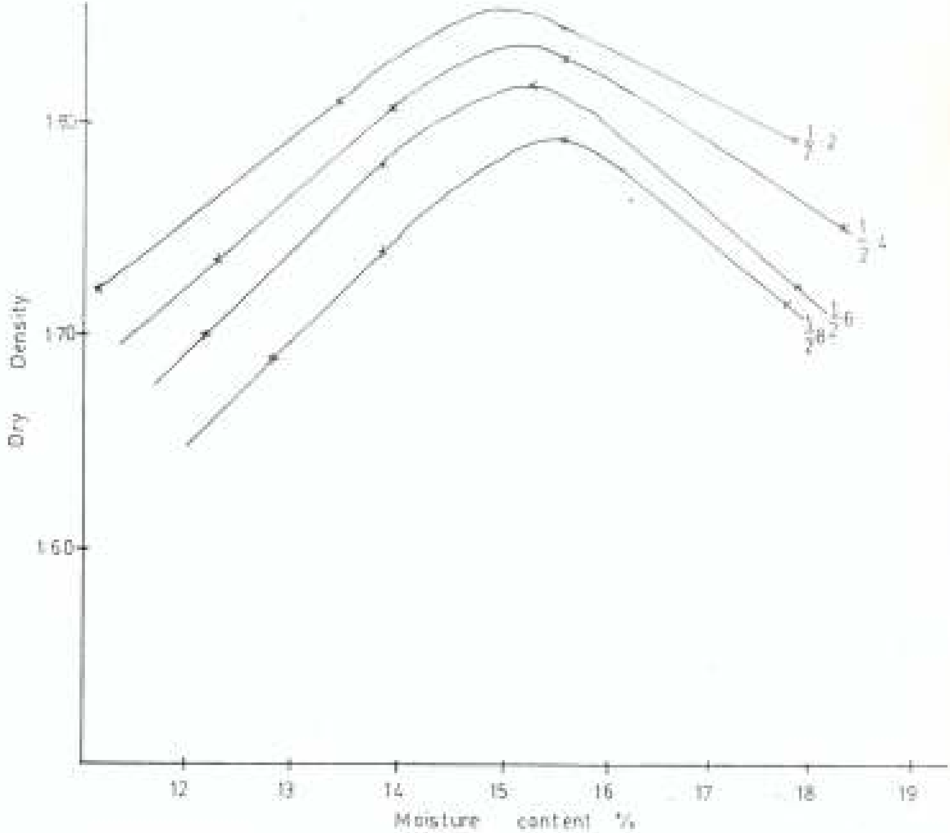


Fig.6.10: variation of Dry Density and Moisture content with varied % of Asphalt Emulsion modified with $\frac{1}{2}$ percent cement content [sample A]

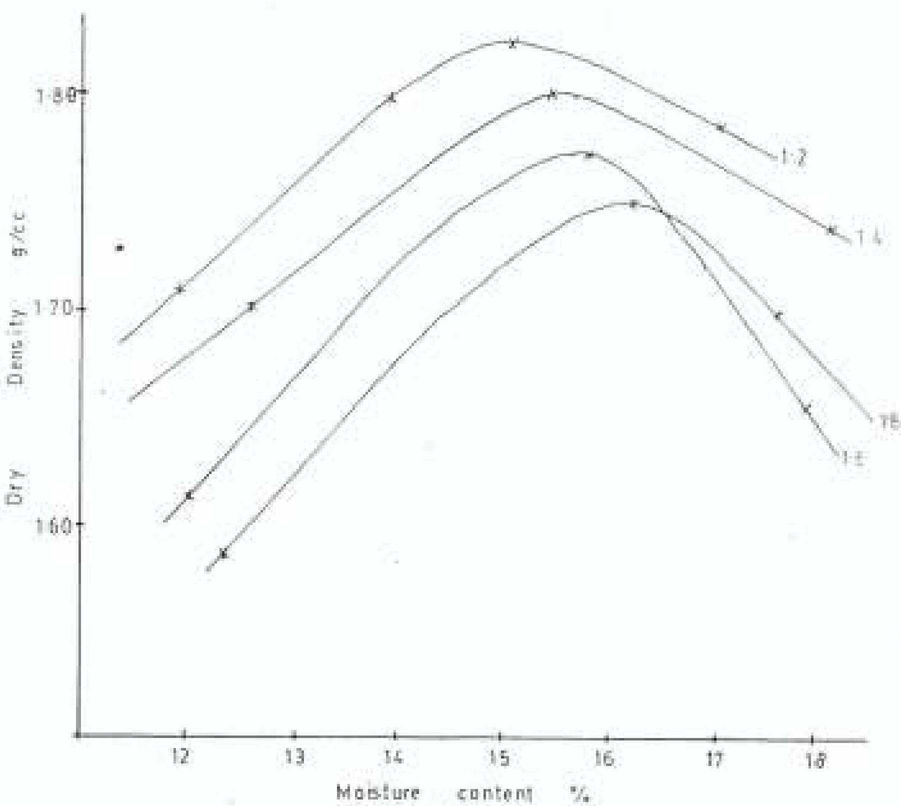


Fig.6.11 : variation of Dry Density and moisture content with varied % of Asphalt Emulsion modified with 1 percent cement content [sample A]

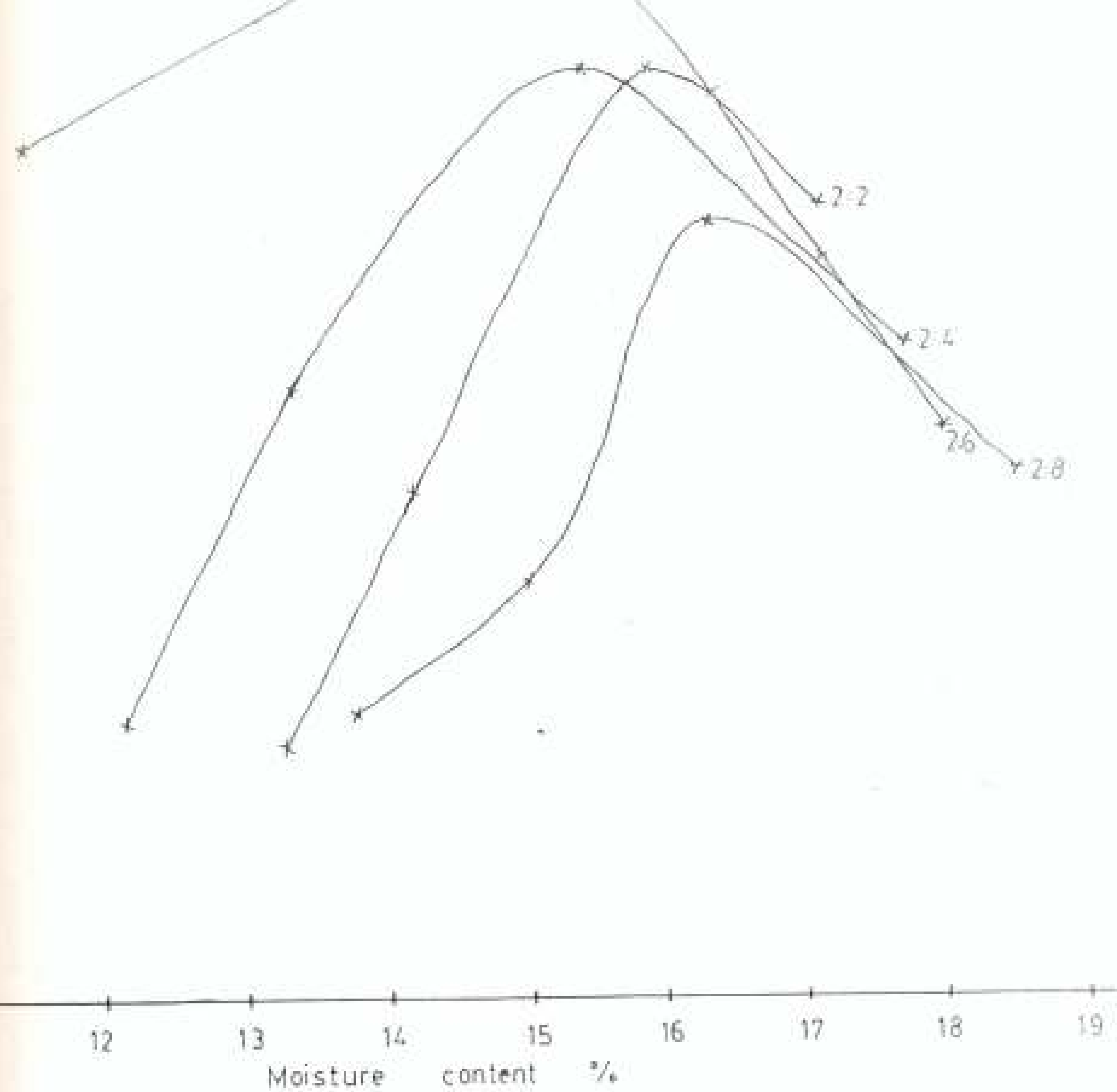


Fig4.12 Variation of Dry Density and moisture content with varied % of Asphalt-Emulsion modified with 2 % cement content [sample A]

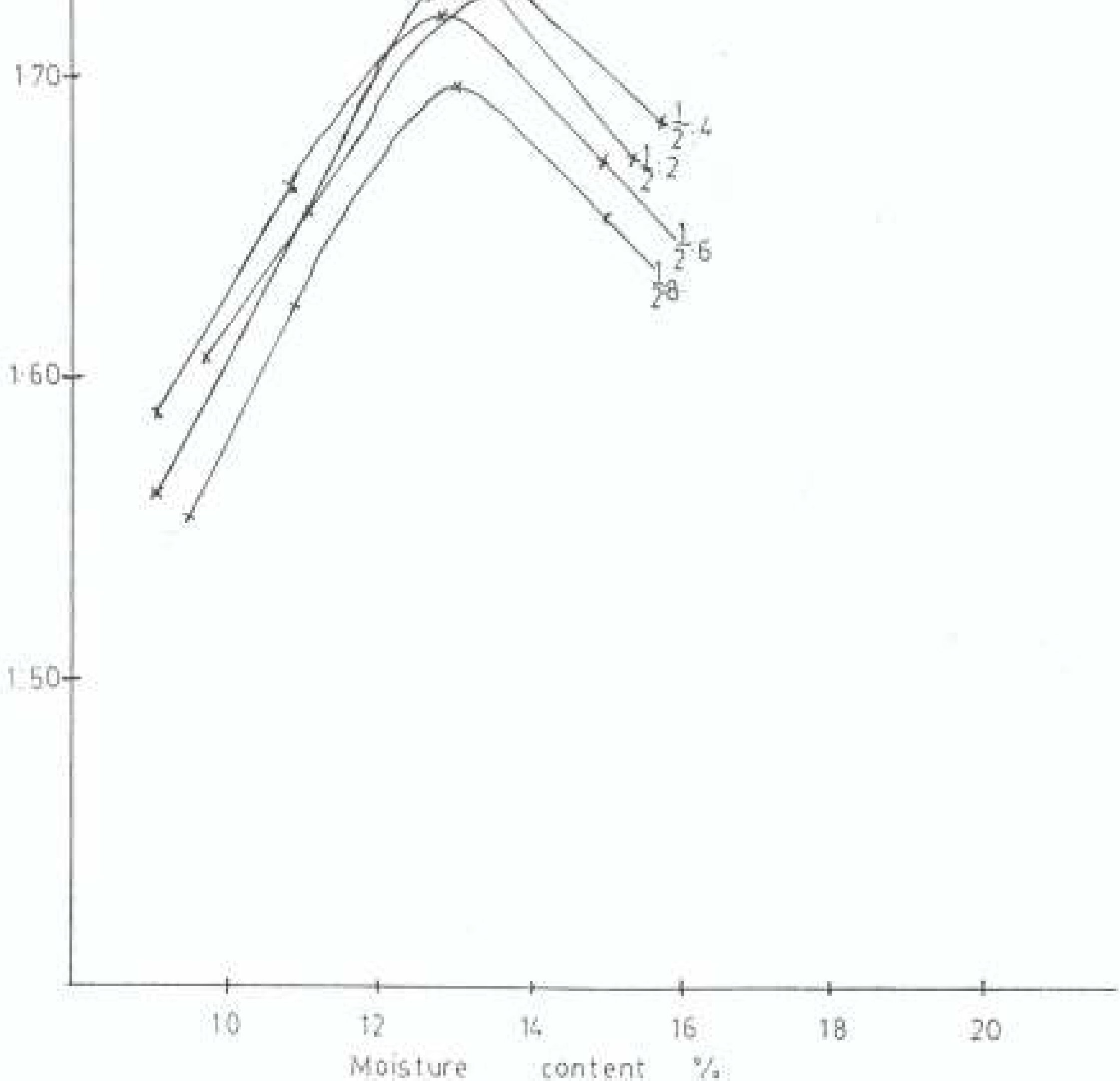


Fig.4·13 Variation of Dry Density and mosture content with varied % of Asphalt Emulsion modified with $\frac{1}{2}$ percent cement content

I Sample II I

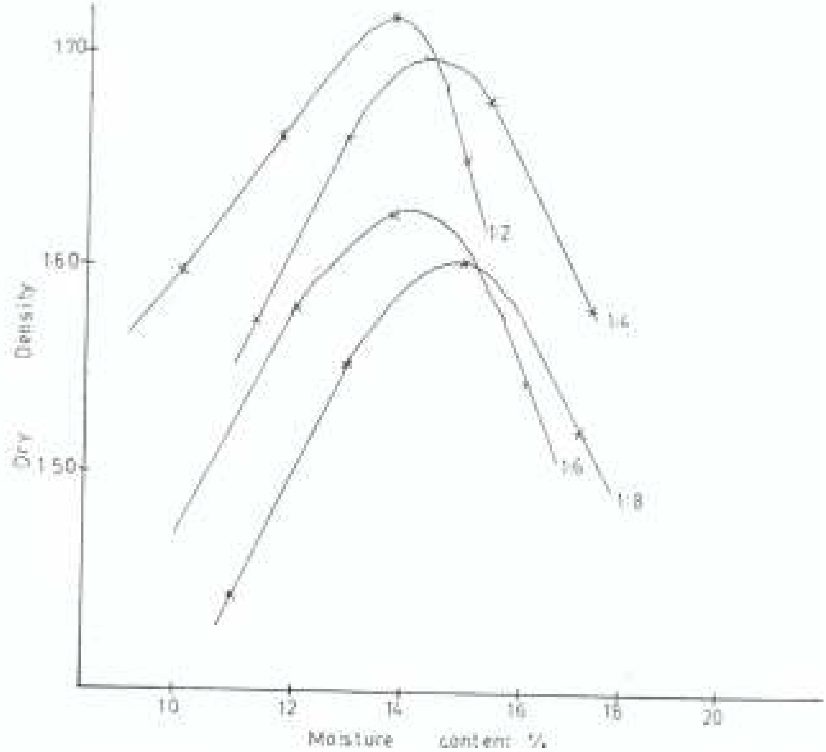


Fig.4.14: Variation of Dry Density and moisture content with varied % Asphalt-Emulsion modified with 1 percent cement content (sample B)

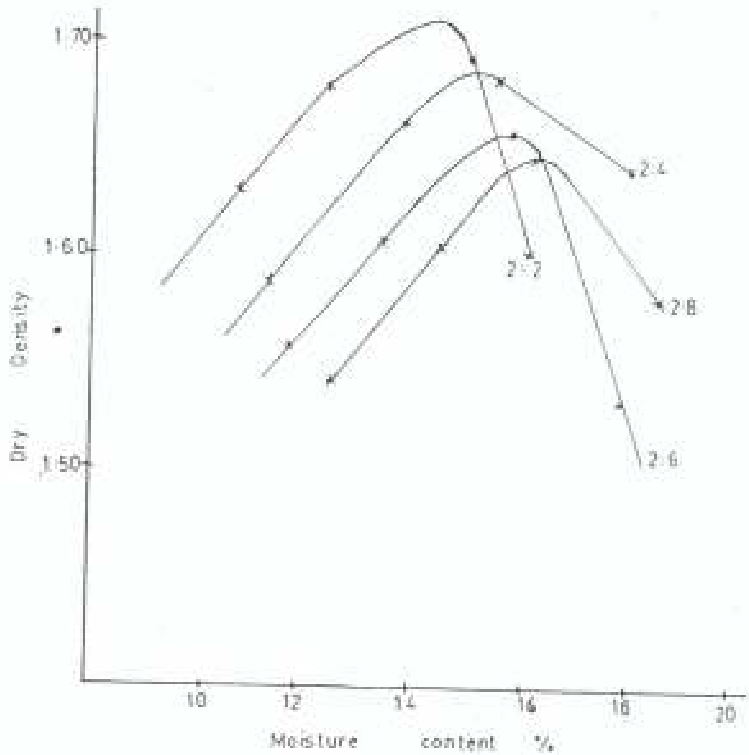


Fig.4.15: Variation of Dry Density and moisture content with varied % Asphalt-Emulsion modified with 2 percent cement content [sample B]

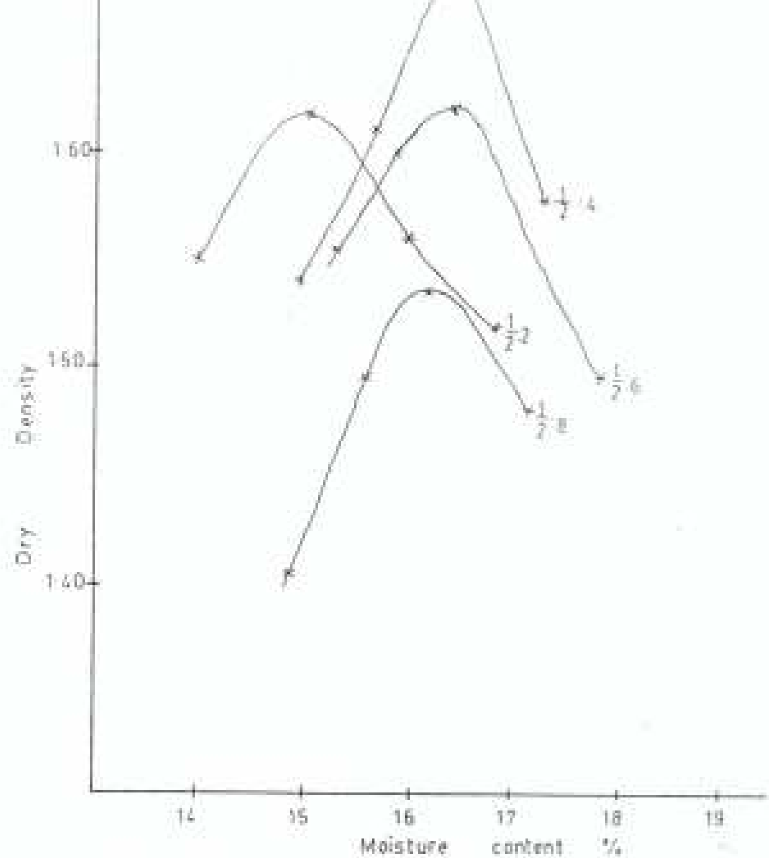


Fig 4.4-Variation of Dry Density and moisture content with varied Asphalt – Emulsion modified with $\frac{1}{2}$ percent cement content [sample C]

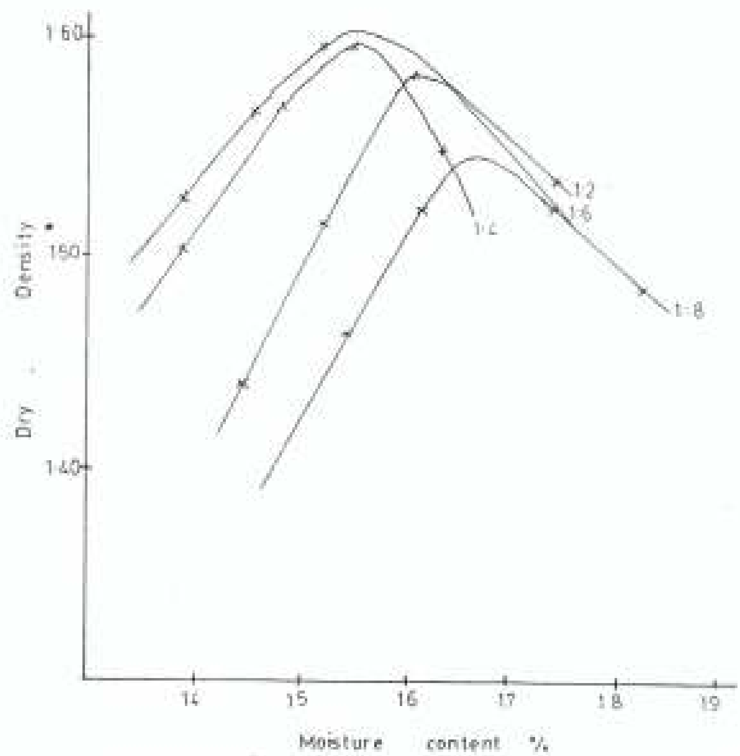


Fig 4.11-Variation of Dry Density and moisture content with va
% of Asphalt – Emulsion modified with 1 percent ceme
content [sample C]

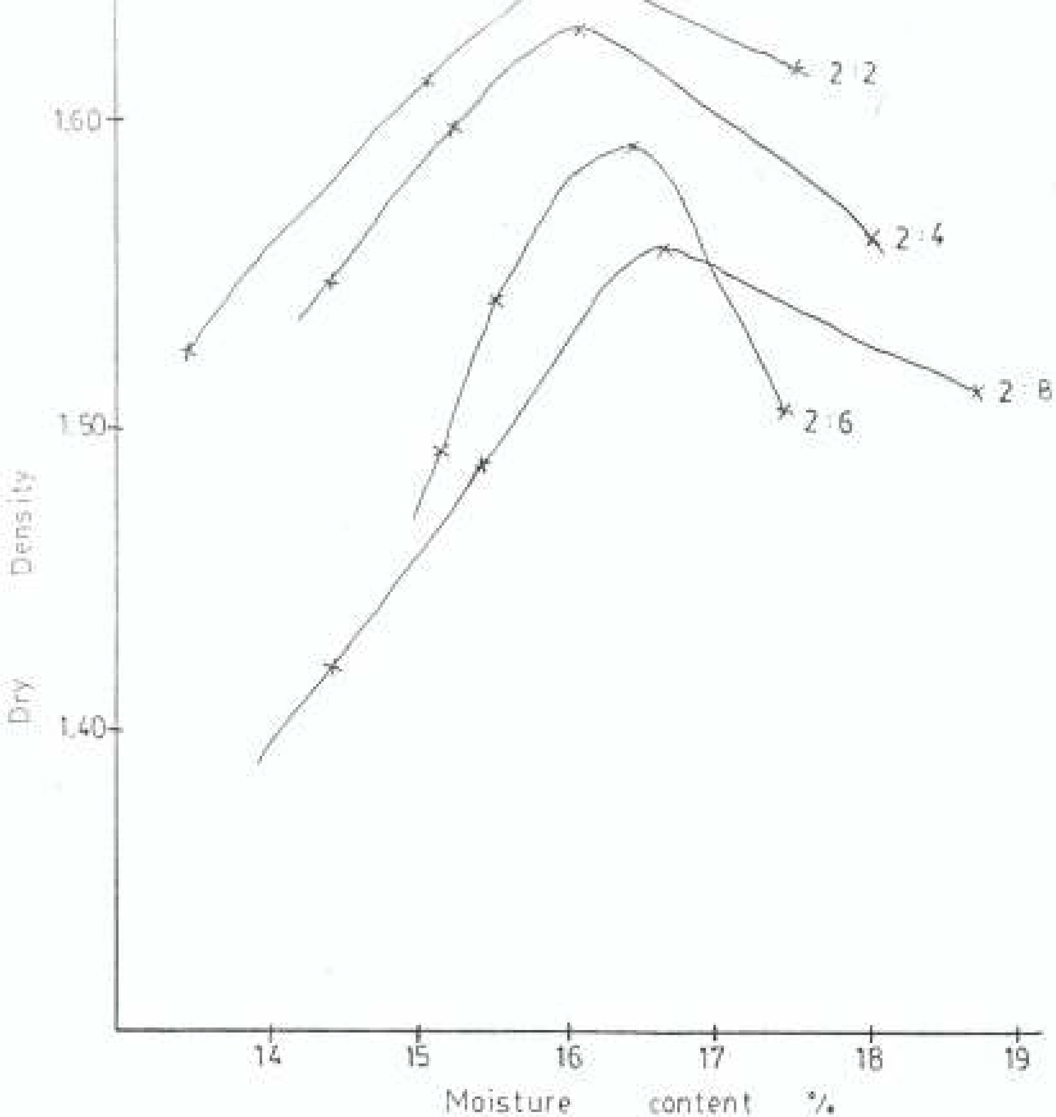


Figure Variation of Dry Density and moisture content with varied % of Asphalt-Emulsion modified with 2 percent cement [sample C]

Sample C also has an increase from its natural C.B.R value of 8% to 102% using 8% cement content indicating that strength of the materials increases as cement content increases within the limits of the percentages used. Sample A due to its coarse nature has the highest CBR values at all percentages of cement used when compared to the other samples. Sample C has the lowest value due to high percentage of fines present in it. The variations of CBR values with cement contents for the three samples are shown on figures 4.19 to 4.22.

4.2.2.2 Asphalt-Emulsion Treated Samples

Shown on Table 4.5 are results of CBR tests on samples A, B and C treated with 2-8% asphalt-emulsion contents. The CBR values of samples A and B increase as asphalt-emulsion content increases to a maximum at 6% emulsion content after which the CBR values decrease on further addition of emulsion.

At 0% emulsion content, sample A has a CBR value of 20% which increases continuously as emulsion content increases to a maximum value of 140% at 6% emulsion content. Using 8% emulsion led to a decrease in CBR value to 91% showing that the optimum asphalt-emulsion content to be used for treating sample A is 6% for maximum strength but for a base material which requires a CBR value of 100%, the optimum emulsion content for sample A should be 4% which gives a CBR value of 110%.

For soil B, there is an increase in CBR value from 18% at 0% emulsion content to a CBR value of 80% at 6% emulsion content and at 8% emulsion, the CBR value decreased to 60% showing that for sample B, the optimum emulsion content is 6%.

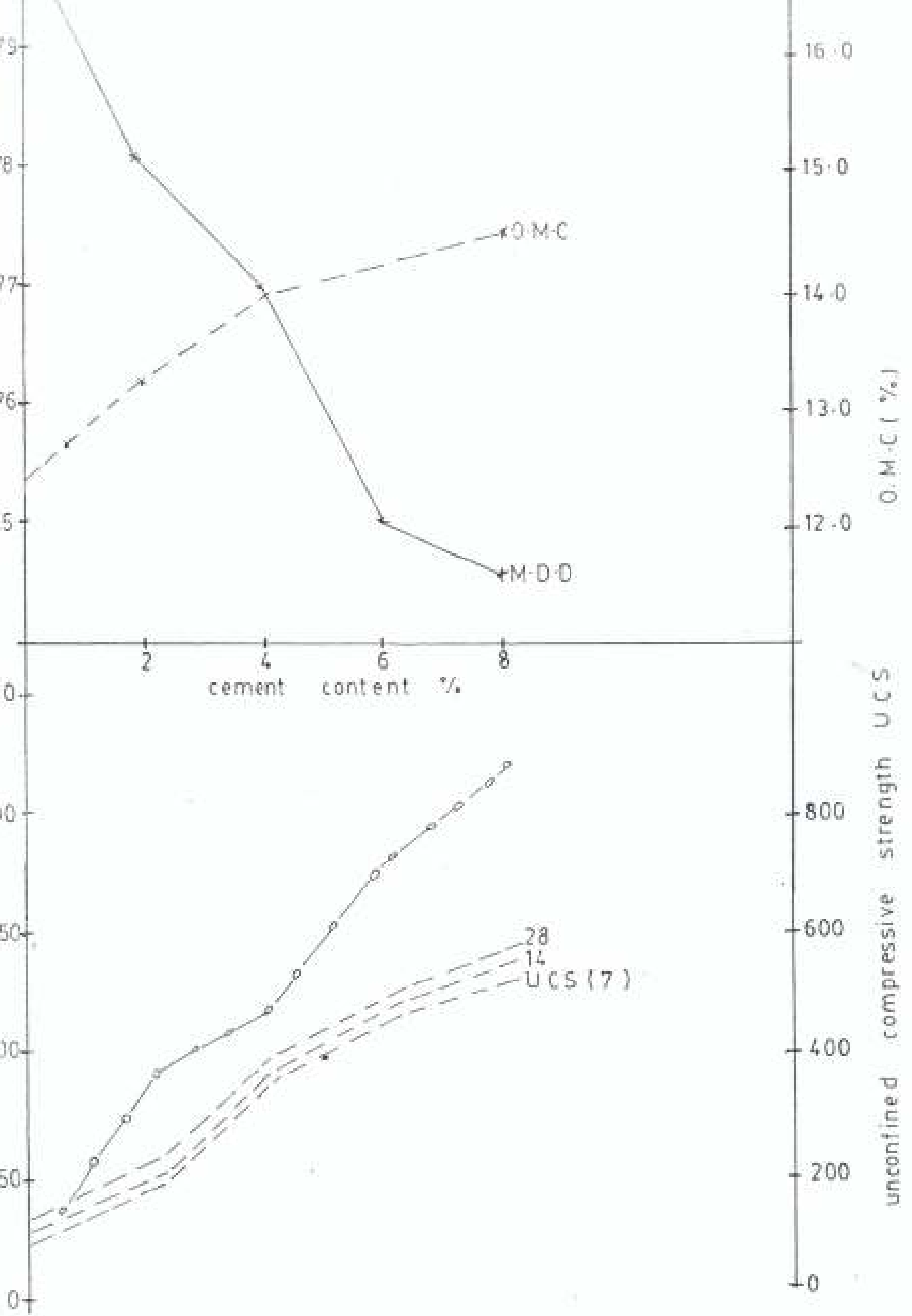


Fig.4.19: Variation of M.D.D, O.MC, C.B.R and UCS with cement content
[sample A]

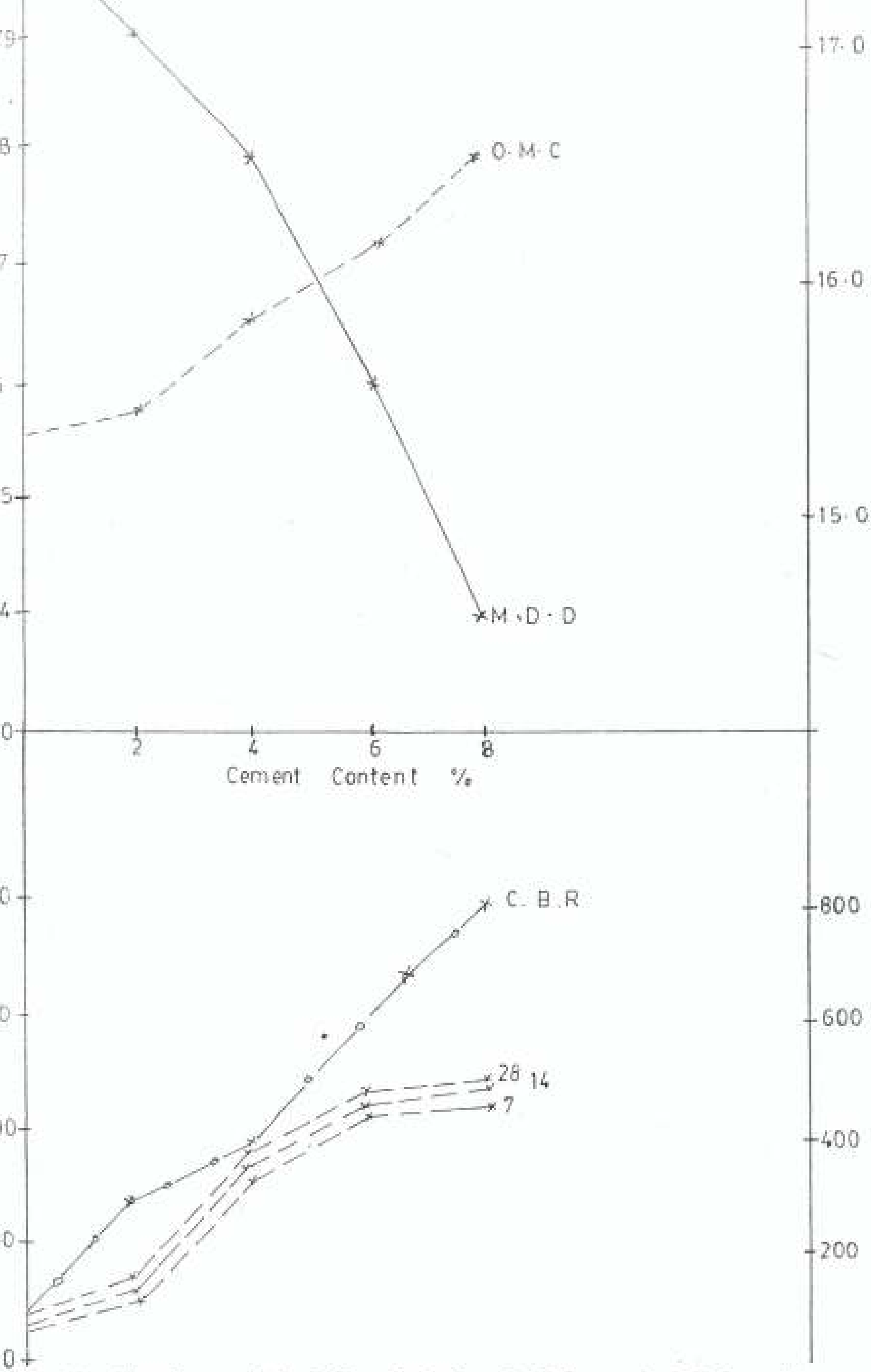


Fig.4.20: Varation of M.D.D., O.M.C., C.B.R and U.C.S with cement content [Sample B].

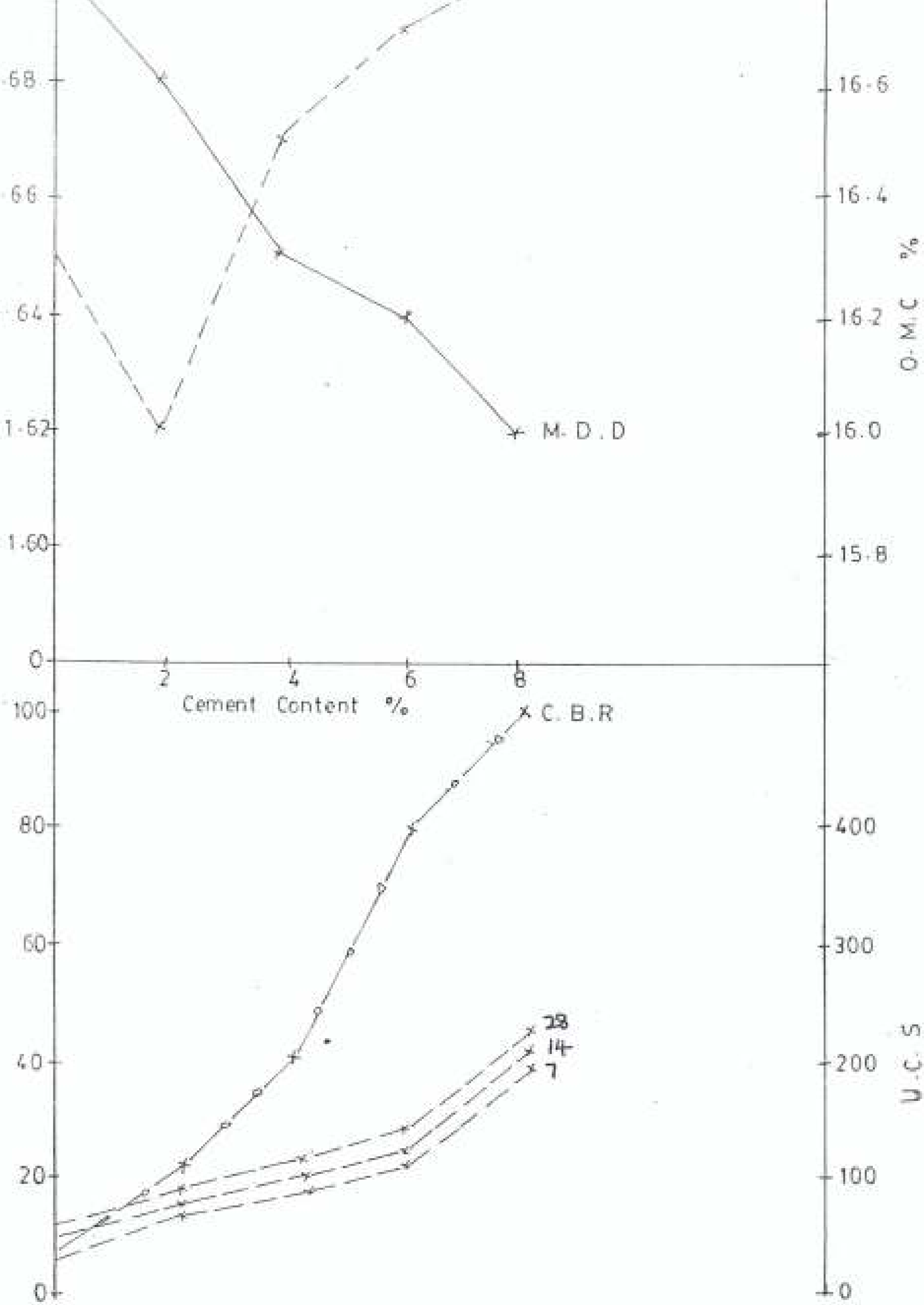


Fig.4.21: Variation of M.D.D, O.M.C, C.B.R and U.C.S with cement content [Sample C]

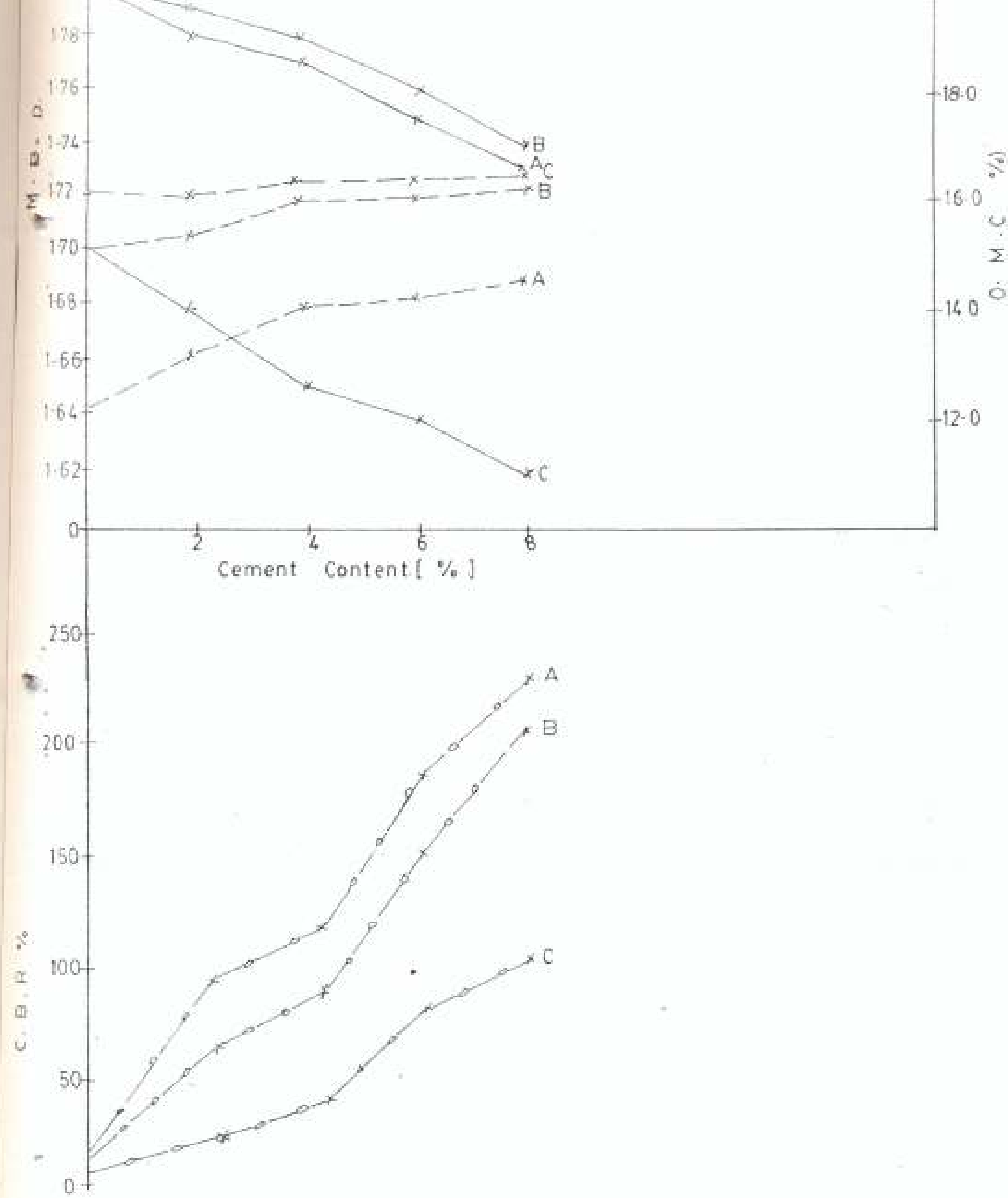
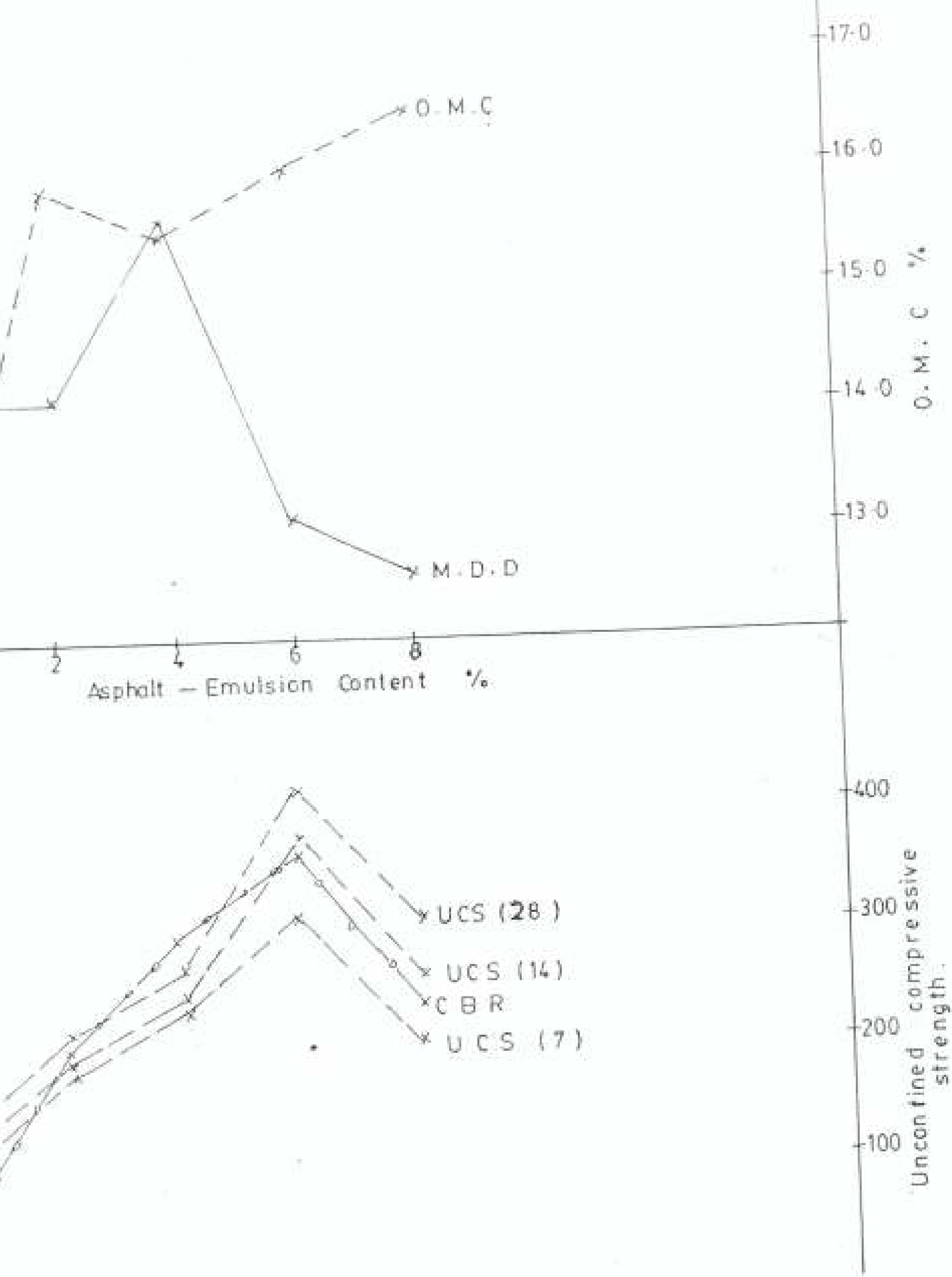


Fig.4.21: Variation of M.D.D, O.M.C, C.B.R and U C S with cement content [Sample A, B and C.]

The CBR values of sample C increase as asphalt-emulsion content increase but with low percentage of increment. It increases from a CBR value of 8% at 0% emulsion to a maximum value of 60% at 8% emulsion content. Addition of more emulsion will be required to bring the material for use as a base material. This low CBR values of sample C is due to presence of excessive amounts of clay which made mixing and compacting difficult in concerning to the work of L.D coyne and R.M Ripple of Chevron Asphalt company Emulsified Asphalt Mix Design and Construction, (1975) which shows that materials containing excessive amounts of clay are not suitable for treatment with asphalt-emulsion due to difficulty in mixing and rolling and high amounts of emulsions required to achieve necessary water resistance thus making the economics of treatment unattractive. The variations of CBR values with asphalt-emulsion content are related in Figures 4.23 to 4.25 for samples A, B and C.

4.2.2.3 Cement-Modified Asphalt-Emulsion Mixtures

Cement in varying proportions of 0.5, 1 and 2% were added to samples A, B and C before treating with asphalt-emulsion. Unsoaked CBR tests were carried out on the specimens to determine the influence of cement on strength of soil-asphalt-emulsion mixes.



g.4.23: Variation of M.D.D, O.M.C, C.B.R and U.C.S with Asphalt - Emulsion content of sample A.

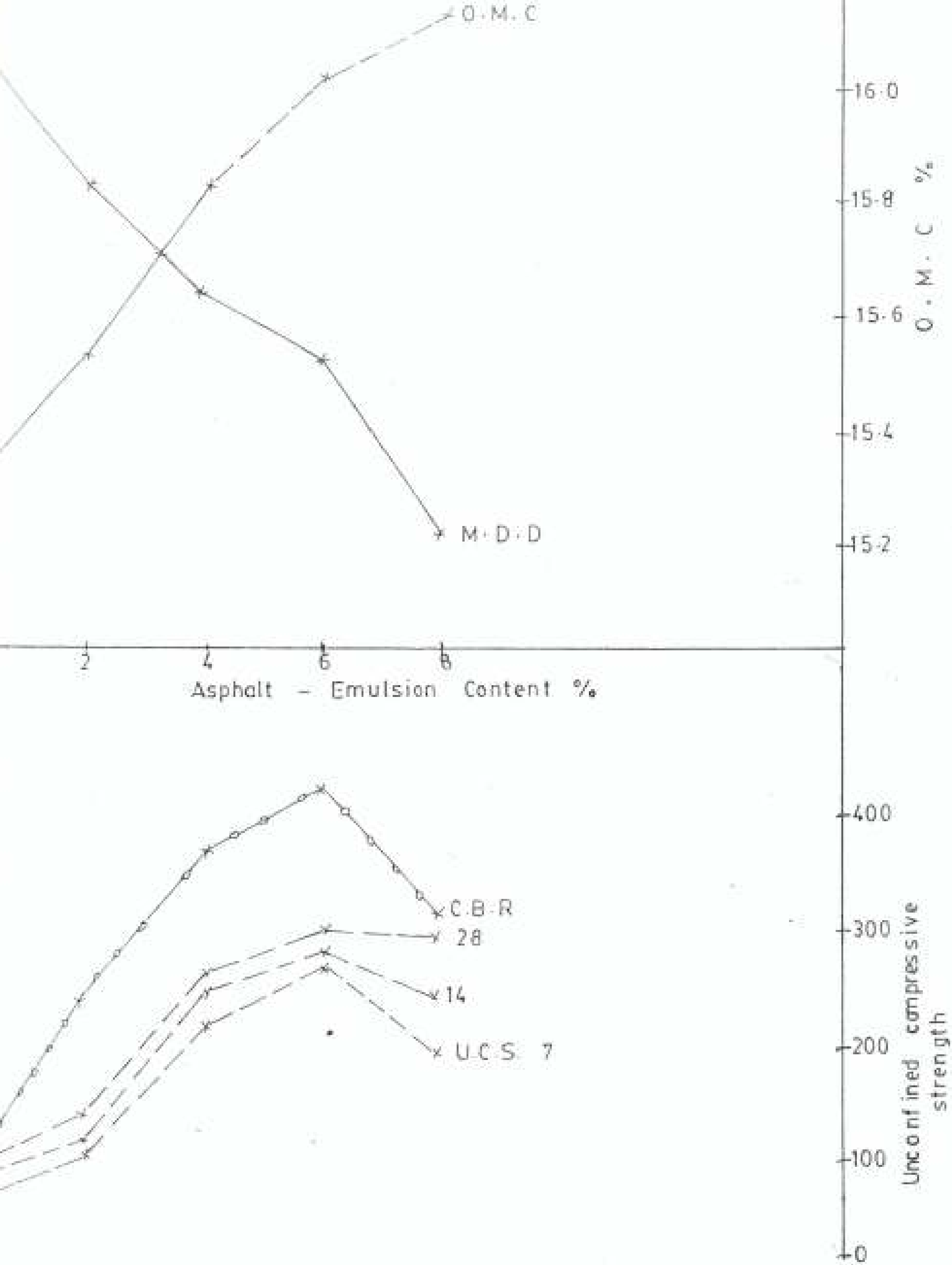
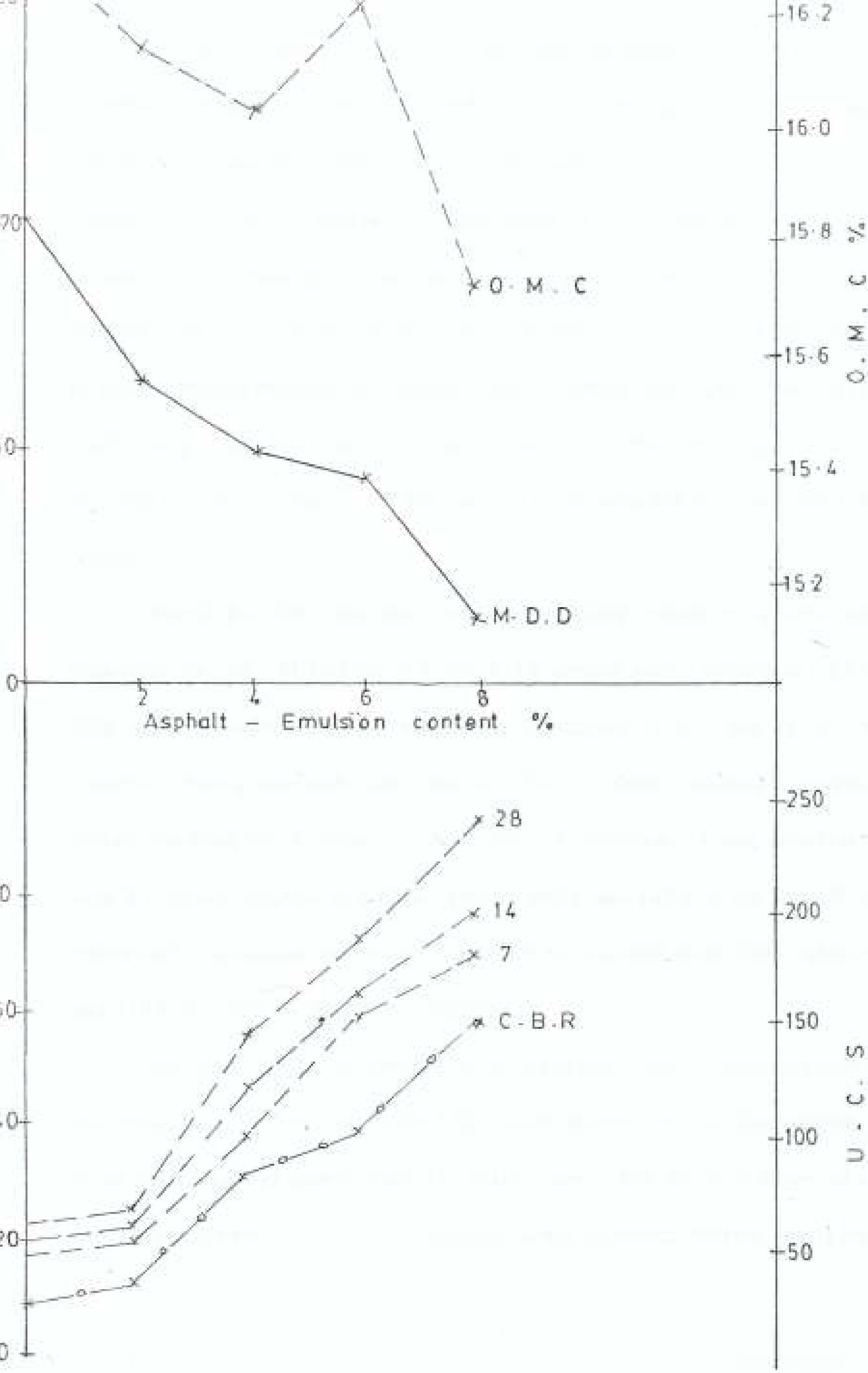


Fig.4.24: Variation of M.D.D, O.M.C, C.B.R and U.C.S with Asphalt - Emulsion content of sample B.



Fig·4·25 Variation of M·D·D, O·M·C, C·B·R and U·C·S with Asphalt – Emulsion content of sample C.

Shown in Tables 4.6 to 4.8 are CBR values of asphalt-emulsion treated samples modified with cement. Addition of 0.5% cement with asphalt-emulsion contents for sample A increases the CBR value from 85% with 2% emulsion to 145% using 6% emulsion and with 8% emulsion, a CBR value of 100% was obtained. Adding 1% cement to the different percentages of emulsion increased the CBR value to a maximum of 150% with 6% emulsion and on further increment of cement, the CBR value reduced to 120%. Mixing the emulsion contents with 2% cement gave CBR values of 120% and 200% using 2 and 4% emulsion contents respectively but increasing emulsion content over this percentage reduces the CBR value to 125% using 8% emulsion with 2% cement contents.

Sample B's CBR value also increases by adding cement to asphalt-emulsion for improving the soil. Mixing the soil with 0.5% cement gave a maximum CBR value of 95% with 6% asphalt-emulsion which later reduced to a CBR value of 80% with 8% emulsion. Also a maximum CBR value of 119% was obtained using 1% cement and 6% asphalt-emulsion which reduces to 80% with 8% emulsion. Mixing emulsion contents with 2% cement resulted in a CBR value of 100% and 140% at 2% and 4% emulsion respectively. Increasing emulsion contents led to reduction in the CBR values to 125% and 115% at 6 and 8% emulsions respectively.

Sample C, due to the presence of too much clay, requires high emulsion contents for modification with cement. The CBR values increase as emulsion contents increase at all percentages of cement used for modification. For the percentages of emulsion used, the maximum CBR value was obtained at 8% emulsion. Mixing with 0.5% cement gave a value of 25% at 2% emulsion which increases to 80% at 8% emulsion and using 1% cement gave a CBR value of 90% with 8% emulsion content. Using 2% cement for modification gave the best result at all percentages of emulsion. It gave a CBR value of 40% with 2% emulsion and a maximum value of 120% at 8% emulsion.

Comparing the results of adding cement to asphalt-emulsion and using asphalt-emulsion alone for improving the three samples tested shows that small addition of cement materially improves the strength of asphalt-emulsion treated samples. The variation of CBR with modified Asphalt-Emulsion mixtures are shown in figures 4.26 to 4.28.

4.2.3 Unconfined Compressive Strength Test (UCS)

To determine the suitability of samples for treatment with the chosen admixtures, unconfined compressive strength tests were carried out on the three samples as mentioned previously. Curing of samples was carried out by wrapping test specimens in nylon bags and placing them in a humidity room. The samples were tested at 1, 7, 14 and 28 days to determine the effect of age on strength of the samples.

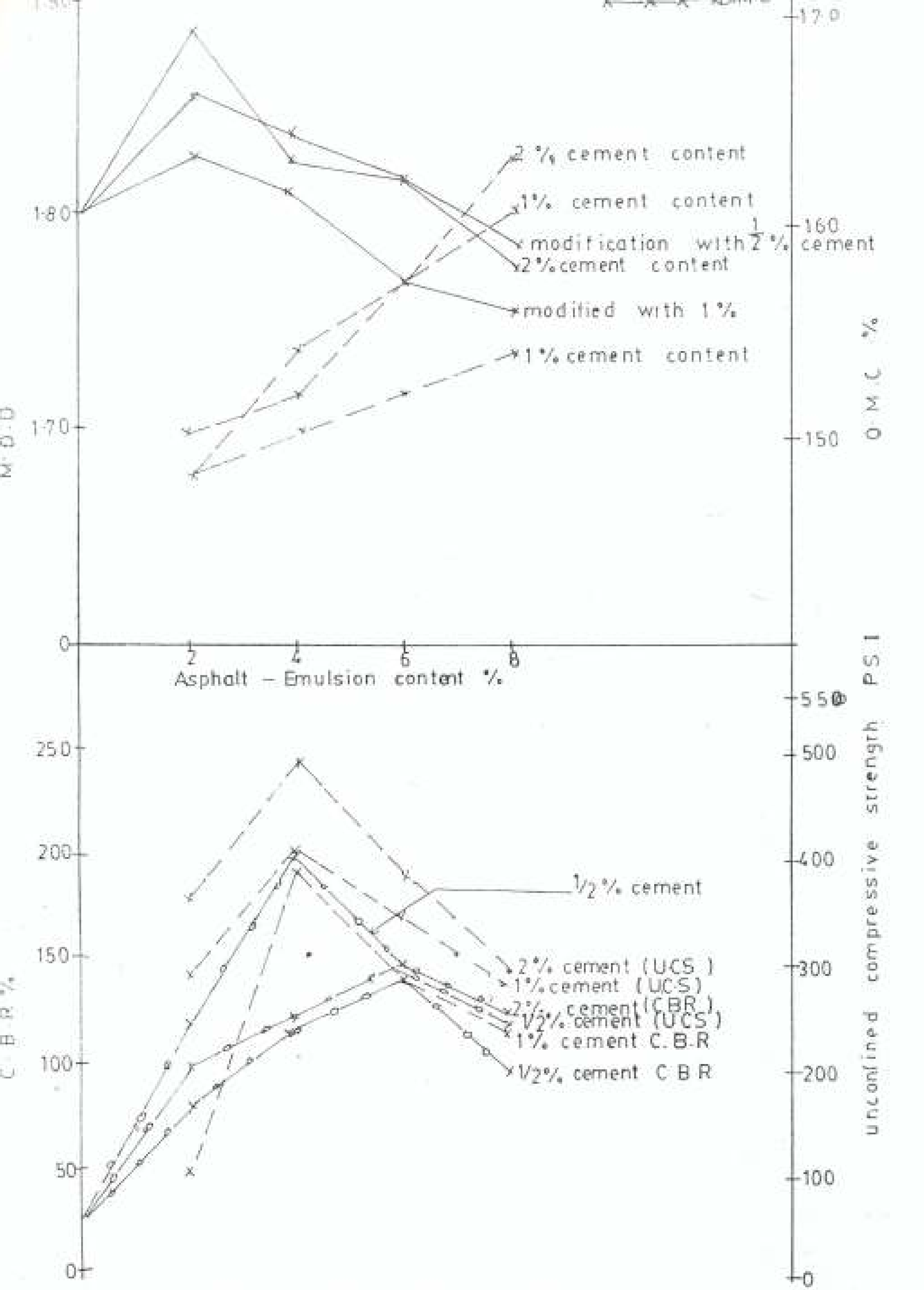


Fig 4.36: Variation of M.D.D, O.M.C, C.B.R and U.C.S with Asphalt-Emuls content of sample A modified with 1/2-2 percent cement co

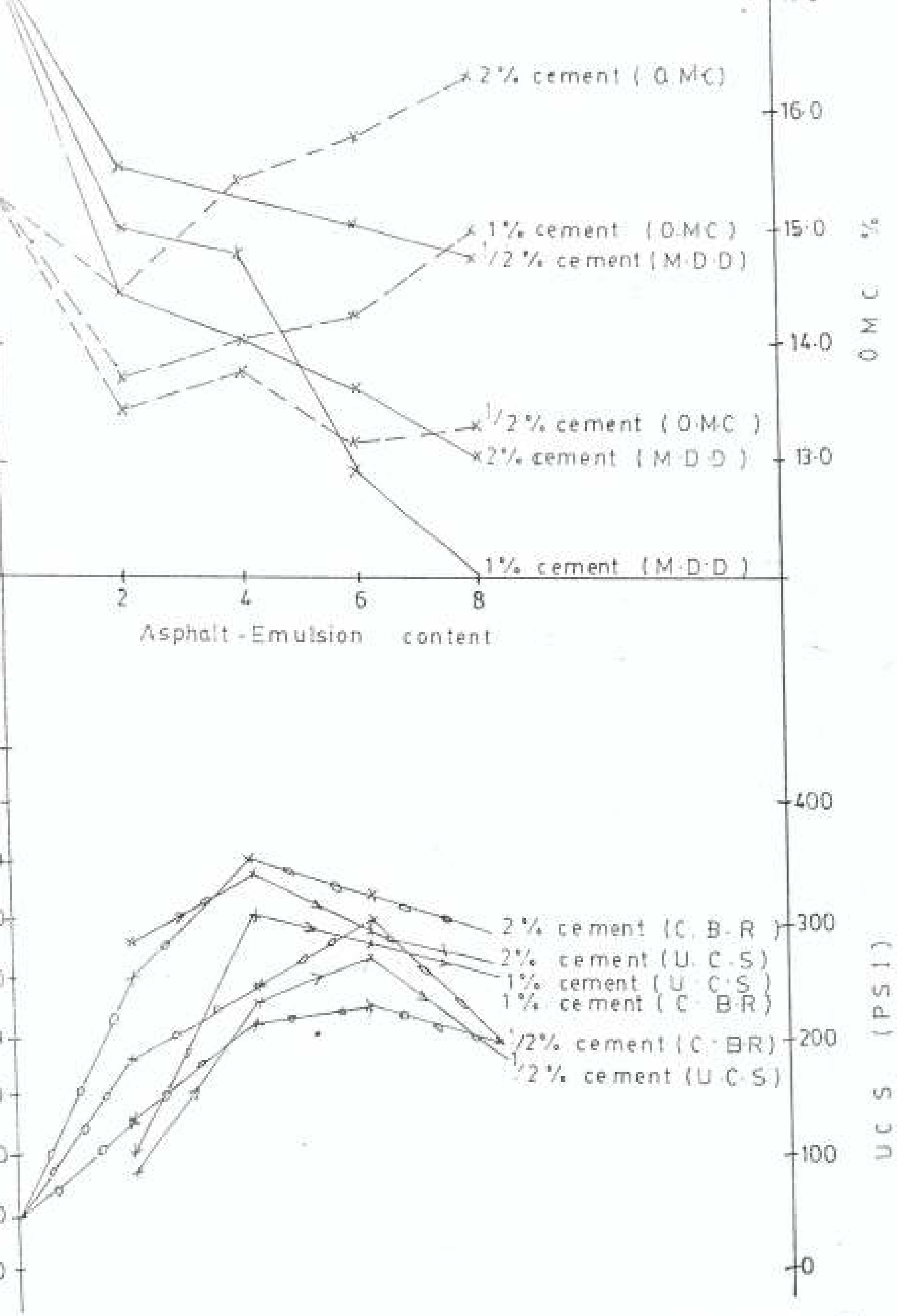


Fig.4.27 variation of M D D, O M C, C B R and U C S with Asphal[t]
Emulsion content of sample B modified with 1/2–2 percent cem[ent]
content

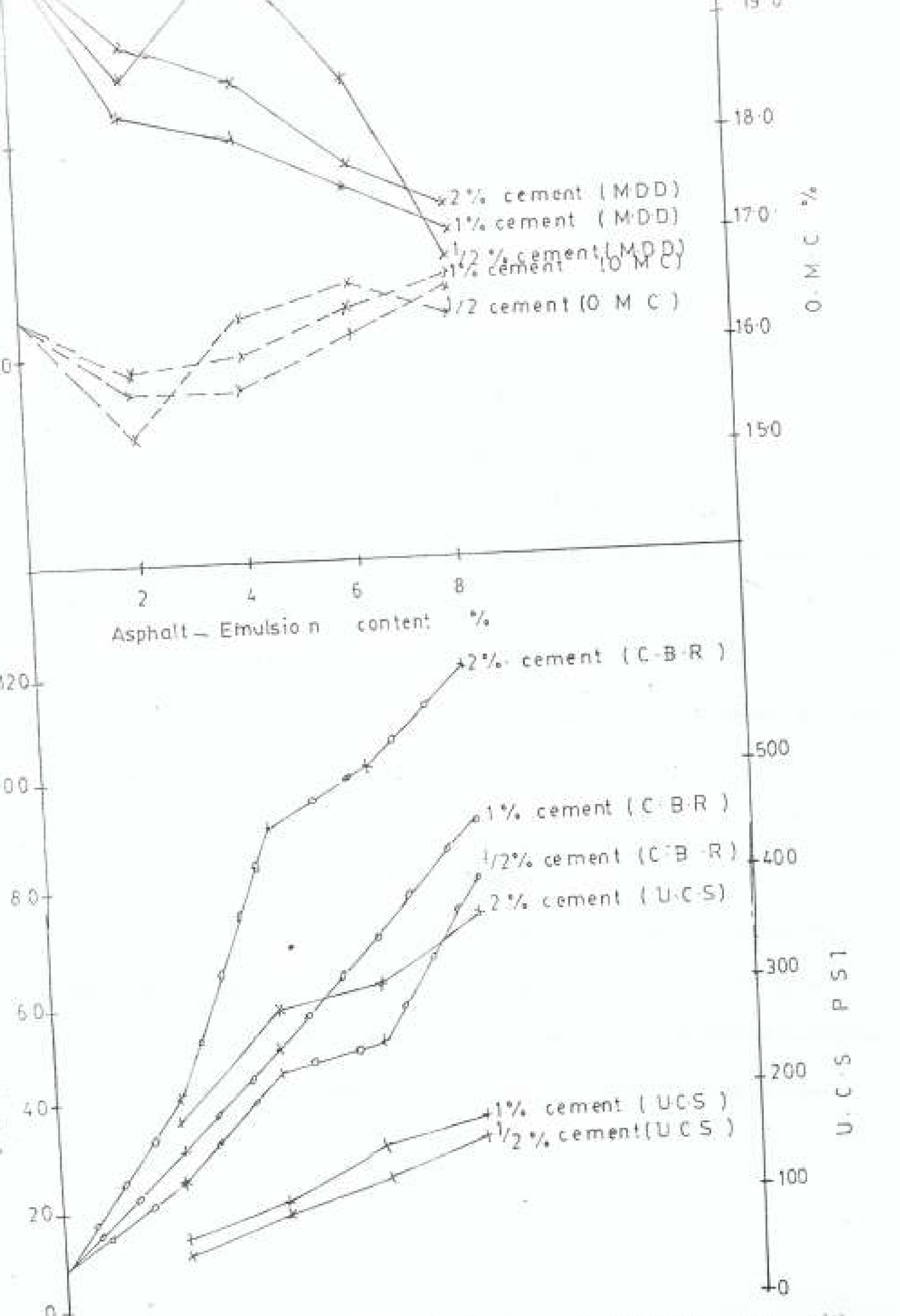


Fig. 4.28: Variation of M D D, O M C, C B R and U C S with Asphalt-Emulsion content of sample C modified with ½–2 per cement

4.2.3.1 Cement-Treated Samples

Table 4.4 shows results of unconfined compressive strength on the samples treated with varying percentages of cement.

From Figures 4.29 to 4.31, samples A, B and C increased in UCS with age and as cement content increases as in concrete.

At 2% cement content, sample A has a 7 days UCS of 1.98 MN/m^2 which increases to 2.20 MN/m^2 at 28 days. Using 8% cement content a maximum 7 and 28-day UCS of 5.2MN/m^2 and 5.61 MN/m^2 were obtained. Addition of cement to this sample is clearly beneficial in that it gives added strength to the material.

Sample B has 7 and 28-day UCS of 1.25 MN/m^2 and 1.50 MN/m^2 at 2% cement content and at 8% cement a UCS of 4.84 MN/m^2 at 7 and 28-day were recorded. With 2% cement, sample C has a 7 and 28-day UCS of 0.68 MN/m^2 and 0.9 MN/m^2 respectively. Using 8% cement increased the 7 and 28-day UCS to 2.0MN/m^2 and 2.2 MN/m^2 respectively. The variations of UCS with cement contents for samples A, B and C are shown in Figures 4.19 to 4.22.

4.2.3.2 Asphalt-Emulsion Treated Samples

The variations of unconfined compressive strength with age for asphalt-emulsion stabilization are shown in Table 4.5. From the result, the unconfined compressive strength increases with increase in amount of emulsion content from 2% to 6% emulsion but the UCS decreases on further increase in emulsion content for samples A and B.

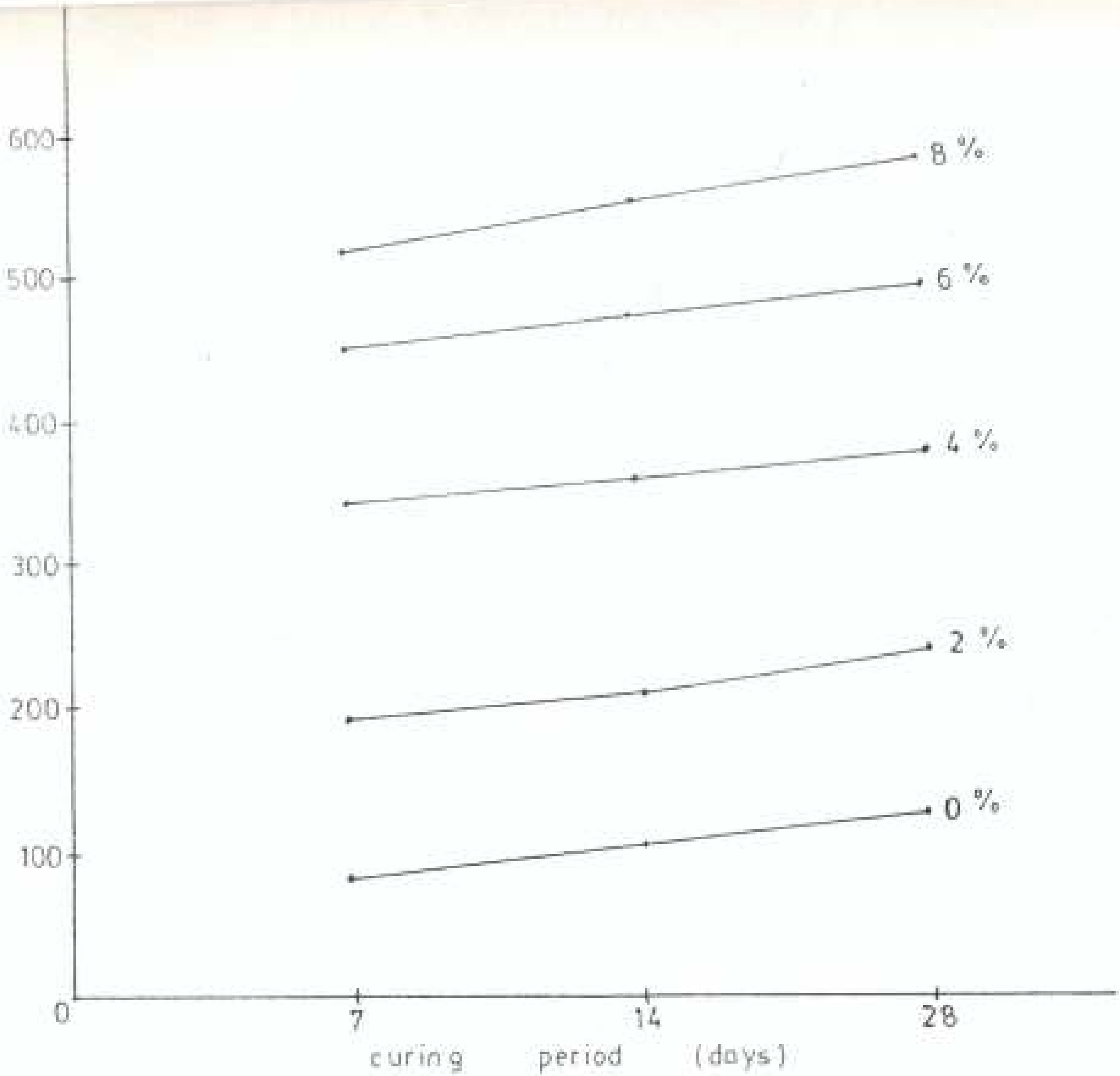


Fig.4.29:Influence of curing on compressive strength of cement stabilized soil [sample A]

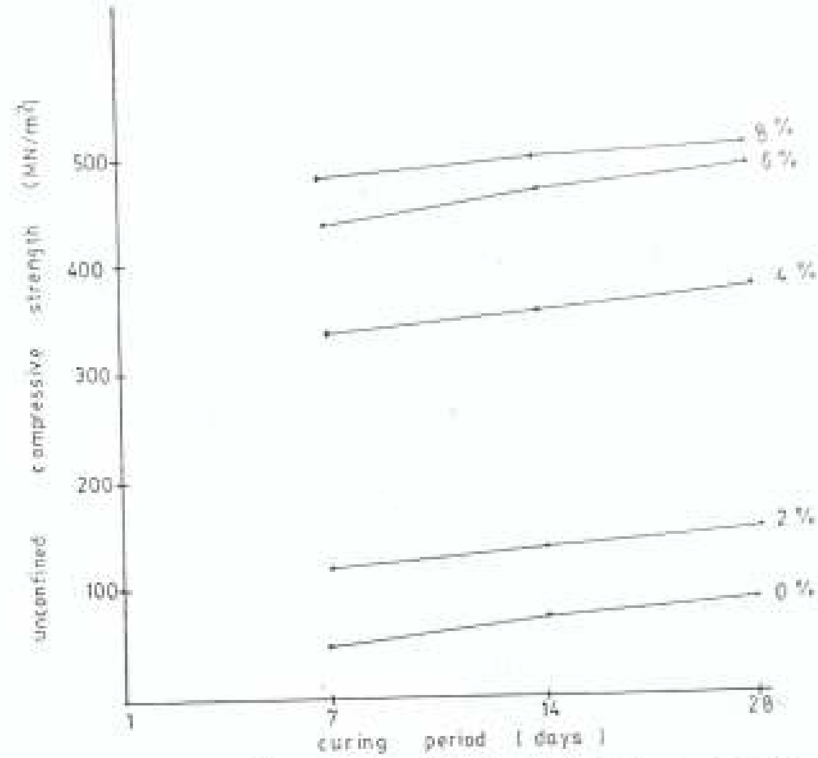


Fig.4.30: Influence of curing on compressive strength of cement stabilised soil [sample B]

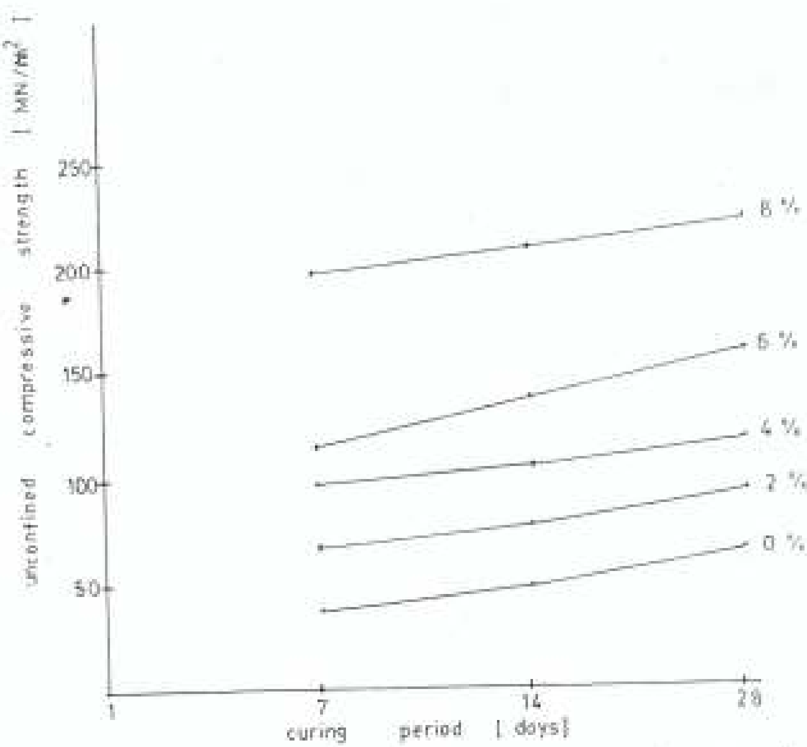


Fig.4.31: Inflеnce of curing on compressive strength of cem stabilised soil [sample C]

For sample A, using 2% emulsion, a 7-day UCS of 1.61 MN/m^2 was obtained and increased to a 28-day UCS of 1.8 MN/m^2. At 6% emulsion, it has a 7-day strength of 3.0 MN/m^2 and 4.1 MN/m^2 at 28-day. With 8% emulsion content, results show a UCS of 2.0MN/m^2 and 2.25 MN/m^2 for 7 and 28-day strength respectively showing reduction in strength with too much asphalt-emulsion content. Sample B has a UCS of 0.85 MN/m^2 and 1.2 MN/m^2 at 7 and 28-day using 2% asphalt-emulsion. Increasing the amount of emulsion to 4%, UCS values of 2.01 MN/m^2 and 2.45 MN/m^2 were obtained for the 7 and 28-day. Using 6% emulsion further increased the 7 and 28-day strength to 2.59 MN/m^2 and 2.82 MN/m^2 respectively and decreased to 1.95 MN/m^2 and 2.35 MN/m^2 the 7 and 28-day UCS at 8% asphalt-emulsion.

Sample C also increases from a 7-day UCS of 0.5 MN/m^2 to a 28-day UCS of 0.69 MN/m^2 with 2% emulsion content. Increasing the asphalt-emulsion content increases the UCS to a maximum 7-day strength of 2.0 MN/m^2 and a 28-day strength of 2.43 MN/m^2 at 8% emulsion content which implies that age hardening of asphalt increases unconfined compressive strength. The variations of UCS with varying proportions of emulsion are shown in Figures 38 to 40 in the Appendix with the effect of age hardening on the samples shown in Figures 4.32 to 4.34.

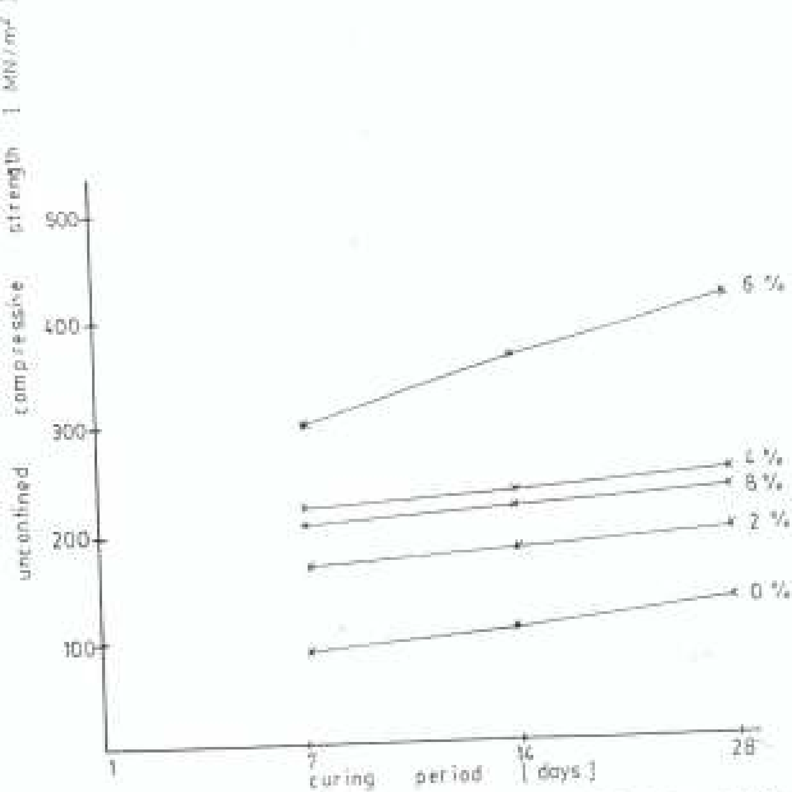


Fig.4-32: Influence of curing on Asphalt-Emulsion stabilization of sample A

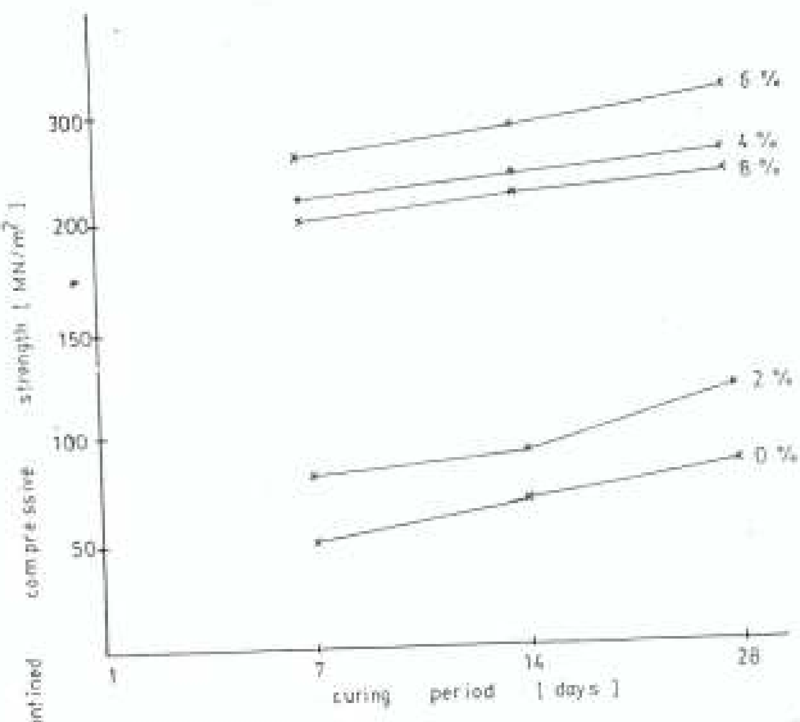
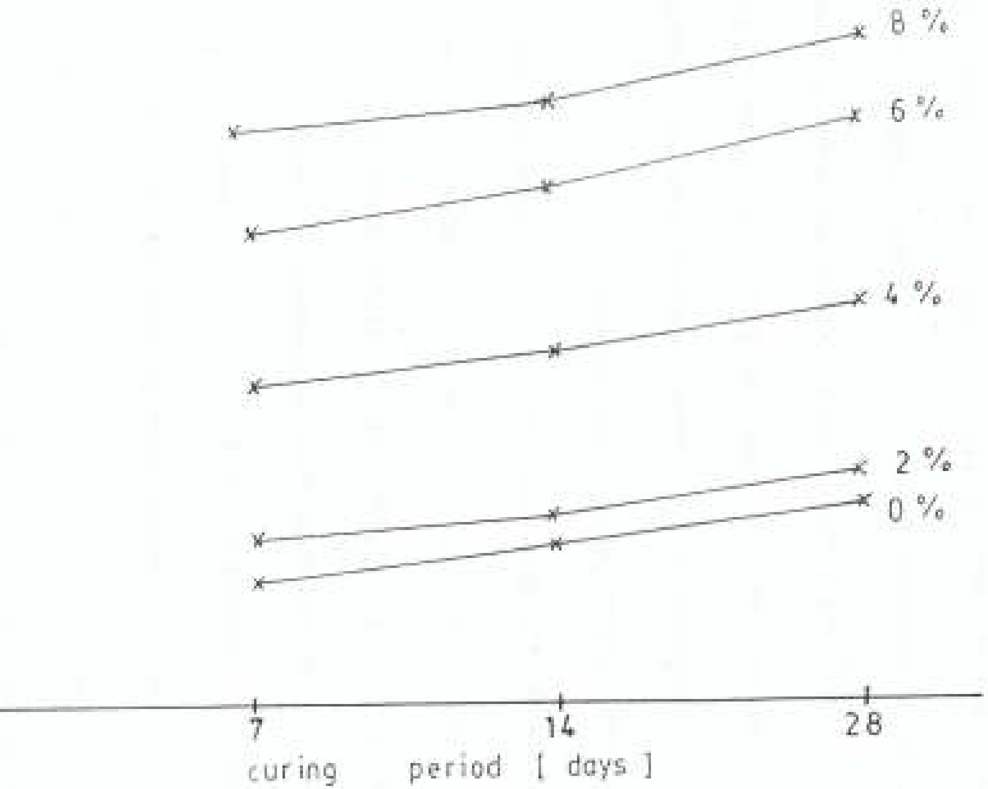


Fig 4-33: Influence of curing on Asphalt - Emulsion stabilizo of sample B



ig 4.34 Influence of curing on compression strength of Asphalt-Emulsion stabilization of sample C

4.2.3.3 Cement-Modified Asphalt-Emulsion Mixtures

Using specified percentages of 0.5-2% cement content to modify the properties of asphalt-emulsion treated samples, unconfined compressive strength tests were performed on the three samples and the results are as shown in Tables 4.6 to 4.8.

From the results, there is an increase in strength from 2-4% emulsion modified with 0.5% cement for sample A. With 2% emulsion, a UCS of 1.02 MN/m^2 at 7-day and 1.34 MN/m^2 at 28-day were obtained. Treating with 4% emulsion gave a 7 and 28-day UCS of 3.9 MN/m^2 and 4.32 MN/m^2 respectively. Increasing emulsion content to 6% reduced the UCS to a 7 and 28-day values of 3.0 MN/m^2 and 3.6 MN/m^2. At 8% emulsion, a further reduction in UCS to a 7-day strength of 2.2 MN/m^2 and a 28-day strength of 2.53 MN/m^2 were obtained.

Addition of 1% cement to varying emulsion contents gave a maximum UCS of 4.0 MN/m^2 for 7-day and 4.66 MN/m^2 for 28-day at 4% emulsion content before decreasing to 3.5 MN/m^2 and 2.7 MN/m^2 with 6 and 8% emulsion contents respectively. Varying emulsion contents with 2% cement yielded a maximum 7 and 28-day UCS of 4.85 MN/m^2 and 5.12 MN/m^2 at 4% emulsion content. And at 6% emulsion, result shows a 7-day strength of 3.8 MN/m^2 and a 28-day strength of 4.21 MN/m^2. There is a reduction in strength using 8% emulsion with 2% cement to a 7 and 28-day strength of 2.86 MN/m^2 and 2.98 MN/m^2.

A minimum 7-day strength of 1.02 MN/m^2 was obtained with 2% emulsion treated with 0.5% cement and a maximum 28-day strength of 5.12 MN/m^2 at 4% emulsion combined with 2% cement contents.

Using 0.5% cement for modification of asphalt-emulsion content of B resulted to content and maximum strengths of 2.70 MN/m² and 3.01 MN/m2 at 6% emulsion content for the 7th and 28th days strengths respectively which reduced to 7 and 28-day UCS of 2.0 MN/m² and 2.4 MN/m² at 8% emulsion content. Mixtures of asphalt-emulsion with 1% cement increased in UCS from a 7-day strength of 0.96 MN/m² with 2% emulsion to 3.19 MN/m² at 4% emulsion content. Increasing the percentage of emulsion reduced the UCS to 2.5 MN/m² (7-day) at 8% emulsion. Combining emulsion percentages with 2% cement gave a maximum 7-day strength of 3.5 MN/m² with 4% emulsion and a reduced strength of 2.60 MN/m² with 8% emulsion. A 7-day UCS of 2.9 MN/m² was obtained using 2% emulsion with 2% cement contents.

The strength of sample C increased on addition of 0.5% cement and as the cement content increases but with a low range of increment. It increased from 7-day strength of 0.58 MN/m² to 1.60 MN/m² using 2 - 8% emulsion contents.

Generally speaking, addition of a small percentage of cement to soil-asphalt-emulsion mixes has a beneficial effect on strengths of tested specimens. Using 1% cement for modification of sample C increases the compressive strength as emulsion content increases. Addition of 1% cement to 2% emulsion gave a 7-day strength of 0.75 MN/m² with 8% emulsion. Mixtures of emulsion with 2% cement gave a 7 and 28-day UCS of 1.86 MN/m² and 2.54 MN/m² at 2% emulsion combination and increased to 2.80 MN/m² using 4% emulsion with 2% cement. With further increment in emulsion content, an increased UCS of 3.70 MN/m² was obtained at 8% emulsion content. Figures 4.26 to 4.28 show the variations of UCS with cement - modified emulsion mixes with the influence of age of curing on strength shown in figures 4.35 to 4.43.

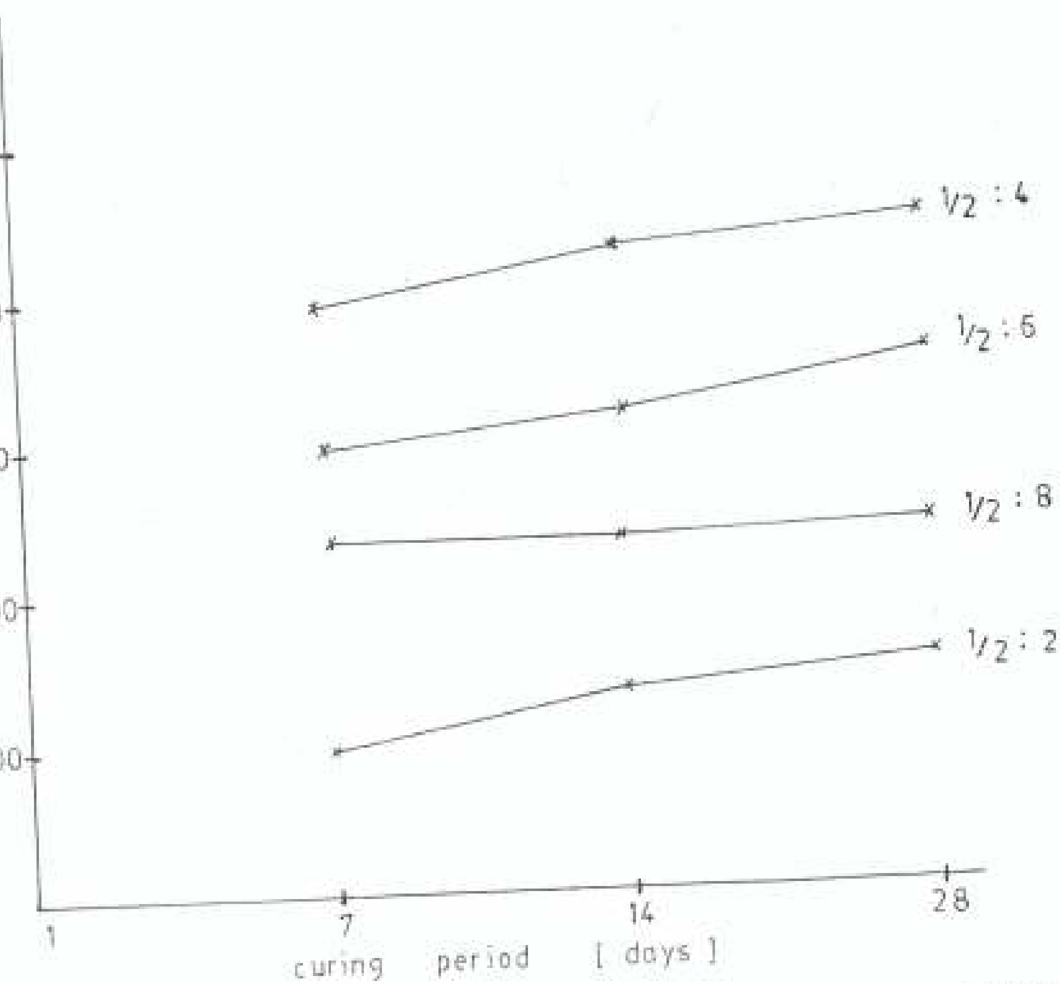


Fig 4.35: Influence of curing on compressive strength of Asphalt-Emulsion stabilization of sample A modified with 1/2 percent cement content

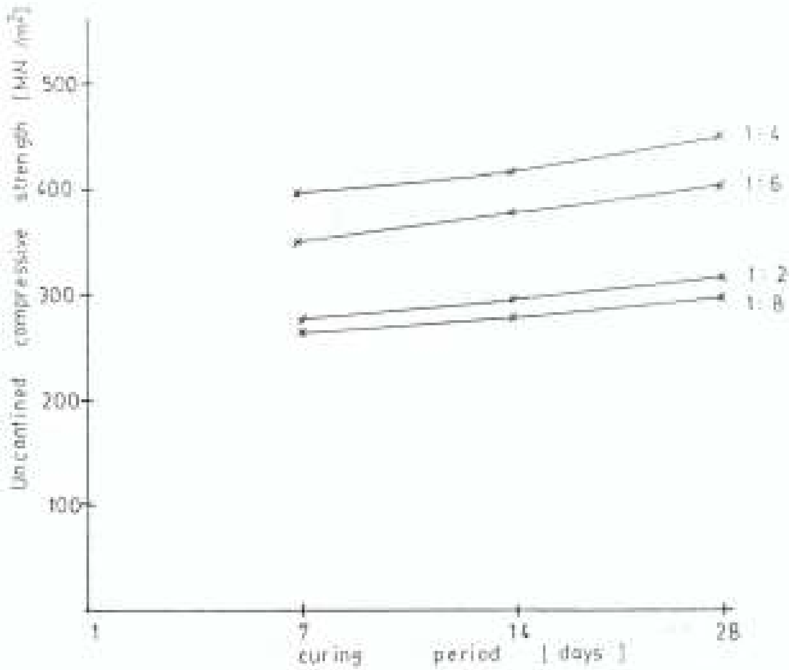


Fig.4.36: Influence of curing on compressive strength of asphalt – Emulsion stabilization of sample A modified with 1 percent cement content

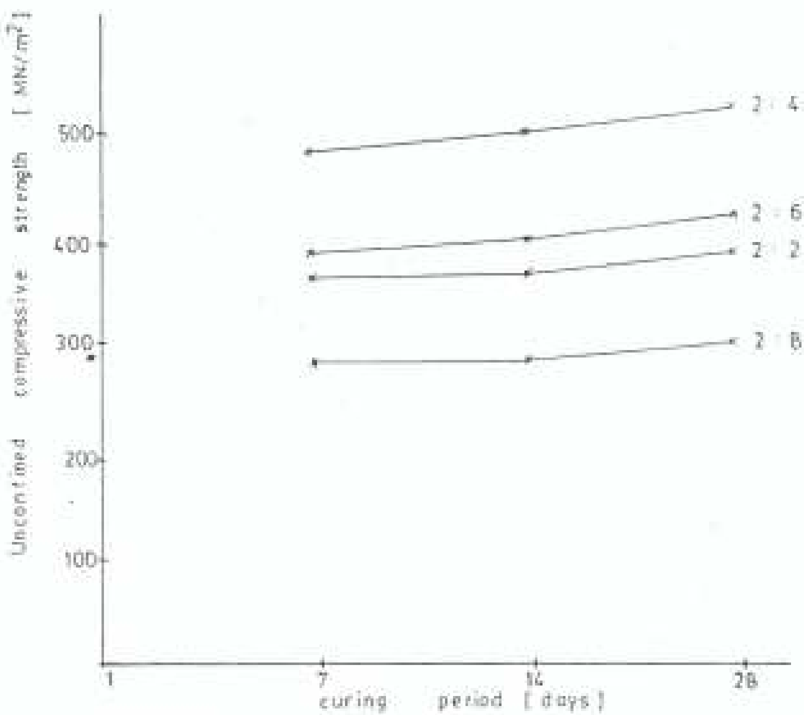


Fig.4.37: Influence of curing on compressive strength of asphalt – Emulsion stabilization of sample A modified with 2 percent cement content

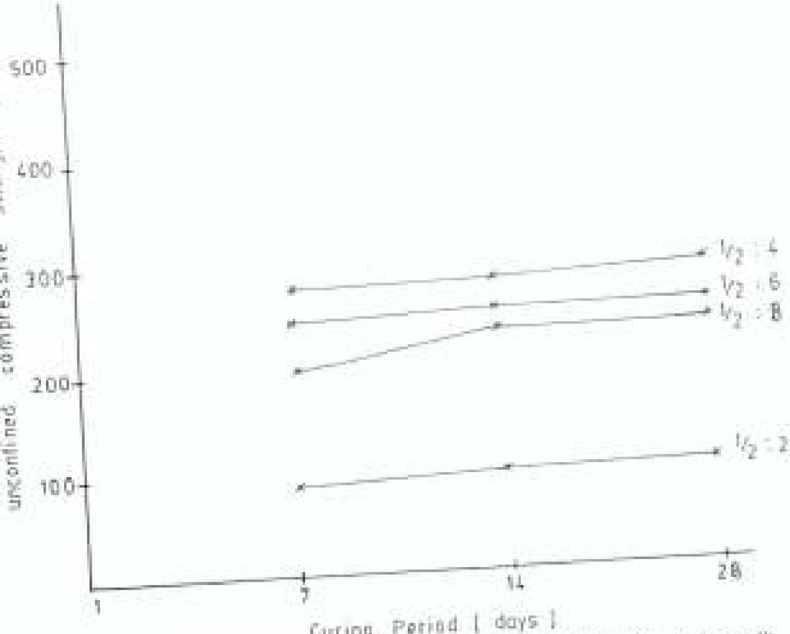


Fig-4.38: Influence of curing on compressive strength of asphalt — Emulsion stabilization of sample B modified with 1/2 percent cement content

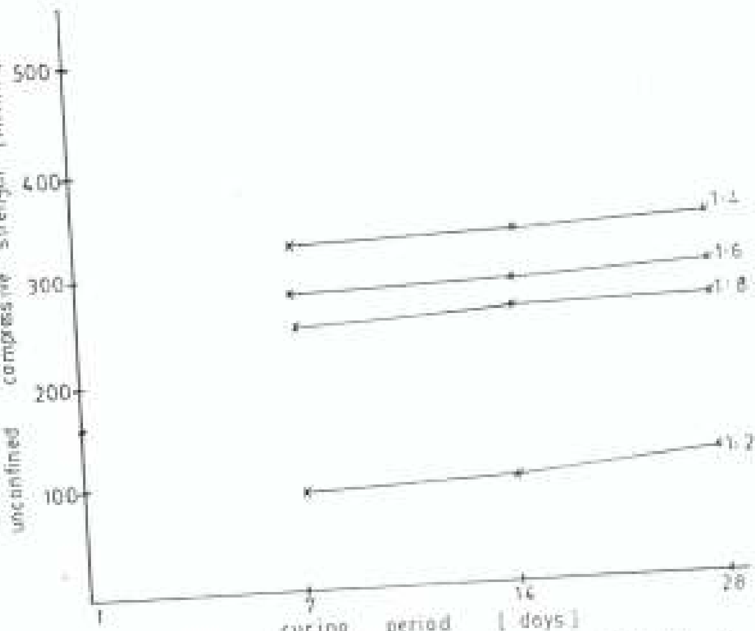


Fig -4.39: Influence of curing on compressive strength of Asphalt – Emulsion stabilization of sample B modified with 1 % cement content

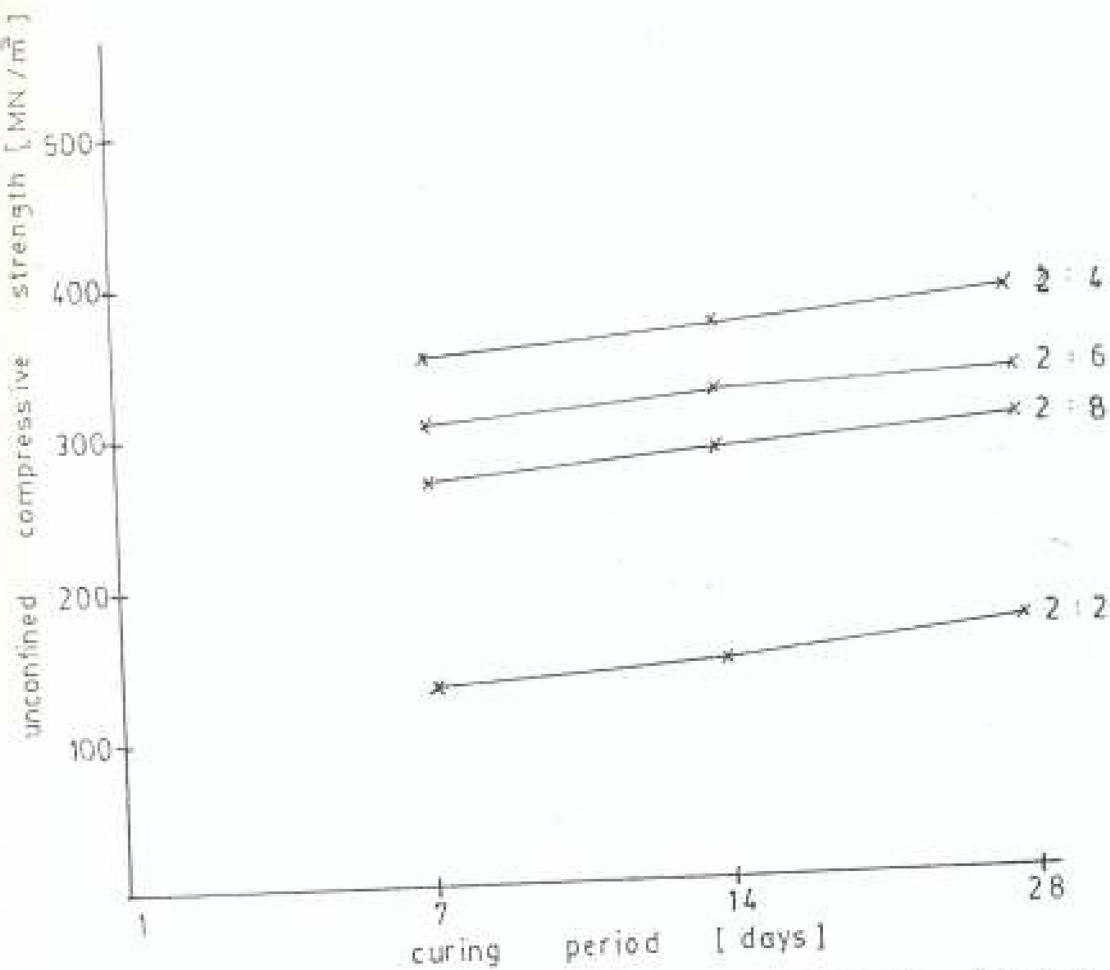


Fig.4.40: Influence of curing on compressive strength of Aspha
Emulsion stabilization of sample B modified w
2% cement content.

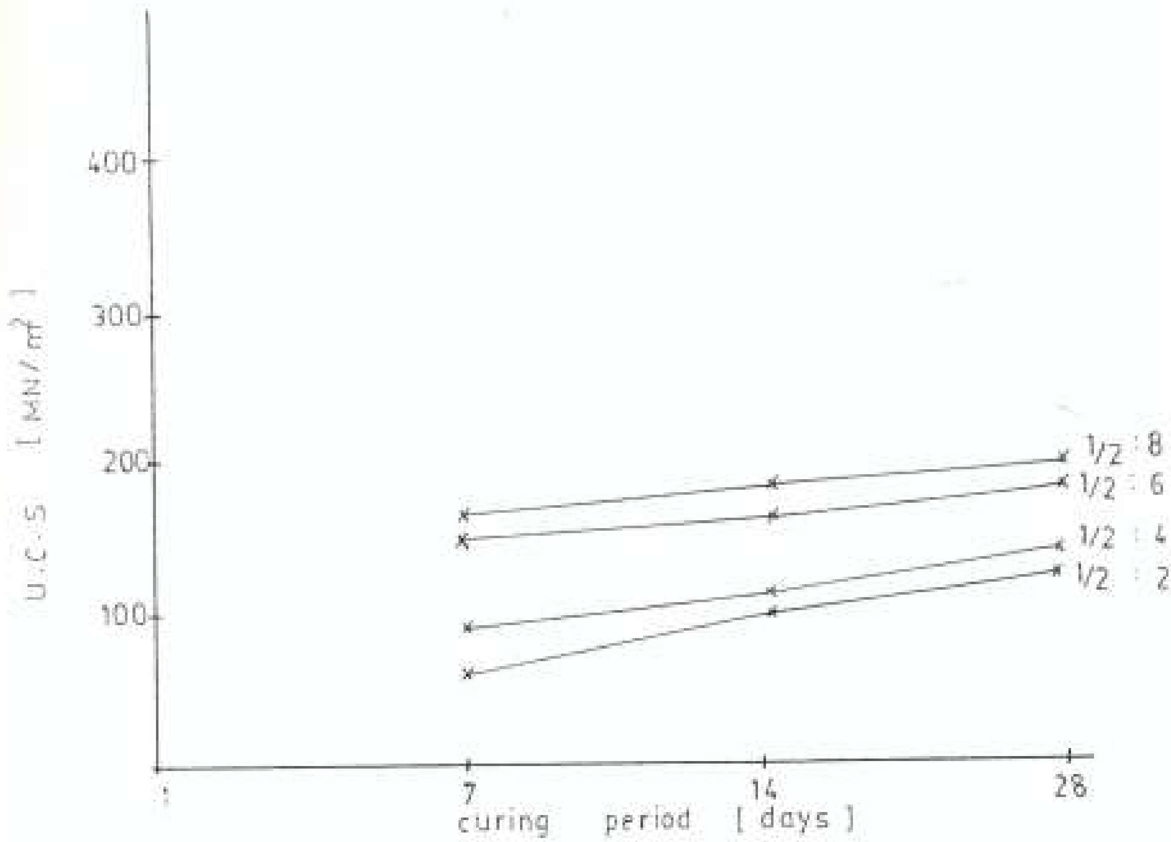


Fig 4.4: Influence of curing on compressive strength of asp
Emulsion stabilization of sample C modified with $\frac{1}{2}$
cement content.

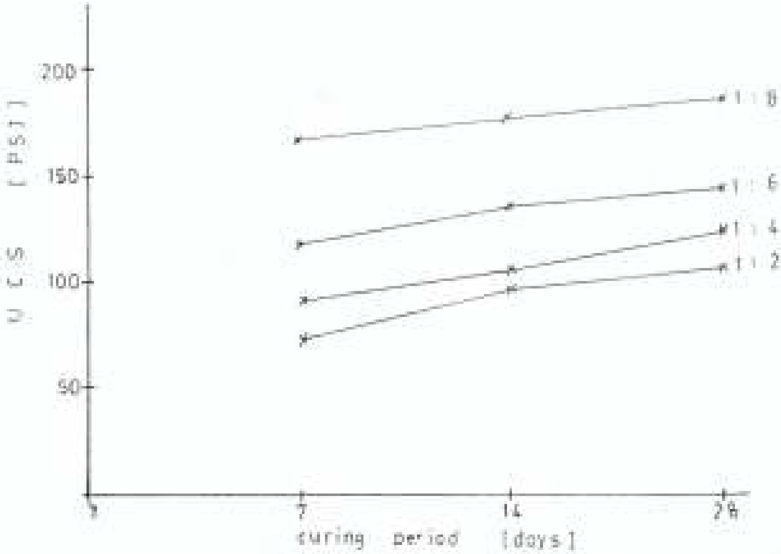


Fig.4.42:Influence of curing on compressive strength of Asphalt — Emulsion stabilization of sample C modified with 1 percent cement content.

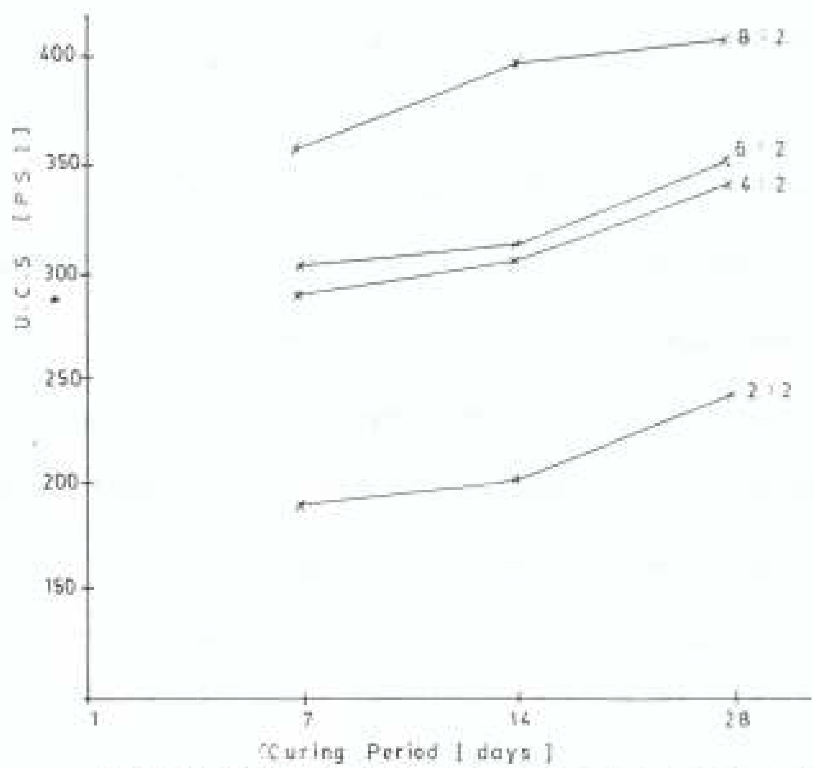


Fig.4.43:Influence of curing on compressive strength of asphalt — Emulsion stabilization of sample C modified with 2 percent cement content.

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 OBSERVATIONS ON THE RESULTS

Results of the various tests carried out on the three samples show that addition of cement to samples treated with asphalt-emulsion resulted in increased strength over that of samples treated only with asphalt-emulsion. This is in accordance with the work of Coyne, (1976) which shows that the addition of small percentages of cement will improve the early curing strength of emulsified asphalt mixes under adverse construction conditions and after moisture exposure.

The Atterberg Limits of the samples studied range from 31-55 % for Liquid Limits with plasticity Indices between 9 and 26. The different percentages passing the no. 200 sieves are 34.2%, 32% and 55.5% for samples A, B, and C respectively. The maximum dry densities and optimum moisture contents when untreated, are 1.80, 1.70g/cc and 12.3, 15.3 and 16.3% with CBR values of 20, 18 and 8% respectively. From these results, soil A is classified according to AASHO as A-2-5, Soil B as A-2-7 and soil C as A-7-6 which is a sandy soil of high plasticity.

The addition of chemical stabilizers to samples generally increases the optimum moisture content and reduce the maximum dry densities and this latter is more pronounced with cement stabilized materials because the added cement resulted into flocculation of the soil fines and creation of loosely-bonded aggregations and requires more water for proper hydration to take place as cement content increases as in concrete (Bagonsa, (1987). This hydration of cement forms cementitious materials, calcium silicate, aluminate hydrates and hydrated lime which cause secondary reactions with any reactive elements especially in clay soils such as sample C and then binds the soil particles together. This is why cement can be used to stabilize nearly all soils but uneconomical with clay soils due to high amounts required for treatment.

California Bearing Ratio tests results show appreciable increase in CBR values for all samples treated with cement and as cement content increased as shown in the summary. The increase in CBR values indicates strength increase with cement treatment of the samples. Sample A's CBR increased from 20% at 0% cement content to 220% at 8% cement content while sample B increases from 18% at 0% cement content to 199% at 8% cement content. Sample C also has increased CBR values though with a low increment range from 8% CBR value at 0% cement content to 102% using 8% cement contents.

Treating samples with asphalt-emulsion and the combination of asphalt-emulsion with cement also increases the CBR values as emulsion content increases but when emulsion contents become too much, the CBR values reduce except for sample C which increases in strength as emulsion content increases. That is sample C requires high amount of asphalt-emulsion to be added before desired strength can be attained in contrast to samples A and B which got their maximum values at 6% asphalt-emulsion contents.

The unconfined compressive strength values also increased as cement content increases from 0% to 8%. Curing of treated samples also shows increase in strength with age of curing for all types of additives used. Stabilizing samples with asphalt-emulsion shows reduction in strength which is more pronounced with sample C but addition of cement for pre-treatment of the samples resulted in increased strengths over the use of only asphalt-emulsion.

The benefit of cement addition under marginal curing conditions was illustrated in a field test at Oakland International Airport Coyne and Ripple (1975) where in-place mixing of the runway shoulders with a cationic medium setting type of emulsion (CMS) in wet condition of construction caused construction delays of 1-3 weeks due to the slow rate of curing of the solvent. A small test section using a slow setting type of asphalt-emulsion and cement was then included in the project. Tests on cores from the cement treated section confirmed that cement modified asphalt-emulsion mixes developed high early strength in wet construction conditions.

The added cement causes the emulsion to break, changes the water film on soil particles, modifies clay minerals in the soil to some extent and decreases soil plasticity, absorbs some of the resulting free moisture in the soil by hydration; promotes good dispersion of the asphalt phase throughout the soil, and gives added strength to the processed and compacted soil when it had hardened.

5.2 Economics And Benefits of Cement-Modified Asphalt-Emulsion Mixes

The addition of cement and asphalt-emulsion to soils will possibly increase operational cost of incorporating two additives instead of one into the soil but it has many advantages.

It is advantageous in that it improves the workability of the mixtures in that the added cement will decrease soil plasticity with the asphalt-emulsion remaining stable for a short time thus promoting good dispersion of the asphalt phase throughout the soil and making the material workable, and easy to mix and consequently reduces the time required to achieve specified degree of pulverisation over that of using only asphalt-emulsion. Another advantage of the added cement is that the cement will absorb some of the excess free moisture in the soil by hydration and will give added strength to the processed and compacted soil when hardened. Laterite soils, when treated with mixtures of cement and asphalt-emulsion have properties intermediate between those of soil-cement and soil-asphalt-emulsion with the resulting mix possessing some rigidity and water resistance.

Now, based on the criteria that materials to be used as road bases should satisfy the normally applied minimum UCS of $1.7MN/m^2$ or a CBR value of 100 percent (20), comparisons of the different admixtures are made in terms of the results of their CBR and 7 day UCS strength on the assumption that strength is a measure of quality. For sample A, satisfactory minimum 7-day UCS of $3.4MN/m^2$, $2.2MN/m^2$ and $2.81MN/m^2$ with CBR values of 120%, 110%, 105% and 120% were obtained using 4% cement content; 4% asphalt-emulsion content; 2% asphalt-emulsion modified with 1% cement contents; 4% asphalt-emulsion with 0.5% cement and 2% asphalt-emulsion with 2% cement contents respectively. From the economic consideration, the soil-asphalt-emulsion-cement mixture gives a saving of 1% of additive material and is more economical as will be seen in the cost analysis later.

Sample B gave a CBR value of 150% and a 7-day UCS of $4.42MN/m^2$ with 6% cement content and a maximum UCS and CBR values of $2.59MN/m^2$ and 80% with 6% asphalt-emulsion contents respectively. Using 2% asphalt-emulsion with 2% cement content gave CBR and UCS values of 100% and $2.90MN/m^2$ respectively. Again, there is a saving in the quantity and cost of additive materials comparing the relative costs of these additives.

The best strength results were obtained with the addition of cement and asphalt-emulsion to sample C. Although 8 percent of cement and 8 percent of asphalt-emulsion gave a maximum 7day UCS of 2.0MN/m^2 and 1.80MN/m^2 and CBR values of 102% and 60%, an admixture of 2% cement to 6% asphalt-emulsion raised the 7-day UCS and CBR values to 3.05MN/m^2 and 105%.

Details of the cost analysis are shown in Appendix 1, but the summary is outlined below:

Chemical Content	Cost/tonne
Sample A	
4% Cement	₦1,300
4% Asphalt-emulsion	₦1,500
2% Asphalt-emulsion with 1% cement	₦1,200
4% Asphalt-emulsion with ½% cement	₦1,600
2% Asphalt-emulsion with 2% cement	₦1,300
8% Asphalt-emulsion with ½% cement	₦2,550
Sample B	
6% Cement	₦1,550
6% Asphalt-emulsion	₦1,950
6% Asphalt-emulsion with ½% cement	₦2,100
2% Asphalt-emulsion with 2% cement	₦1,300

Sample C

8% Cement	₦1,950
8% Asphalt-emulsion	₦2,500
8% Asphalt-emulsion with 1% cement	₦2,650
6% Asphalt-emulsion with 2% cement	₦2,300
2% Asphalt-emulsion with 2% cement	₦1,300
8% Asphalt-emulsion with ½% cement	₦2,550

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The results of this investigation have showed that beneficial effects are obtained by the addition of small amounts of cement to soil-asphalt-emulsion mixtures; and specifically the results led to the following conclusions:

1. Cement stabilization improves the strength of all soils but at different rates. It is best suited for coarse grained soils and not economical for plastic soils.
2. Pretreatment of fine grained soils facilitates mixing-in of emulsion and hence improves workability.
3. For each soil-additive mixture, there is an optimum amount of of additive which gives a maximum compressive strength depending on the type of soil.
4. The optimum moisture content for maximum density and the optimum moisture content for maximum strengths of the samples are not always the same.
5. Addition of cement increases the compressive strengths of soil-asphalt-emulsion mixtures.
6. Curing of treated samples increases the compressive strengths.
7. The increase of strength with addition of cement, in terms of percentage, is higher for soils with high clay content and for soil-asphalt-emulsion mixtures with lower emulsion content.
8. Soil-cement mixtures harden much faster after compaction than soil-asphalt-emulsion and a mixture of soil-asphalt-emulsion with cement.
9. Although the cost of asphalt-emulsion is higher than that of cement, it is still economical to a mixture of asphalt-emulsion and cement due to reduced additive

The economic advantage of the simultaneous use of asphalt-emulsion and cement for all the samples treated is paramount. The combination favours soil sample C which does not respond appreciably to treatment with cement and asphalt-emulsion. It has also been possible to obtain samples stabilized with small percentages of emulsion combined with small percentages of cement and yet possessing strengths comparable with those of samples stabilized with higher amounts of cement or asphalt-emulsion as in soils A and B.

6.2 RECOMMENDATIONS

On the basis of the test results, observations and conclusions, the following recommendations are being made:

i. The use of asphalt-emulsion modified with cement as a soil improvement technique should be encouraged.

ii. The cement to asphalt-emulsion ratio to be used for the soils investigated i.e. A-2-5, A-2-7 and A-7-6 soils should be 1:2, 2:2 and 2:6% respectively. However, these need to be further investigated to ascertain their general applicability.

iii. It is recommended that delay in mixing time should be minimized in order to achieve/obtain higher dry densities.

iv. The use of different asphalt-emulsion types with different soils should be investigated to know the best emulsion for each soil type.

v. Further studies should be carried out on the effect of varying compactive efforts on the properties of cement-modified asphalt-emulsion mixes.

REFERENCES

1. ADEBAYO, D. F. (1992) : Improvement Of Laterite Soil By Stabilisation For Road Use Using Cement as the admixture. Undergraduate project, Civil Engineering Dept. UNILORIN.

2. ADELANA, A.A. (1988): Field Study and Geochemistry of lateritic Weathering Profiles in some parts of Ondo state, Geology Dept. FUTA.

3. ADENIRAN, Morufu Adeoye (1991): Asphalt as a paving material and its substitution with molasses, Civil Engineering Dept. UNILORIN.

4. ADEOYI, M. Ugwu and UKA, A.B. (1984): Soil Stabilisation by Inextensible Earth Reinforcement, Civil Engineering Dept., UNILORIN.

5. ADETUMBI, Kamoru Inaolaji (1985): Effect of cement - rice husk Ash mixtures on some Geotechnical properties of lateritic soil, Civil Engineering Dept., OAU.

6. ADEYERI, J.B, IMIRUAYE, M.E and UMANA, E.O. (1993): Properties of some Compacted Residual Soils from the Ibadan formation, Geotechnical Laboratory Report, GLR01, Civil Engineering Dept., OSUA.

7. ADEYERI, J.B, ILOGHALU, O.A and ERUCHALU, O.E (1994): Stabilization of some Laterites from Nigeria, Geothechnical Laboratory Report, GLR02, Civil Engineering Dept., OSUA.

8. AJAYI, Jimoh Joseph (1988): The use of Rice Husk Ash as Pozzolans, Civil Engineering Department, UNILORIN.

9. ALAGBON, B.D (1994): Assessment of kernel shells as suitable Aggregates in

Concrete and Laterite blocks, Civil Engineering Dept., FUTA.

10. ALEXANDER, L.T and CADY, Y.G (1962): Genesis and Hardening of laterites in soils, U.S Dept. of Agric Technology, Bulletin No. 14.

11. AREMU, K.A. (1985): Black Liquor from paper mill in soil stabilisation, Civil Engineering Dept., Faculty of Tech, OAU.

12. ASINDI, I.C. (1985): Effect of Compactive effort on Characteristics of Stabilized lateritic soils, Civil Engineering Dept., UNILORIN.

13. ANWAR, E.Z.W and RURRICK, H. (1964): Chemical stabilization of selected Tropical soils. MIT Massachusetts. Dept., Massachusetts Inst. of Tech. Massachusetts.

14. AWOFISAYO, O.D (1992): Strength Characteristics of A cement and lime stabilized laterite soil, Civil Engineering Dept., OAU.

15. AYODELE, Ibrahim (1977): Research into the failure of soil/sand Bituminous stabilized Base on Maiduguri Gambou Road, Borno State, Nigeria and its job solution, proceedings of the conference on materials testing.

16. BAG0NSA, S.J.M. Peete, R. Freer - Hewish and D. Newill (1987): Carbonation of stabilized soil - cement and soil - lime mixtures, Overseas Unit, TRRL, Crowthorgne Berkshire, U.K., Crown Copyright.

17. BRITISH Lime Association (1990): Lime stabilisation manual, ICI Chemicals and Polymers Ltd., Second Edition.

18. BULMAN, J.N. (1972): Soil Stabilization in Africa, Report No LR 476, TRRL

19. Cementitions Stabilizers in Road Construction, Draft TR H13, Technical

Recommendation for Highways, Pretora, South Africa.

20. CHARMAN, J.H. (1975): Laterite in Road Pavement, ODA, TRRL.

21. COYNE, L.D. and RIPPLE R.M. (1975): Technical Paper on Emulsified Asphalt Mix Design and Construction, Annual meeting of the Association of Asphalt Paving Technologist.

22. COYNE, L. D. (1976): Emulsion Stabilization Mix Design, Technical Paper No. 172, Chevron Asphalt Company, San Francisco.

23. DANIEL, W.H. (1990): An Investigation of the use of stabilised soils in road construction, Civil Engineering Department, Ilorin.

24. DE-GRAFT-JOHNSON, J.W.S and BHATIA, H.S (1969): Engineering properties of laterites, Proc. 7th Int. Conf. on soil mechanics and foundation. Eng, Vol. 2 specialty session.

25. ESUKPA, U. (1990): The occurrence, nature and origin of laterite in Ondo State, Geology Dept. FUTA.

26. GIDIGASU, M.D (1976): Laterite Soil Engineering Pedogenesis and Engineering Principles, Elsevier Scientific Publishing Company, Amsterdam.

27. GEORGE, S.Z., PONNIAH, D.A. and LITTLE, J.A. (1992): Effect of Temperature on Lime-Soil Stabilization, Journal of Construction and Building Materials Vol. 6, No.4.

28. Guide to stabilization in Roadworks (1986): National association of Australia State Road Authorities, Technical Information and Library Services, Sydney TRRL.

29. GUISEPPE, F.K (1969): Engineering classification of characteristics of laterit

Soils, Proc. of the specialty session of Engrg. properties of laterite soil

Vol. 1.

30. Highway Research Record, No 125: Highway Transportation Research, Educatio

and Technology Abroad, Highway Research Board NAAS Washington

31. INGLES, O.G and METCALF, J.B (1973): Soil stabilization principles ar

practices, Butterworth, London.

32. Introduction to soil stabilisation (1987): Overseas Unit, TRRL, Crowthorn

Berkshire United Kingdom, Crown Copyright.

33. IWUALA, C.O. (1992): Comparative stabilisation of lateritic soils from son

parts of Akure North-West Ondo State, Geology Dept.

34. JACKSON, N. and DHIR. R.K. (1988): Civil Engineering Materials, Four

Edition, ELBS.

35. KARI, W.J. (1969): Design of Emulsified Asphalt Treated Base Course

Technical paper No. 155.

36. KEZDI, A. (1979): Stabilized Earth Roads Development in Geotechni

Engineering, Elserier Scientific Publishing Co. New York.

37. LEVINSON, A.D (1974): Introduction to Exploratory Geo-Chemistry, Appl

Publishing Ltd., Marywood, Illinois.

38. LITTLE, A.L. (1969): Engineering Properties of Lateritic soils (vii), Int. C

Soil Mech. Fdn, Engineering, Mexico.

39. MARTINS, C.F and DOYNE, M.A (1930): Laterite and Lateritic soils in Si

Leone, Journal of Agric. Science, Vol. xvii.

40. MOHR, T.R and MAZHAR, B.M (1969): A research on the study of factors that affect Laterization Geology, Journal No.1.

41. ODA TRRL: Laterites in road pavement, IRIA Special publications.

42. O'FLAHERTY, C.A. (1974): Highways and Traffic. Vol. 1, second edition, Edward Arnold.

43. OGBUMOR, A.A. (1990): Cement stabilisation of problem soils in some parts of Ondo State, Geology Dept., FUTA.

44. OGHUO, Reginald Ikechukwu (1985): Effects of cement, Lime and Rice Husk Ash on CBR characteristics of laterite soils, OAU.

45. OGUNJIDE, Adetayo Magbagbeola (1983): Effect of grain sizes on the strength characteristics of stabilised lateritic soil, Civil Engineering Dept., OAU.

46. OGWENO-BONYO, N. (1997): "Built to last", African Review of Business and Technical Interment Report.

47. OJIE, Solomon Ossai and FEYISETAN, O.A. (1989): The significance of source of laterite on the strength of cement stabilised laterite blocks, Civil Engineering Dept., OAU.

48. OLA, S.A. (1977): Laboratory Investigation of the influences of Cement, Lime and Bitumen on soils, Proceedings of the conference on materials Testing, Control and Research.

49. OLA, S.A. (1983): Tropical Soils of Nigeria in Engineering Practice, A. A. Balkema, BR. Rotterdam, Netherlands.

50. OLA, S.A. (1985): Engineering properties and Behaviours of stabilised unstabilised compressed Bendel soils, proceedings of the seminar on the use of clay bricks and blocks for the provision of cheaper and marble housing, Zariat.

51. OLORUNFEMI, A.O. (1984): Structural Analysis and Design of stabilised lateritic soils on road, Civil Engineering Dept. UNILORIN.

52. OWOLABI, A. O. (1995): Sustaining the Construction Industry in Nigeria through Local Materials Metamorphosis and Utilization, Proceedings of the National Engineering Conference.

53. OWOSANYA, R.A. and ANOKWU Fidelis Chinedu (1994): Some Engineering Properties of a cement stabilised laterite soil in Ile-Ife, OAU.

54. Portland Cement Association, Soil Cement Laboratory Handbook.

55. SAMSON, O. (1991): Geotechnical and Physical Properties of laterites in parts of Ondo State, Geology Dept., FUTA.

56. THOMPSON, M. R. (1972): Deep-flow lime stabilization for pavement construction, transportation journal, ASEE vol. 98.

57. VALLERGA, B.A and VANTIL C.J(1969): Engineering properties of lateritic materials used on Thailand Roads, Conf. Spec. session. Engineering properties of laterite soils, Vilsmee, No.2.

58. WEST, G. (1959): A Laboratory Investigation of Elapsed Time after mixing on the compaction and strength of soil cement, Geotechnique 9 (1).

59. YODER, E. J. and WITCZAK M. W. (1976): Principles of Pavement Design, Second Edition, John Wiley and Sons Inc. New York.

APPENDIX I

COST ANALYSIS OF TREATED SAMPLES

Based on a relative cost deduced from a market survey of Akure in Nov. '98 of ₦12,000 per tonne at ₦600/bag for cement and ₦16,000 per tonne for asphalt-emulsion and using a trip of laterite which is about 5 tonnes as basis for calculation, the cost analysis for the chosen mix design for each treated was carried out as follows:

A. Sample A

i. <u>Stabilization using 4% cement</u>

		₦
1 trip of laterite	=	1,300
4% Cement (0.2 tonnes)	=	2,400
Basic Cost	=	3,700
Labour 20% of basic cost	=	740
Overhead 10% " " "	=	370
Taxes 10% " " "	=	370
Others 2.5% " " "	=	92.50
Total	=	5,272.50
Profit 15% of Total	=	790.95
Grand Total	=	6,063.45
Rate = $\frac{6063.45}{5.2}$	=	₦1,300/tonne

ii. <u>Stabilization using 4% asphalt-Emulsion</u>

		₦
1 trip of laterite	=	1,300
4% emulsion (0.2 tonnes)	=	3,200

Basic Cost	=	4,500
Labour 20% of basic cost	=	900
Overhead 10% " " "	=	450
Taxes 10% " " "	=	450
Others 2.5% " " "	=	112.50
Total	=	6,412.50
Profit 15% of total	=	961.88
Grand total	=	7,374.38

Rate $= \frac{7,374.38}{5.2} =$ ₦1,500/tonne

iii. <u>Using 2% Asphalt-emulsion with 1% cement</u>

		₦
1 trip of laterite	=	1,300
2% emulsion (0.1 tonnes)	=	1,600
1% Cement (0.05 tonnes)	=	600
Basic Cost	=	3,500
Labour 20% of basic cost	=	700
Overhead 10% " " "	=	350
Taxes 10% " " "	=	350
Others 2.5% " " "	=	87.50
Total	=	4,987.50
Profit 15% of total	=	748.13
Grand Total	=	5,735.63

Rate $= \frac{5735.63}{5.2} =$ ₦1,200/tonne

iv. Using 4% asphalt-emulsion with ½% cement

			N
1 tip of latente		=	1,300
4% emulsion (0.2 tonnes)		=	3,200
½% cement (0.025 tonne)		=	300
Basic cost		=	4,800
Labour 20% of basic cost		=	960
Overhead 10%		=	480
Taxes 10%		=	480
Others 2.5%		=	120
Total		=	6,840
Profit 15% of total		=	1,026
Grand Total		=	7,866
Rate	$= \frac{7,866}{5.2}$	=	₦1,600/tonne

v. Using 2% asphalt - emulsion with 2% cement

		₦
1 trip of laterite	=	1,300
2% emulsion (0.1 tonne)	=	1,600
2% cement (0.1 tonne)	=	1,200
Basic cost	=	4,100
Labour 20% of basic cost	=	820
Overhead 10% of basic cost	=	410
Taxes 10% of basic cost	=	410
Others 2.5%	=	102.50

Total	=	5,822.50
Profit 15%	=	873.38
	=	6,695.88
Rate = $\frac{6,695.88}{5.2}$	=	₦1,300/tonne

vi. <u>Using 8% Asphalt - Emulsion with 1/2% cement</u>

		₦
1 trip of laterite	=	1,300
8% emulsion (0.4 tonne)	=	6,400
0.5% cement (0.025)	=	300
Basic cost	=	8,000
Labour 20% of basic	=	1,600
Overhead 10%	=	800
Taxes	=	800
Others 2.5%	=	200
Total	=	11,400
Profit 15% Total	=	1,710
Grand Total	=	13,110
Rate = $\frac{13,110}{5.2}$	=	₦2,550/tonne

B. <u>Sample B</u>

i. <u>Stabilization Using 6% cement</u>

		₦
1 trip of laterite	=	1,300
6% cement (0.3 tonne)	=	3,600

Basic cost	=	4,900
Labour 20% of basic	=	980
Overhead 10%	=	490
Taxes 10%	=	490
Others 2.5%	=	122.50
Total	=	6,982.50
Profit 15% Total	=	1,047.38
Grand Total	=	8,029.88

Rate $= \frac{8,029.88}{5.2} =$ ₦1,550/ tonne

ii. <u>Stabilization using 6% Asphalt - Emulsion</u>

		₦
1 trip of laterite	=	1,300
6% emulsion (0.3 tonne)	=	4,800
Basic Cost	=	6,100
Labour 20% of basic cost	=	1,220
Overhead 10% basic cost	=	610
Taxes 10% basic cost	=	610
Others 2.5%	=	152.50
Total	=	8,692.50
Profit 15% Total	=	1,303.88
Grand Total	=	9,996.38

Rate $= \frac{9,996.38}{5.2} =$ ₦1,950/tonne

iii.	Using 6% Asphalt-Emulsion with 0.5% cement		₦
	1 trip of laterite	=	1,300
	60% Asphalt-Emusion (0.3 tone)	=	4,800
	0.5% cement	=	300
	Basic cost	=	6,400
	Labour 20% of Basic	=	1,280
	Overhead 10% of Basic	=	640
	Taxes 10% of Basic	=	640
	Others 2.5% of Basic	=	320
	Total	=	9,280
	Profit 15%	=	1,392
	Grand Total	=	10,672
	Rate = $\frac{10,672}{5.2}$	=	₦2,100/tonne
iv.	Using 2% Emulsion with 2% cement		₦
	1 trip of laterite	=	1,300
	2% Emulsion (0.1 tonne)	=	1,600
	2% Cement (0.1 tonne)	=	1,200
	Basic Cost	=	4,100
	Labour 20% of Basic	=	820
	Overhead 10% of Basic	=	410
	Taxes 10% of Basic	=	410
	Others	=	102.50

Total			=	5,842.50
Profit 15% Total			=	876.38
Grand Total			=	6,718.88
Rate	=	$\frac{6,718.88}{5.2}$	=	1,300/tonne

C. Sample C

i. Stabilization using 8% cement

		₦
1 trip of laterite	=	1,300
8% cement	=	4,800
Basic cost	=	6,100
Labour 20% basic	=	1,220
Overhead 10% basic	=	610
Taxes 10% basic	=	610
Others 2.5% basic	=	152.50
Total	=	8,692.50
Profit 15% Total		1,303.88
Ground Total		9,996.38
Rate = $\frac{9,996.38}{5.2}$	=	₦1,950/tonne

ii. Stabilization using 8% Asphalt-Emulsion

		₦
1 trip of laterite	=	1,300
8% Emulsion	=	6,400
Basic cost	=	7,700

Labour 20% basic	=	1,540
Overhead 10% basic	=	770
Taxes 10% basic	=	770
Others 2.5% basic	=	192.50
Total	=	10,972.50
Profit 15% Total	=	1,645.88
Ground Total	=	12,618.38

Rate $= \frac{12,618.38}{5.2} =$ ₦2,500/tonne

iii. <u>Using 8% Asphalt-Emulsion with 1% cement</u>

		₦
1 trip of laterite	=	1,300
8% Emulsion	=	6,400
1% Cement	=	600
Basic cost	=	8,300
Labour 20% basic	=	1,660
Overhead 10% basic	=	830
Taxes 10% basic	=	830
Others 2.5% basic	=	207.50
Total	=	11,827.50
Profit 15% Total	=	1,774.13
Ground Total	=	13,601.63

Rate $= \frac{13,601.63}{5.2} =$ ₦2,650/tonne

iv. Using 6% Asphalt-Emulsion with 2% cement

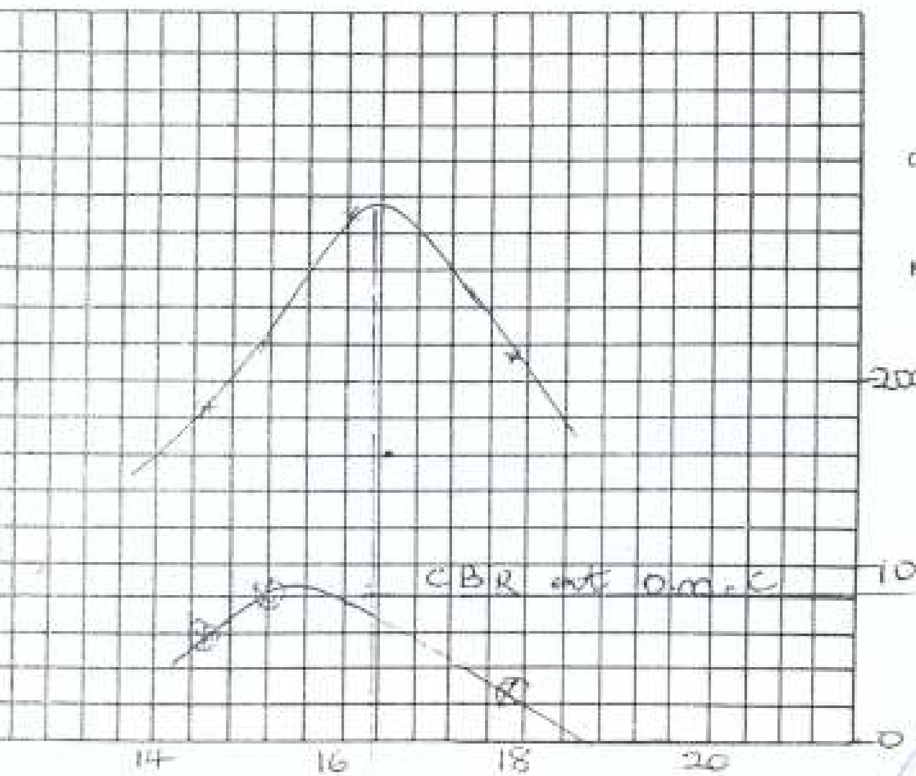
				₦
1 trip of laterite			=	1,300
6% Emulsion			=	4,800
2% Cement			=	2,200
Basic cost			=	7,300
Labour 20% basic			=	1,460
Overhead 10% basic			=	730
Taxes 10% basic			=	730
Others 2.5% basic			=	182.50
Total			=	10,402.50
Profit 15% Total			=	1,560.38
Ground Total			=	11,962.88
Rate	=	$\frac{11,962.88}{5.2}$	=	₦2,300/tonne

From the cost analysis of the various mixtures of additives with the three samples above, the mix that gives the least cost and also at the required strength for a base material 2% asphalt-emulsion with 1 % ₦1,200 per tonne of laterite, 2% asphalt-emulsion with 2% cement for sample B at a cost of ₦1,300 per tonne of laterite and 8% cement at a cost of ₦1,950 per tonne for sample C. It can be sen that some laterite soils can be stabilized economically with a well-designed mixtures of asphalt-emulsion and cement.

0 % cement Content

TEST DATA

	17		20		25		30	
Sample + Mold	8381.0		8646		8741.5		8698	
...ld	4120		4220		4161		4115	
... sample	4261.0		4426.		4580.5		4583	
...l sample	2341		2342		2337		2338	
...ity	1.82		1.89		1.96		1.96	
	10	15	1	5	15	7	11	16
...Sample + Cont	115.3	115.9	120.2	120.6	113.4	114.1	119.8	123.3
...mple + cont	105.4	106	109.4	109.5	102.9	103.4	107.2	110.4
	9.9	9.9	10.8	11.1	10.5	10.7	12.6	12.9
	37.2	37.0	37.3	37.2	37.4	37.2	37.1	37.2
...mple	68.2	69.0	72.1	72.3	65.5	66.2	70.1	73.2
...content %	14.6	14.4	15.0	15.4	15.8	16.2	18.0	17.6
...moisture content %	14.5		15.2		16.0		17.8	
...y	1.59		1.64		1.69		1.66	
...ED CBR 24HRS %	--		6		8		3	



O.M.C.: 16.3 %

M.D.D.: 1.70 g/cc

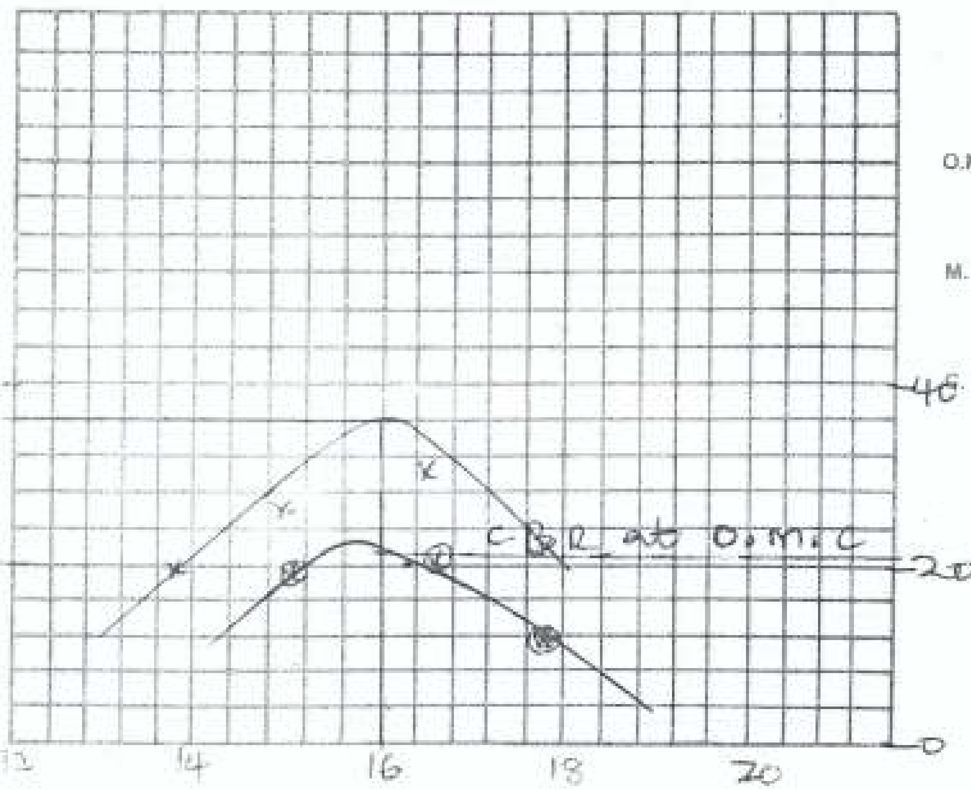
C.B.R.: 8 %

Fig.1 : Moisture - Density - CBR Relations

2 % Cement Content

TEST DATA

d No								
Wet Sample + Mold	8396		8655		8856		8905	
of mold	4256		4301		4297		4352	
of wet sample	4140		4354		4559		4553	
ume of sample	2339		2341		2350		2347	
density	1.77		1.86		1.94		1.94	
No	A	C	B	E	G	H	I	10
Wet Sample + Cont	112.9	116.1	117.8	119	121.5	122.7	121.4	122.7
dry sample + cont	103.5	106.6	107.4	108.2	109.7	110.4	108.6	109.8
water	9.4	9.5	10.5	10.8	11.8	12.3	12.7	12.9
cont	37.0	38.5	37.3	37.2	37.6	37.4	37.1	36.9
dry sample	66.5	68.1	70.1	71.0	72.1	73.0	71.5	72.9
sture content %	14.2	14.0	15.0	15.2	16.3	16.9	17.9	17.7
age moisture content %	14.1		15.1		16.5		17.8	
density	1.55		1.62		1.67		1.65	
AKED CBR 24HRS %	—		18		20		12	



O.M.C. : 16.0 %

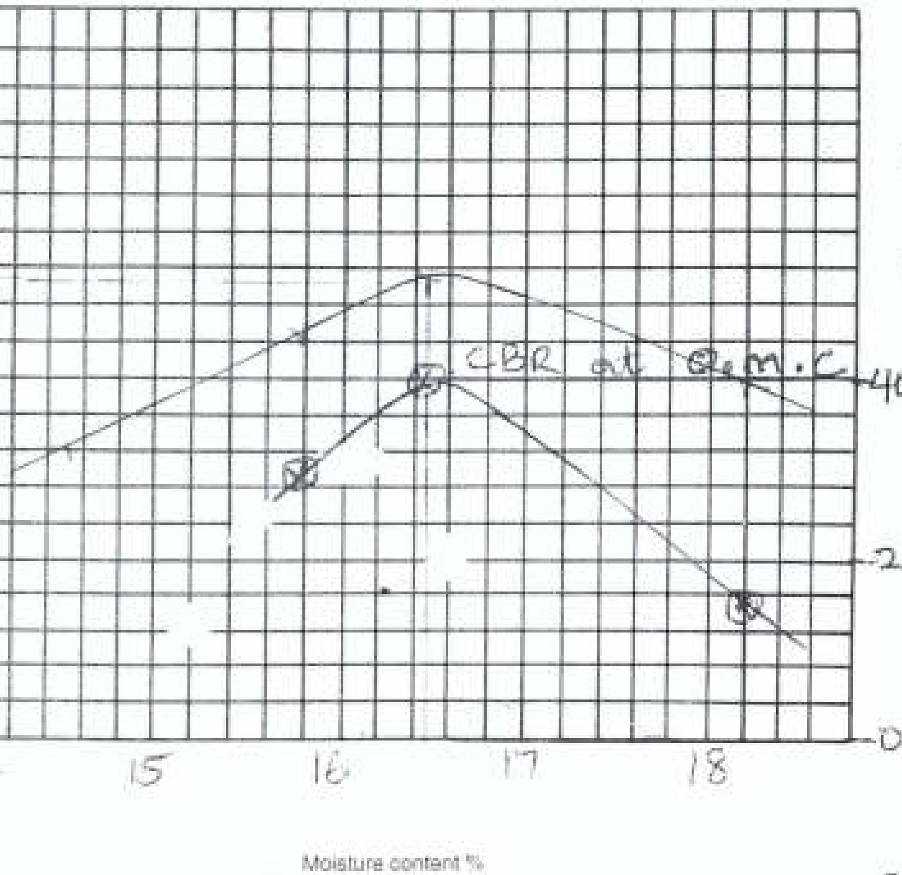
M. D. D : 1.68gk

C. B. R : 22 %

Moisture content %

Fig. 2 : Moisture - Density - CBR Relations

	6		10		15		31	
...ample + Mold	8418.8		8377		8438		8408	
...ld	4300		4015		4010		4042	
... sample	4118.8		4362		4428		4366	
...f sample	2301		2320		2306		2310	
...ity	1.79		1.88		1.92		1.89	
	F	Z	21	50	75	B	73	G
...ample + Cont	117.2	114.8	121.7	121.8	118.8	118.6	118.8	120.2
...mple + cont	107	109.3	110.3	110.2	107.2	106.7	106.2	107.6
	10.2	10.5	11.5	11.7	11.6	11.9	12.7	12.6
	36.9	37.0	37.2	36.8	37.1	36.9	37.2	37.5
...mple	70.1	72.3	73.1	73.4	70.1	69.8	69.0	70.1
...content %	14.5	14.5	15.7	15.9	16.5	16.5	18.4	18.0
...moisture content %	14.5		15.8		16.5		18.2	
...y	1.56		1.62		1.65		1.60	
...ED CBR 24 HRS %	—		28		40		16	



O.M.C. : 16.5%

M. D. D : 1.65 g/cc

C. B. R : 40 %

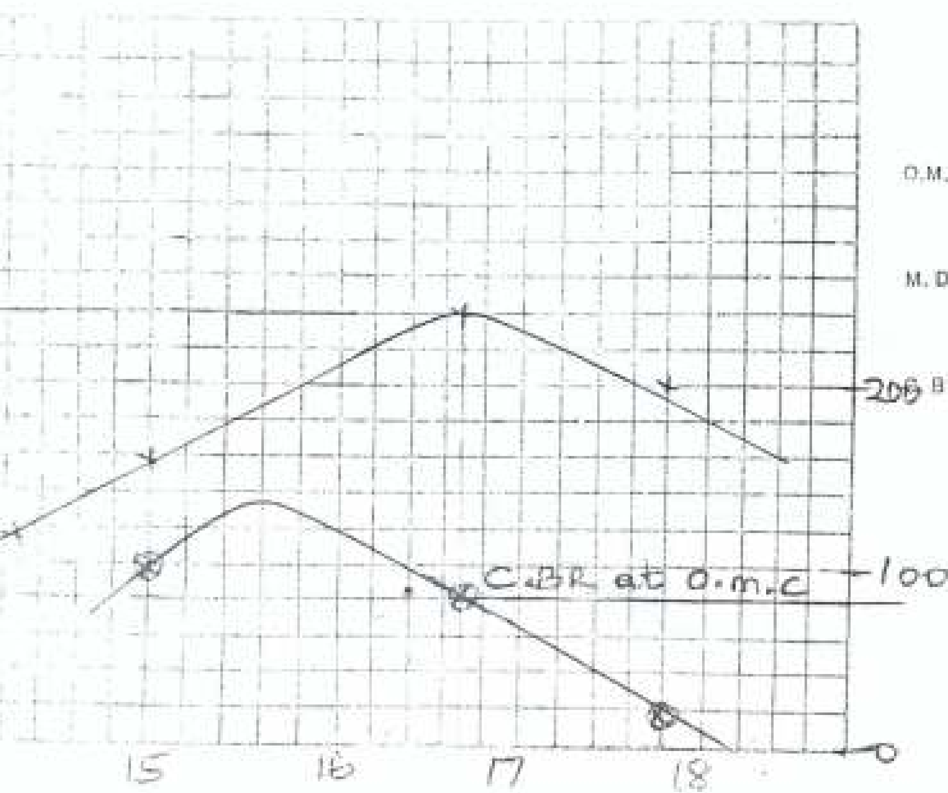
Tested by

Fig. 3 : Moisture - Density - CBR Relations

Sign

TEST DATA

[illegible]	71		15		28		35	
[illegible]	8153		8295		8588		8518	
[illegible]	4120		4115		4052		4121	
[illegible]	4033		4180		4536		4397	
[illegible]	2331		2335		2326		2339	
[illegible]	1·73		1.79		1·91		1.88	
[illegible]	2	1	10	15	F	G	3	6
[illegible]	120.0	122.8	123.1	121.4	122.4	123.6	126.7	124.5
[illegible]	109.6	112.1	111.9	110.4	110.2	111.3	113.2	111.4
[illegible]	10.4	10.7	11.2	11.0	12.2	12.3	13.5	13.1
[illegible]	37.1	36.9	38.0	36.8	37.3	37.2	37.6	37.3
[illegible]	72.5	75.2	73.9	73.6	72.9	74.1	75.6	74.1
[illegible]	14.4	14.2	15.1	14.9	16.7	16.7	17.9	17.7
[illegible]	14.3		15.0		16.7		17.8	
[illegible]	1.51		1.56		1.64		1.60	
...ED CBR 24HRS %	—		100		80		20	



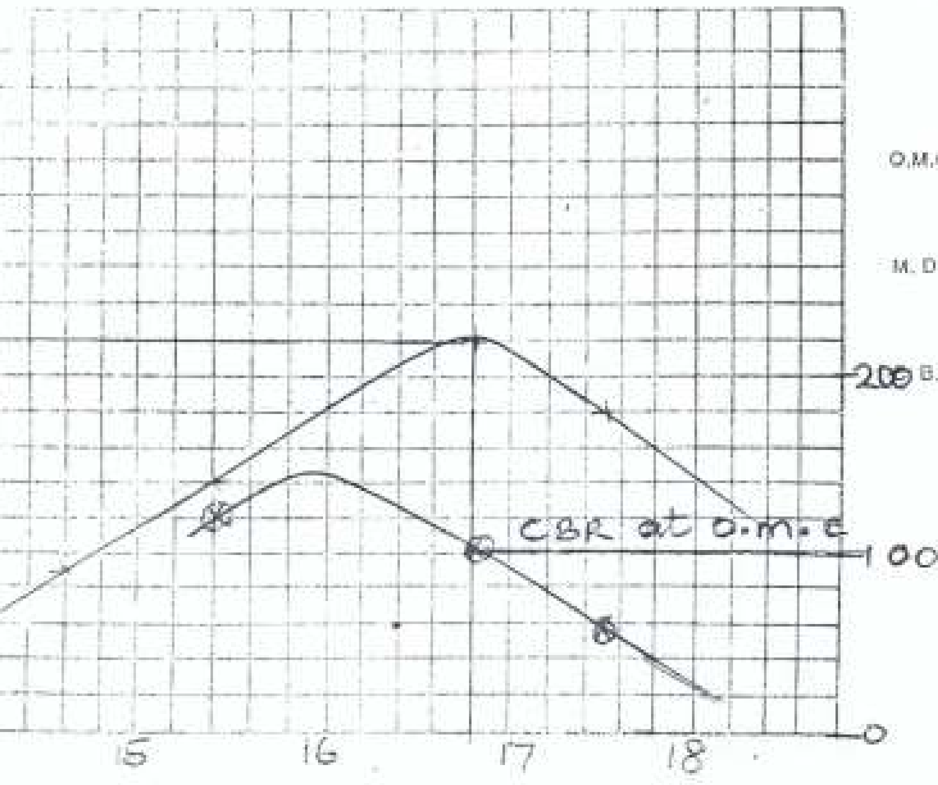
O.M.C.: 16.7 %

M.D.D.: 1.64 g/cc

C.B.R.: 80 %

Fig. 4 : Moisture - Density - CBR Relations

	21		8		16		23	
	8106		8350		8509		8390.4	
	4135		4130		4056		4110	
	3971		4220		4453		4280.4	
	2336		2371		2356		2339	
	1.70		1.78		1.89		1.83	
	8	11	Z	A	10	5	2	13
	117.5	116.4	119.5	120.6	122.9	132.2	123.3	119.8
	107.3	106.4	108.4	109.5	110.5	110.0	110.4	107.5
	10.2	10.0	11.1	11.1	12.4	12.2	12.9	12.3
	37.8	37.5	36.9	37.2	37.4	37.1	36.9	37.0
	69.5	68.9	71.5	72.3	73.1	72.9	73.5	70.5
	14.7	14.5	15.5	15.3	16.9	16.7	17.6	17.4
	14.6		15.4		16.8		17.5	
	1.49		1.54		1.62		1.56	
D CBR 24HRS %	—		120		100		60	



O.M.C.: 16.8 %

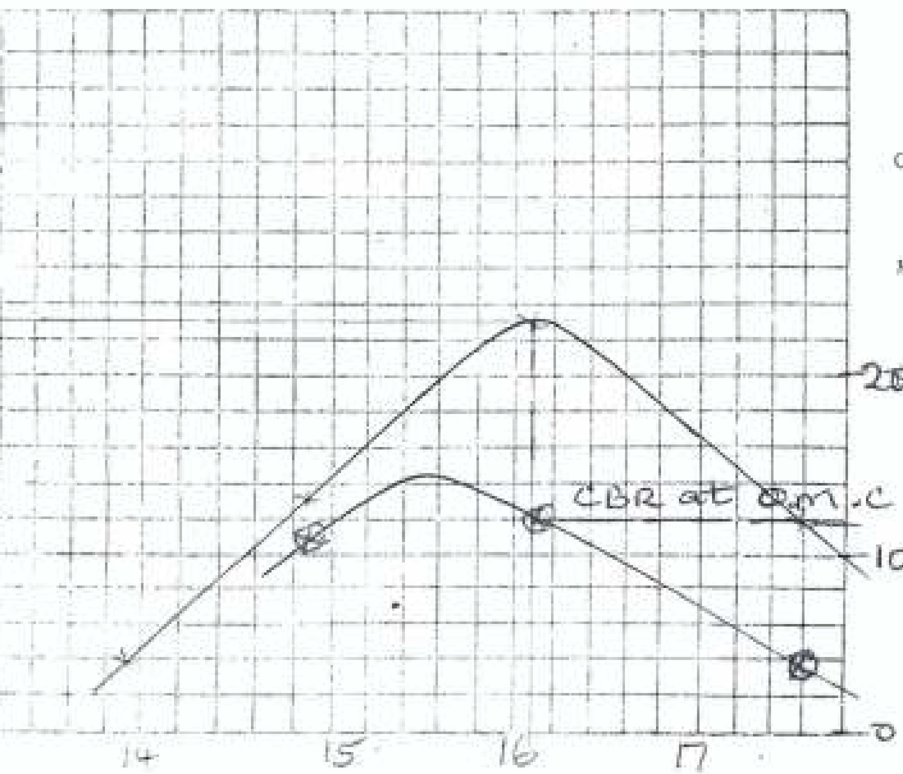
M.D.D: 1.62 g/cc

C.B.R: 102 %

Moisture content %

Fig. 5 : Moisture - Density - CBR Relations

	56		72		83		51	
	7948.8		8449		8685.9		8418	
	4216		4300		4276		4269	
	3732.8		4149		4409.9		4149	
	2333		2305		2321		2318	
	1.60		1.80		1.90		1.79	
	P	1	8	2	11	21	31	16
	116.8	120.1	117.5	115.8	120.9	117.5	120.6	122.8
	107.1	110.1	107.1	105.7	109.5	106.3	108.2	110.0
	9.7	10.0	10.4	10.1	11.4	11.2	12.4	12.8
	37.0	38.9	37.6	37.2	38.5	37.1	37.2	37.5
	70.1	71.2	69.5	68.5	71.0	69.2	71.0	72.5
	13.8	14.0	15.0	14.8	16.0	16.2	17.5	17.7
Moisture content %	13.9		14.9		16.1		17.6	
	1.44		1.53		1.63		1.52	
CBR 24HRS %	–		11		12		4	



O.M.C. 16.1 %

M.D.D. 1.63 g/cc

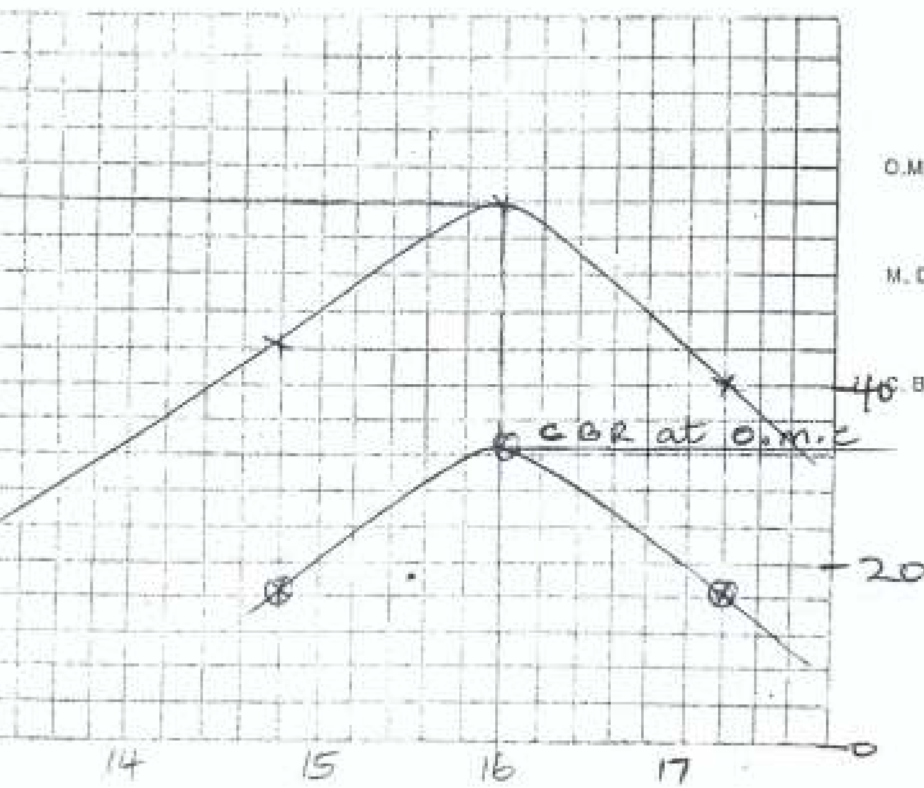
C.B.R. 12 %

Moisture content %

Fig. 6 ; Moisture - Density - CBR Relations

TEST DATA

	10		65		82		90	
	8241.4		8334.7		8428		8365	
	4110		4130		4115		4128	
	4131.4		4204.7		4313		4237	
	2402		2349		2319		2328	
	1.72		1.79		1.86		1.82	
	F	14	24	K	P	32	41	D
	122.8	121.8	122.5	121.2	116.6	120.6	123.7	120.8
	112.4	111.4	111.5	110.5	105.7	109.1	111.1	108.8
	10.4	10.4	11.0	10.7	10.9	11.5	12.6	12.0
	38.9	38.5	37.9	38.0	37.2	37.6	37.6	39.0
	73.5	72.9	73.6	72.5	68.5	71.5	73.5	69.8
	13.1	13.3	14.9	14.7	15.9	16.1	17.2	17.2
	13.2		14.8		16.0		17.2	
	1.51		1.56		1.60		1.55	
CBR 24HRS %	—		16		33		16	



O.M.C. : 16.0 %

M.D.D : 1.60g/cc

C.B.R : 33%

Moisture content %

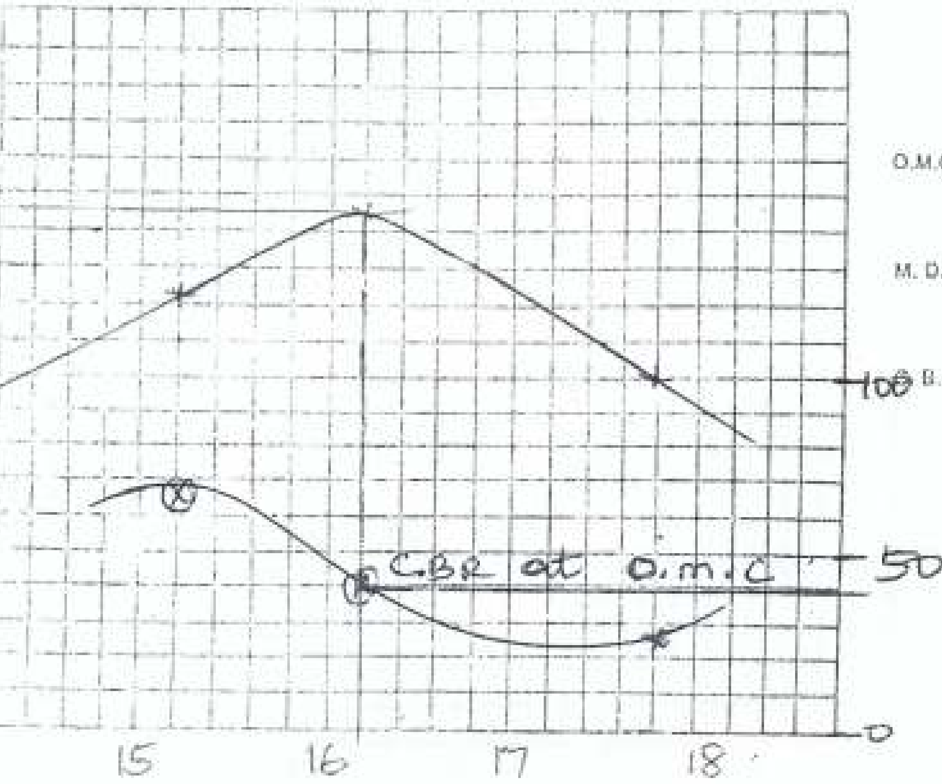
Tested by

Fig. 7 : Moisture - Density - CBR Relations

Sign

TEST DATA

	40		36		61		75		
ple + Mold	8128		8361		8473		8355		
	4229		4236		4228		4229		
	3899		4131		4245		4126		
	2335		2308		2307		2331		
	1.65		1.79		1.84		1.77		
	R	1	⓪	10	17	31	55	73	
mple + Cont.	121.8	121.8	122.1	121.9	123.1	122.6	123.7	123.9	
mple + Cont.	110.8	111.5	111.2	110.7	111.1	110.9	111.0	110.6	
t	10.3	10.3	10.9	11.2	12.0	11.7	12.7	13.3	
	38.0	38.5	38.3	38.1	38.0	37.9	38.1	37.6	
ple	72.8	73.0	72.9	72.6	73.1	73.0	72.9	73.0	
ontent %	14.1	14.1	15.0	15.4	16.4	16.0	17.4	18.2	
isture content %	14.1		15.2		16.2		17.8		
	1.45		1.55		1.59		1.50		
D CBR 24HRS %	—		65		40		25		



O.M.C.: 16.2 %

M.D.D.: 1.59 g/cc

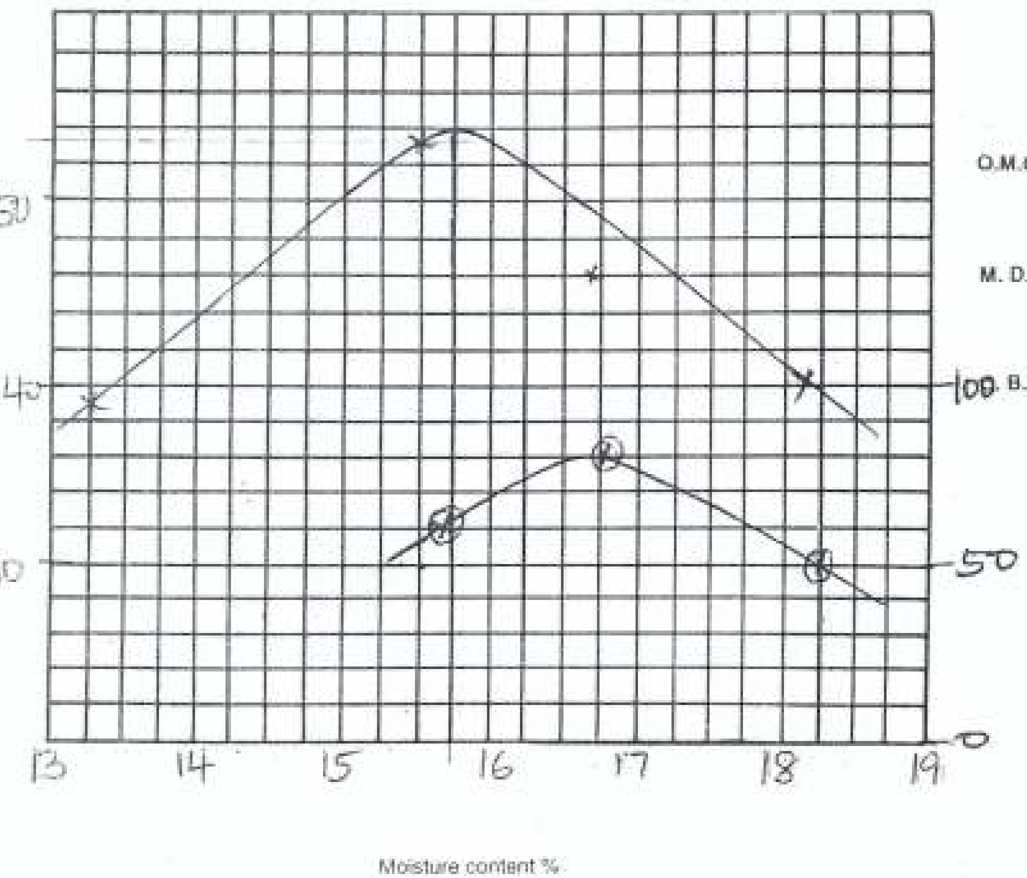
B.R.: 40 %

Moisture content %

Fig. 8 : Moisture - Density - CBR Relations

TEST DATA

Mold No	31		46		64		11	
Wt. Wet Sample + Mold	7689		8157		8086		7865	
Wt. of mold	4050		4061		4036		4040	
Wt of wet sample	3639		4096		4050		3825	
Volume of sample	2318		2314		2318		2318	
Wet density	1.57		1.77		2.61		1.65	
Cont No	71B	50P	100	58	L	82C	56	12
Wt. Wet Sample + Cont	119.1	115.8	121.5	111.5	107.1	116.3	119.6	105.5
Wt. dry sample + cont	108.7	106	110.1	100.8	96.5	104.8	106.7	94.9
Wt. water	10.4	9.8	11.4	10.7	10.6	11.5	12.9	10.6
Wt. cont	31.3	32.0	36.3	31.8	33.0	36.1	36.2	35.8
Wt. dry sample	77.4	74.0	73.8	69.0	63.5	68.7	70.5	59.1
Moisture content %	13.4	13.2	15.5	15.5	16.7	16.7	18.3	18.0
Average moisture content %	13.3		15.5		16.7		18.1	
Dry density	1.39		1.53		1.46		1.40	
SOAKED CBR 24HRS %	—		60		80		50	



O.M.C. 15.7%

M.D.D. 1.53

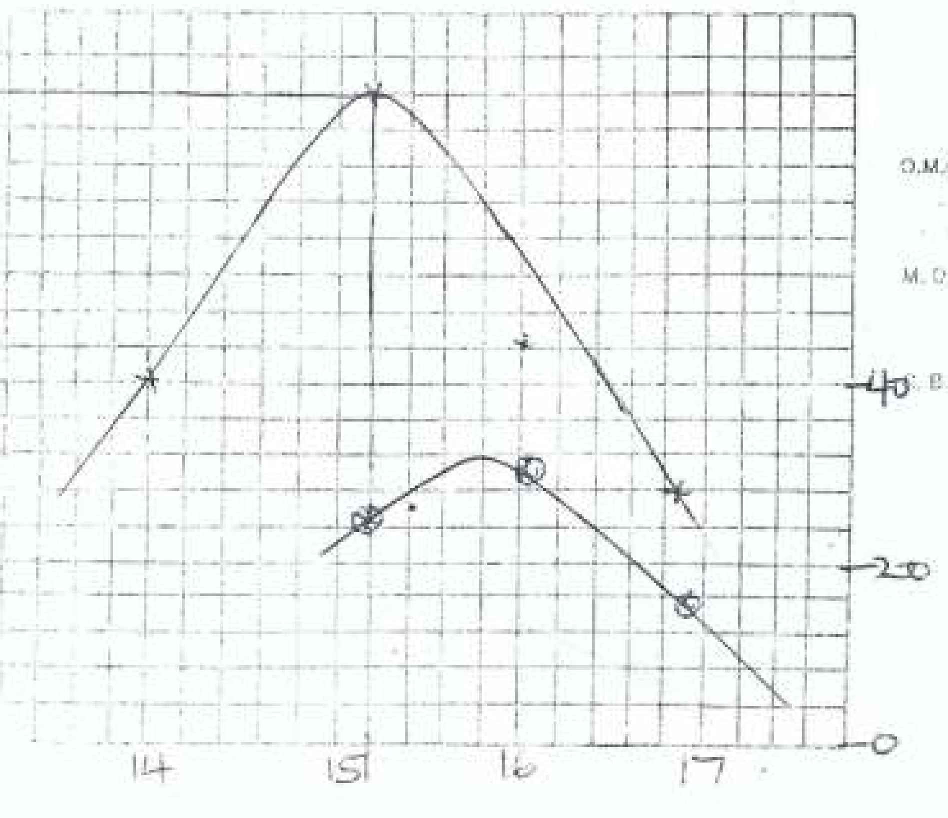
C.B.R. 60%

Fig. 9 : Moisture - Density - CBR Relations

2 % Asphalt-Emulsion : ½ % Cement Content

TEST DATA

	74		91		80		66	
	8403		8527		8347.3		8245	
	4131		4130		4130		4128	
	4272		4397		4217.3		4117	
	2400		2339		2330		2329	
	1.77		1.88		1.81		1.78	
	14	17	32	33	41	48	16	10
	120.5	124.2	120.7	121.1	121.5	122.1	118.9	123.1
	110.3	111.0	109.8	110.1	110.0	110.4	107.2	110.8
	10.2	10.2	10.9	11.0	11.5	11.7	11.7	12.3
	37.8	38.0	37.9	37.6	38.0	38.1	37.7	37.8
	72.5	73.0	71.9	72.5	72.0	72.3	69.5	73.0
	14.0	14.0	15.2	15.2	15.9	16.2	16.9	16.9
	14.0		15.2		16.0		16.9	
	1.55		1.63		1.56		1.52	
ED CBR 24 HRS %	—		25		30		16	



O.M.C. : 15.2 %

M.D.D. : 1.63 g/cc

C.B.R. : 25 %

Moisture content %

Tested by

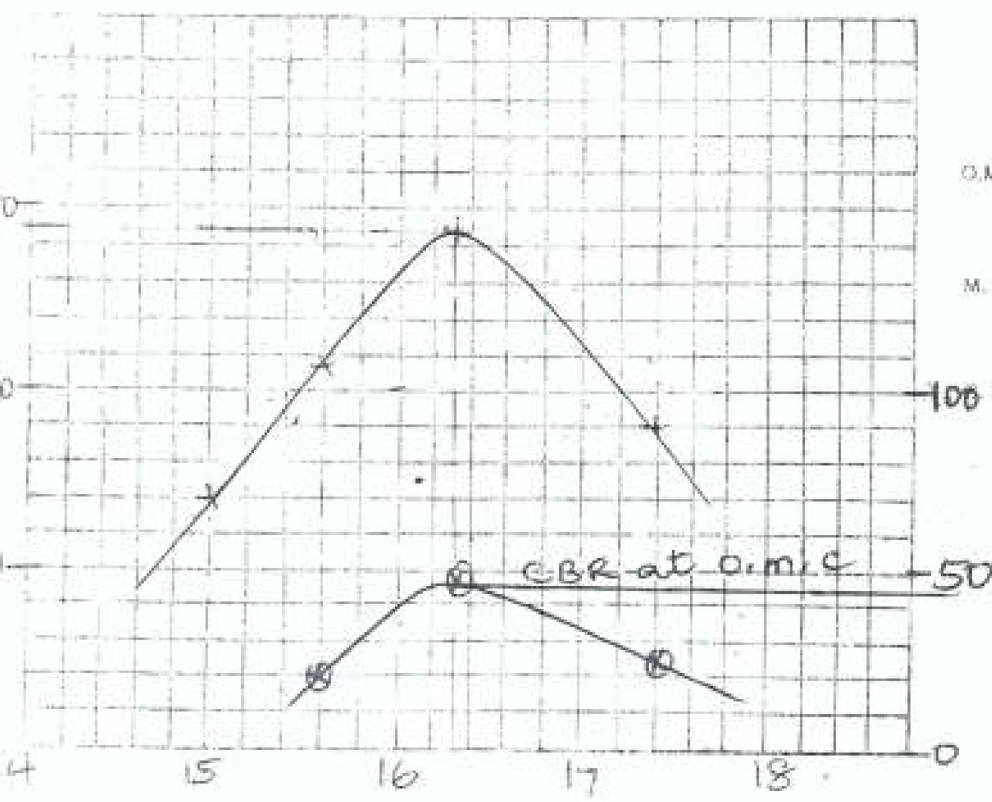
Fig. 10 : Moisture - Density - CBR Relations

Sign

4% Asphalt - Emulsion : ½ % Cement Conten

TEST DATA

...No	5		12		62		100	
Wet Sample + Mold	8171		8387.3		8842.5		8363	
...mold	4100		4100		4085		4091	
...sample	4071		4287.3		4757.5		4272	
...sample	2300		2305		2415		2309	
...density	1.77		1.86		1.97		1.85	
...No	A	C	D	F	G	2	F1	P.4
Wet Sample + Cont	121.9	120.9	122.6	121.7	117.3	121.6	123.0	120.3
Dry sample + cont	111.0	110.0	111.2	110.3	106.1	109.7	110.2	108.2
...water	10.9	10.9	11.4	11.4	11.2	11.9	12.8	12.1
...cont	37.9	37.5	38.0	38.2	36.9	37.2	31.5	38.0
Dry sample	73.1	72.5	73.2	72.1	69.2	72.5	72.7	70.2
...content %	14.9	15.1	15.6	15.8	16.2	16.4	17.6	17.2
...moisture content %	15.0		15.7		16.3		17.4	
...density	1.54		1.61		1.69		1.58	
...AKED CBR 24HRS %	--		20		45		25	



O.M.C. : 16.3 %

M.D.D. : 1.69 g/c

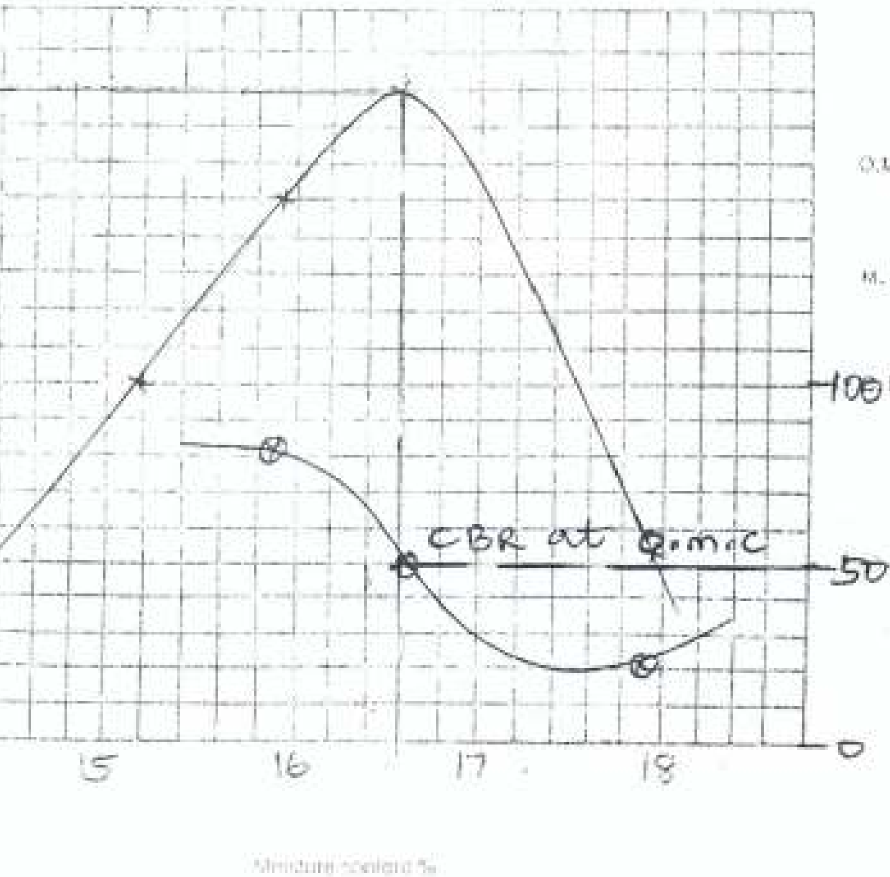
C.B.R. : 45 %

Moisture content %

Fig. 11 : Moisture - Density - CBR Relations

TEST DATA

	51		32		20		16	
... + Mold	8217		8652		8633		8098	
	4100		4190		4101		4100	
	4117		4462		4532		3998	
	2300		2412		2385		2259	
	1.79		1.85		1.90		1.77	
	A	4	D	10	2	6	11	5
... + Cont	110.7	110.3	112.7	117.6	115.4	111.6	109.5	118.2
... cont	101.0	100.0	102.4	106.4	104.2	101.1	98.4	106.0
	9.7	10.3	10.3	11.2	11.2	10.5	11.1	12.2
	36.5	32.5	37.1	36.2	36.4	37.0	36.2	38.0
	64.5	67.5	65.3	70.2	67.8	63.5	62.2	68.0
...%	15.1	15.3	15.7	16.0	16.6	16.6	17.8	18.0
... content %	15.2		15.9		16.6		17.9	
	1.55		1.60		1.63		1.50	
CBR 24HRS %	—		85		50		20	



O.M.C.: 16.6 %

M.D.D.: 1.63 g/cc

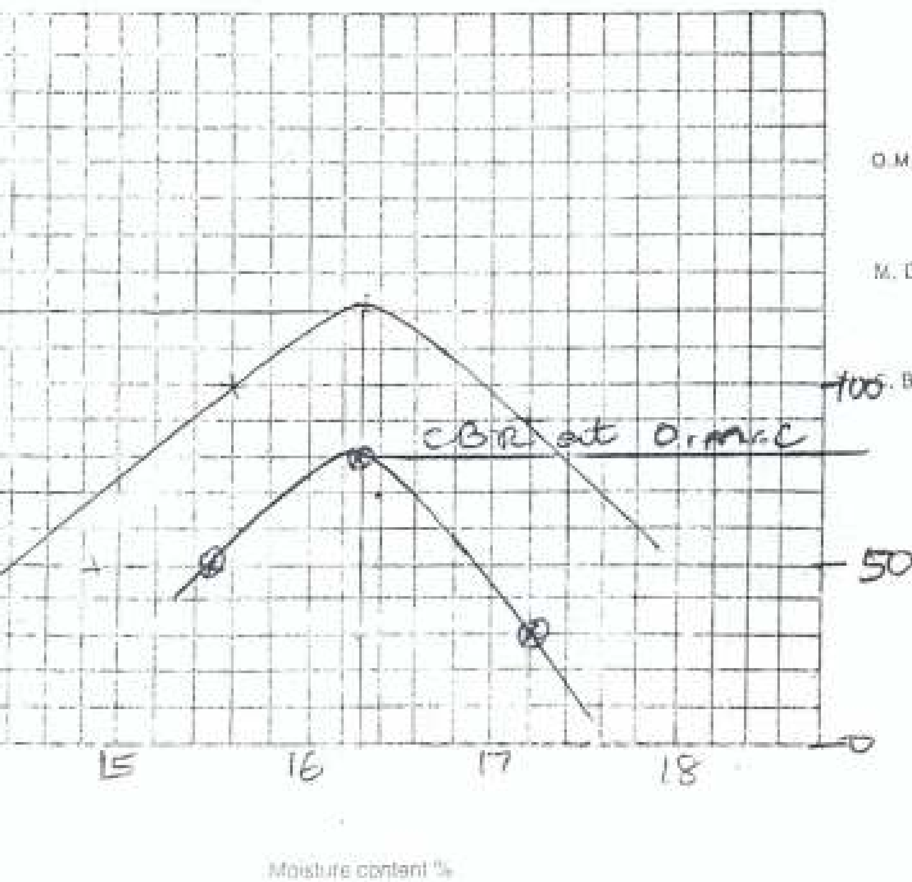
C.B.R.: 50 %

Fig. 12 : Moisture - Density - CBR Relations

% Asphalt - Emulsion : ½ % Content Content

TEST DATA

	39		41		53		40	
	7894.2		8252		8367		7976	
	4101		4100		4087		4099	
	3,793.2		4152		4280		3877	
	2356		2400		2391		2228	
	1.61		1.73		1.79		1.74	
	10	16	21	32	15	22	17	35
	121.8	121.5	121.0	122.6	117.2	123.0	123.6	118.4
	110.9	110.7	101.9	111.0	106.1	111.0	111.1	106.4
	10.9	10.8	11.1	11.6	11.1	12.0	12.5	12.0
	37.9	38.1	38.0	37.5	37.6	37.9	38.1	36.9
	73.0	72.6	71.9	73.5	68.5	73.1	73.0	69.5
	14.9	14.9	15.4	15.8	16.2	16.4	17.1	17.7
...ure content %	14.9		15.6		16.3		17.2	
	1.40		1.50		1.54		1.48	
CBR 24HRS%	—		50		80		30	



O.M.C.: 16.3 %

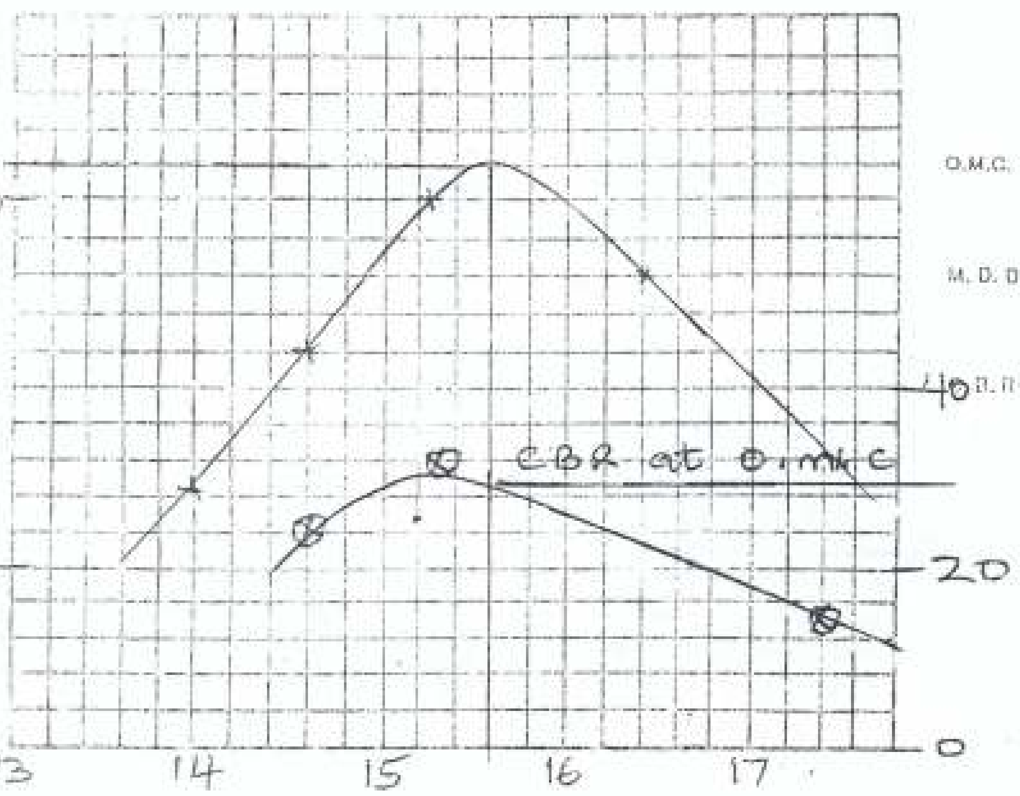
M.D.D.: 1.54 g/cc

C.B.R.: 80 %

Fig. 13 : Moisture - Density - CBR Relations

%c Asphalt-Emulsion : 1% Cement Content

[illegible]	39		53		101		91	
[illegible] Sample + Mold	8428		8512		8459.2		8421.4	
[illegible]	4101		4100		4108		4105	
[illegible]	4327		4412		4351.2		4316.4	
[illegible]	2551		2465		2352		2398	
[illegible]	1.73		1.79		1.55		1.80	
[illegible]	11	6	21	5	P.5	A	9	15
[illegible]	126.4	128.6	110.0	111.9	115.3	118.6	121.3	123.0
[illegible]	115.4	117.2	100.6	102.3	104.8	107.8	108.8	110.1
[illegible]	11.0	11.4	10.0	9.6	10.5	10.8	12.5	12.9
[illegible]	36.3	37.0	36.8	37.2	36.1	37.3	37.2	37.0
[illegible]	79.1	80.2	63.2	65.1	68.7	70.5	71.6	73.1
[illegible] content %	13.9	14.2	14.5	14.7	15.3	15.3	17.4	17.6
[illegible]ge moisture content %	14.0		14.6		15.3		17.5	
[illegible]nsity	1.57		1.56		1.60		1.53	
[illegible]KED CBR 24 HRS %	—		24		32		14	



O.M.C. 15.6%

M.D.D. 1.61

C.B.R. 30%

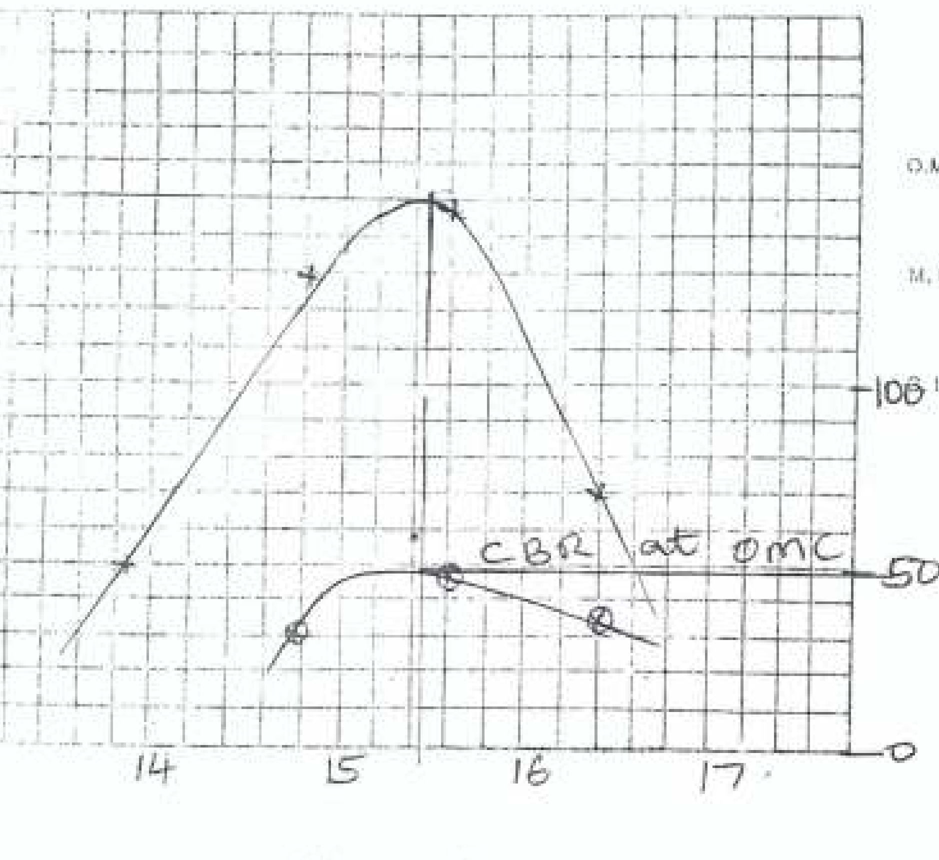
Moisture content %

Fig. 14 : Moisture - Density - CBR Relations

Tested by__________

% Asphalt-Emulsion : 1% Cement Content

	101		93		84		18	
	8132		8312		8388		8254	
	4110		4105		4100		4092	
	4021.9		4206.6		4288.3		4161.8	
	2352		2337		2318		2325	
	1.71		1.80		1.85		1.79	
	3	7	12	16	20	F1	G	C
	120.1	120.2	121.7	121.2	121.1	117.2	117.1	120.8
	110.[illegible]	110.[illegible]	111.0	110.4	109.9	106.4	105.9	109.0
	10.1	10.2	10.7	10.8	11.2	10.8	11.2	11.8
	36.9	37.1	38.0	37.9	38.0	36.9	37.0	37.2
	73.1	72.9	73.0	72.5	71.9	69.5	68.9	71.8
	13.8	14.5	14.7	14.9	15.6	15.6	16.3	16.5
	13.9		14.8		15.6		16.4	
	1.50		1.57		1.60		1.54	
ED CBR 24HRS %	—		30		50		35	



O.M.C. 15.5 %

M.D.D. 1.60 g/cc

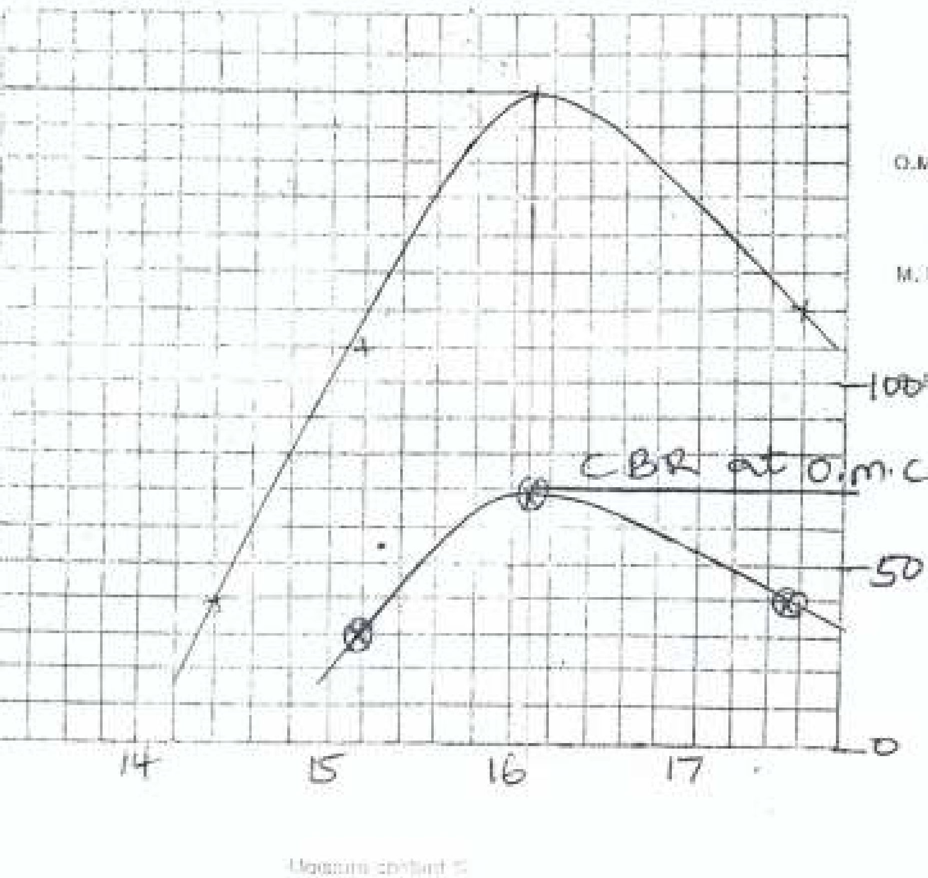
C.B.R. 50 %

Fig. 15 : Moisture - Density - CBR Relations

to Cement Content

TEST DATA

	88		121		67		74		
…mple + Mold	7977		8196		8473		8280		
	4101		4105		4081		4099		
…ample	3876		4091		4392		4181		
…mple	2349		2351		2400		2336		
	1.65		1.74		1.83		1.79		
	3	7	13	18	21	16	4	F	
…ple + Cont	119.5	120.8	122.3	124.9	118	117.1	119.3	124.2	
…ple + cont	109.5	109.9	111.1	110.6	106.8	105.9	107	111.1	
	10.0	10.9	11.2	11.3	11.2	11.2	12.3	13.1	
	37.0	36.9	37.6	37.1	37.1	37.0	36.9	37.2	
	72.5	73.0	74.1	73.5	69.7	68.9	70.1	73.9	
…%	13.8	15.0	15.1	15.3	16.0	16.2	17.5	17.7	
…ture content %	14.4		15.2		16.1		17.6		
	1.44		1.51		1.58		1.52		
…D CBR 24HRS %	—		30		70		40		



O.M.C. : 16.1 %

M.D.D. : 1.58 g/cc

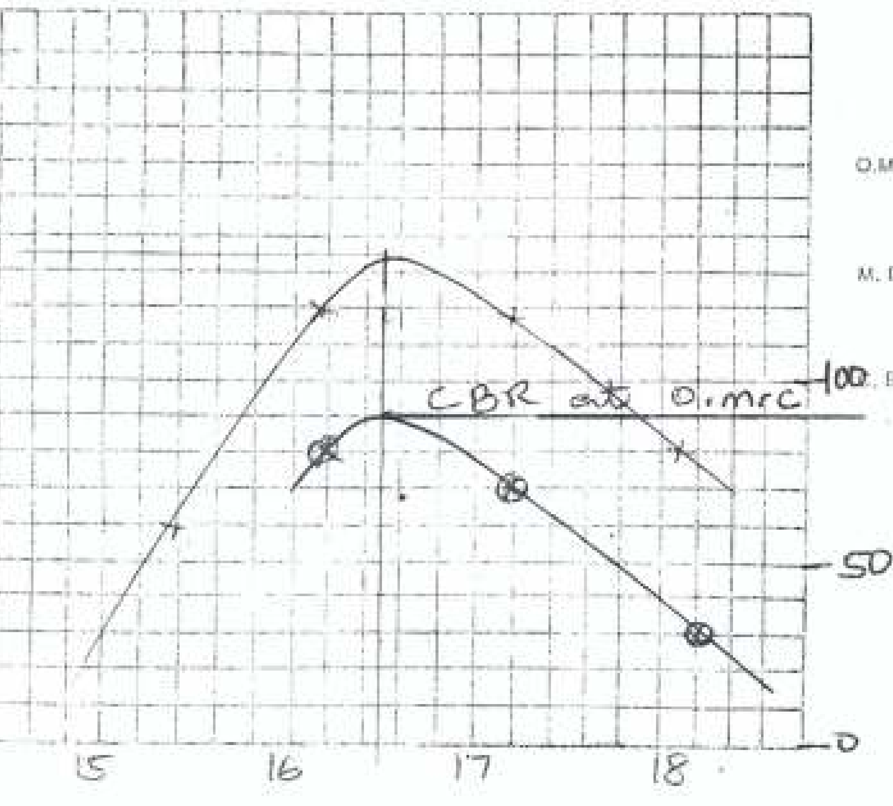
C.B.R. : 70 %

Fig.16 : Moisture -Density-CBR - Relations

Asphalt-Emulsion : 1% Cement-Content

TEST DATA

	63		59		65		61	
	8060		8205		8374		8192	
	4102		4100		4100		4101	
	3958		4105		4274		4091	
	2356		2319		2401		2338	
	1.68		1.77		1.78		1.75	
	6	7	5	4	8	2	7	1
	116.5	115.2	119.4	121.0	119.2	121.3	123.2	122.7
	106	104.9	108.1	109.4	107.2	109	110.0	109.6
	10.5	10.3	11.3	11.6	12.0	12.3	13.2	13.1
	37.5	38.1	38.0	37.9	37.3	37.5	36.9	37.1
	68.5	66.8	70.1	71.5	69.9	71.5	73.1	72.5
	15.3	15.5	16.1	16.3	17.2	17.2	18.1	18.1
... content %	15.4		16.2		17.2		18.1	
	1.46		1.52		1.52		1.48	
CBR 24HRS %	—		80		70		30	



O.M.C. : 16.5%

M.D.D : 1.55 g/cc

C.B.R. : 90%

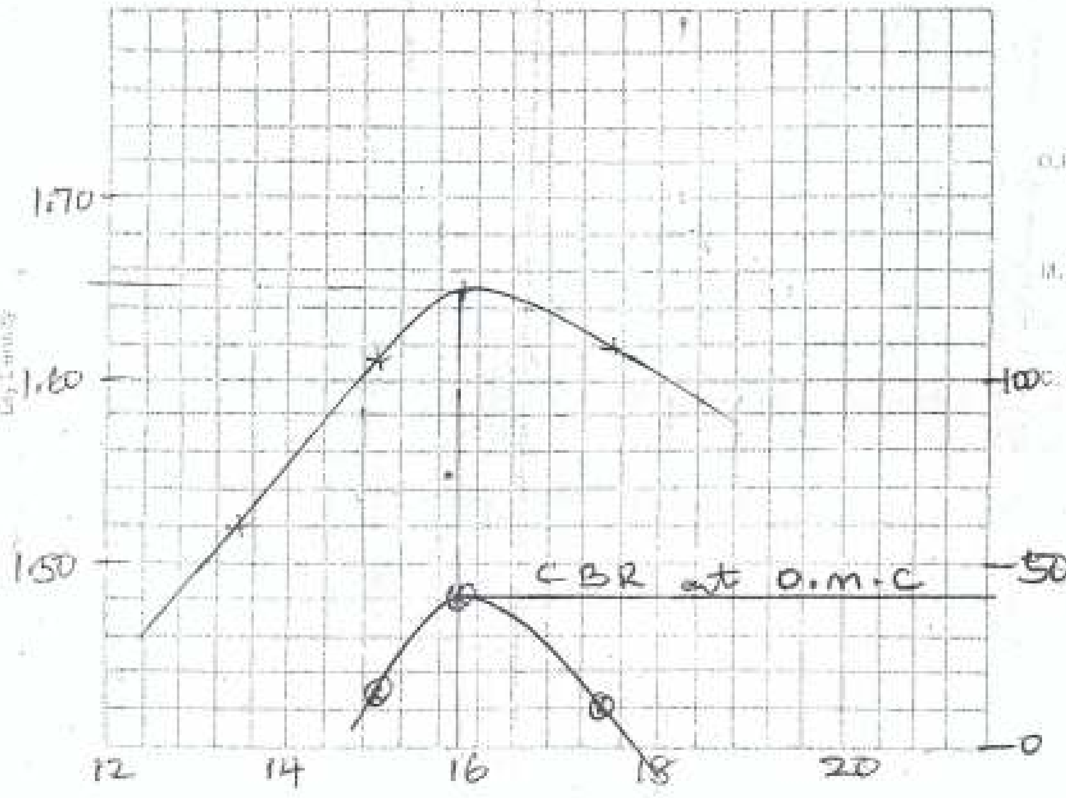
Moisture content %

Fig 17 : Moisture - Density - CBR - Relations

Type of Test:

2 % Asphalt-Emulsion : 2 % Cement-Cement

TEST DATA								
Mould No.	70		64		46		50	
Wt. Wet sample + Mould	8192		8503		8683		8641	
Wt. of mould	4101		4100		4099		4085	
Wt. wet sample	4091		4403		4584		4556	
Volume of sample	2365		2380		2400		2398	
Wet density	1.73		1.85		1.91		1.90	
Can No.	5	12	B	C	Q	R	4	7
Wt. Wet sample + can	116.6	118.5	117.4	117.9	119.2	119.4	119.5	119.4
Wt. dry sample + can	107.1	108.8	106.9	107.4	108.0	108.2	107.4	107.0
Wt. water	9.5	9.7	10.5	10.5	11.2	11.2	12.1	12.4
Wt. can	36.6	37.0	37.1	37.2	37.0	37.1	37.1	37.2
Wt. dry sample	70.5	71.8	69.8	70.2	71.0	71.1	70.3	69.8
Moisture content %	13.5	13.5	15.0	15.0	15.8	15.8	17.2	17.8
Average moisture content %	13.5		15.0		15.8		17.5	
Dry density	1.52		1.61		1.65		1.62	
SOAKED CBR 24HRS %	—		15		40		10	



O.M.C. : 15·8 %

M.D.D. : 1.65g/c

C.B.R. : 40 %

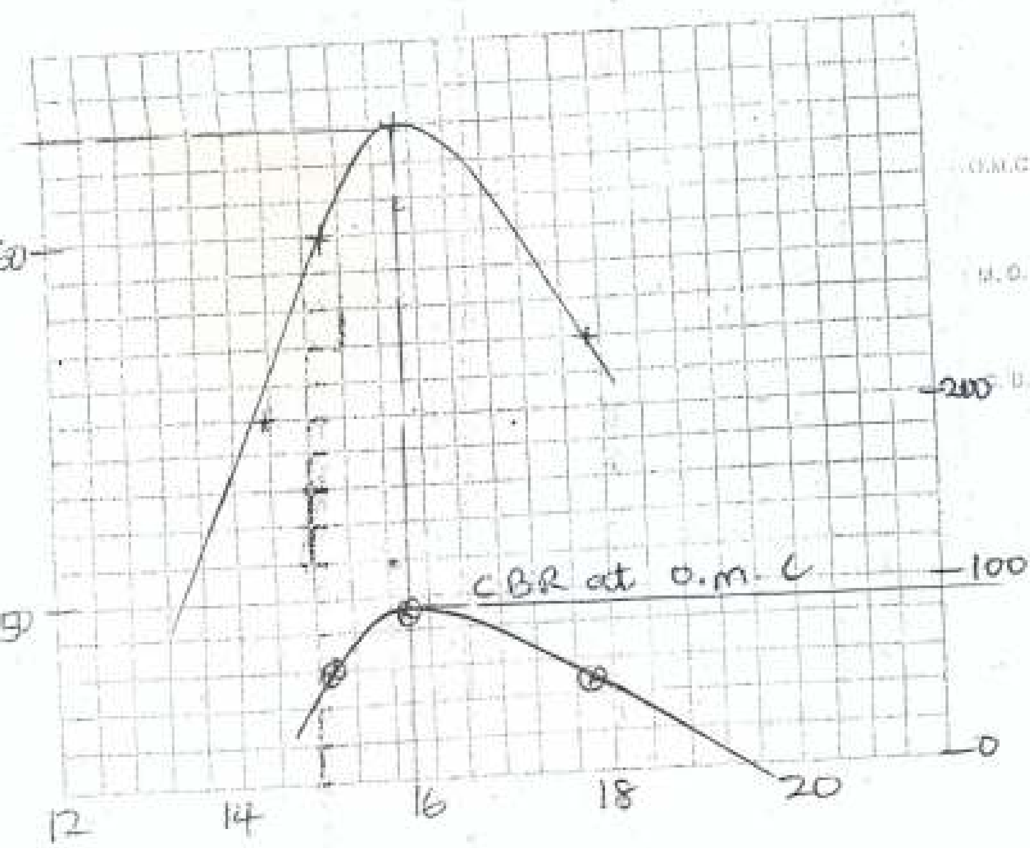
Fig.18 :Moisture – Density –CBR –Relations

Tested by..................

Asphalt-Emulsion

TEST DATA

	115		75		87		100	
	8350		8626		8595		8535	
	4100		4100		4101		4105	
	4250		4526		4494		4431	
	2401		2460		2378		2395	
	1.77		1.84		1.89		1.85	
	51	16	25	40	18	31	13	19
	121.1	116.1	116.3	116.0	115.2	114.1	119.1	120.0
	110.6	106.1	105.9	105.8	104.6	103.5	106.9	107.1
	10.5	10.0	10.4	10.2	10.6	10.6	12.2	12.9
	37.1	36.6	37.1	37.5	38.1	36.9	37.0	36.9
	73.5	69.5	68.8	68.3	66.5	66.6	69.9	70.2
	14.4	14.4	15.1	14.9	15.9	15.9	17.5	18.4
	14.4		15.0		15.9		17.9	
	1.55		1.60		1.63		1.57	
KED CBR 24HRS %	—		60		90		50	



O.M.C: 15.9 %

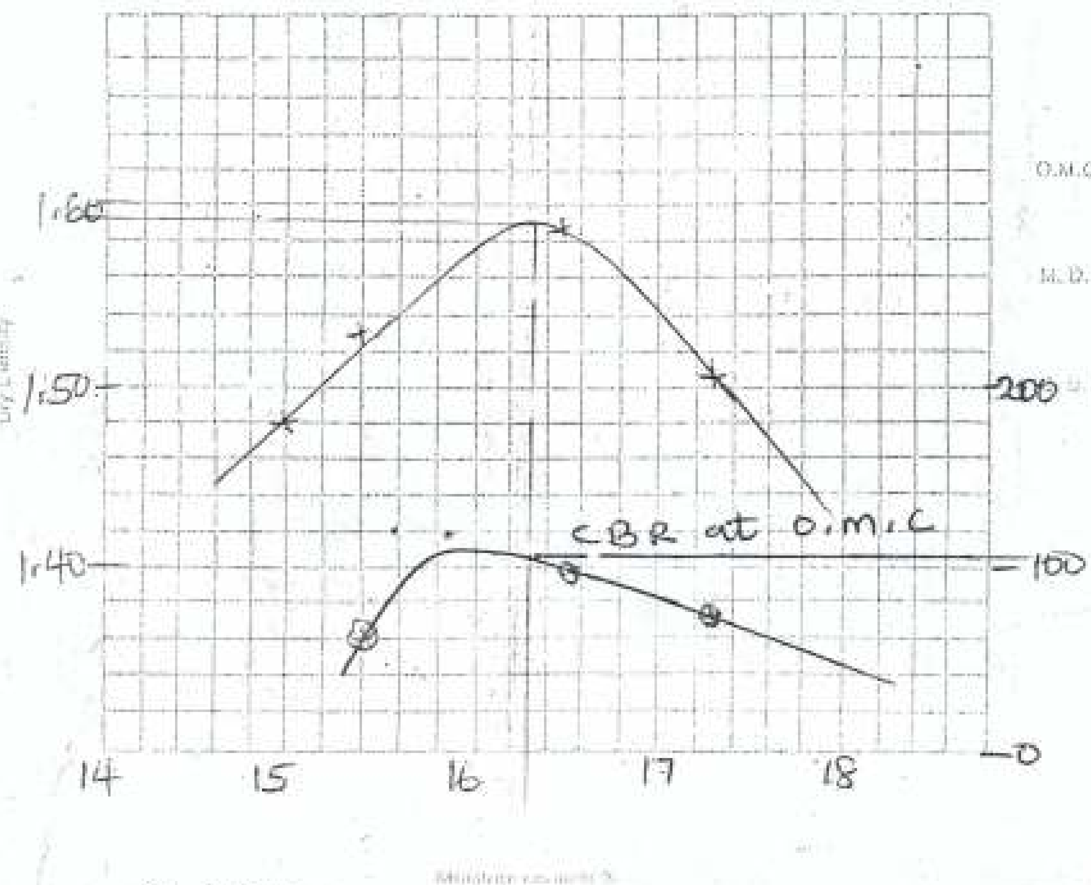
M.D.D: 1.63g/c

C.B.R: 90%

Fig. 19 ! Moisture -Density -CBR -Relations

6% Asphalt-Emulsion : 2 % Cement Content

TEST DATA									
Mould No.	88		15		161		P.81		19
Wt. Wet sample + Mould	8110		8493		8440		8319		
Wt. of mould	4010		4050		4100		4080		
Wt. of wet sample	4100		4443		4340		4239		
Volume of sample	2412		2510		2346		2395		
Wet density	1.70		1.77		1.85		1.77		
Cont. No.	19	22	16	13	F.2	P.1	11	15	
Wt. Wet sample + Cont.	119.2	116.8	116.4	118.3	118.9	123.2	122.0	109.7	
Wt. dry sample + Cont.	108.5	106.3	105.9	107.4	107.3	111.1	109.6	107.4	
Wt. water	10.7	10.5	10.5	10.9	11.6	12.1	12.4	12.3	
Wt. cont.	37.0	36.8	37.1	36.9	37.1	38.0	37.7	36.9	
Wt. dry sample	71.5	69.5	68.8	70.5	70.2	73.1	71.9	70.5	
Moisture content %	14.9	15.1	15.3	15.5	16.5	16.5	17.2	17.4	
Average moisture content %	15.0		15.4		16.5		17.3		
Dry density	1.48		1.53		1.59		1.51		
SOAKED CBR 24HRS%	—		60		100		70		



O.M.C. : 16.3 %

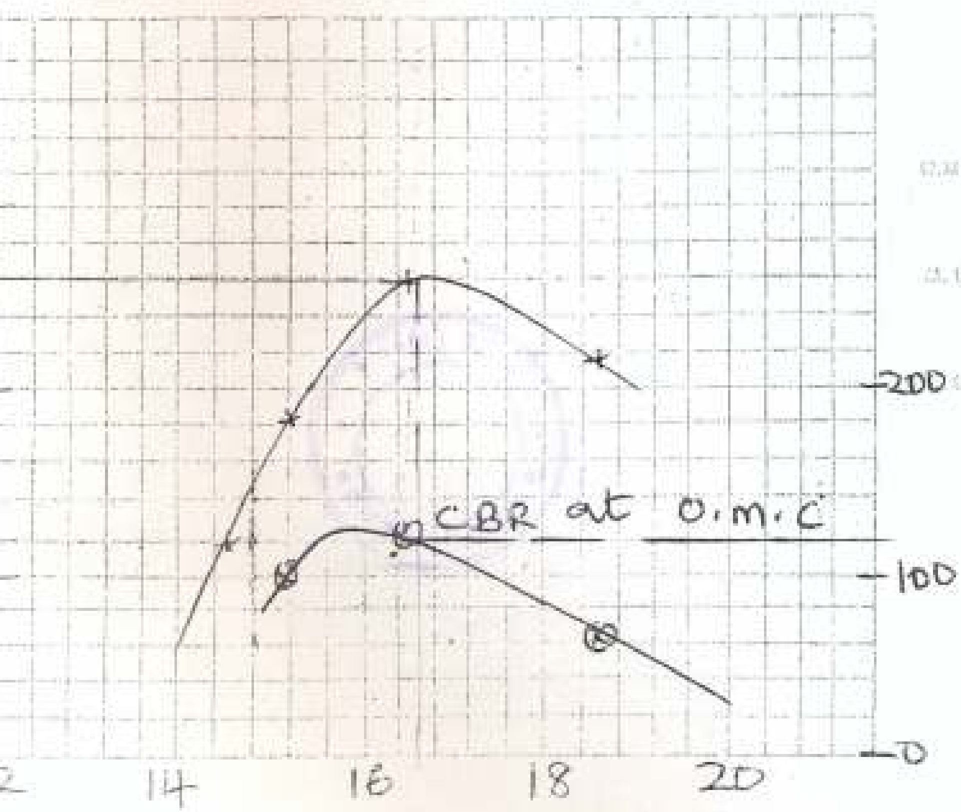
M.D.D. : 1.59 g/c

C.B.R. : 105 %

Fig 20 : Moisture -Density -CBR -Relations

Emulsion : 2

	11		33		42		14	
[illegible]	8217		8113		8472		8443	
[illegible]	4100		4101		4100		4100	
[illegible]	4117		4012		4372		4343	
[illegible]	2526		2346		2402		2413	
[illegible]	1.63		1.71		1.82		1.80	
	Z	P	A	C	1	6	F	12
[illegible]	116.4	115.	111.2	122.4	122.9	116.6	121.0	122.8
[illegible]	106.4	105	101.9	111.2	110.8	105.1	107.8	109.6
[illegible]	10.0	10.1	10.1	11.2	12.1	11.5	13.2	13.2
	36.9	36.2	36.8	37.1	36.9	37.0	37.3	37.5
[illegible]	69.5	68.8	65.1	74.1	73.9	68.1	70.5	72.1
[illegible]	14.4	14.6	16.5	15.1	16.3	16.9	18.7	18.3
[illegible]	14.5		15.3		16.6		18.5	
[illegible]	1.42		1.48		1.56		1.52	
...ED CBR 24HRS %	—		100		120		60	



O.M.C. 16.5 %

M.D.D. 1.56 g/c

C.B.R. 120 %

Fig.21 : Moisture -Density -CBR -Relations