UNIVERSITY OF SCIENCE AND TECHNOLOGY
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SCHOOL OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

THE EFFECT OF BITUMEN EMULSION ON SELECTED ENGINEERING PROPERTIES OF LATERITIC GRAVEL AND THE POTENTIAL FOR REDUCING EROSION OF UNPAVED ROADS

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A thesis submitted to
The Board of Postgraduate Studies
Kwame Nkrumah University of Science and Technology, Kumasi,
In Partial fulfillment of the requirement for award of the
Degree of Master of Philosophy in Civil Engineering

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June 2001

CERTIFICATION

This is to certify that this thesis is the candidate's own account of his Research

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Dedicated to my Family

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Acknowledgement

My Greatest thanks to the Lord God Almighty who helped me through this entire Research study, keeping and providing me with the strength and resources needed for the whole time. I am also greatly indebted to Dr SIK Ampadu my supervisor who meticulously guided me through this work with constructive criticism, support in all aspects and many more than I can mention here, to him I say God shall reward you accordingly. My Special thanks also goes to the whole Staff of the Civil Engineering Department who helped me in various ways to achieve this success, especially Dr YA Tuffour, Mr. Gilbert Fiadzo, Mr. Asamoah and Miss Florence Awumee just to mention a few. I will also like to appreciate the Staff of BRRI who helped in directing me through this Laboratory work and thesis analysis. My gratitude also goes to Ghana Emulsion Company Limited for supplying me with free samples of their product for the laboratory experiment.

To all my Loved ones who through their special prayers and support I have come this far, I say God Bless you and repay you for all that you gave for my successful completion of my M.Phil Thesis.

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NYANSAPƆ W ƆSANE NO BADWENMA

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Abstract

In Ghana the road network accounts for the overwhelming proportion of both passenger and freight traffic. The network is about 40,000km long and is divided into three functional classes of feeder roads, trunk roads and urban roads. Over 82% of the network is unpaved and unpaved roads can be found in all functional classes of roads and distributed in all the regions of the country. One of the characteristics of unpaved roads is that they tend to deteriorate faster than paved roads. Like in many developing countries, the funds available for maintenance in Ghana is far below that required to keep the roads at the minimum level of service. The unpaved roads are also mostly low volume roads with average daily traffic levels not exceeding 100 even on trunk roads. Given the rather high rainfall in the southern parts of the country, it appears that the major cause of deterioration of unpaved roads in these parts of the country is rainfall-induced erosion. Any financially affordable effort that leads to a delay in the deterioration of these unpaved roads will therefore contribute towards an improvement of the road network. Stabilization is known to be a simple and often affordable method of improving the resistance of unpaved roads to erosion. This project therefore seeks to investigate first how stabilization of lateritic gravel using bitumen emulsion can affect certain engineering properties of lateritic gravel and then secondly to investigate the potential for using this material to reduce rainfall induced erosion on unpaved roads.

The study first reviews the factors that affect the deterioration of unpaved roads, the effect of rainfall characteristics on erosion, the rainfall patterns and zones in the country and their effect on the formation of the different types of lateritic gravel. It also reviews the experience of the effects of cement, lime and bitumen emulsion on different lateritic gravel. An anionic bitumen emulsion produced locally was used in the laboratory investigation. The laboratory work consisted of an investigation of the effect of different percentages of the bitumen on the index properties, compaction characteristics, CBR and permeability of samples of lateritic gravel obtained from five borrow pits in two agro-ecological zones of the country The results established an optimal nominal bitumen content of about 2% for improved compaction and strength characteristics. A model pavement prepared with this optimum bitumen content was constructed and the rate of erosion of material from the pavement was compared with a non-stabilized model pavement in the H313 hydrological (rainfall simulation chamber) apparatus. The results showed a four-fold reduction in the amount of material eroded from the model pavement compared with the unstabilized material. .

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List of Abbreviations

AASHTO	American Society of State and Highway and Transportation Officials
AC	Asphaltic Concrete
ASTM	American Society for Testing Materials
BRRI	Building and Road Research Institute
BS	British Standards
BSD	Bitumen Surface Dressed
CBR	California Bearing Ratio
DFR	Department of Feeder Roads
DUR	Department of Urban Roads
GHA	Ghana Highways Authority
HDM	Highway Design and Maintenance Standard Manual
IRI	International Roughness Index
LL	Liquid Limit
MDD	Maximum Dry Density
MRT	Ministry of Road and Transport
OMC	Optimum Moisture Content
PC	Precast Concrete
PCA	Portland Cement Association
PL	Plastic Limit
RTIM	Road Investment Model for Developing Countries
TRRL	Transport and Road Research Laboratory
UCS	Unified Classification System
NMC	Natural Moisture Content
AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic

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CHAPTER ONE

1 INTRODUCTION

1.1. TRANSPORTATION SYSTEM

Ghana has a well-developed transportation system consisting of two large deep-sea ports, a 944 km long railway system, and a 40,186 km of road network system consisting of 12,395 km of trunk roads, 24,000 km of feeder roads and 2,909km of urban roads. There is also limited transportation on the large inland Volta Lake. Ghana has one international airport and an international airline serving routes to African, European, and North American cities with two companies providing domestic aviation services.

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Like most developing countries the agriculture sector forms the backbone of the economy accounting for about 45% of GDP and employing about 70% of the population. In Ghana the main cash crop cultivated for export are cocoa and coffee even though lately the cultivation of other non-traditional exports crops like pineapple, cashew and sheanut have also increased.

Roads are the predominant mode of transport in Ghana currently accounting for about 94% of freight and 97% of traffic movement. For the movement of these agricultural products there are no viable alternatives to roads other than for the movement of bulk commodities such as timber, cocoa, bauxite and manganese ore by rail from collection centers to the ports. The railway network is limited to Accra, Kumasi and Takoradi and the inland water transport is limited to Lake Volta. So the main mode of transporting of export products to their processing centers and/ or to ports and harbours or local markets as well as the movement of food crops from their production centers to the market centers and also for the transportation of people from one place to the other is by road since it is the most reliable transportation network in the country.

1.2. ROAD NETWORK IN GHANA

The Ministry of Roads and Transport is responsible for the design, construction, maintenance and operation of the road network in Ghana. The road network in Ghana can be classified into three functional categories and each category is managed by a different subsidiary agency as shown in the Table 1.1. The table also shows the length of network and the proportion paved.

Table 1.1 Length of Roads by Agency Showing Paved and Unpaved Road Length (1998)

Category	Agency Responsible	Total Length of Road	% of Road Network Size	% Paved	% Unpaved
Trunk Roads	The Ghana Highways Authority (GHA)	13,507km	33	45	55
Feeder Roads	The Department of Feeder Roads (DFR)	24,000km	59.7	1	99
Urban Roads	The Department of Urban Roads (DUR)	2909km	7.2	57	43
	Total	40,186 km	100	18	82

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1.2.1. *The Trunk Road Network*

The trunk road network in the country is managed by the Ghana Highway Authority (GHA), which was first formed in 1974 but restructured later in 1982. The responsibility of GHA is the planning, designing, construction and maintenance of the country's trunk roads. The current classification of trunk roads is shown in Table 1.2. In this system the roads are grouped into the National, Inter-Regional and Regional roads, reflecting their national and socio-economic importance. The unpaved roads consist of graveled roads and earth roads.

Table 1.2 Classifications of Roads by Class and Surface Type (GHA Classification, 1999)

CLASS	PAVED (km)	UNPAVED (km)	TOTAL (km)
National Roads	2,562	1,548	4,110
Inter-Regional Roads	970	1,529	2,499
Regional Roads	1,614	4,173	5,787
Total	5,146	7,250	12,396
TOTAL %	41.5	58.5	100

Note: The figures above exclude the town roads(882km) and missing links (850km) under GHA.

The regional distribution of trunk roads and their surface types as at 1998 is shown in Table 1.3.

Table 1.3 Regional Distributions of Road Pavement Types (GHA-1998)

REGION	*AC (km)*	*BSD (km)*	*UNPAVED (km)*	*TOTAL (km)*
Ashanti	348	552	473	1373
Brong Ahafo	212	546	1033	1791
Central	154	832	195	1181
Eastern	71	1082	630	1783
Greater Accra	101	347	16	464
Northern	250	166	1953	2369
Upper East	40	131	323	494
Upper West	0	52	991	1043
Volta	0	643	871	1514
Western	150	367	978	1495
Total	1326	4718	7463	13507
% of Total	**9.82**	**34.93**	**55.25**	**100**

AC=Asphaltic concrete
BSD=Bitumen surface dressed

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The Table shows that in 1998 about 55% of the total trunk roads were unpaved and that every region has unpaved trunk roads. Currently with the re-classification, unpaved roads contribute 58.5% of trunk roads. Thus unpaved roads constitute a significant percentage of trunk roads in the country and can be found in every region.

1.2.2. *Feeder Road Network*

*A feeder road is a public track or an engineered way for vehicular use connecting a rural community to another rural community or a rural community to a road classified as a trunk roa*d. The Department of Feeder Roads was established in 1981 to have the sole responsibility for planning, developing and maintenance of the feeder road network in the country. The feeder road network consists of about 99% unpaved and 1% paved roads as shown in Table 1.4 below which indicates the regional distribution of the roads and the surface type distribution.

Table1.4 Regional Distribution of Pavement Type Under DFR (1998)

Region	BSD (km)	Unpaved(km)		*Total Length (km)*
		Gravel	Earth	
Greater Accra	145	539	148	*832*
Volta	9	1,001	1,371	*2,381*
Eastern	20	1,078	1,217	*2,315*
Central	63	1,145	890	*2,098*
Western	0	1,059	1,877	*2,936*
Ashanti	45	2,179	1,076	*3,300*
Brong Ahafo	0	1,286	2,177	*3,463*
Northern	0	1,194	1,187	*2,381*
Upper East	0	448	473	*921*
Upper West	0	457	1,092	*1,549*
Total	282	10,385	11,508	*22,176*
% of Total Network	*1*	*99*		*100*

Note : DFR acquired some roads from the GHA under the new classification system hence the change in the total length of roads from 22, 176km to 24,000 km

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1.2.3. *Urban Road Network*

The Department of Urban Roads was established in 1988 to be initially responsible for the roads within the cities of Accra, Kumasi, Tema, Sekondi-Takoradi totaling about 2100km. In 1985 DUR became responsible for the roads within Tamale municipality and there are plans of taking charge of roads in the other regional capitals soon. Currently the Department is responsible for the construction, rehabilitation and periodic maintenance works on a total urban road network of 2,900km in the cities shown in the Table 1.5.

Table 1.5 Distribution of road network under DUR (1999)

Region	City	Paved	Unpaved	*Total*
Greater Accra	Ga	38	331	*368*
	Tema	169	127	*296*
	Accra	918	200	*1,118*
Ashanti	Kumasi	333	289	*622*
Western	Sekondi-Takoradi	120	100	*220*
Northern	Tamale	71	214	*284*
Total		*1,649*	*1,260*	*2,909*
% of Total Network		*56.7*	*43.3*	*100*

The distribution of pavement type in the urban centers is also shown. It is clear from the above review that unpaved roads constitute significant percentage of all categories of roads in the country and can be found in regions.

1.3. FUNDING FOR ROAD MAINTENANCE

Funding road maintenance is a heavy task especially for the governments of many developing countries including Ghana. In Ghana the Road Fund, the Consolidated Fund and Donor Funding support the road sub-sector's investment programme for development and maintenance. However, the Road Fund is the main source of funding for road maintenance in the country. The Road Fund seeks to finance routine and periodic maintenance and the rehabilitation of public roads and to assist metropolitan, municipal and districts in their functions relevant to public roads. The road fund was able to raise a total of $77, 923, 000 (GHA, 2000) and out of this more than 90% is from levies on petroleum product.

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For the medium term plan the GHA wants to move from the 1994 road condition state of 40% good, 27% fair, 33% poor to attain a new condition state of a minimum of 70% good, about 20% fair and less than 10% poor BY 2020. The total financial requirement for attaining this target for the year 1995-2000 is $1553million. The financial plan was to receive $404million from External Donors, $274million from the Road fund and $332million from Consolidated fund. This gives a total of $1010million which already has a short fall of $543million. Indications are that in 1995, only 40% of the total planned work was achieved due to budgetary constraints. The current situation is such that only a certain number of roads are maintained every year out of the total number of roads that require maintenance. This causes the un-maintained roads to deteriorate further and become impassable in some cases. The situation where financial constraints prevent the targeted maintenance requirement to be carried out is a normal trend over the years as the financial allocations to the various agencies most of the time far below the amount of money that the agencies budget for. There is the need therefore to find ways by which the life span of the unpaved road network (which is the focus of this study) can be extended before the next maintenance activity will be carried.

1.4. DETERIORATION OF UNPAVED ROADS

One of the main characteristics of unpaved roads is that they are susceptible to deterioration faster than paved roads. The defects on unpaved roads are more pronounced and spread faster than the same defects on paved roads. There are many factors affecting deterioration of unpaved roads but the most critical ones affecting road pavements in a

tropical climate like Ghana are traffic, rainfall, topography and workmanship including the quality of the construction material.

Generally on unpaved roads in Ghana the volume of traffic is low so the effect of traffic on deterioration of the road pavement is minimal. Rainfall has a very severe impact on the erosion of pavement material from unpaved roads and also contributes significantly to the development of other road defects.

1.5. JUSTIFICATION OF STUDY

It is clear from the foregoing discussion that unpaved roads in Ghana can be found in all parts of the country both in the cities and rural areas and they form about 82% of the total road network and thus plays a vital role in the transportation sector of the country. The population distribution of the country is such that a clear majority of the population live in rural areas and depend on farming and small scale trading for their livelihood which requires that they be transported from one point to the other mostly on these unpaved roads.

These unpaved roads deteriorate rather quickly. But since the volume of traffic on unpaved roads is very small in most part of the country the major contributing cause of deterioration may be said be rainfall. Hence any reduction of the rate of rain-induced erosion on these roads will greatly increase the life span of these roads and hence reduce the budget requirements for maintenance.

It is in this light that an attempt is being made to delay the deterioration on these roads by treating the naturally occurring lateritic road base gravel material with bitumen emulsion with the aim of increasing its resistance to rainfall-induced erosion without adversely affecting the load carrying properties of the pavement material.

The main binders available in the country are cement, lime and bitumen. Bitumen emulsion has the advantage over the other two types of binders because of its relative cheap cost and also because the demand on it is not as high as in the case of cement. It is also produced locally and the potential for expanding the supply in large quantities should the demand for the product increase is available since the companies are currently producing far below their capacities.

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1.6. OBJECTIVE

The objective of this work can thus be stated as:

(1) To investigate the effect of bitumen emulsion stabilization on selected engineering properties of typical Ghanaian lateritic soils used for construction of sub-bases and base

(2) To measure the resistance of bitumen emulsion treated natural gravel model pavement to simulated rainfall induced erosion in a rainfall chamber.

1.7. SCOPE OF WORK

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The next chapter reviews the mechanism of deterioration on unpaved roads and the factors that affect deterioration. Chapter three discusses the soils of Ghana and their formation as well as their engineering characteristics. A review of stabilization including the local experience is covered in Chapter four. The methodology used in the study which covers the laboratory procedures as well as the model pavement preparation and rainfall simulation is described in Chapter five. Chapter six covers the analysis and discussion of the results obtained from this study, while the conclusions and recommendations are summarized in Chapter seven.

CHAPTER TWO

2 REVIEW OF DETERIORATION OF UNPAVED ROADS

2.1. DEFECTS ON UNPAVED ROADS

The common types of defects on unpaved roads, the possible causes and the functions of the pavement that are affected are discussed below:

(1) **Potholes**: These are bowl shaped depressions in the pavement. They can have steep or gentle sloping sides and may be of irregular shape. They can be caused by a combination of excessive moisture and traffic action, and inadequate structural strength in the roadway due to insufficient thickness. It can increase in size and multiply in number in the rainy season if not checked. It is the commonest of the surface defects on both paved and unpaved roads in Ghana.

(2) **Corrugation (wash-boarding):** This is a transverse undulation, closely and regularly spaced with wavelengths less than 1m. Corrugations always occur with the ripples perpendicular to the direction of travel and more pronounced at the wheelpaths, although it can and does cover the whole pavement surface area. Possible causes are traffic action combined with loose gravel, acceleration and deceleration areas such as curves, downhill or uphill and intersections. Insufficient pavement thickness could be a possible cause. It is most common in the dry season.

(3) **Loose gravel:** It is best described as unbound fine or coarse gravel material on the road pavement surface. This is easily seen as gravel in wind-rows along the center of the road alongside the wheel track, or along the shoulder, all parallel to the direction of traffic. Possible causes are insufficient compaction at construction or during regravelling. Traffic action also segregates coarse aggregates from the fine particles and then moves loosened aggregate away from the wheel tracks to form wind-rows parallel to the direction of traffic over the less traveled section of the roadway. It is also caused by the action of wind or water transportation of materials onto or away from the roadway surface. It is considered as one of the common defects.

(4) **Rutting**: Rutting is characterised by a longitudinal depression in the road surface that occur in the wheelpaths of a roadway. Causes of this defect are wear by attrition due to traffic loading or erosion of surface material, inadequate wet strength of subgrade or pavement layer, excessive loose material and traffic compaction of subgrade or pavement.

(5) **Loss of camber**: For this defect, the camber of the road is flattened and non-existent, or becomes reverse camber with road edges higher than the center line of the surface, thereby trapping or preventing surface water from draining away. This is caused by poor construction or poor maintenance practice.

(6) **Slippery surface**: The surface is slippery during the wet seasons and causes danger to traffic especially at steep gradients and sharp curves. Slippery surfaces are caused by materials with high percentages of clays or fines.

(7) **Breakup or Softspot**: This is seen as the effect where the subgrade soil punches up through the gravel surface, usually with broken surface area surrounded by depression or dishing type of distortion. They are most likely to occur in the wheel tracks. The normal causes are shear failure of the base or subgrade soil. Traffic action combined with excessive moisture from improperly drained surface cause breakup or soft spot.

(8) **Dust**: This is as a result of traffic action creating a dust cloud, which reduces safe sight distance for trailing and on-coming vehicles. Traffic action causes segregation of fine aggregate particles from the coarse aggregates, and these fine particles become airborne from the whirlwind and slipstream caused by the moving vehicles.

(9) **Gullies in Carriageway**: These are longitudinal depressions in the road that normally occur in the wheel path and the sides of the roadway. This erosion is caused by rainwater running along the wheel paths. This is due to poor transversal drainage or high road gradient. It is a severe road defect that needs immediate attention. Gullies form a very important defect since it is directly affected by rainfall and it affect the pavement as well as the subgrade.

(10) **Vegetation encroachment**: In high rainfall areas this is a constant treat to unpaved roads. When left without maintenance, vegetation can encroach onto the ditch and roadway affecting drainage and safety sometimes the road will practically disappear.

2.2. FACTORS INFLUENCING THE DETERIORATION OF UNPAVED ROADS

The deterioration of a road surface could be distinguished into functional or structural. Functional deterioration of a pavement means that the riding quality of the road decreases, i.e. the road gives poorer service to the users i.e. the road becomes more uncomfortable to drive on and/ or safety is reduced. Structural deterioration of a pavement means that the pavement loses some of it's bearing capacity. Normally structural deterioration also leads to functional deterioration. There are many factors responsible for the generation of these defects on unpaved roads but the most critical ones affecting road pavements in the tropical climate like Ghana include the following, which are discussed below

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(i) Traffic levels

(ii) Rainfall

(iii) Topography

(iv) Workmanship and quality of the material

2.2.1. *Traffic*

The load imposed by passenger cars do not contribute significantly to the structural damage caused to the road pavements (for paved roads) by traffic. Therefore, for the purpose of structural design of pavement, private cars are ignored and only the total number and the axle loading of the heavy vehicles that will use the road during the design life are considered. Heavy vehicles in this context are defined as those having unladen weight of 3000kg or more. Road Note 31 (TRRL 1993) relates the damaging effect of axle load to a standard axle of 80kN using the following conversion model (AASHO, 1962).

$$N_{esa} = \left(\frac{P}{80}\right)^{4.5} N_p \quad \text{.....} \quad \text{Equation 2.1}$$

N_{esa} = number of equivalent standard axle
N_p = Number of axle with load P.

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Unlike the paved roads, small axle loads affect unpaved roads even though the effect is not the same as for heavy axle loads. TRRL has done some studies and on a correlation between the cumulative traffic volume and the roughness on lateritic gravel roads. Fig 2.1 is adapted from a relationship between the cumulative traffic level since the last grading and the roughness level on lateritic gravel roads developed by the TRRL. The figure shows that for traffic up to 50,000 cumulative vehicles using the road since the last grading there is a relatively small increase in roughness, but beyond 50,000 cumulative vehicles there is a rapid increase in roughness.

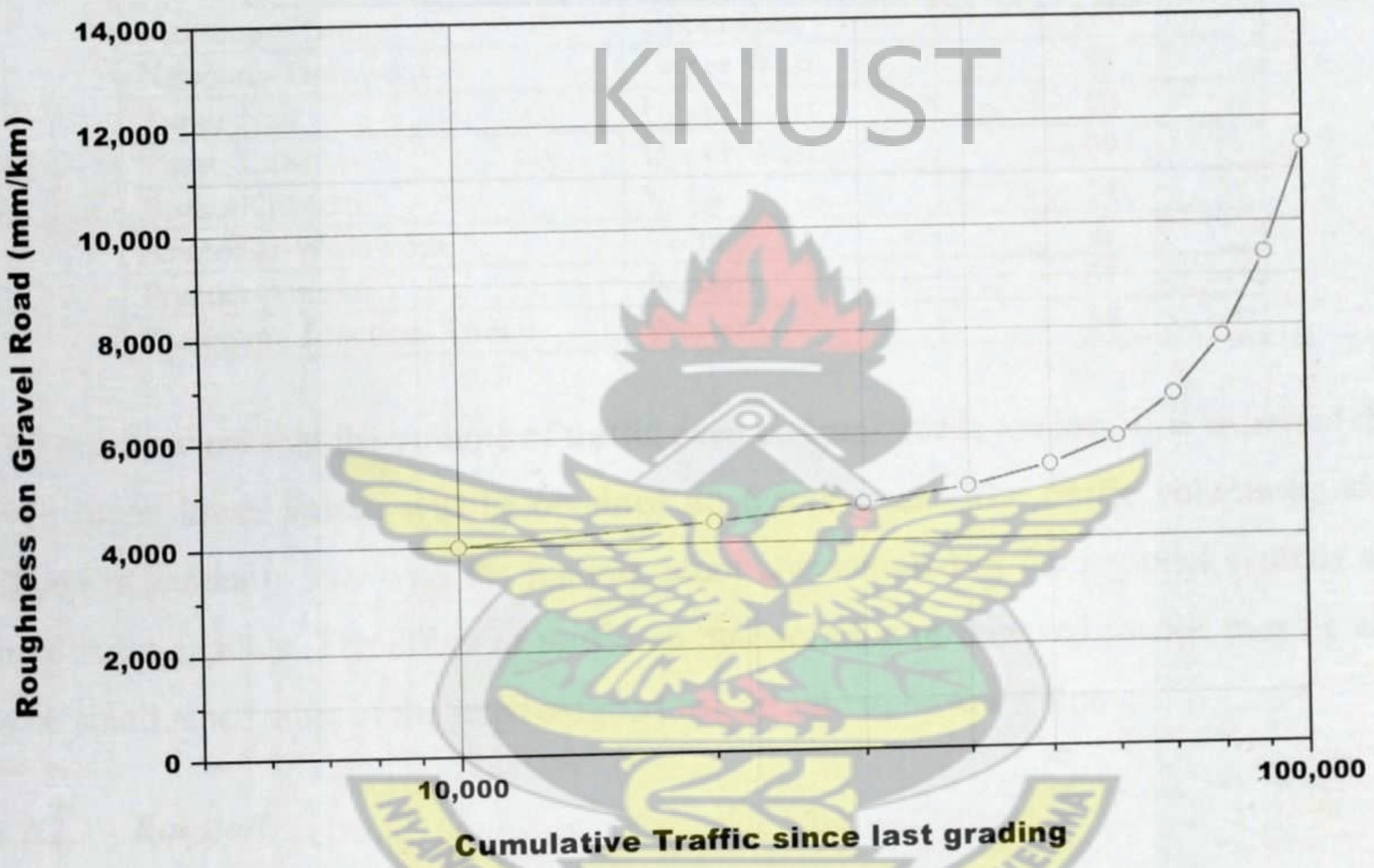

Fig 2.1 Relationship between the cumulative traffic volume and roughness
(after TRRL, Report 723)

Twenty-four hour traffic counts were conducted on a number of selected trunk roads in some regions in Ghana and the average daily traffic (ADT) volume were obtained. Some of the results are shown in the Table 2.1

Table 2.1 ADT for Some Gravel Roads in Ghana (Source GHA 2001)

Road	Region	Average ADT
Akim Ofoase Jn-Juaso	Ashanti	194
Ejura-Nkoranza	BA/ Ashanti	174
Atronie-Sunyani	Brong Ahafo	183
Atebubu-Kumfia	Brong Ahafo	47
Asesewa-Mpraeso	Eastern	9
Domeasi-Begoro-Bonsu	Eastern	74
Abosso-Begoro	Eastern	37
Yendi-Saboba	Northern	41
Damongo-Sawla	Northern	34
Navrongo-Tumu	Upper East	156
Nandom- Domweni	Upper West	39
Tumu-Han	Upper West	40
Tumu-Lawra	Upper West	90
Borae-Kpandai	Volta	54
Abotoase-Worawora	Volta	6
Preatea-Amoku	Western	51
Essamang Junction-Atieku	Western	58

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The results show that the volume of traffic even on trunk roads are low. It is expected that even much lower values will be obtained on feeder roads. The traffic volume trend in Ghana is generally low with the highest count concentrated in the regional capitals and the district capitals. The effect of traffic on deterioration of unpaved road is may be said to be small since most of the unpaved road can be said to be low volume.

2.2.2. *Rainfall*

Rainfall is the most important factor that affects the erosion of particles from the surface of the road pavement. Rainfall is usually measured in depth of fall per unit time, e.g. cm per hour or per day. A cm of rainfall would cover the ground to a depth of 1 cm if the water did not run off or seep into the soil (i.e. assuming the ground is perfectly flat and impervious).

2.2.2.1. Duration, Intensity and Frequency of Rainfall

Duration is simply the time interval between the start and end of a rainfall event. It is usually measured in minutes or hours. The intensity of rainfall refers to the amount of rainfall falling in a given time. It is determined as the ratio of the depth of rainfall to the duration of rainfall measured at a given point. High intensity of rainfall is associated with increasing drop size rather than an increase in number of drops (Drop size is measured in

terms of drop diameter). Average intensities for short periods (thunderstorm-type downpour) are much greater than those for longer time periods, i.e. the greater the intensity of rainfall, the shorter the rainfall duration. The frequency refers to the average time-period within which rainfall of a specified amount or intensity is expected to occur once. It is normally referred to as the return period.

2.2.2.2. Mean Monthly, Annual and Areal Extent of Rainfall

Areal extent refers to the size of the area over which a given downpour falls. Generally, for a given period or duration, the amount of rainfall for any particular downpour decreases with increasing areal extent. The annual rainfall of a given area is the average of the total amount of rainfall measured for all the rain gauges in the area over a period of one year. The mean annual rainfall is obtained when the annual rainfall records are averaged over an observational period of about 30 or 35 years. Similarly, the mean monthly rainfall is obtained by averaging the total monthly rainfall recorded for all gauge stations in the given area over the same observational period. In highway engineering, knowledge of rainfall intensity and return period is very useful for estimating the peak flows of streams and rivers which are very essential for the design of cross-drainage structures.

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2.2.3. ***Rainfall Pattern in Ghana***

Principally, rainfall in Ghana is seasonal in character and it also exhibits year-year variability. The average distribution of rainfall in the country varies considerably during the year. In general, January is the driest month throughout the country, although the driest month in the eastern coastal district is August. Variations between successive rainy seasons are very considerable in terms of time of onset, duration and amounts recorded. Individual rainfall events are numerous in some seasons whereas they are scattered and infrequent in others. Rainfall event is rarely prolonged over any part of the country and the average duration of rain is between two and three hours. Rain persisting for over twelve hours is not common. During the dry seasons, total rainfall duration is likely to be less than ten hours a month. In the rainy seasons, the total duration of rainfall averages between 30 to 40 hours per month. Rainfall intensity varies considerably and up to about 20mm/hour may be reached or even exceeded for short periods. Generally, six major types or zones of rainfall may be recognized as indicated in Fig 3.2, although adjacent types may grade into each other. No definite lines of demarcation exists between the six

rainfall zones or types as they are a consequence of the north - south drift of the I. T. C. Z and its associated weather zones.

Generally rainfall values are higher in the southern half than in the northern half. In the former, maximum 24hour values decrease from SW towards NE as far as northern parts of the Volta Region from where they increase South-Eastern as far as to the eastern coastline. There is a low region around the Accra Plains just below the Akwapim scarp. There is also a low area enclosed by 100mm isohyets in the middle section of the country extending from Sunyani area as far as the boundary between Northern and Upper regions and also extends eastwards beyond Tamale (Dankwa, 1974).

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2.2.4. *Momentum and Kinetic Energy*

The interactions of raindrop size, velocity and shape, the duration of the storm and the windspeed, control the erosive power of rainfall. As raindrops increase in size their terminal velocity increases

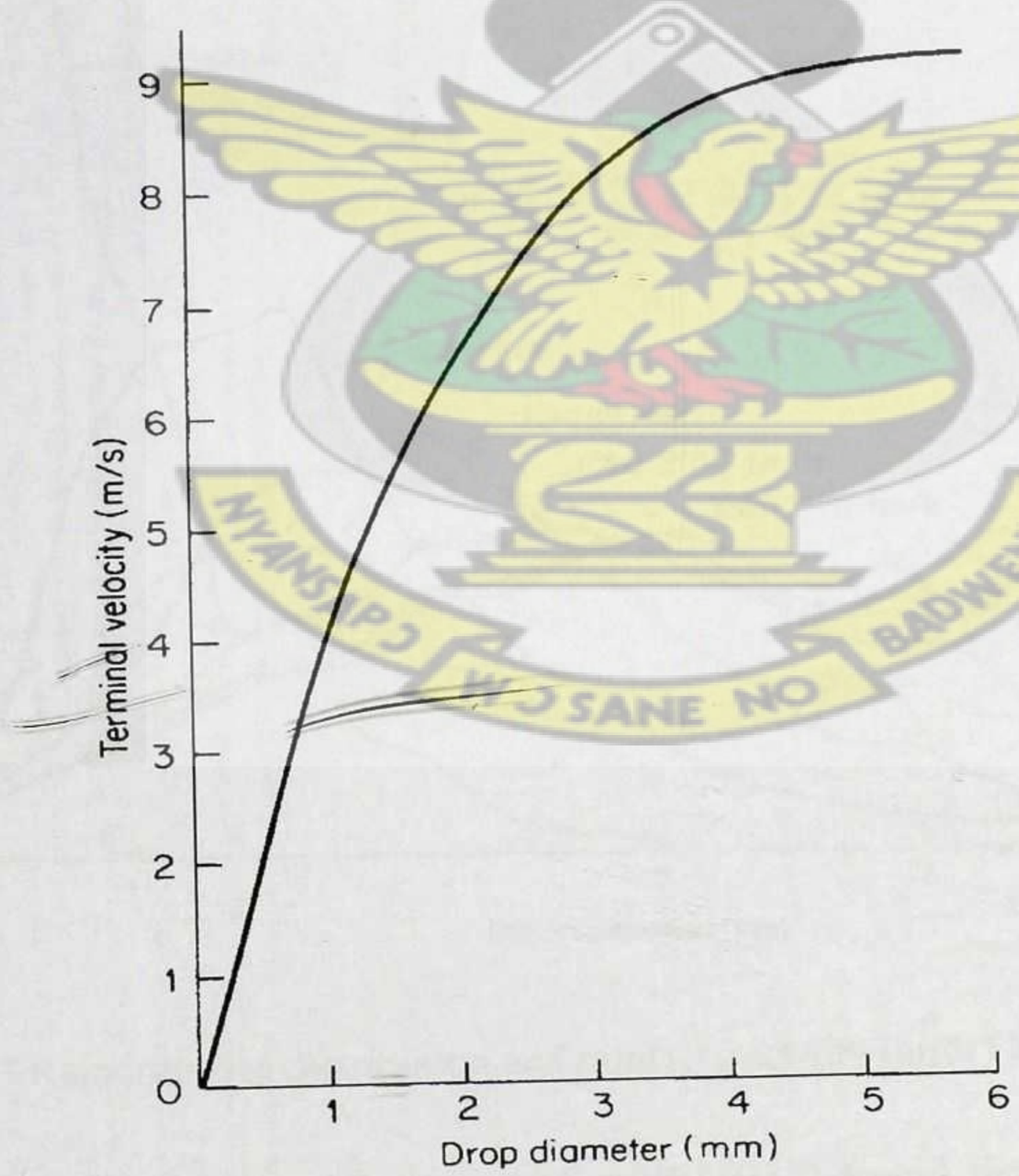

Fig 2.2 Terminal velocities of water droplets in stagnant air (after Gunn and Kinzer, 1949)

The momentum of a raindrop, which is its mass x velocity, also increases rapidly with drop size up to about 4 mm diameter, therefore the kinetic energy of rainfall, which is the energy of the total number of raindrops at a given intensity, is estimated from the

distribution of raindrop size for a given intensity. Carter *et* al. (1974) and Hudson (1963) showed that the raindrop size distribution includes a greater proportion of larger drops above 4 mm diameter at intensities between 50-100 mm per hour and more than 200 mm. per hour (Figure 2.2); at other intensities there are many smaller (< 2.5 mm) drops. Drops larger than 5.5-6.0 mm are unstable because of turbulence of the air (Blanchard, 1950) and break up; however, at intensities above 200mm per hour coalescence of smaller drops again takes place. The kinetic energy of rainfall, therefore, is at a maximum at rainfall intensities between 50 and 100 mm per hour and greater than 250 mm per hour (Figure 2.2). Wischmeier and Smith (1958) did not allow for this change in distribution of kinetic energy, and overestimated kinetic energy for rainfalls greater than 100 mm. per hour.

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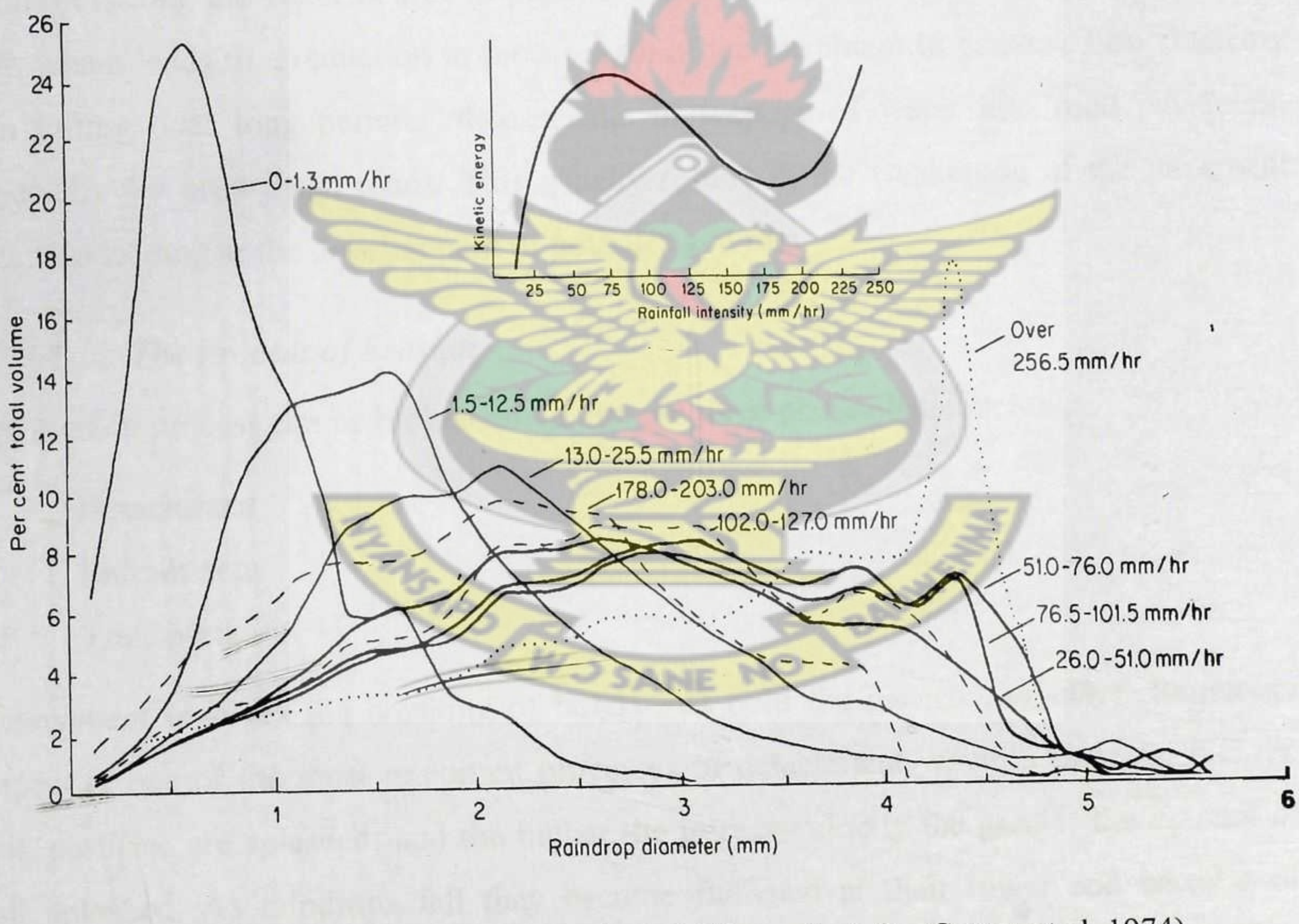

Fig 2.3 Raindrop size distribution and rainfall intensity (after Carter, et al, 1974)

Wischmeier (1959) and Wischmeier and Smith (1958) found that of the rainfall factors studied, kinetic energy explained most of the measured soil loss from field-plots. The best measure of energy was the maximum rainfall intensity occurring over 30 minutes (EI30). However, Hudson (1971) notes that this measure was not as good as one which assumed

that there is an erosive threshold, of 25 mm rain per hour, and that only rainfalls of more than this amount are of importance in causing erosion.

2.2.5. *Mechanism of Erosion on Unpaved Roads*

Erosion on unpaved roads in the tropics is the removal of material from the pavement surface, either by the action of rainfall or wind. It may be facilitated by vehicular traffic. Bare surfaces such as pavement surface is most susceptible to water erosion, and large amounts of soil can be removed in one storm or during a single wet season. The factors determining soil loss are the rainfall characteristics such as rainfall intensity and duration, soil characteristics such as soil particle size distribution and properties related to this such as surface roughness and aggregation, and slope form. The rate of deterioration of the road pavement increases with an increased duration of rainfall period. When the rainfall duration is long the water is able to penetrate into the pavement layer making it wet and soft, which leads to a reduction in the strength of the pavement in general. Low intensity rain falling over long periods often results in seepage of water into road pavement, especially for unsurfaced roads. This usually results in the weakening of the pavement structure leading to the development of potholes and ruts

2.2.5.1. The Process of Erosion

The erosion process can be broken down into the three phases listed below,

ii. Detachment
iii. Entrainment
iiii. Transportation

Detachment involves the breaking of bonds that hold the particles together. Raindrops impact is one of the most important processes of detachment; when a raindrop hits the soil, particles are splashed; and the higher the impact velocity the greater the amount of soil splashed. As raindrops fall they become flattened at their lower end because of frictional drag (Blanchard, 1950); this effect is greater for larger drops. The area of impact of the drop is increased therefore. Two-thirds of the energy of the raindrop is expended forming an impact crater and moving soil particles, the remainder of the energy to forming spray (Mihara, 1951). Drop impact is more effective when a thin film of water covers the soil surface and maximum dispersion of soil particles occurs when the depth of water is about the same as the diameter of the raindrop. Terminal velocity and mass of

raindrop also affect the detachment of the material. In general smaller soil particles are eroded more readily than larger ones.

Entrainment is the action of picking up of a soil particle by water. Entrainment and detachment are closely related and in most cases that they become one. Rain splash becomes a more effective process as slope steepens and as windspeed strengthens. Wind speed imparts a horizontal force to failing raindrops so that when the drop hits the surface there is a greater directional effect of splashing of soil particles.

Transportation involves the carrying of the particles that have been detached from their original location to a new location (Briggs et al, 1989). Water action is intermittent and is really effective only during and after prolonged or heavy rainfall. When water falls on a slope, unless the road is already saturated, the water will percolate into the ground and there will be no runoff. As the soil gradually becomes saturated, the rate of infiltration will slow down and in time become constant. This constant rate is determined by the infiltration capacity of the soil. Any excess of rainfall over the infiltration capacity will collect on the surface, forming individual puddles in small depressions. In time this will begin to flow as a sheetwash or rainwash in a downslope direction as well as in the direction of the camber. If the water layer is very shallow and the road surface smooth, the flow may be of the 'laminar' type, but if the water is deeper and the surface rough, it will become 'turbulent' with much eddying and a considerably increased capacity to pick up and transport fine particles. Irregularities of the surface may also cause the concentration of the rain-wash into rills, which subdivide and rejoin. Rills are continuous channels of narrow width and shallow depth and can be obliterated by defects on the road surface. Rills and gullies remove much larger volumes of soil per unit area than does sheet wash. Rills and gullies form when the velocity of water flow increases, probably at speeds in excess of 30 cm per second (Ellison, 1947a) and flow becomes turbulent. This increase in hydraulic gradient may come about for a number of reasons, for example, an increase in slope gradient; an increase in rainfall intensity; or because surface storage is exceeded and incision takes place at the point of flow.

2.2.5.2. Effect of Rainfall Characteristics

Very high intensity rainfall also causes the development of erosion gullies on unsurfaced roads. Generally the higher the rainfall intensity the higher the rate of erosion of material from the pavement surface hence the faster the rate of deterioration of the pavement.

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When the rainfall intensity is high the size of the droplets are bigger. Bigger droplets dislodge the fine particles that bind the gravel material together much easier than smaller droplets. When the rainfall intensity is high the volume of runoff per unit time is high and thus the runoff is able to carry with it the material that is loosened easier and this brings about a greater loss of material within a short period. With time the bigger gravel particles are loosened and then becomes easy to carry by rainwater, which eventually renders the pavement susceptible to numerous defect types.

The effect of rainfall on the road pavement becomes severe with higher rainfall intensity and longer rainfall duration. Potholes, ruts and other road defects are able to develop faster under such conditions. Rainfall is thus one of the main causes of deterioration on unpaved road surfaces. Knowledge of the rainfall pattern in a given area is of vital importance to the highway engineer who must consider the effect of rainfall in the design of the road

Whether rills or gullies form probably depends on soil factors as well as the velocity and depth of water flow. This to a large extent depends on the level of compaction of the road pavement as this affects the rate and amount of water that will infiltrate the pavement. The higher the level of compaction the lower the infiltration rate hence the greater the volume of runoff. The interaction of rain splash and sheet wash is important, each process acting separately is less efficient at moving soil particles than when the processes are acting together. This is because the soil particles are brought into suspension by raindrop splash and then transported by sheet flow. Also, raindrop splash imparts turbulence to laminar flow. In the field, turbulent erosive flow only takes place where flow is confined. Downslope the amount of surface water will increase, and the rills may become sufficiently powerful to initiate gullies.

The impact of the raindrops nourishing the wash is important both in directly dislodging soil particles. The amount of rainwash generated on a slope will depend on a number of factors including the intensity of the rainfall (fine drizzle is unlikely to exceed the infiltration capacity of the soil), the steepness of the slope (runoff is generally greater for on a steep slope, because the increased velocity reduces the time available for loss due to percolation), the infiltration capacity which depend on the level of compaction since the more the level of compaction the less amount of water that can infiltrate the ridding surface (Small, 1996).

2.2.5.3. Erodibility Potential of Soils

Generally, erodible soils have restricted clay content. Soil, which is already wet when rain falls upon it, will attain its final infiltration rate more quickly. The angle of slope is an important factor governing the efficacy of splash erosion; as slope angle steepens more soil is splashed downslope. As slope length increases erosion is assumed to increase in severity. From the above discussion some of the factors affect erodibility of soil are infiltration rate, total water capacity, dispersion, splash, abrasion and transporting forces. The critical time for erosion is when rainfall intensity or duration is such that infiltration is exceeded. A means of measuring inherent erodibility of a particular soil is erodibility factor, K, which is used by the soil scientist in the agricultural sector and it indicate how easy it is to erode a particular type of soil.

Two qualitative tests for helping to assess the erodibility potential of a soil are the crumb test and the pinhole test. In the crumb test a small intact air–dried piece of the soil sample (about 1.0cm in diameter) is placed in a beaker of distilled water and the behaviour at the interface between the soil crumb and the distilled water is observed. In the crumb test, quick disintegration of the crumb is an indication of the erodibility potential.

In the pinhole test, a 50mm diameter cylindrical sample is prepared in the Dietert compactor. The flat ends of the sample are covered with a molten wax and a 1.0mm diameter hole is made in the sample. Distilled water is allowed to flow through the hole at a rate of 1.3ml/s from a 1.0mm diameter hypodermic needle. The effluent is observed after half a liter of water has passed. In the pinhole test rapid enlargement of the hole, passing cloudy effluent (ease of entrainment) is an indication of the erodibility potential. The indications are that in a tropical climate like that of Ghana which has seasonal variations of rainfall, when an unpaved road is constructed using good material and the road is not trafficked, the road will still go on to deteriorate due to the effects of the climatic elements like rainfall.

2.2.6. ***Topography***

It has been found out that defects like erosion gullies and gravel loss are most prevalent on slope with their effect increasing generally with increasing slope gradient. Fig. 2.2

shows some unpublished results from Departmental research work. The graph shows the increase in the rate of development of Ruts with time on slopes of different gradients measured on one of the study road in the country. It is observed that the development of such defects increases with the gradient of the pavement slope. On steep slopes the ruts initiate gully formation.

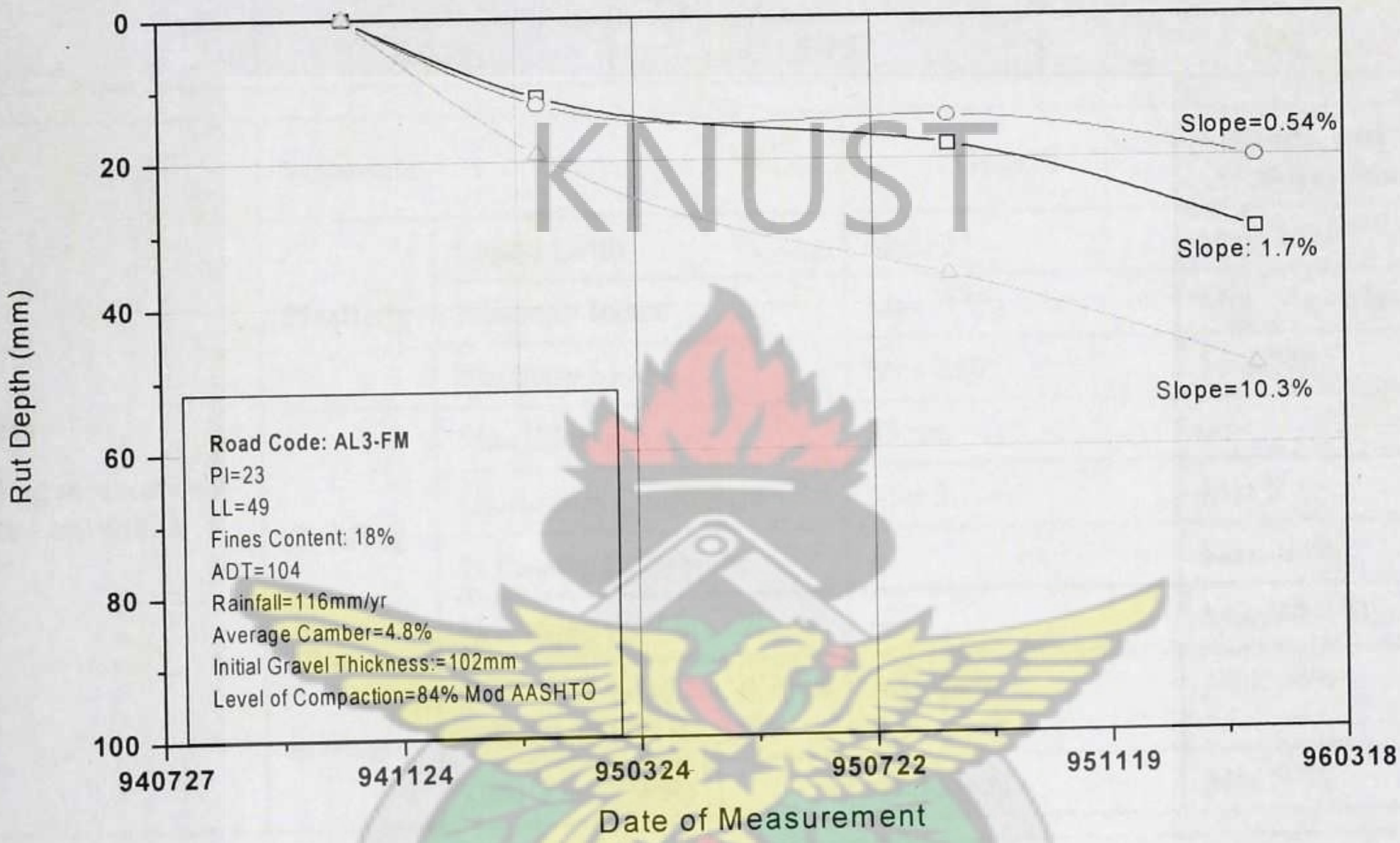

Fig 2.4 Rate of Development of Ruts over time with Slope Angle. (UST, 1997)

On flat areas the difficulty of drainage leads to softening of the pavement leading to deterioration of the pavement.

2.2.7. *Material and Workmanship*

In Ghana natural gravel material (laterite) for road base and subbase must meet the specifications as indicated in the Table 2.2 below after placement and compaction.

Table 2.2 Material Requirement for natural gravel after placing and compaction
Source: Standard Specification for Roads and Bridges, 1991 MRT, Ghana

Designation		**Type 1**	**Type 2**
Grading for Subbase and Base, and Including mechanically Stabilized materials. (Used with bituminous surfacing)	*Sieves mm*	*% of weight passing*	
	75	100	100
	37.5	80-100	80-100
	20	60-85	75-100
	5	30-55	30-75
	2	20-45	20-50
	0.425	8-26	8-33
	0.075	5-15	5-22

	Materials		**Gravels**	**Sands, silty and clayey sands**
Sub-base (Including mechanically stabilized materials)	**Plasticity**	Liquid Limit	Max. 35%	Max. 35%
		Plasticity Index	Max. 15%	Min. 5% - Max. 12%
		Plasticity Modulus	Max 250	Max 250
	Grading	Max. Size	75mm	--
		Uniformity Coefficient	Min 5	Min 5
		% Passing 2mm sieve	--	Max. 95%
		% Passing 0.075mm sieve	--	Min. 10 – Max. 30%
	Strength	CBR – 95% MDD, 4 days soak (AASHTO)	Min 40%	Min. 40%
		10% Fine (Wet)	Min 50kN	Min 50%

	Materials		**Type 1**	**Type 2**
Base (Including mechanically stabilized materials)	**Plasticity**	Liquid Limit	Max. 25%	Max. 30%
		Plasticity Index	Max 10%	Max 15%
		Plasticity Modulus	Max 200	Max 400
	Strength	Los Angeles Abrasion Test	Max. 50%	Max. 50%
		Aggregate Crushing Value	Max 35%	Max 35%
		10% Fine (Wet)	Min 50kN	Min 50kN
		CBR – 95% MDD, 4 days soak (AASHTO)	Min 80%	Min. 60%
	Note: For the Base, Type 2 requirements are for use with surface dressing only and where the traffic levels do not exceed 300 equivalent standard axles (8200kg) per day.			

For the natural occurring gravel material, the grading, Atterberg limits, compaction and 4 days soaked CBR test strength are the main consideration for the selection as road base and subbase material. For most unpaved roads, the running surface is the subbase layer. The natural occurring gravel material may be lateritic, calcareous with some quartzitic gravel. When material not meeting the specification for road construction is used for construction of the pavements, then in a very short time the pavement begins to show

compacted at moisture level below the optimum moisture content or at a low compactive effort.

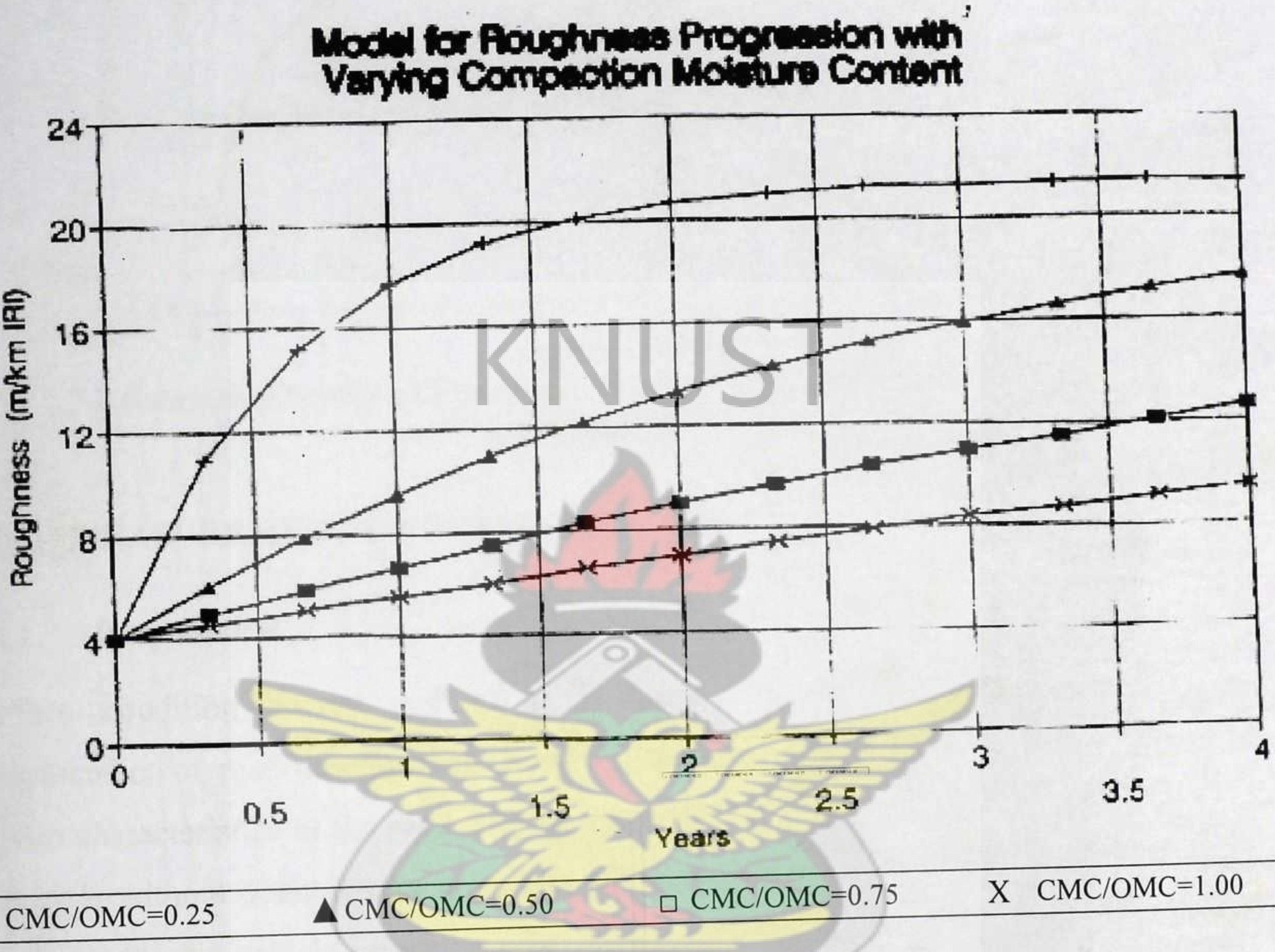

Fig 2.6 Modelled Roughness Progression with Varying Compaction Moisture Content (source TRL PA3460/99)

The key factors, which influence the compaction process, are material properties, moisture content and the available compaction equipment. It is important to have some estimate of the effectiveness and productivity that can be expected from the different types of equipment available. An example of the increase in density with the number of roller passes for a particular material compacted at OMC is shown in Figure 2.5.

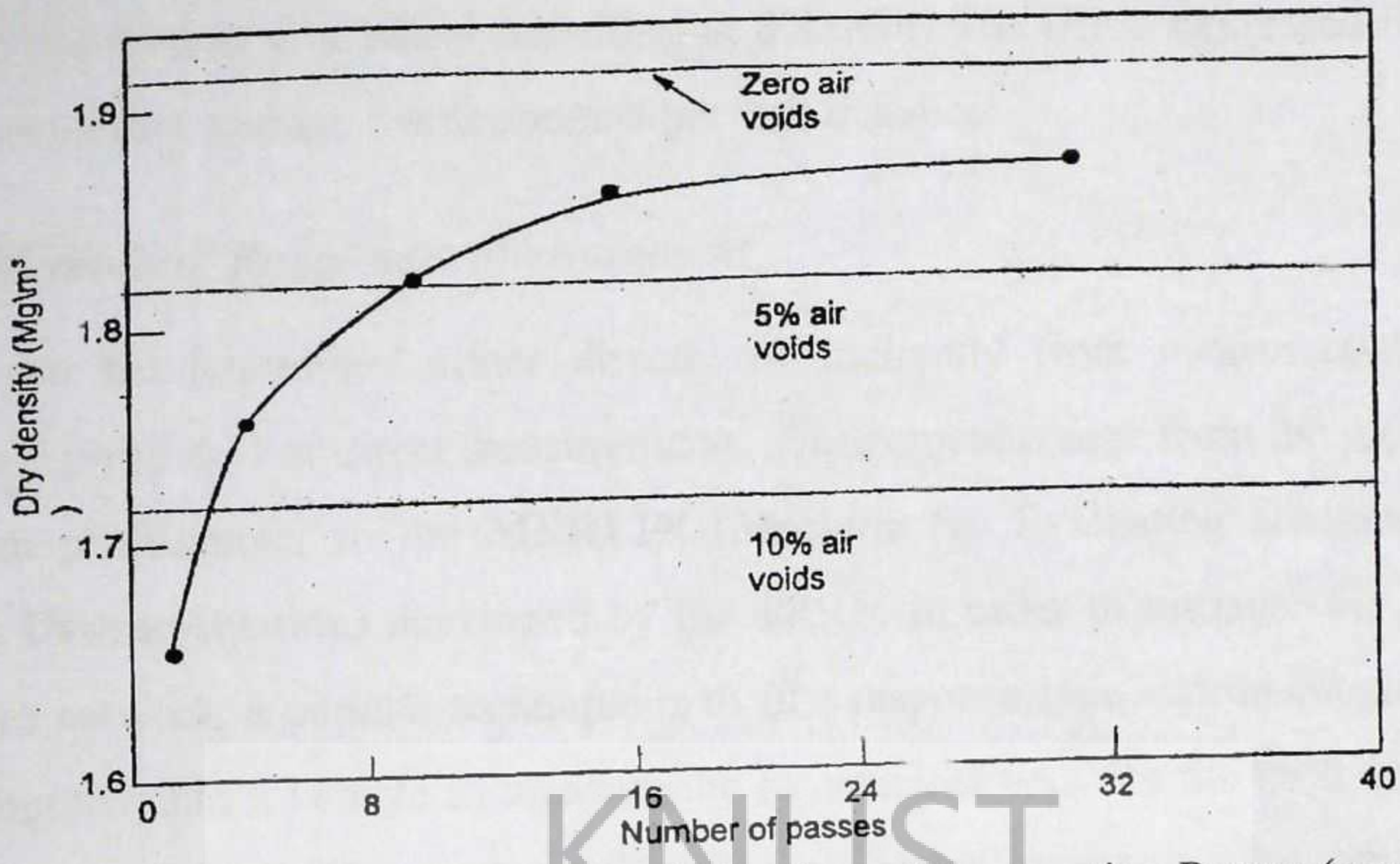

Fig 2.7 Relationship between Density and Number of Compaction Passes (source TRL PA3460/99)

2.2. MEASUREMENT OF DETERIORATION

2.2.1. *Introduction*

Surface condition survey and rating procedure is an important component of measurement of road deterioration. Road deterioration can be measured by comparing certain characteristics of the road with the characteristic of a good riding surface. Riding quality is without doubt a very important factor for the road user, influencing both user comfort and also vehicle operating cost. Surface condition is related to several factors, including structural integrity, structural capacity, roughness, and rate of deterioration. Direct measurements of these factors require expensive equipment and highly trained personnel. However, these factors can be assessed by observing and measuring the distress of the surface. Riding quality is often measured using the Roughness Index, even though this is not entirely reliable when it comes to unpaved roads. The longitudinal unevenness of a road surface which is called the roughness is usually measured on a standard roughness scale such as the Bump Integrator Scale or the International Roughness Index. The International Roughness Index (IRI) is a reference measure of the road surface smoothness that resulted from an international cooperative study undertaken through the World Bank. The IRI is a measure of the impact of the road profile on the ride and dynamic response of a moving vehicle. It is defined by a mathematical processing of the absolute longitudinal profile of road surface elevation in a wheel path,

simulating the motion of a wheel travelling at 80km/hr. The IRI is expressed in units of m/km, representing average displacements per unit distance.

2.2.2. *Methods of Roughness Measurement*

The IRI can be determined either directly of indirectly from measurements of the longitudinal profiles. For direct measurements, instruments range from the sophisticated laser beam profilometer to the **MERLIN** (**M**achine for **E**valuating **R**oughness using **L**ow-cost **IN**strumentation) developed by the TRRL. In order to measure the roughness over a road network, a popular technique is to fit a response-type instrumentation such as bump integrator into a vehicle to measure the movements between the back axle and the body (indirect method). The equipment is then calibrated by running the vehicle over a series of test sections of known roughness. The MERLIN was devised to measure the roughness of the calibration sections.

Another indirect method of roughness measurement is by subjective estimation, using broad guidelines by serviceability description such as the Unsurfaced Road Condition Index (URCI) developed by the US Army Corps of Engineers. The roughness depends on the extent and severity of road surface defects such as potholes, corrugations, rutting, and gullies in the road surface. A more acceptable means of measuring road quality on unpaved roads is by using visual assessment and actual measurement of defects on the riding surface.

2.2.3. *Measurement of Deterioration in Ghana*

A more acceptable means of measuring road quality on unpaved roads is by using visual assessment and actual measurement of defects on the riding surface. In Ghana both GHA and DFR use the indirect measurement to assess the road roughness conditions. GHA used the visual assessment supplemented by actual measurement of some of the defects to rate the conditions of the roads riding surface. The DFR uses an empirical correlation developed by TRRL between average comfortable speed of travel on the road and the roughness (IRI). This is more acceptable to DFR than the more sophisticated methods of using measuring instrument like the Bump Integrator and the fifth-wheel bump meter. This is because

1. Roughness levels for gravel roads are so high that they render these response-type instruments ineffective and inaccurate.

2. When the roads to be checked are many then this will call for a large number of the device, which means more money.

The correlation gives the following ranges of speed and the corresponding IRI (m/km) for unpaved roads, as used by the DFR. The DFR also developed another relation for assessing the IRI using the severity and extent of the four main defects that contribute to roughness.

Table 2.3 Correlation of Speed and Corresponding IRI (DFR Report 1988. TRRL)

SERVICEABILITY DESCRIPTION	IRI (M/KM)
Recently completed or graded gravel road	1.5-2.0
Ride comfortable at 80-100km/hr	3.5-4.5
Ride comfortable at 70-80km/hr	7.5-9.0
Ride comfortable at 50km/hr	11.5-13.5
Ride comfortable at 30-40km/hr	16.0-17.5
Ride comfortable at 20-30km/hr	20.0-22.0

The results of these deterioration measurements are used for planning of maintenance works. They may be used in any of the two investment models i.e. the TRRL's Road Investment Model for Developing Countries (RTIM) (TRRL) and the Highway design and Maintenance Model (HDM) (World Road Association).

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CHAPTER THREE

3 SOILS OF GHANA

3.1. INTRODUCTION

Soils in Ghana are mainly residual in nature with most of them being lateritic in nature. The major factors that influence their formation are climate and vegetation. The climatic factors that are of critical importance to their formation are rainfall and temperature. These factors also tend to influence the type of vegetation in addition to the properties of the soil. With respect to climate the most important factor is probably the absolute quantity and periodicity of the annual rainfall. Laterite forms over a wide variety of parent rocks provided that the conditions necessary for its formation are available. In Ghana, like many other tropical countries laterites are in abundance hence they are encountered widely and form the major road construction material.

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3.2. CLIMATE AND VEGETATION OF GHANA

Two of the important climatic factors in Ghana are rainfall and temperature. The effect of these factors varies as one travels from one part of the country to the other especially as one moves away from the Southern part towards the Northern part. Attempts have been made to zone the country into areas with similar characteristics base on especially rainfall, temperature, vegetation etc. The type of vegetation in an area is greatly influenced by the type and amount of rainfall received averagely in a year and the distribution pattern throughout the year. Ghana can be divided into six climatic areas of which the boundaries are not so clearly demarcated based on the rainfall pattern, vegetation variation, humidity and to an extent the amount of sunshine, which is directly related to the temperature. Table 3.1 shows the main characteristics of these areas.

Table 3.1 General Characteristics of Climatic Areas (Ghana Metrological Department, 2000)

Climatic Area	Vegetation Type	Annual Rainfall (mm)	Maximum Temperature (^{0}C)	Relative Humidity (%)
One	Sudan Savanna	1,000	34.5	40
Two	Guinea Savanna	1,150	33.0	47
Three	Transitional	1,300	31.5	57
Four	Deciduous Forest	1,450	30.5	66
Five	Rain Forest	2,200	29.3	77
Six	Coastal Savanna	950	30.2	74

These six areas are shown with their general characteristics in Fig 3.1

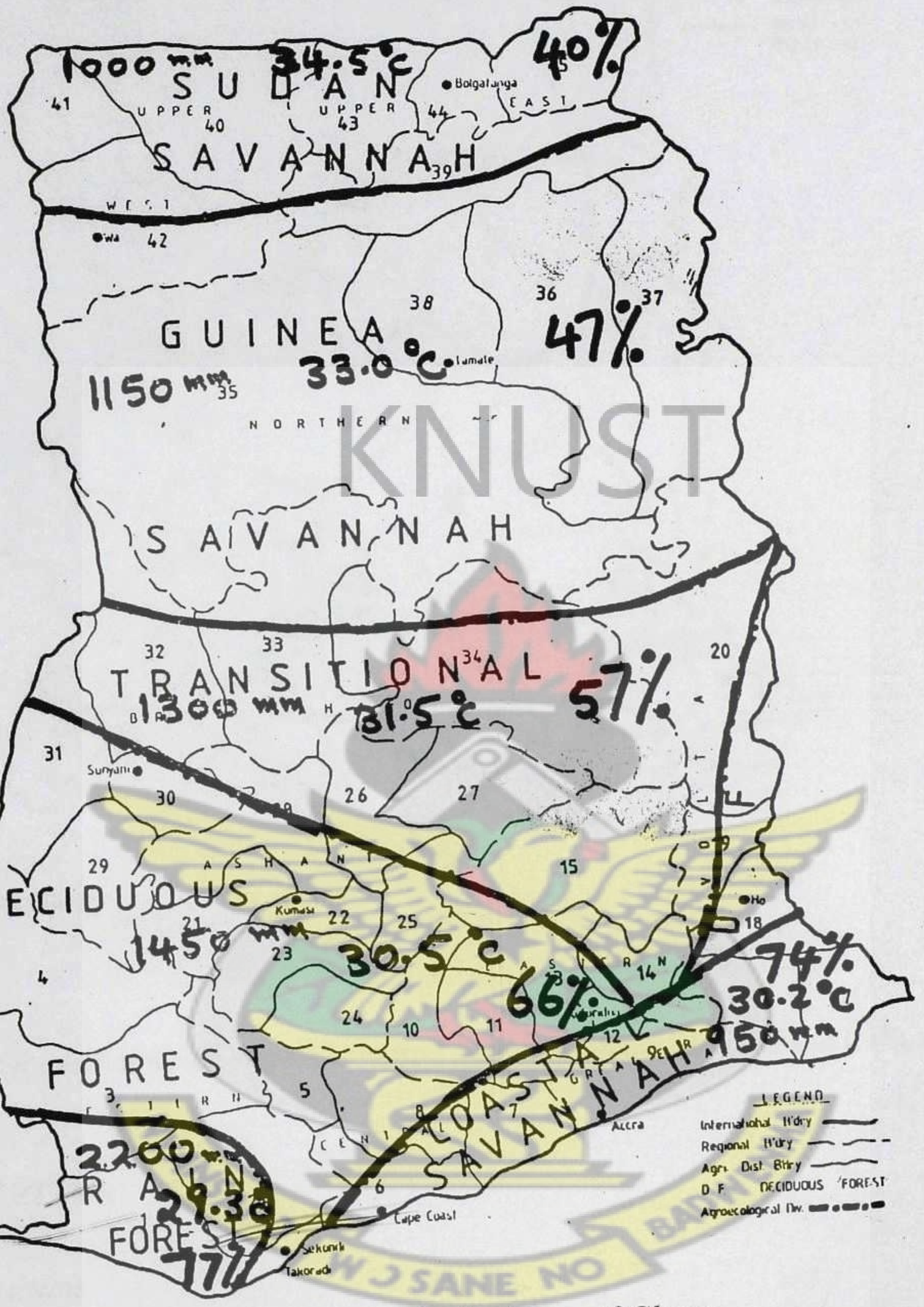

Fig 3.1 Agro-ecological map of Ghana
(Source: Ghana Meteorological Services Department)

Fig 3.1 can be further simplified to give four agro-ecological zones as shown in Fig 3.2 (Roberts and Gaituah, 1980) with the indicated characteristics, i.e. the two savannas can be grouped to give a single zone and part of the transitional deciduous forest will be taken to add up to the forest zone to give a zone with the remaining being a zone. The coastal savanna and the land east of the Volta River will merge to give another zone. For convenience this grouping is done using the regional administrative boundaries as a guide.

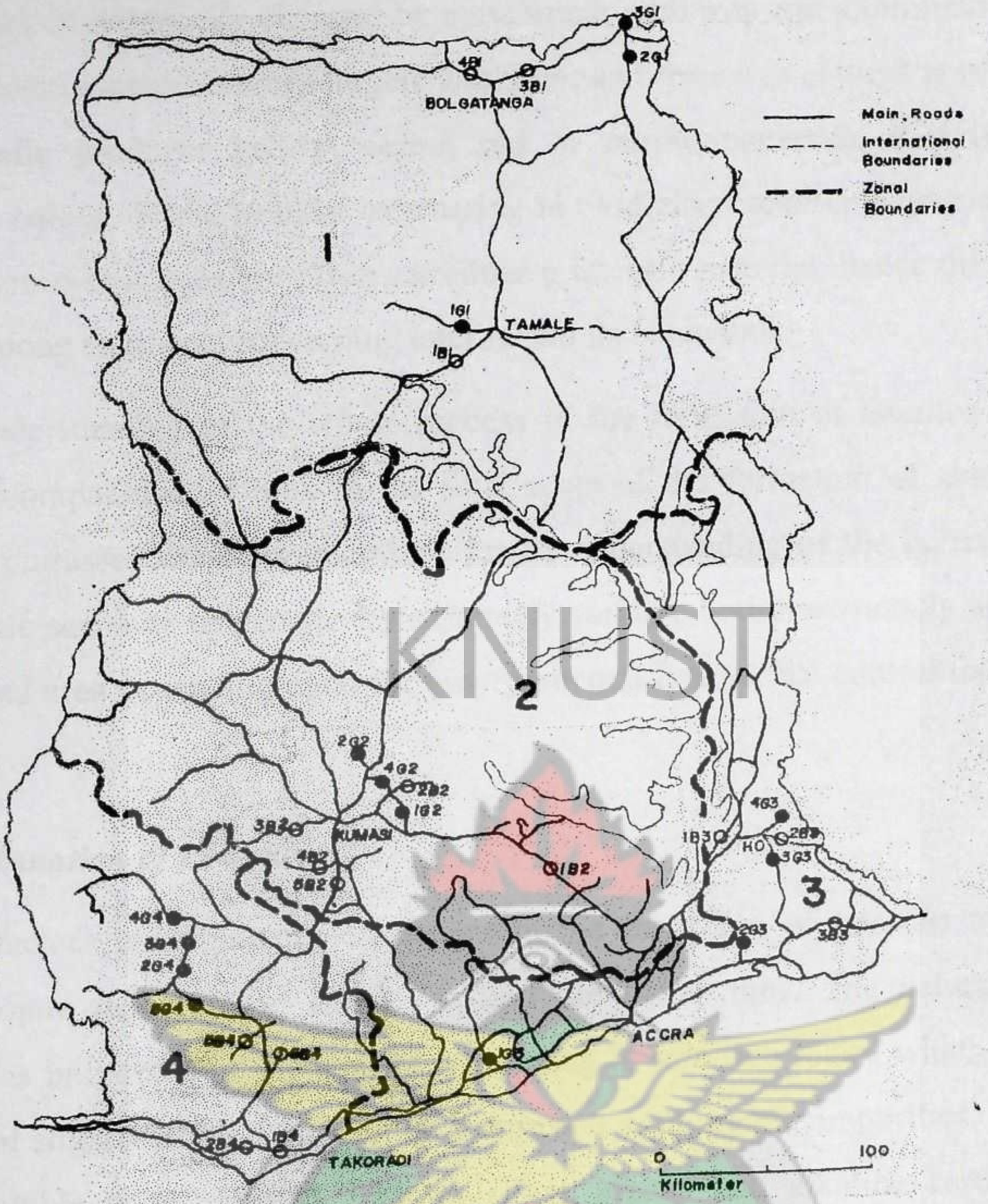

Fig 3.2 Showing a Simplified Agro-Ecological Zones of Ghana (Roberts and Gaituah, 1980)

3.3. LATERITES

3.3.1. *Definition*

Lateritic soils are a class of tropical soils, rich in iron and aluminium oxides and poor in alkaline oxide ranging from soft pebbly clays to hard rock-like concretionary gravels, which commonly form a surface layer on residual soil mantles. Laterite could also be defined as a *hardened or soft weathered product of tropical and sub-tropical weathering which is leached of bases but enriched in sesquioxides of iron and alumina, in the form of clay minerals especially kaolinite and secondary iron minerals such as goethite, limonite and hematite*. There is little or no combined silica in laterite but depending on the parent rock, laterite may have high quantities of quartz (Ayetey and Castel, 1970). Laterite are also defined as a product of tropical weathering process which has the following effects:

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the parent rock is chemically changed by enrichment with iron and aluminium oxide; the clay mineral component becomes largely kaolinite; and the silica content is reduced. This process usually produces yellow, ochre, red or purple materials. Red is often the predominant colour. While tropical weathering in oxidizing conditions generally leads to reddening, however it does not always produce a lateritic material, hence the widespread confusion among engineers concerning laterite and its behaviour.

A proper understanding of the whole process of the formation of laterites from initial chemical decomposition of rock to the final stage of the formation of aluminious and ferruginous cuirasses (rock) is important for an understanding of the behavior of these soils. Lateritic soil may be genetically extremely variable both horizontally and vertically over a limited area depending upon the environmental factors that control the laterization process.

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3.3.2. *Formation of Laterites*

The three factors predominantly important in the formation of laterites are, *iron rich rocks*, *alternate dry and wet conditions* and the *topography*. The natural process of weathering is initiated by the chemical weathering in iron rich rocks, which is caused by the action of slightly acidic rainwater contaminated with organic impurities. This tends to dissolve soluble rock minerals such as silica, alkalis and alkaline earth at tropical temperatures, leaving behind a concentration of hydrates of iron and aluminum. During wet periods (rainy season) the soluble minerals are eliminated, whereas during the dry season the iron is precipitated as ferric hydrate, which finally hardens up by dehydration. It has been observed that most lateritic soils develop at annual temperatures of about 25^0C. It is also known that where definite dry periods exist the end products of lateritic weathering are considerably enriched in ferric oxide and Tatania whereas in the absence of a dry period alumina is the dominant constituent of the surface horizon. Such laterite formations are usually called primary laterites. Dehydration as is well known is a continuous process with yellow gel of iron hydrate changing to brown gel and finally crystallizing as limonite and haematite. The change in laterites concretions in becoming harder and darker with time is as a result of these chemical changes. A large number of profiles studied in Ghana have pisolites with yellow colour indicating that they are still in the process of maturing.

In a few of the profiles from the forest zones of Ghana the hydrate of iron is observed to have concentrated at a certain depth below the ground surface. The soil at the time of digging is wet and soft, under a thick blanket of vegetation. As soon as the vegetation is cleared the supply of oxygen from the air and exposure of the soil surface to the sun sets off a process of oxidation and dehydration, thus changing the soft material into a hardened brick like mass, within months of vegetation clearance. These formations called "*ground water laterites*" are formed by the precipitation of iron dissolved and transmitted by the ground water in the profiles.

In a number of profiles in Ghana where the topography of the area is not plain, the iron from upper slopes is brought to the mid terraces and lower slopes, either by the flow of underground water or as a result of surface drainage. The concentration of such irons brought from external sources under such favourable conditions tend to hydrate and then dehydrate thus producing hardened mass with time (de Graft Johnson et al 1969).

Though lateritic soils occur in rainforest vegetation, well-developed lateritic soils are commonly formed under low forest. Hard superficial lateritic soils are a common feature in the north and a savanna region where the conditions most favour oxidation and dehydration and the hydrated lateritic soils. The vegetation cover provides the humiferous horizon, the thickness of which is a factor influencing the availability of organic acid in the soil, which have direct bearing on the pH. The pH and the oxidation potential of the environment in which the laterite is to be formed affect the transportation and deposition of lateritic soil forming materials (Gidigasu, 1982).

3.3.2.1. Influence of climate on the distribution of Lateritic Soils in Ghana

The rainfall pattern in Ghana has already been discussed in chapter 2. The seasonal variation and the dry and wet seasons are significant for the formation of laterites. Table 3.3 shows the average annual rainfall amounts and also the mean number of rainy days in the various zones discussed in Table 3.2. The amount of rainfall that occurs in the various climatic zones of the country is such that the formation of laterites is possible in all the parts of the country given the temperature values that occur in the various part of the country as indicated in Fig 3.1.

Table 3.2 Long-term average Rainfall for Agro-ecological zones
(Ghana Meteorological Department, 1961 - 1990)

ZONES	REGION	REP. STATION(S)	MEAN ANNUAL RAINFALL (mm)	MEAN NUMBER OF RAINDAYS PER YEAR	Terrian/ Vegetation
1	Northern	Bole, Yendi	1,165	96	Flat/ Savanna
	Upper East	Navrongo	986	79	
	Upper West	Wa	1,023	87	
	Average		**1,058**	**87**	
2	Ashanti	Kumasi, Ajura	1,385	120	Rolling/ Forest
	Eastern	Akirn Oda, Akuse	1,314	121	
	Brong Ahafo	Wenchi, Sunyani	1,212	113	
	Average		**1,304**	**118**	
3	Volta	Kete Krachi, Akatsi	1,143	84	Coastal Plain/ Forest
	Greater Accra	Accra, Ada	838	71	
	Central	Agona Swedru, Saltpond	1,129	105	
	Average		**1,037**	**87**	
4	Western	Tarkwa	1,874	160	Rolling/ Rain Forest
	Average		**1,874**	**160**	

Based on Data from Ghana Meteorological Services Department, Head Office, Accra. (November, 1996).
Note : The mean annual rainfall for the regions was derived from the average of the sum of the mean monthly rainfall values for the representative station(s) for each region.

3.3.3. *Laterites Compared to Temperate Zones Soils*

Whereas the engineering behavior of the major soil types of the temperate zone have been the subjects of detailed studies and countless publication, there has been very little concern shown for some lateritic soils. One of the difficulties lies in defining these soils with sufficient precision to discuss them as an entity (Gidigasu, 1970). The factors that affect the formation of laterites include the presence of iron rich rocks, alternative dry and wet conditions and the topography of the area (de Graft-Johnson et al, 1969).

One of the major problems confronting geotechnical engineers in the tropics is the fact that most local soils are not amenable to standard pre-test preparations and testing procedures resulting in variations of the test results. For example, classification test for some lateritic soils are very sensitive to moulding moisture content, degree of pre-test drying, time of mixing, type of dispersing agent, degree of manipulation (such as during

compaction), period of pre-test soaking and competence of the technician involved in the testing. The extent to which these factors affect the test results also depend upon the weathering processes through which these soils have been formed, the degree of weathering, type and extent of post formation changes (such as degree of desiccation, aggregation, cementation, structure and fabric, physical, chemical and mineralogical composition) as well as position of the soil sample in the profile (Gidigasu, 1970).

The significant difference between Temperate Zone soil and lateritic soils is that Temperate Zone soils are generally mechanically (i.e. physically) weathered soils, and moderately chemically weathered, i.e. soils of which the degree of weathering does not proceed beyond the clay forming stage. For such soils, the standard Temperate Zone soils specification is appropriate. This specification is however not applicable to soils formed through intensive chemical weathering processes occurring in tropically high rainfall and temperature environment. Soil classification tests for temperate climate soils have been standardized and comprise the determination of the particle size distribution and of the liquid and plastic limit of the soil. From knowledge of these properties several other engineering characteristics can be inferred from the information available on other soils of similar classification properties (de Graft Johnson et al, 1969).

The simple adoption of these tests for the classification of lateritic soils has proved unsuccessful for a number of reasons: These classification tests do not yield reproducible results since they are influenced considerable by methods of preparation and handling of materials. Since the material is a decompositional product it may contain materials with different degrees of weathering. Thus these tests could not be adequate for predicting engineering properties without some definition of the degree of weathering.

The engineering properties of lateritic soils in the field are influenced considerably by their chemical as well as mineralogical content and also by the environment. This is so because under extreme tropical climatic conditions, the weathering is so intensive that even the clay minerals are broken down leading to the formation of hydrated oxides of iron, aluminium and titanium, etc. Some of these soils also contain such unstable clay minerals as hallosite and alophane. Soils containing these minerals undergo considerable changes during drying for classification test or during construction in the field. For such soils it is difficult to predict field performance unless the laboratory and field drying conditions are the same. The development of realistic material acceptance specification and construction control procedures for lateritic soils should be related then not only to

the weathering processes, composition and morphology but also to the controlling factors of the environment.

Its been realized that no one criterion of soil classification has been adequate for the classification of engineering properties of lateritic soils. Even though the classification system based on the particle size distribution and Atterberg limits is the oldest and widely used method, it is inadequate to classify tropically weathered soils, since the soil behavior also depends on the morphological characteristics, geological history, soil genesis and actual moisture conditions (Gidigasu, 1970).

Pedological soil classification is important in the stabilization of natural soils. This classification system is based on the fact that soils formed on the same parent materials under similar climatic and drainage conditions and supporting similar vegetation will have similar physical and chemical properties. Once the stabilizer requirements of a given soil series has been determined through laboratory tests only the identification of the particular soil series and horizon and a minimum exploratory check tests are required.

3.3.4. ***Grouping of Laterites***

3.3.4.1. Grouping Based on Physical Characteristics

On the basis of a study of several profiles from the different regions of Ghana, the laterites have been grouped as shown in the Fig. 3.3. This conforms to the universally accepted division of primary and secondary laterites. The gravels that have been used extensively in Ghana for road construction have been further studied and have been identified as

(i) Nodular or concretionary laterites

(ii) Iron Stone hard pans or cap rock

(iii)Groundwater laterites with detrital quartz

(iv)Colluvials and terrace laterites

The physical features of each group of laterites are shown in the Table 3.3 below

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Table 3.3 Showing the Features and Mechanical Characteristics of Different Groups of Laterites of Ghana (de Graft Johnson et al, 1969)

Group	*Colour and Description*	*Specific Gravity*	*Void Ratio** e*	*Absortion 96 Hours %*	*Mod. Agg. Impact Value %*	*Agg. Crushing Value %*	*Los Angeles Abration Value %*
i	Dark-Brown	3.582 (6)*	0.212 (6)	7.45 (4)	31.42 (4)	35.27 (2)	36.4 (1)
	Light-Brown	3.390 (5)	0.284 (5)	10.24 (3)	37.63 (5)	41.45 (2)	40.5 (1)
	Yellowish-Brown	3.182 (6)	0.334 (6)	13.10 (4)	46.50 (4)	51.20 (2)	--
ii	Dark-Brown (Honey combed)	2.981 (5)	0.382 (5)	16.30 (5)	41.24 (4)	38.10 (3)	--
	Dark-Brown (Homogenous)	3.472 (4)	0.291 (4)	8.15 (4)	29.23 (4)	32.41 (2)	--
	Light Brown or Reddish Brown	3.041 (4)	0.311 (4)	18.42 (4)	43.60 (4)	41.67 93)	--
iii	Hard Pans (Accra Plains)	3.341 (9)	0.262 (9)	11.42 (5)	34.66 (5)	32.43 (2)	39.60 (1)
	Hard Pans (Forest Zone)	3.164 (7)	0.306 (7)	8.51 (5)	42.43 (4)	45.44 (2)	51.21 (1)
	Cemented Clay or Pseudo-boulders	2.972 (4)	0.344 (4)	17.44 (5)	54.24 (3)	48.42 (1)	--
iv	Detrital Irregular laterites	3.120 (3)	0.340 (3)	13.49 (3)	47.62 (3)	45.48 (2)	--
	Concretionary Gravel, Cemented with clay (lower slopes)	3.260 (4)	0.306 (4)	12.65 (3)	39.62 (2)	41.61 (1)	--

* The figures in the brackets give the number of test, for which the average is given in the table.
** Void ratio is for natural formation.

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3.3.4.2. Grouping based on Genetic Characteristics

The lateritic Soils in Ghana can also be classified into three groups based on their genetic basis and the amount of leaching that has taken place within the structure. These are Ferruginous tropical Soil, Ferrisols and Ferrallitic Soils (yellow, brown red, humic) (D'Hoore, 1964). All these three categories of lateritic soils are found overlying various types of rocks. {In Ghana they are found on granites, phyllites, gneiss etc. Based on the degree of weathering laterites can be classified into three groups depending on the stage of laterization that the soil has gotten to (Duchaufour, 1982)}

(i) Fersiallitization (2:1 lattice clays dominant)

(ii) Ferrugization (Kaolinite and 2:1 lattice clays) and

(iii) ferallitization (kaolinite and gibbsite),

The three categories belong to three phases of the cycle of weathering necessary for the development of residual soil in the tropics, the end stage of which is ferrallitization. In sub tropical climates with a marked dry season stage (i) is rarely exceeded; in a dry tropical climate development the process stops at stage (ii); it is only in humid equatorial climates that stage (iii) is reached. The increase in the speed of prodigenesis, owing to rise of temperature on the one hand and increase of precipitation on the other is

fundamental to the final equilibrium stage that is reached. The three phases are characterized by increasing weathering of primary minerals, increasing loss of silica and increasing dominance of new clay minerals formed from dissolved materials. Note that ferrisols exist as a transitional stage between the ferruginous and ferrallitic soils.

A research carried out by BRRI with the aim of identifying the laterite distribution in the country as well as saprolites led to the identification of various types of laterites as indicated in the Fig 3.3 below. This map is a guide to identifying the various types of laterites.

Fig 3.3 Engineering Soil Maps lateritic Soils of Ghana (BRRI, 1975)

Gravelly Laterite (Pisolitic)		Distribution General, excepts along water courses. Laterite horizon thick with gravel layer. Generally from 1m and above
Gravelly Laterite (Quartzitic)		Distribution General: found even along watercourses except that watercourses gravel are not lateritic but mainly detrital quartz. Lateritic gravel found within a thin horizon. Quartzitic gravel found throughout profile.
Clayey to sandy laterite		Distribution strictly or distinctly high ground. Absent on low grounds. Laterite gravel forms very thin horizon (less than 1m), generally with laterite profiles thickness decreasing from high ground to low grounds
Laterites with gravel pebbles-boulder admixture		Profile very variable with horizons. Generally not easily discernible apart from variable horizons of laterite gravel these may be quartz gravel pebbles from sandstone or conglomerates and boulders from the receding Voltaian as well as quartz veins.
Sandy clay only slightly lateritezed		Profile rather generally not well developed. Area generally low lying and predominantly sand and clayey sands. Laterite gravel scanty with horizon thickness well below 2m.
Clayey laterite		Profile poorly developed. Lateritic gravel scanty with practically no definite horizon. Clay very dispersive in places
Heavy clays		Predominantly heavy clays only slightly lateritezed on high ground which are very limited in the area where lateritic profile is developed. It is not thick and gravel horizon is very thin.
Sands (unlateritezed)		Sands, cohesionless.

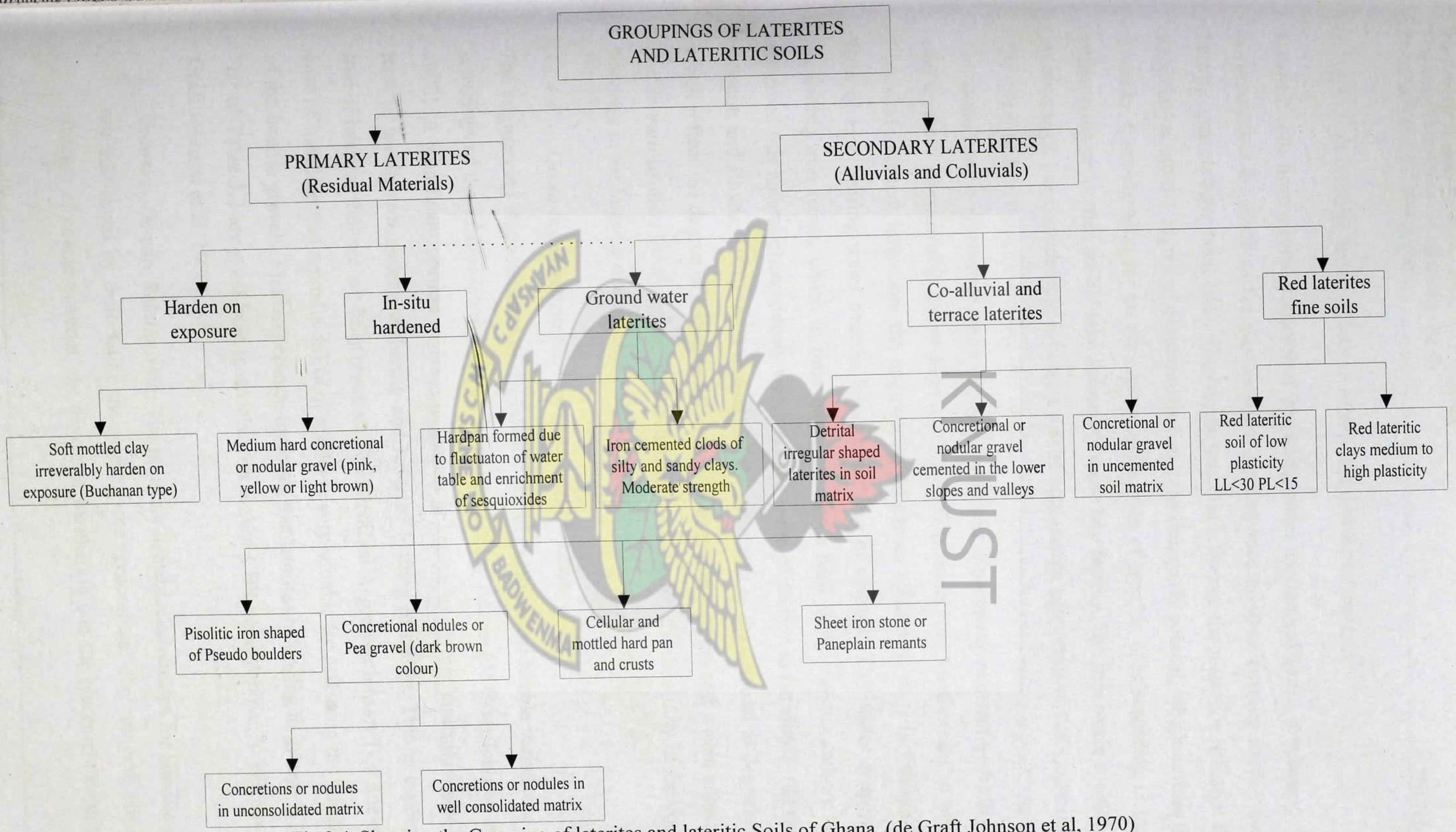

Fig 3.4 Showing the Grouping of laterites and lateritic Soils of Ghana. (de Graft Johnson et al, 1970)

3.3.4.3. Groupings based on degree of decomposition and maturity

Lateritic soils have a great potential of degrading under mechanical stress, this behaviour is responsible for much of the unsatisfactory performance of some existing roads where lateritic gravels have been used. The two factors that influence the materials potential for degradation are the degree of decomposition and the iron oxide content, which defines the maturity. Consideration for an effective classification of lateritic soils according to their engineering properties should take account of these two factors. The iron oxide content of lateritic soils has considerable influence on the engineering properties of these materials. *The effect of iron oxide in binding into larger ones is considered to account partly for the successful road performance under tropical conditions of surfacing material with silt and clay contents considerably higher than accepted ASTM standards*. Another way in which iron oxide content influences the engineering properties of lateritic soils is through the flow of iron bearing water over or through the face of cuttings. This water evaporates depositing iron oxide, which in time builds up into a hard crust. Various authors have observed this natural phenomenon, which affords some protection to cut slopes. (de Graft Johnson and Bhatia, 1970). As a measure of the resistance of the material to degradation which reflect the degree of decomposition as well as maturity of the soil within a lateritic profile various tests for assessing the mechanical strength and the durability of the coarse fractions in the lateritic material have been adopted.

3.3.4.4. Grouping Based on Engineering Characteristics

The engineering characteristics of the lateritic gravel exhibit considerable variations. The groupings of the various laterite gravels do not follow any pattern (de Graft Johnson et al, 1970). A significant portion of lateritic gravels is known to be mechanically weak and tend to breakdown under weathering and repeated loading of traffic. This is especially true of laterites that are not fully matured. The Modified Aggregate Impact Test due to its ease of handling and reproducibility of results is very suitable for assessing the durability of the laterite gravels. Field experience indicates that laterites belonging to groups "i" and "ii" of Table 3.2 are good base materials with soaked CBR values above 70 percent (De Graft Johnson et al, 1970).

1. *Moisture- Density Relationship:* The moisture density relationships for lateritic soils are influenced by factors like the grading, the predominant clay mineral, crushing strength of coarse material, the degree of weathering and the placement conditions

of the material. The compaction curves for most lateritic soils when compacted from dry to wet show increasing dry density with increasing moisture content, up to a maximum dry density beyond which the dry density decreases. The maximum dry density generally increases and the optimum moisture content decreases with increasing compactive effort. Lateritic soils in a relatively dry state in-situ particularly behave in this way. They tend to have high maximum dry densities and low optimum moisture contents. Drying of the material also affects the compaction characteristics of humid tropical soil. The compaction curves for some tropically weathered soils also yield two peaks rather than one. Studies on the compaction characteristics of Ghana lateritic soils would indicate that the change in the moisture density relationship is greatly influenced by the initial grading of the material as well as the mechanical strength of the particle and that the resulting density could be increased or reduced during compaction.

2. *Strength characteristics:* From the simplified geological map of Ghana, it is observed that the most important rocks (i.e. rocks which form laterites with particle strengths favourable for use as road construction material) are respectively gneiss's in the coastal Savannah zone, granite and phyllites in the forest zone, granite, sandstone and shale in the Savannah zone. The geomophological and physical features depend mainly on the geology. Most of the hill and ranges consist of hard resistant rocks such as quartzite, whereas the valleys and lower grounds are carved out of softer rocks such as shale, sandstone, phyllites and schist (Gidigasu, 1970). Within the lateritic profile the shear strength parameters will vary with depth according to the mode of formation and will be influenced by parent rock, depth of water table and its variation, precipitation and degree of laterization, chemical and mineralogical content of the materials. In addition there are time effects on in-situ strength of lateritic soils that have not been extensively studied. Alternate wetting and drying will result in hardening of the lateritic soil depending on the texture of the material and iron contents underlying deposits of gravel. It has been found that clay after the initial hardening was not affected by subsequent wetting (Ackroyd, 1959). Unconsolidated undrained test on kneading compacted lateritic soils from the forest zones of Ghana (De Graft-Johnson et al, 1968) show c_u and ϕ_u to be influenced by density, moulding water content, and structure. High values were recorded for c_u and ϕ_u for the unsoaked samples, which were reduced considerably

upon soaking. In both the soaked and unsoaked samples increasing the compactive effort wet of optimum decreased ϕ_u considerably. This was considered to be the structure sensitivity of the material.

3. ***California Bearing Ratio:*** The CBR of a compacted soil is influenced by such factors as placement water content, dry density, method of compaction, clay structure, compactive efforts, type of clay mineral etc. For most lateritic soils increasing the compactive effort resulted in an increase of the unsoaked CBR. However, for some soils, depending on the type of clay mineral present, increasing the compactive effort resulted in a reduction of the unsoaked CBR as well as the soaked CBR, tests on Ghana lateritic gravels confirm this pattern (De Graft Johnson et al, 1969). The effect of increased compaction effort causing reduced CBR wet of optimum is attributed to the existence of the kaolinite type mineral in the soil, which is structure sensitive and tends to get dispersed with increased compaction wet of optimum. Generally, soaked CBR values for lateritic soils are much lower than the unsoaked CBR (De Graft Johnson et all, 1970).

4. ***Swelling Characteristics:*** Though some lateritic soils are known to contain significant proportions of clay minerals with the expanding lattices by far. The largest proportion of them do not contain such clays and as such most lateritic soils are not susceptible to excessive swelling. Many specifications for the use of lateritic soils in road construction state limit of consistency though not the limit for swelling. Experience has shown that some materials not acceptable on the basis of consistency limits have proved to perform satisfactorily if their swelling did not exceed 10%. Test on typical lateritic clays from the forest zone of Ghana yielded values of swell of 0.6 %. The swell decreased with increasing moisture content (De Graft Johnson et all, 1970).

5. ***Permeability and Consolidation Characteristics:*** The porous and granular types of material are the most permeable particularly in-situ. These material exhibit low permeabilities when compacted or remoulded. The permeabilities of these laterites are of the order of 10^{-2} to 10^{-1} cm per sec. Permeability test on a typical lateritic clay for Ghana, showed that moulding moisture content and dry density affect the peameability. For the samples subjected to modified AASHO compaction the permeability ranged from 10^{-4} to 10^{-6} cm per sec (De Graft Johnson et all, 1970).

Table 3.4 shows typical engineering properties obtained for some lateritic soils formed over various rock types in Ghana during laboratory experiments.

Table 3.4 Engineering Properties of Some Ghanaian Lateritic Soils
(Ayetey and Castel, 1970)

Location	Parent Rock	Horizon	Gravel	Sand	Fines	LL	PI	SG	OMC (%)	MDD (Mg/m^3)
Barekese	Granite	iii	48.0	26.0	26.0	44.4	22.0	2.82	10.5	1.978
		iv	22.0	20.0	58.0	44.0	20.1	3.0	26.5	1.457
		v	38.0	32.0	30.0	50.5	29.0	-	27.4	1.505
Accra	Quartzite	iii	70.5	26.5	3.0	15.8	NP	2.52	-	-
		iv	54.0	38.0	8.0	23.7	9.7	2.58	11.4	2.015
		v	74.0	22.5	3.5	-	-	2.58	-	-
Saltpond	Amissian beds	iii	63.0	30.5	6.5	39.8	23.2	2.71	12.0	2.054
		iv	36.0	36.0	28.0	38.5	21.3	2.60	14.8	1.813
		v	24.8	47.2	28.0	40.2	23.8	2.69	-	-
Saltpond By-pass	Pegmatite	iii	69.0	23.6	7.4	29.8	15.0	2.67	-	-
		iv	16.0	46.7	37.3	44.0	20.1	2.64	14.5	1.826
Ho	Gneiss	iii	70.0	22.0	8.0	26.4	15.6	2.52	11.5	2.012
		iv	68.0	11.5	10.5	44.0	26.2	2.60	12.0	1.980
		v	29.0	55.0	16.0	61.2	36.9	2.64	20.0	1.585
Asikuma-Boso Road	Serpentinite	iii	60.0	22.0	18.0	58.7	32.2	2.71	13.0	1.938
		iv	65.0	24.0	11.0	74.1	42.1	2.74	22.0	1.762
Kumasi-Bekwai Road. Mile 18	Phyllite	iii	47.0	21.0	32	59.8	35.9	2.74	30.0	1.490
		iv	26.0	23.0	51	63.1	37.7	2.68	36.0	1.378
		v	13.0	13.0	74	42	15.0	2.71	29.0	1.169
Asuofua near Barekese	Granite	iii	0	54	46	40.5	20.4	2.21	21.2	1.602
		iv	0	44	56	40.0	19.8	2.60	20.0	1.595
		v	0	50	50	42.0	20.6	2.68	-	-

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CHAPTER FOUR

4 REVIEW OF SOIL STABILIZATION

4.1. GENERAL SOIL STABILIZATION

The process of altering the properties of a natural soil to meet specific engineering requirements is known as soil stabilization. Soil stabilization can also be said to be the manipulation of foundation or base soils with or without admixtures to increase their load carrying capacity and resistance to physical and chemical stress of the environment over the service life of the engineering facility. Properties such as strength, stiffness, compressibility, permeability, workability, swelling potential, water sensitivity and volume change tendency may be altered by various methods of soil stabilization. Amongst many theoretical and practical possibilities of stabilizing soils, the following have been identified as practical and economical solutions

(1) *Granular stabilization (Mechanical Stabilization):* This is a combination of physical and chemical stabilization methods in which granular bearing skeleton is modified with pore-filling and/or cementing natural and extraneous material (clay and other concretes and mortars).

(2) *Chemical stabilization:* This is a general term for all those methods in which chemical rather than physicochemical and physical interactions play a predominant role. Some of the widely used and emerging systems are summarized below.

(i) Soil-cement
(ii) Soil-lime
(iii) Soil-bitumen
(iv) Soil-resin
(v) Soil-Power plant waste
(vi) Other (salt, acids, lignin)

(3) *Thermal stabilization:* This is a physical method of stabilization that utilizes heating or freezing for long or short-term improvement of properties of difficult soils.

(4) *Electro-kinetic stabilization:* This is the method that uses the influence of an electric field to facilitate consolidation of fine-grained soils and also movement of stabilizing agents through dense soils.

4.1.1. *Mechanical Stabilization*

This is by far the most practiced stabilization method in Ghana. For most GHA projects, mechanical stabilization is frequently recommended where material meeting base and sometimes subbase specification is difficult to find. Attempt have been made to optimize the proportion of the gravel and fines fractions to obtain the highest dry density and bearing capacity in terms of CBR and dry density. Studies in Ghana have shown that, the content of fines has considerable effect on the moisture-density relation, as well as on the CBR of the compacted lateritic gravel (Gidigasu and Mate-Korley, 1980).

The contribution of sand stabilization to dry density has been widely reported. It may also considerably improve the CBR of the soil and reduce swell associated with specimen soaking for CBR test.

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4.1.1.1. Lateritic Gravels - Fines Stabilization

Lateritic gravels are known to exist in various forms ranging from those with silt and clay content of about 40 % (Gidigasu, 1972) to those with, practically no fines (de Graft-Johnson, et al, 1972). This poses a lot of compaction problems in the field, and attempts have been made to optimize the proportion of the gravel and fines fractions to obtain the highest dry density and bearing capacity. Studies on Ghanaian lateritic soils have revealed that they give the most desirable highway geotechnical properties when they have around 75% gravel size content and 25% fines content. Characteristics CBR values vary considerably in relation to the moulding moisture contents. Generally, in the same way that the particle size distribution affects the properties of Temperate zone soils, addition or subtraction of certain soil fraction may modify to a great extent the moisture-density relations of a typical lateritic gravel formed over phyllite. The shear strength parameters (i.e. apparent cohesion and angle of shearing resistance) are also considerably affected by the relative content of the fines and the gravel sizes. The gravel size content of about 75% and 25% of the fines appears to give the highest values of angles of shearing resistance with the highest values of apparent cohesion occurring around 25% content of gravel size and 75% fines content (Gidigasu and Mate-Korley, 1980).

4.1.1.2. Stabilisation of Lateritic Gravels Using Sand

Results of studies have been reported on the use of sand for improving the geotechnical properties of laterite gravel-clays. Such stabilization is most useful in situations where

laterite gravel-clays with high plasticity and low CBR values abound and sand could be cheaply obtained nearby. Difficulties have been reported however, in dry-mixing sand and laterite gravel-clays, however addition of a small amount of water may facilitate thorough mixing of the laterite gravel-clay with sand (Castel, 1970). Most laterite gravels are characterized by gap grading showing deficiency in sand content so that sand stabilization is an attempt to improve the particle size distribution to produce a well graded material. Sand stabilization reduces the plasticity of the soil. However, the degree to which it affects these properties is a function of the particle size of the sand; the medium and coarse sand tend to reduce the plasticity index faster than the fine sand.

The effect of sand stabilization on dry density has also been reported for Ghanaian gravels. The optimum value of the sand fraction varies from gravel to gravel in relation to the initial grading characteristics and degree of deficiency in sand size fraction. Sand stabilization has also been shown to give considerable improvement to lateritic gravels in terms of increase in bearing strength and reduction in the amount of swell. (Gidigasu and Mate-Korley, 1980)

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4.1.1.3. Laterite-Quartz Gravel Particles Stabilisation

One of the main characteristics of lateritic gravelly materials formed over quartz rich parent rocks is that the materials are a mixture of quartz particles (weathered to various degrees) and the concretionary laterite particles in a matrix of fines, (Gidigasu, 1972). The evaluation of the mechanical strength of the washed quartz-laterite gravel particle mixes for base construction appears to have some future prospects. In this respect the effect of the relative content of the quartz and concretionary gravel sizes is of interest to the roads engineer. Studies undertaken to investigate this problem revealed that the mixture of the two materials may yield strength and durability characteristics superior to that of either of them. The strength of each of the two materials is however, an important factor. As a general rule for the same drainage condition crystalline rocks such as granite may produce concretionary aggregates of higher strengths than those formed over softer rocks such as phyllite, schist, shale, etc. (Bani, 1971). Topography and degree of desiccation also affect the durability of concretionary gravels. Thermal treatment of lateritic gravels also gives higher durability. It would seem from the foregoing discussion that laterite gravels and aggregates may be improved considerably for road base construction through selected mechanical stabilization.

4.2. CHEMICAL STABILIZATION

The most commonly used chemical stabilizing agents are Portland cement, lime, and bitumen (in the form of Bitumen Emulsions, cutbacks etc) in the order of decreasing use. Portland cement, lime and fly ash fall into the category of active agents whereas bitumen is an inert agent. The active agents react chemically with soil constituents and/or other admixture whereas inert agents provide a stabilized matrix by coating and cementing the soil particles and aggregates. Effectiveness of chemical stabilization depends partly on the interaction between soil particles and the stabilizing agent and partly on the properties of the agent. Water affinity and water retention capacity, ion exchange capacity, clay content, grain-size distribution and porosity of the soil are some of the factors that affect the interactions between soil particles and the admixture.

Available publications indicate that there has been some research work on stabilization of lateritic soils of Ghana. The Building and Road Research Institute (BRRI) have done a lot of research on stabilization of lateritic soil over a period of time. Information on the use of certain types of stabilizers is though limited and notable amongst them is the use of bituminous products. Considerable contribution has been made on the evaluation of factors, which influence the results of chemical stabilisation of laterite soils. The significant factors include the genetic soil type, composition of the soil, the soil structure, the mineralogy, the method of sample preparation during test, the testing procedure etc. Table 4.1 below is an attempt to show the use of some types of stabilizers and the types of material that are best suited for the particular situation.

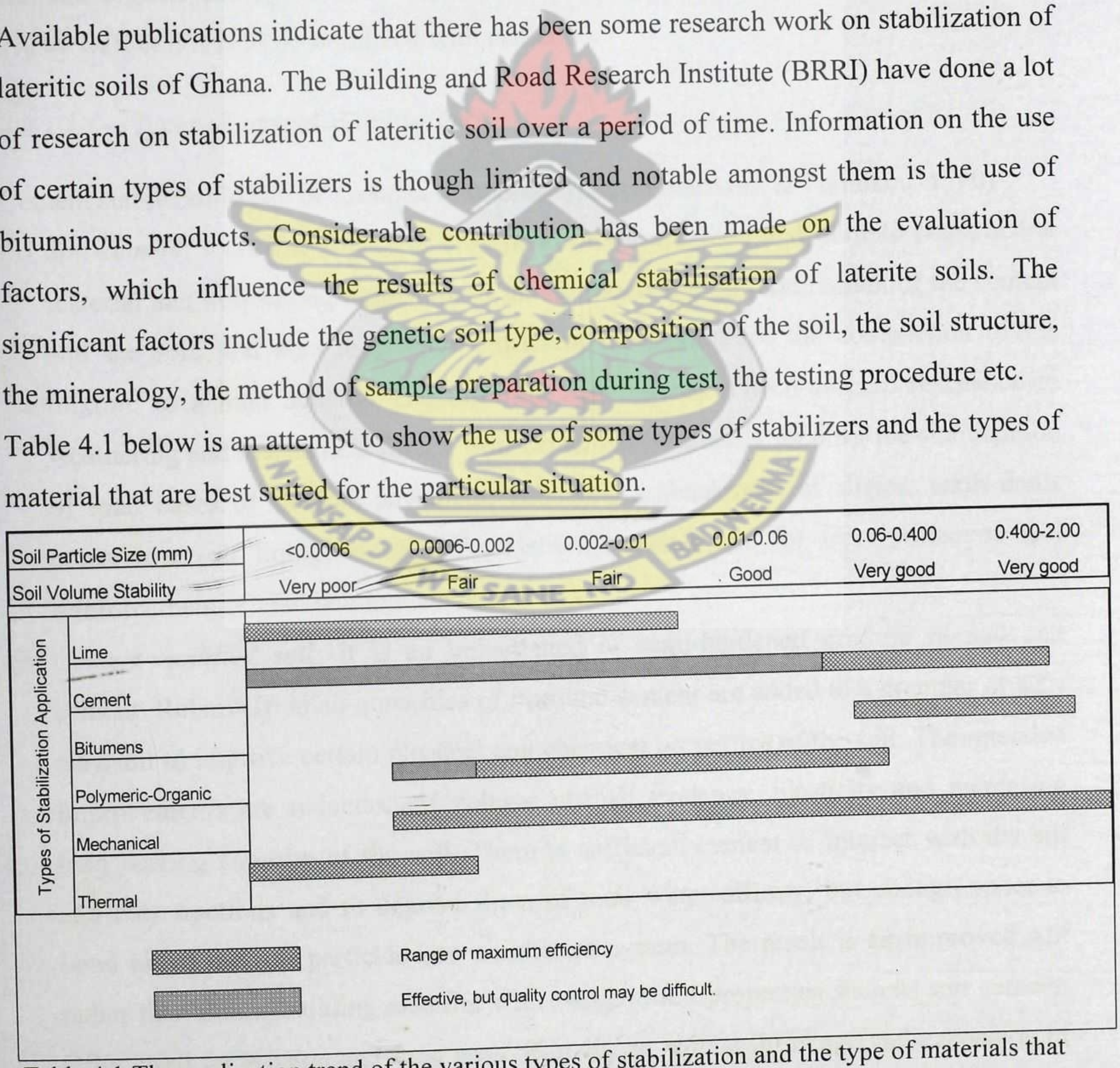

Table 4.1 The application trend of the various types of stabilization and the type of materials that they best stabilize. (Source Ingles & Metcalf, 1974)

4.2.1. *Cement Stabilization*

Cement stabilization of soil involves mixing of pulverized soil, cement and water and compacting this mix to a high density which renders the material resistant to various physical, thermal and chemical stresses. Depending on the type of soil and size of aggregates used, there are different products of cement stabilization. As the cement hydrates, a gel is formed, which upon hardening forms a cellular matrix that encapsulates the soil particle or form a strong bridge (spot welding) between the aggregates thus producing a hard, durable structural material. If the size of the soil particle is smaller than that of the cement, the soil particle surrounds the cement particle and weaker bonds are formed. Beneficial soil cement reaction is strongly impeded or neutralised when the soil contains organic matter. Thus most specifications limit a soils organic matter content to 1-2% by weight if it is to be stabilized with cement.

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4.2.1.1. Types of cement stabilization

Cement stabilization can be grouped into three types (Winterkorn & Pamukcu, 1990)

(a) *Soil-cement:* Contains sufficient cement to produce a hard and durable construction material and only enough moisture to satisfy the hydration requirement of the cement and the soil, and also to provide sufficient lubrication for the compaction of the mixture to a high density. The resulting material has a well-defined resistance to weathering and mechanical forces. Soil-cement is commonly used for the stabilization of road bases of flexible pavement, subbases, embankment of slopes, earth dams cores, reservoir lining, building foundation, trenches and for frost protection and reinforcement of load bearing layers.

(b) *Cement-modified soil:* It is an unhardened or semi-hardened mixture of soil and cement. Relatively small quantities of Portland cement are added to a granular or silty clay soil to improve certain physical and chemical properties of the soil. The intended improvements are reduction of volume change tendency, plasticity and increasing load bearing capacity of the soil. There is sufficient cement to interact with the silt and clay fractions and to deprive them of their water affinity, but enough water to bond all of the soil particles into a coherent system. The result is an improved soil rather than a new building material with standardized properties such as soil cement. Often used for erosion and frost protection and to reduce shrinkage and expansion of foundation and base layer.

(c) *Plastic soil-cement:* This results in a hardened product but contains at the time of placement, sufficient water to produce a consistency similar to that of a plastering mortar. This allows it to be placed on steep or irregular areas where access of construction equipment is difficult or impossible. This material compare with soil-cement, and like soil-cement is required to satisfy strict strength and durability conditions. It is commonly used for lining of ditches, irrigation canals, and trenches and for the protection of such surfaces against erosion.

4.2.1.2. Application of Soil Cement:

Soil Types

Soil for soil-cement construction can be divided into three groups:

(i) Sandy and gravelly soils with 10-35 percent silt and clay content.

(ii) Sandy soils deficient in fines.

(iii) Silty and clayey soils.

To achieve maximum strength and durability in soil-cement mixtures it is necessary that soils be pulverized and intimately mixed with cement and water. Treatment (curing and compaction) and the amount of cement and water used vary with these soil groups.

Sandy and gravelly soils with 10-35 percent silt and clay content have granular bearing skeleton and sufficient fines to fill partly the void between the aggregates without interfering with the grain-to-grain contact. These soils require the least amount of cement for adequate hardening. Included are water deposited sands and gravel, and almost all-granular materials of which 55% pass the No 4 sieve. If the soil is well graded it may contain up to 65% gravel retained on No 4, and still have sufficient fines for effective binding. This group of soils is easily pulverized and mixed and can be used under a wide range of weather conditions.

Sandy soils that are deficient in fines (e.g. some beach glacial sands, and wind blown sands) require slightly more cement than the first group. There is difficulty in moving construction materials over these soils. In the field the sand has to be kept wet and track type of equipment used. Silty and clayey soils can produce a satisfactory soil-cement mixture. The cement content increases with the amount and water affinity of the clay in the soil. It is difficult to pulverize these soils especially those with high clay content. Weather conditions also affect this group of soils more than the other two groups.

4.2.1.3. Water and Cement requirement

Practical limitations and susceptibility of soil to cement stabilization derive from the water requirement during the compaction and hardening period. The system must contain enough water for hydration of cement and silt-clay constituents and for workability of the soil. In the working of the soil, water acts as an inter-particle lubricant.

Water used in soil-cement should be relatively free of harmful amounts of salt, alkali's acids, or organic matter. Water fit to drink is satisfactory. However seawater has been used satisfactorily when fresh water was unobtainable. In general however since some water is expected to be lost, addition of water slightly in excess of the optimum (about 1 or 2 percent more than the optimum) can be expected to result in a moisture content close to the optimum.

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Table 4.2 Typical Cement Requirements For Various Soil Types. (PCA, 1978)

CLASSIFICATION		NORMAL RANGE OF CEMENT REQUIREMENT	
AASHTO	**UNIFIED**	**% BY VOLUME**	**% BY WEIGHT**
A-1-a	GW, GP, GM, SW, SP, SM.	5-7	3-5
A-1-b	GM, GP, SM, SP	7-9	5-8
A2	GM, GC, SM, SC	7-10	5-9
A3	SP	8-12	7-11
A4	CL, ML	8-12	7-12
A5	ML, MH, CH	8-12	8-13
A6	CL, CH	10-14	9-15
A7	MH, CH	10-14	10-16

A well graded soil containing gravel, coarse sand and fine sand with or without small amount of silt or clay require 5 percent or less amount of cement by weight. The remaining sandy soils generally require 7 percent. Moderately plastic soils require about 10 percent and plastic soils 13 percent. Also additional cement may be required for severe exposure conditions such as slope protection.

4.2.1.4. Shrinkage, Cracking and Curing

As the hydration of cement proceeds, drying and evaporation of the surplus water results in shrinkage of the soil-cement system. Since the base of the system is generally restrained by friction, this result's in build up of tensile stresses. When the level of stress

exceeds the tensile strength of the system, cracking occurs. The severity of the phenomenon increases with increasing water affinity of the soil. This sets a natural limit to the types of soil that can be practically stabilized with Portland cement.

Reducing the plasticity of soil used, thorough pulverization of soil and thorough mixing with cement has been demonstrated to produce good results with respect to control of shrinkage cracking. In inhomogeneous mixtures the shrinkage process is non-uniform and therefore results in separation of strata or formation of fissures. However in some cases a certain amount of strength non-uniformity may be desirable, as early development of cracks can alleviate strain build-up that is likely to lead to large crack widths. Effective load transfer has been shown to occur when the crack openings are less than 0.7-1.0mm. For cohesive soils the required cement content increases with the water affinity of the soil. The density and cement content also influences the amount of shrinkage. Increased cement content and density increases the thermal coefficients of expansion of a soil-cement system, which renders it more susceptible to temperature variations. However increased cement content reduces volume change tendencies and thus shrinkage. It also increases water absorption capacity and reduces the overall permeability of the system.

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4.2.1.5. Mixing and Compaction

Depending on the site and condition of the project, soil stabilization with Portland cement or any other stabilizer may be achieved with means that range from the most primitive hand tools to sophisticated single-pass machines. The basic steps in the construction of a soil-cement base are as indicated in Fig 4.1.

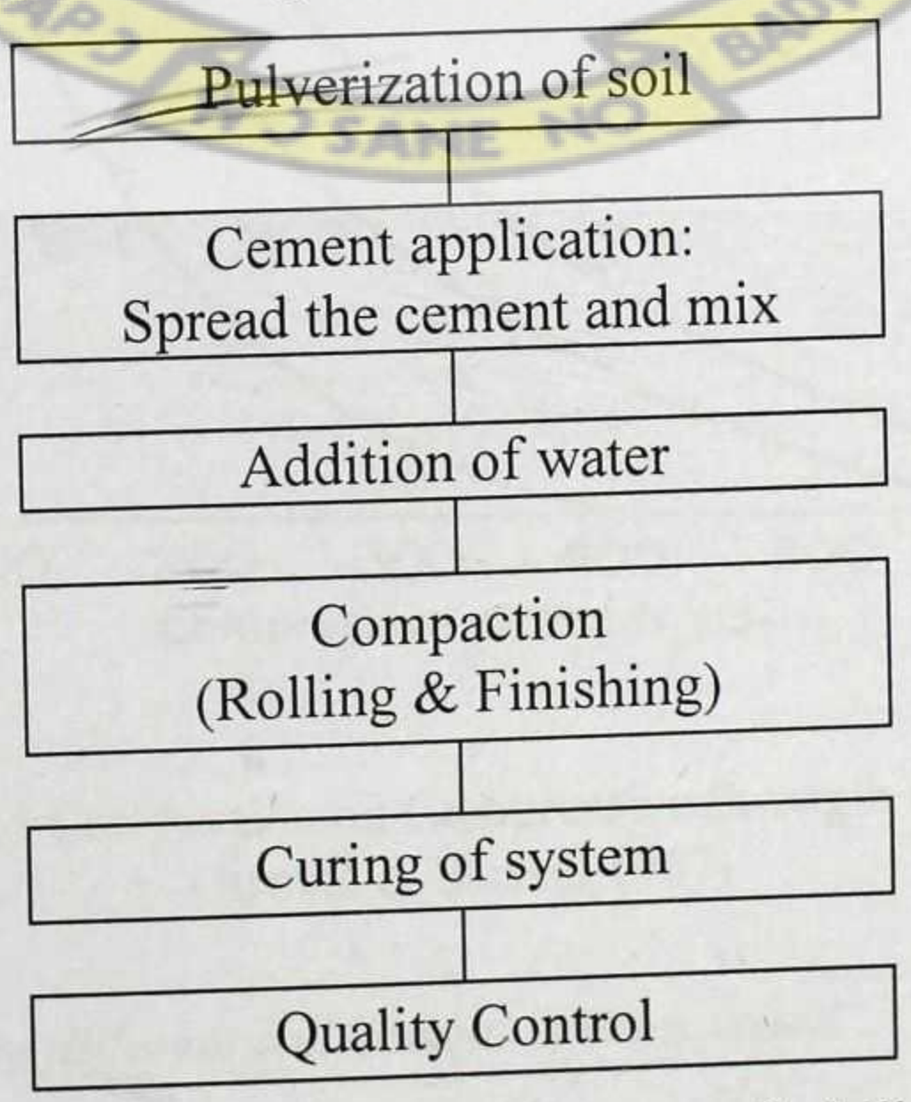

Fig 4.1 The Process of Soil-Cement Stabilization

Pulverization of the soil and thorough mixing are essential factors in achieving satisfactory soil-cement system. Pulverization of the soil should be achieved such that, with the exception of stones and gravel, 100% of the soil must pass through 1" sieve, and 80% must pass through No 4 sieve. However in the case of our local lateritic soils, since the soil itself is mostly pulverized already this stage can however be minimised.

The moisture content should be at or near optimum during pulverization therefore aeration or wetting may be necessary depending on the moisture content of the soil. In-situ mixing equipment may present problems when working to pulverize higher plasticity soils (generally PI $\geq$ 18). In addition, higher-plasticity clays require larger amounts of cement, which may not be economically viable. In general cement stabilization of clays is limited to clays of PI less than 18 and LL not greater than 40 (Winterkorn & Pamukcu, 1990).

It has been demonstrated through laboratory and field studies that a delay of two or more hours in compaction of the soil-cement after mixing results in a reduction in durability, compressive strength, and density of the soil-cement system. Figures 2.2 and 2.3 illustrate the findings of the effect of delayed compaction on compressive strength and density of the soil-cement systems (Arman and Saifan, 1967).

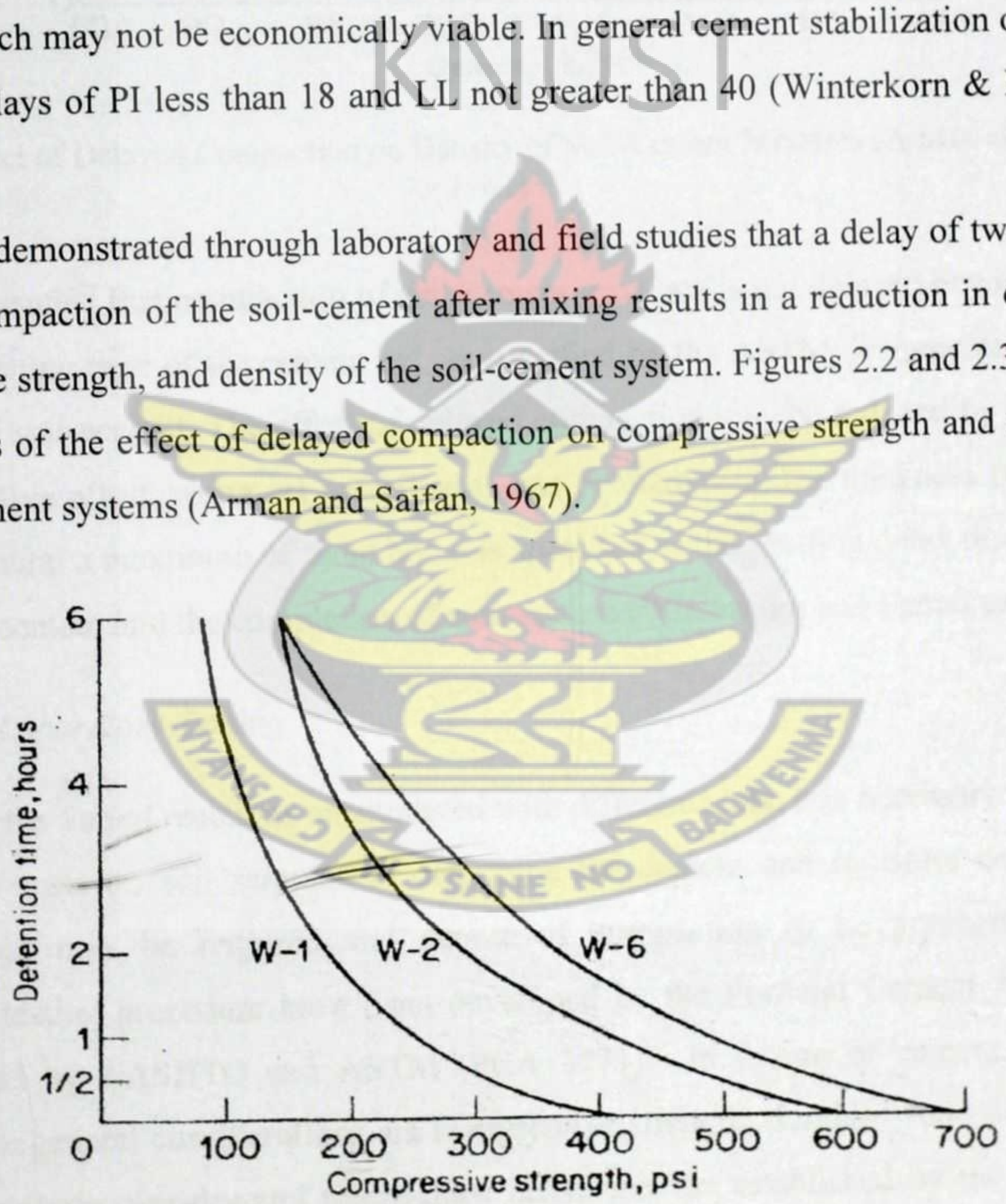

Fig 4.2 Effect of Delayed Compaction on Compressive Strength of Soil-Cement Mixtures (Arman & Saifan, 1967)

Where W-1, W-2 and W-6 are different soil-cement systems tested.

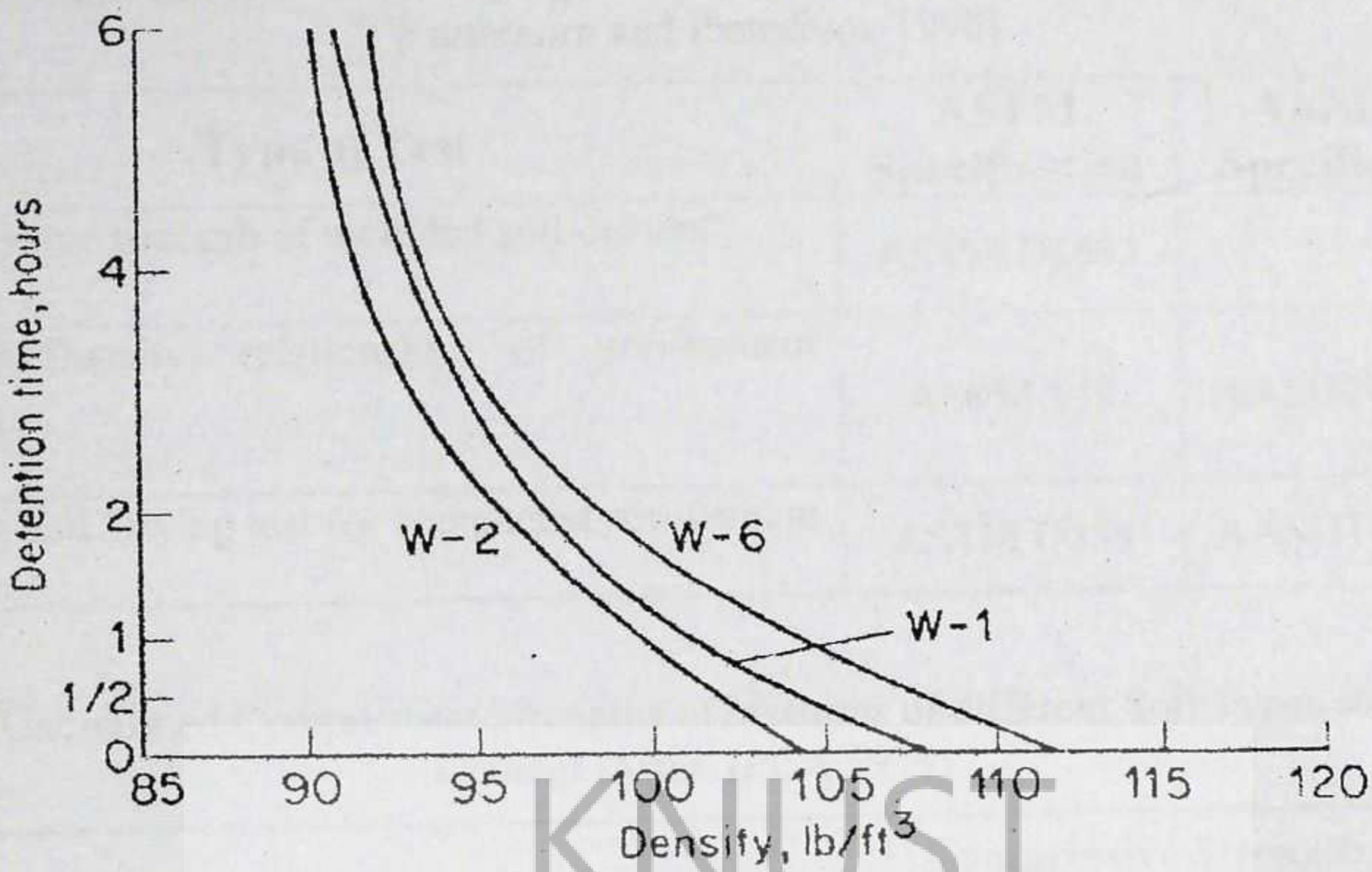

Fig 4.3 Effect of Delayed Compaction on Density of Soil-Cement Mixtures (Arman and Saifan, 1967)

It is recommended that compaction of soil-cement mixtures is not delayed beyond 0.80 of the initial setting time of the cement gel, as specified by the ASTM designation C266 for plant mixed soil-cement. The effect of delayed compaction may be reduced by increasing the compactive effort, using set retarding agents or increasing the thickness of the base layer. In general a maximum of three hours is specified as the limiting delay time between mixing the cement and the completion of compaction (Winterkorn and Pamakcu. 1990).

4.2.1.6. Laboratory Testing

Because of the varied reactions encountered with different soils, it is necessary to conduct preliminary tests on soil samples to determine the cement and moisture content, any additive that may be required and degree of compaction to be attained. Detailed laboratory testing procedure have been developed by the Portland Cement Association and adopted by AASHTO and ASTM (PCA 1971). In design of cement Stabilized Systems the general considerations are compressive strength, durability and density. The durability criteria, wet-dry and freeze-thaw resistance, are established by the PCA. The basic tests to determine the above criteria are

Table 4.3 Various Testing Specification for Soil-Cement Stabilization. (Winterkorn and Pamakwu, 1990)

Type of Test	ASTM Specification	AASHTO Specification
Compressive strength of moulded soil-cement	ASTM D1633	
Moisture-Density relationship of soil-cement mixture	ASTM 558	AASHTO T134
Wetting and Drying test for compacted soil-cement mixtures.	ASTM D559	AASHTO T135

Table 4.4 Unconfined Compressive Strengths of mixtures of different Soil Types stabilized by Cement. After (PCA 1978)

Soil Type	Compressive Strength (MPa)	
	7 days curing	28 days curing
Sandy and Gravelly soils AASHTO group: A-1, A-2, A-3 Unified group: GW, GC, GP, GM, SW, GC, SP, SM	2.1-4.1	2.8-8.3
Silty Soils AASHTO: A-4 and A-5 Unified: ML and CL	1.7-3.5	2.1-6.2
Clayey Soils AASHTO: A-6 and A-7 Unified: MH and CH	1.4-2.8	1.7-4.1

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Dry density of soil-cement material ranges from 2.16Mg/m^3 for well-graded gravel down to 1.36Mg/m^3 for Silty or clayey soils. (Winterkorn and Pamakwu, 1990)

4.2.2. *Lime Stabilization*

Lime stabilization is about the oldest known method of chemical stabilization. It was used by the Romans to construct the Appian Way. Experience has shown that mixtures of most clay soils with quick or hydrated lime and water will form cementatious products in a reasonable period of time, certain soils however may necessitate the addition of Siliceous compounds such as pozzolans or fly-ash to facilitate the reaction.

Three basic chemical reactions take place when pozzolanic clays and lime are mixed in the presence of water.

(i) Cation exchange and flocculations-agglomeration

(ii) Cementation (pozzolanic reaction)

(iii) Carbonation

Cation exchange and flocculations-agglomeration: These reactions results from the replacement of univalent sodium (Na^+) and hydrogen (H^+) ions of soil with divalent (Ca^{2+}) calcium ions of lime. This reaction binds clay, resulting in reduction of clay content and thus plasticity. Cation exchange and flocculation-agglomeration are the initial reactions between soil and lime and cause immediate improvement of soil plasticity, workability and uncurred strength. The reaction takes place within 96 hours. Lime Contents of 3 to 18% by volume are used to reduce plasticity of clays and renders them manageable for Compaction manipulation or stabilization with other chemicals. This is referred to as lime "modification" of soils. Agglomeration reaction of lime and soil is used to destroy collapsible characteristics of some silts.

Cementation or Pozzolanic Reaction: When SiO_2, Fe_2O_3 and Al_2O_3 of soil react with available calcium in lime, they produce very stable calcium silicates and aluminates that act as natural cement (tobermorite gel) similar to Portland cement. Pozzolanic or cementation reactions are time and temperature dependent. These reactions may continue over several years, with temperatures less than 55^0C retarding the reactions and temperatures over 55^0C accelerating them. Soils with plasticity as high as 37 can be stabilized with single application of 9 to 24 percent by volume of hydrated lime or quicklime. Soils with higher plasticity can be stabilised with double application of lime. In this case part of the lime is applied thoroughly and uniformly to obtain cementation and thus stabilization. Cementation is a time dependent slow reaction. Lime can also be used to stabilize some organic soils.

Carbonation: Carbonation is an undesirable reaction that occurs when the lime added to soil does not react with the soil but draws CO_2 from air or soil to form $CaCO_3$. This occurs when the soil does not contain adequate amounts of pozzolanic clay or because excessive amount of lime has been added. $CaCO_3$ is a plastic material and it increases the plasticity of the soil and binds lime so that it cannot react with pozzolanic materials, therefore excessive addition of lime to soil does not produce beneficial results.

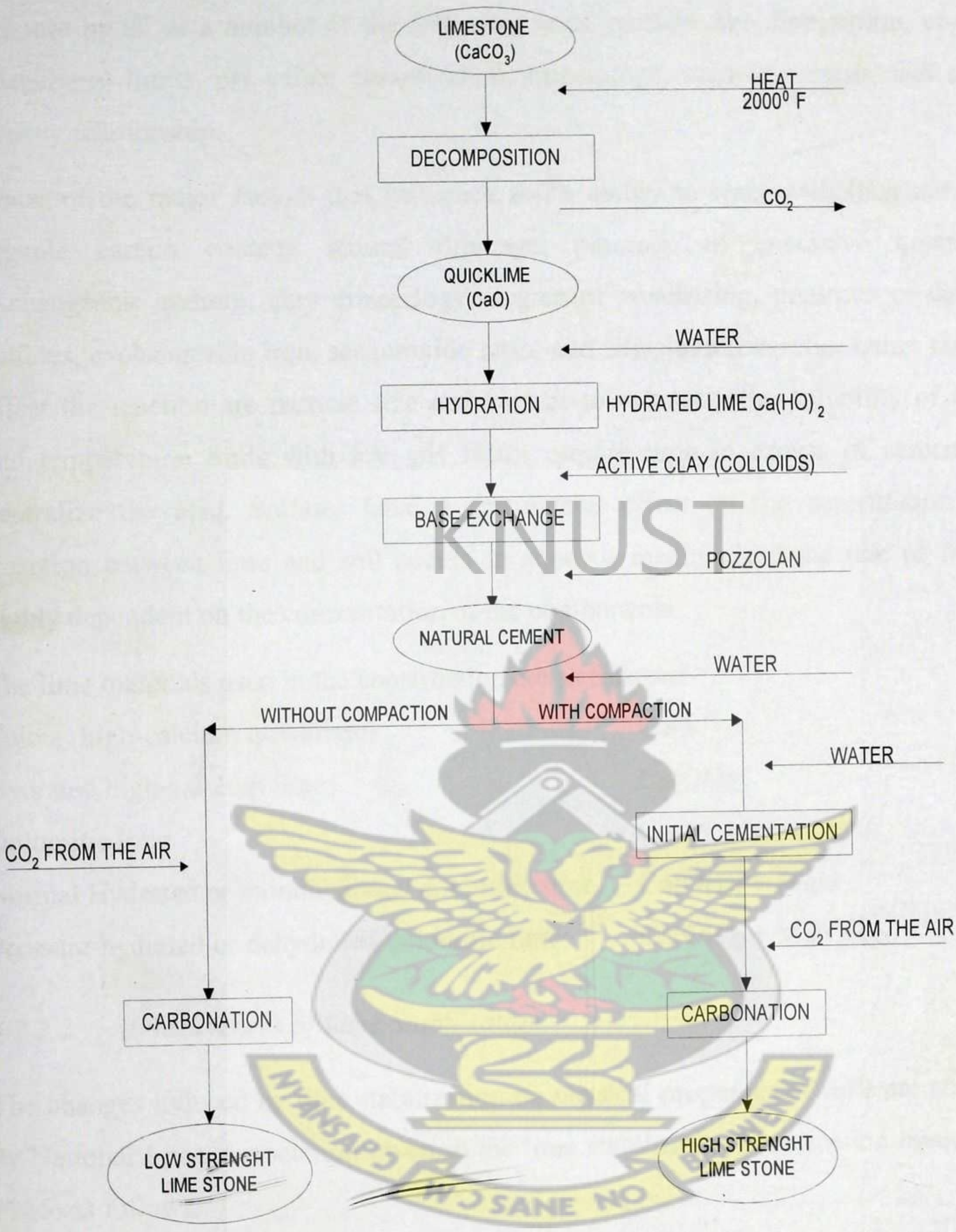

Fig 4.4 Flow diagram of reaction that takes place in the lime-clay-water system (After Arman, 1988)

4.2.2.1. Types and Properties of Lime and Lime-Clay-Water System

The higher the magnesium content of the quick or hydrated lime, the less the water affinity and the heat developed in mixing with water. Depending on the raw material, lime may differ in the properties that affect their reaction with different soils. Therefore it may be critical to evaluate the properties of lime as well as the soil. Some of the laboratory tests for characterization of lime are chemical constituents, pH value, specific gravity, colour and odour. Likewise it is important to characterise the soil intended for the

mixture by all or a number of the following tests, particle size distribution, consistency (Atterberg) limits, pH value, classification, mineralogy, organic content, and moisture-density relationship.

Some of the major factors that influence soil's ability to react with lime are soil pH, organic carbon content, natural drainage, presence of excessive quantities of exchangeable sodium, clay mineralogy, degree of weathering, presence of carbonates, sulfates, exchangeable iron, sesquioxide ratio, and silica-alumina ratio. Other factors that affect the reaction are particle size and surface-to-volume ratio, solubility of $Ca(OH)_2$, and temperature. Soils with low pH factor require lime in excess of cementation to neutralize the acid. Sulfates have a detrimental effect on the cementation process. Reaction between lime and soil occurs in aqueous medium and the rate of reaction is highly dependent on the concentration of the components.

The lime materials used in the construction are as follows:

Calcia (high-calcium quicklime)	CaO
Hydrated high-calcium lime	$Ca(OH)_2$
Dolomitic lime	$CaO + MgO$
Normal Hydrated or monohydrated dolomitic lime	$Ca(OH)_2 + MgO$
Pressure-hydrated or dehydrated dolomitic lime	$Ca(OH)_2 + Mg(OH)_2$

4.2.2.2. Effectiveness of Lime Stabilization

The changes induced by lime stabilization on physical properties of soils are summarised by National Lime Association given in the lime stabilization construction manual (NLA, 1985) as follows.

(1) The plasticity index of the soil drops sharply by a factor of 4 or more in some instances. This is generally due to liquid limit decreasing and plastic limit increasing.

(2) The soil is agglomerated, deereasing the soil binder or clay content (minus No 40 sieve mesh size) substantially.

(3) Lime, by pulling water, accelerates breaking up of clay clods during mixing. As a result of agglomeration and disintegration the soil becomes more friable and can be worked readily.

(4) Lime aids in drying out wet soils quickly, thus speeding up compaction.

(5) The shrinkage and swell characteristics of soil are reduced markedly.

(6) After curing, unconfined compressive strength increases considerable. This increase can be as much as 40 fold.

(7) Load bearing values as measured by various tests (CBR, plate bearing etc) increases substantially.

(8) The tensile or flexural strength as measured by various test (cohesionmeter, split tensile etc) increases markedly. Thus the stabilized layer develops beam strength.

(9) The lime-stabilized layer forms a water-resistant barrier by impeding penetration of gravity water from above and capillary moisture from below. Thus, the layer becomes a firm working table, shedding rainwater readily and remaining stable.

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According to the US experience, treatment with lime is most effective for

(i) Stabilization of gravel material to serve as bases for pavements where 2 to 4% of $Ca(OH)_2$ by weight of soil is used.

(ii) Stabilization of heavy clay soils to serve as bases (5 to 10% by weight of lime) or subbases (1 to 3% by weight of lime) for pavements.

Lime treatment has been found less effective for silty-loam soils. It is not recommended for sandy soils except with addition of clay, fly ash or other pozzolanic constituents. Lime treatment (especially quicklime) may serve as an important construction aid for treatment of access roads to construction sites and of construction sites themselves if they have become impassable owing to excess precipitation.

Soil stabilization by lime should be considered in situations such as

(a) A preparative measure for subsequent stabilization of clay soils with cement or bituminous binders and waterproofing agents.

(b) An additional improving measure in granular soil stabilization by controlling the plasticity of the binder material and increasing it's cementing power.

(c) Improvement of subbase. In addition to increasing the bearing capacity, lime treatment inhibits capillary water movement, thereby preventing water movement beneath the pavement.

(d) Stabilized bases underneath all paved surfaces.

(e) Independent pavement for secondary and tertiary roads. However, surface treatment with bituminous material is recommended in such cases.

Lime-treated soils show improvement in the following properties and characteristics. (TRL, 1987)

(i) Compaction characteristics.

(ii) Plasticity and workability.

(iii) Volume change.

(iv) Strength.

(v) Stress-strain characteristics.

(vi) Fatigue and durability.

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4.2.3. ***Bituminous Stabilization***

4.2.3.1. Bitumen Stabilized Products

Bituminous stabilization refers to those methods in which bituminous material are incorporated into a soil or soil-aggregate mixture to construct base courses and occasionally surface courses capable of carrying traffic loads under normal conditions of moisture and traffic. Cohesive soils usually have satisfactory bearing capacity at low moisture contents, thus the purpose of incorporating bitumen into such soils is to waterproof them as a means of maintaining them at low moisture contents and thus high bearing capacity. In the case of non-cohesive granular soils bitumen serves as a bonding or cementing agent. Depending on the granulometric composition and the physical properties of the soil, there are four types of bitumen-stabilized products as follows (Winterkorn & Pamukcu, 1990).

(1) *Soil bitumen:* This is waterproofed cohesive soil. Best results are obtained with grain sizes such that

(a) Maximum size is not greater than approximately one-third of the compacted thickness or the same as the thickness of a compacted lift if the latter is a fraction of the thickness of the base course;

(b) 50 percent passes No 4 sieve; 35 to 100 percent passes No 40 sieve; 10 to 50 percent passes No 200sieve

(c) The liquid limit does not exceed 40 percent and the plasticity does not exceed18 percent.

Bitumen requirements generally range from 4-7 percent of dry weight of the soil.

(2) *Sand-bitumen:* this is loose sand particle cemented with bitumen. The sand can be beach, river, or wind blown sand. Existing roadway material, substantially free from organic matter, lumps or adherent fills of clay are also included in this category. The sand may require admixture of filler material to meet mechanical stability requirements. The natural sand or sand-filler mixture should normally contain less than 12 % of material passing No 200 sieve fraction. However, in the case of wind-blown or dune sand, up to 25% of passing No 200 fractions may be allowed. This is provided that the portion of sand or sand-filler mixture passing No 40 sieve has a field moisture equivalent less than 20% and linear shrinkage less than 5%. The amount of bituminous binder ranges from 4-10%. Density, strength, and water-resistance test on trial specimen should determine the optimum amount of binder. It should not exceed the pore space of the compacted mineral mix.

(3) *Waterproofed granular stabilization:* a good gradation of soil particles from coarse to fine and having a high potential density, is waterproofed by addition of 1-2% bitumen. The recommended gradation of the soil aggregate materials is shown in Table 4.5 below:

(4) *Oiled earth*: Soil surface consisting of Silty clay material is stabilized by spraying slow or medium-curing bitumen (cutback or emulsion) on it. The coating is made by two or three applications of the oil at a rate of 1 gallon per square yard of soil surface. (Winterkorn, 1934). The main purpose of oiled earth is to produce a water and abrasion resistant surface.

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Table 4.5 Gradations of Soil Aggregate Materials for Bituminous Stabilization (Winterkorn and Pamakcu 1990)

Sieve analysis	***Soil bitumen[a]***	***Sand bitumen***	***Waterproofed granular stabilisation %***		
Passing			A	B	C
1½ inch			100		
1 inch	[b]		80-100	100	
¾ inch			65-85	80-100	100
No 4	>50	100	40-65	50-75	80-100
No 10			25-50	40-60	60-80
No 40	35-100		15-30	20-35	30-50
No 100			10-20	13-23	20-35
No 200	10-50	<12; <25[c,d]	8-12	10-16	13-30
Characteristics of fractions passing No 40 sieve.					
Liquid limit	<40				
PI	<18		<10; <15	<10; <15	<10; <15[e]
Field moisture equivalent		<20[c]			
Linear shrinkage		<5[c]			
Recommended Bitumen requirement	***4-7%***	***4-10%***	***1-2%***		

[a] proper or general
[b] Maximum size not larger than 1/3 of layer thickness; if compacted in several layers, not larger than thickness of one layer
[c] Lower values for wide and higher values for narrow gradation band of sand. If more than 12% passes, restrictions are placed as indicated on field moisture equivalent and linear shrinkage
[d] A certain percentage of 200 or filler material is indirectly required to pass supplementary stability test
[e] Values between 10 and 15 are permitted in certain cases.

4.2.3.2. Bituminous Materials

Bituminous substances consist of almost entirely of carbon and hydrogen with little oxygen, nitrogen and sulphur. They are either solids (asphaltite) or liquids (crude oil). Bitumen is non-aqueous elastic or solid hydrocarbon either naturally occurring (asphaltic) or obtained from destructive distillation (pyrogenic) of organic substances such as tars and pitches.

Asphaltic bituminous materials are obtained from the refining of asphaltic- base crude oils. They are produced within various consistency ranges, measured by standard viscosity and/or penetration tests. These materials are called asphaltic cements (AC). The AC materials are semi-solids and must be heated before use. For working at lower temperatures, they are diluted with solvents (cutbacks) or emulsified in water. For cutback thinned bitumen they enter the soil pores uniformly, coat and cement together the soil particles when the solvent evaporates. Depending on the rate of evaporation of the

solvent, the AC materials are divided into three categories depending on the solvent used to cut it

1. Rapid Curing (RC) – naphtha is used as the solvent
2. Medium Curing (MC) – kerosene is used as the solvent
3. Slow Curing (SC) - heavy diesel oil is the solvent

These are further divided into grades with respect to viscosity (ASTM D2026). The higher the proportion of solvent, the lower the viscosity and the shorter it's curing time. Slow or medium curing cutbacks with diesel fuel or kerosene solvents and 90-100 or 180-200 penetration grade bitumen are mainly used.

Bitumen emulsion is bitumen that has been dissolved in a water medium with the help of emulsifiers. The advantage of bitumen emulsion is that it can be applied under cold temperatures so handling is easy. In the case of emulsions the time required for their setting or breaking determines the grade. They are divided into three groups with the rapid setting being the one that sets fastest after application. Depending on the manufacturer's constituent formula for the various products, the setting time for the three categories are determined.

1. Rapid setting
2. Medium setting
3. Slow setting

Slow or medium setting grades are used, since the distribution and effectiveness of the bitumen is dependent on the stage at which the emulsion breaks. If the emulsion breaks too soon, there will be inadequate penetration, hence rapid breaking bitumen emulsions are not normally used for stabilization of soils as they break on contact with the soil, hence will not allow for the mixing stage to be executed properly. For this research slow setting bitumen emulsion is most suitable since it will allow sufficient time for the bitumen emulsion to be mixed with the sample since the mixing is done by hand and requires sufficient time to enable a uniform mix before the actual test is carried out.

4.2.3.3. Classification of Soil-Bitumen Stabilization Types

A system of scientifically discerning possible types of a soil-bitumen is given below. Most of these systems are currently being used in practice.

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(1) Systems with granular skeleton as main mechanical strength factors, either open (without the No 200 or 75μm sieve size material) or impervious (with the No 200 material).

(a) Bearing skeleton: Coarse aggregate with or without sand

(i) Graded coarse and fine aggregate, the pores of which are filled with silt-clay. Example waterproofed granular soils.

(ii) Bitumen-cemented river and bank gravel with or without small proportions of silt-clay-bitumen. Example of base construction in the former West Germany or open type American road mix.

(iii) Bitumen-cemented coarse aggregate (gravel or crushed stone) of narrow size range. Example: construction of layered drains for roadbeds.

(b) Bearing skeleton: Sand.

(i) Sand-bitumen with pores-filling silt-clay or similar -No. 200 material; utilized in Florida and California.

(ii) Bitumen (or bituminous resin)-cemented sand without pore filling fines. Example military beach stabilization.

(2) Systems without gravel or sand skeleton: waterproofed silt-clay materials.

(a) Stabilization of natural soils with little or no cohesion i.e. predominantly silty and has at most 20% of clay. An example is loess soil stabilization, which renders the material resistant to swelling and shrinkage even after many cycles of wet and dry cycles.

(b) Stabilization of soils with predominantly clay fractions, which occurs in secondary aggregations or crumbs even after loosening of the lumps in the soil and mixing with the bitumen. Examples of such cases are heavy clay soils. It is recommended that such soils be pretreated with 2% or more of hydrated lime.

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4.2.3.4. The Mechanical and Physiochemical aspects of Bituminous Soil Stabilization

The quality of a soil bitumen system depends upon the quantities and characteristics of its components. These are basically *soil*, *bitumen*, and *water*. The objective is to introduce a sufficient amount of bituminous material to form a thin coating over the surfaces of particles without reducing the intergranular friction and yet allow for adhesion and thus cementation between the particles. In systems without granular skeleton, the amount of bitumen required for satisfactory waterproofing will in general increase with increasing clay and colloidal content. However soils with similar clay contents may require different

amounts of bitumen depending on the water affinity of the soil fines. The optimum amounts of bitumen and water should be determined by laboratory testing. Mixing on the wet side of the optimum though more troublesome, produces better soil-bitumen systems after compaction and drying than mixing on the dry side.

At the time of compaction, soil-bituminous mixtures containing appreciable amounts of silt-clay must have sufficient moisture content to satisfy their water affinity (Winterkorn, 1976). This value is usually in the vicinity of the optimum moisture content for proctor compaction. The water plus the liquid bitumen admixture together makeup the moisture content during compaction. If the system becomes too sticky to be mixed properly with available equipment, then pretreatment of soil with quicklime [CaO] or hydrated lime [$Ca(OH)_2$] is recommended. Clays in overly wet state should also undergo similar pretreatment prior for acidic soil (pH<6). Soils with high pH and containing high levels of dissolved salt are often not suitable for bituminous stabilization. As a result of wide ranging investigation of the physicochemical factors of importance in bituminous stabilization of silt-clay soils, the following conclusions were drawn (Winterkorn and Eckert, 1940).

(1) *Influence of type of clay*: the larger the ratio of $SiO_2/(Al_2O_3 + Fe_2O_3)$ in the clay minerals, the greater the bitumen requirement for satisfactory stabilization.

(2) *Influence of exchange of cations on clays*:

a) Bituminous requirements increase with increasing base exchange capacity of the clay and soil.

b) The higher the valence of the exchange cations on the clay (Na^+, Ca^{2+}, Al^{3+}, and others), the higher the efficiency of bituminous stabilization.

c) Amongst the monovalent cations, Na^+ exerts a detrimental effect consistently, while K^+ may be beneficial in cases of illitic clays. It should be noted here that essentially the same effects of clay mineral composition and type of predominant exchange cations hold true in resinous soil stabilization (Winterkorn and Reich, 1962).

(3) *Influence of soil organic matter:* The effect of soil organic constituents depends on the condition under which they were formed and accumulated. Acid organic matter from leached forest and river-bottom spoils appear to be detrimental, while neutral and basic organic matter from arid and semiarid regions does not seem to have a detrimental effect, other than that produced at times by the presence of monovalent cations.

(4) *Influence of bitumen type and composition:* Amongst the material tested by, the water proofing effectiveness on silt-clay materials decreased in the following order: normal (high temperature) coal tars > cutback from cracked asphalt > cutbacks from noncracked asphalt > low-temperature tars. Separating the asphaltic materials into their group components-asphaltenes, asphaltic resins, and oils- showed a strong correlation of increase in stabilizing power with increasing content in asphaltenes.

Increasing bitumen content causes the strength to increase up to a certain percentage of bitumen added and decreases from there on even falling below the strength of the unstabilized soil. The optimum moisture content increases with increasing bitumen content. For sandy clays the maximum strength is often observed at 4% of bitumen addition. Strength generally increases with extended mixing time since this allows the total surface of the particle to be coated with bitumen. The maximum temperature for field use should be 49°C (Winterkorn and Pamakcu, 1990).

Fig 4.5 shows that increasing the amount of cutback bitumen causes the MDD obtained in the BS compaction to be progressively reduced presumably owing to the greater viscosity of the fluid films surrounding the particles while a corresponding increase in OMC is observed.

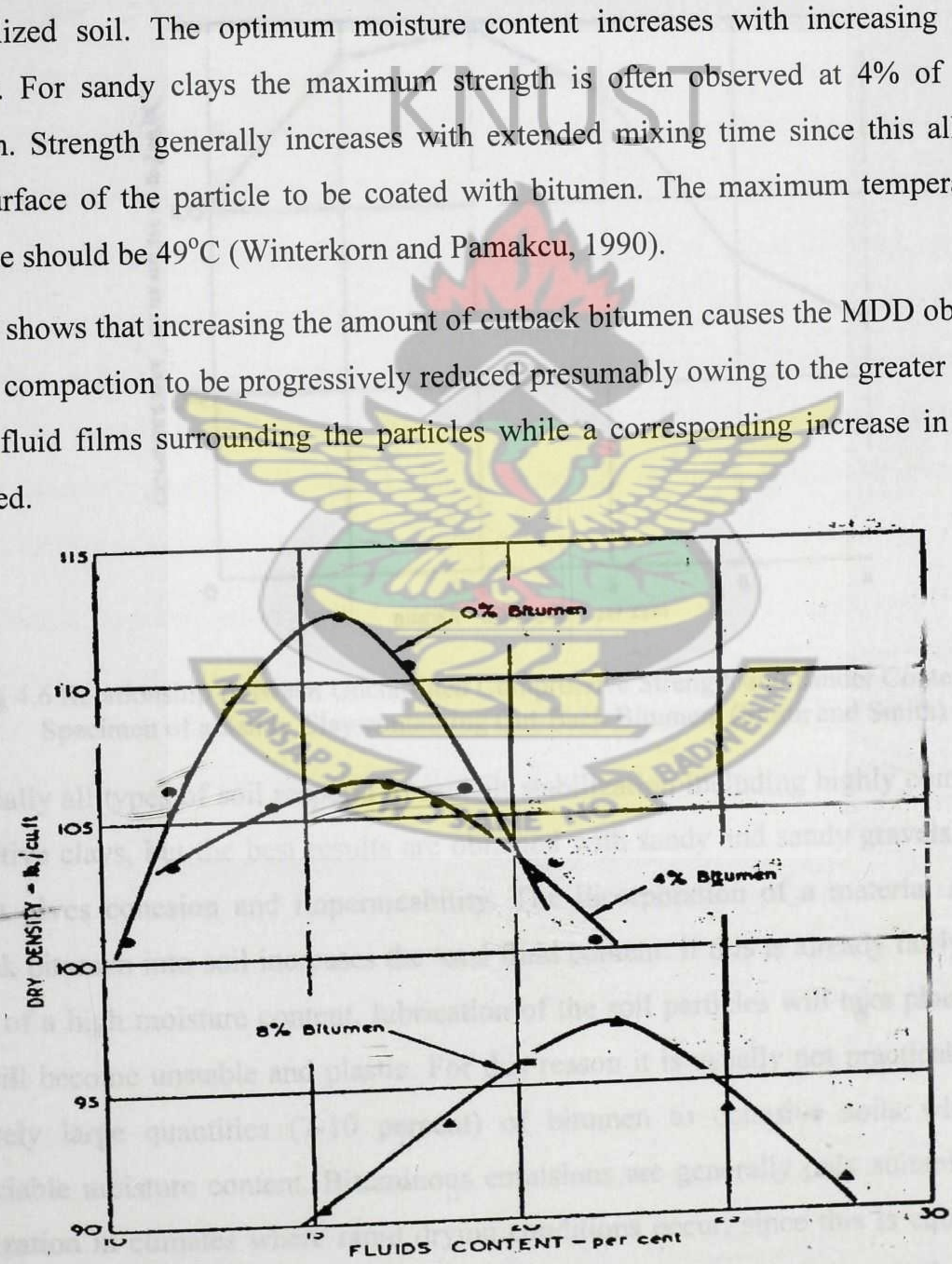

Fig 4.5 Shows the Result of a BS Compaction Test on a Sandy Clay Containing Various Proportions of Cut-Back Bitumen (Smith and Smith)

Fig 4.6 shows the effect of different proportions of the same bitumen on the unconfined compressive strength of specimen of the same soil-bitumen mixture made up at the maximum dry densities obtained with the BS compaction test. The strength of the specimen rises slightly until a binder content of 4 percent is reached after which it decreases progressively until it finally reaches a value lower than that of the untreated soil. This suggests that the binder effect of the bitumen serves initially to increase the strength but beyond a certain point the decrease in dry density due to the resistance of the mixture to compaction offsets the increase in cohesion.

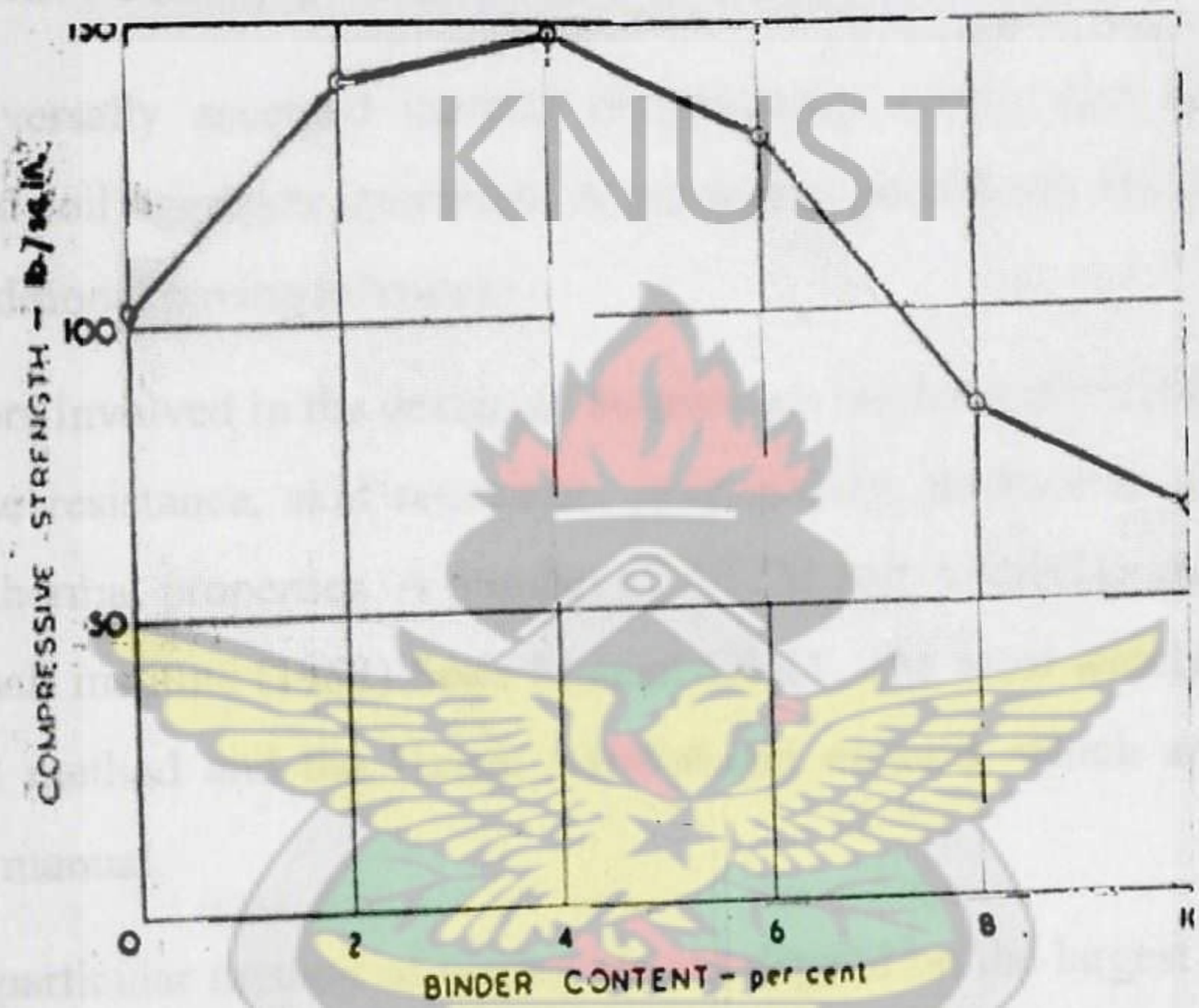

Fig 4.6 Relationship Between Unconfined Compressive Strength and Binder Content for Specimen of a Sandy Clay containing Cut-Back Bitumen. (Smith and Smith)

Practically all types of soil respond to asphalt stabilization including highly compressible and active clays, but the best results are obtained with sandy and sandy gravels to which asphalt gives cohesion and impermeability. The incorporation of a material such as a cutback bitumen into soil increases the total fluid content: if this is already fairly large by virtue of a high moisture content, lubrication of the soil particles will take place and the soil will become unstable and plastic. For this reason it is usually not practicable to add relatively large quantities (7-10 percent) of bitumen to cohesive soils which have appreciable moisture content. Bituminous 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 dry conditions such as Ghana the water in the emulsion may be an advantage since it helps to provide part of the

optimum fluids content for compaction, thereby reducing the amount of water necessary of the purpose.

The properties of bituminous stabilized soil then are-

1. Reduced maximum compacted density as binder content increase
2. A max strength or stability at a optimum bitumen content. The strength increases as the more volatile components evaporates, but decrease at elevated temperatures.
3. Reduced susceptibility to water as bitumen content increases.

4.2.3.5. Laboratory Testing of Bitumen Stabilized Soils

There is no universally accepted method of preparing, curing and testing bitumen stabilized soil and soil aggregate specimen. A number of procedures have however been developed for traditional paving mixtures.

The general factors involved in the design of bituminous mixtures are stability, durability, flexibility, fatigue resistance, skid resistance, permeability, fracture or tensile strength, workability and thermal properties. A number of ASTM and AASHTO specifications are listed in the asphalt institute (1982) Soils Manual ES-11. The most widely used methods are the Marshall method and the Hveen stabilometer method, which are listed in the Asphalt institute manual.

The choice of a particular method of testing should depend on the largest particle size in the mixture, in addition to convenience and dependability. A direct connection between test result and pavement design as in the CBR, triaxial compression, and Hveen stabilometer test is a very desirable feature. All test for bitumen stabilization as well as other pertinent types of stabilization have the following features in common.

1. Determining the particle size distribution and the Atterberg limits.
2. Determining the maximum density - moisture content relation of the whole sample for a selected standardized compaction method.
3. Selecting from previous experience or theory the type and indicated percentage of bitumen required, and determining the density-moisture relation for the soil-water-bitumen mixture. It is a beneficial practice to record the ease or difficulty of mixing and the homogeneity of the resultant mixture during this test.
4. Designing mix and making sets of test of specimen at three different bitumen contents and optimum water contents found in (3) above.

5. Curing the specimen in accordance with the conditions that pertain in the field (rate of water loss) and subjecting them to the temp and moisture conditions simulating severe cases of local conditions.
6. Mechanical testing of exposed specimen by a selected method.

4.2.4. *Effect of Genetic Characteristics on Chemical Stabilization*

The importance of pedological classification in stabilization of Ghanaian soils has been established. The classification system is based on the fact that soils formed on the same parent materials under similar climatic and drainage conditions and supporting similar vegetation will have similar physical and chemical properties. Soils that have all these factors in common are grouped together into soil series; soils in the same group have similar profile characteristics. Soil series with similar profiles but formed on different parent materials are grouped together into Major Soil Groups. The importance of the use of soil series in soil stabilization is that, soils of the same series, horizon and texture require the same amount of stabilizer for adequate stabilization. Once the stabilizer requirements of a given soil series has been determined through laboratory tests, only the identification of the particular soil series and horizon and minimum exploratory check are required (Gidigasu, 1980). Thus, the need for conducting complete soil-stabilizer testing program can be sharply reduced or eliminated in those areas where detailed soil survey data are available. The greatest need therefore is to undertake full-scale experiments to determine the minimum chemical stabilizer with typical soil series within an area having regard for the various soil horizons and then to use this information to stabilize similar genetic soil types encountered elsewhere.

During drying the degree of remoulding (mixing) and drying should be expected to influence the amount of strength gain. Pre-treatment methods also affect the Atterberg limits of cement stabilized lateritic gravels. It has been established that most tropical soils are amenable to cement and lime stabilization and considerable strength gain has been recorded for average materials. However, no studies are available on the effect of pretest preparations and testing procedures on the strength gain or loss for most tropical soils. An example is the effect of lapse of time between mixing and compaction on strength reduction of typical lateritic gravel from Ghana. For example, studies have shown that the degree of drying mixing and remoulding considerably affect the Atterberg limits and strength gain of some lime and cement stabilised laterite soil. In the field, difficulties in

obtaining complete pulverization of the soil and the admixture may be encountered, due mainly to the inefficiency of some mixing plants. Under these conditions original structural arrangement of soil particles may be partly retained in large lumps of soils. Successful stabilization of soils under field conditions depends upon the ability of the additives to penetrate the soils system and to modify the constituents.

Data available from the BRRI reports and in other literature shows that lime and cement are the most used chemical stabilisers for modifying and improving the geotechnical properties of lateritic soils. For example, lime is a good modifier for cutting down the plasticity and swell of laterite soils (Bhatia, 1968). The strength of very poor sub-base laterite soils may be considerably improved by the addition of between 3 and 5% cement. It may be possible that where cement, or lime alone may not give required compressive strength a combination of the two in trial proportions may result in achieving considerable strengths gains BRRI, (1980).

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4.3. CHEMICAL STABILIZATION- LOCAL EXPERIENCE

The effects of stabilizing using cement and lime on the strength of local laterite and other tropical soils have been extensively reported. (T.R.R.L., 1958; Bhatia, 1968; Gidigasu, 1980). With most tropical gravelly soils cement normally produces greater early increase in strength than comparable proportion of lime and it appears further increase in the lime content may not change the situation. With most of the Ghanaian lateritic gravel soils the incorporation of 3 to 5% of either cement or lime is sufficient to provide adequate strength, and the amount of stabilizer used in practice appears to be of this order, for satisfactory distribution in mixing in the field using appropriate mixing equipment.

It has been shown (USAID, 1971) that lateritic soils containing high proportions of alumina show decrease in strength with time when stabilized with cement or lime, probably because of reactions between cement and alumina in the soil and the formation of a compound with poor cementing properties. It has also been reported that there is considerable initial strength gain for laterite soils in relation to some temperate zone soils probably due to the reaction of lime with the iron and aluminium oxides. The degree of mixing and remoulding considerably affect the strength gain of some lime and cement stabilized soils. Since some lateritic soils are known to be structure sensitive, the degree of mixing and remoulding considerably affects the strength when chemically stabilized. Failure of cement stabilized soils is common. (Gidigasu and Mate-Korley, 1980)

Effectiveness of chemical stabilization depends partly on the interaction between soil particles and the stabilizing agent and partly on the properties of the agent. Water affinity and water retention capacity, ion exchange capacity, clay content, grain-size distribution and porosity of the soil are some of the factors that affect the interactions between soil particles and the admixture.

4.3.1. *Cement and Lime Stabilization- local experience*

A major research study was carried out on the subject of cement and lime stabilization of Ghanaian lateritic soils by the Building and Road Research Institute (BRRI), Kumasi, Ghana in collaboration with the LYON Associates Incorporated, Baltimore, Maryland, USA, 1971. Three soils each from the different classification groups of soils Ferrallitic, Ferruginous and Ferrisols in Ghana with the following properties

Liquid Limit, 23-62

Plastic Limit, 12-32

Plastic Index, 11-27

Specific Gravity, 2.78-2.92

were selected and studied, Portland cement produced locally was used for all the tests. The compaction was in accordance with ASTM D1557-70 Method B. The following conclusions were drawn

(a) The PI of all the soils showed a steady decrease with the addition of cement. A greater reduction occurs in the plasticity index with the addition of lime than with cement. There is very little difference in liquid limit between 7 days and 28 days curing periods for cement stabilized Soils. Almost all the lateritic soils tested experienced a decrease in liquid limit with the addition of lime however a few show an increase in liquid limit, but in all cases the plasticity index decreased since there is a greater increase in the plastic limit. The Ferruginous and Ferrallitic soils from sandy parent materials showed a great reduction in the plasticity index at a small percentage of lime. With further increase in the lime content the decrease in the plasticity index was slight.

(b) The CBR values for cement treated soil were much higher than for soil treated with comparative amount of lime. In most cases the highest CBR values of lime treated soils was less than the 28 days CBR for 2% cement content. Most of the cement-treated soils in the present study developed high CBR values with low percentages of

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cement. The values generally increased linearly with increase of cement content, although some soils exhibited smaller increases at 4 to 6 percent. From the CBR test results most lateritic soils can be successfully stabilized as base course material with 3 to 4 percent cement. Peaks in CBR values occurred at about 4 to 6 percent lime by weight. The CBR value for most of the lime treated soils increased linearly with lime contents at low lime contents, but there was a tendency toward a smaller increase or even a slight decrease in strength with higher lime contents.

(c) Cement-treated soils show higher unconfined compressive strengths as compared to lime treated-soils. The Ferruginous gravel when stabilized with cement showed large gains in strength at small percentages of cement, higher than the materials in any other soil groups. It is observed that with small variations in the OMC there could be a considerable change in the compressive strength.

(d) The assessment of the wet-dry durability, properties of lime-soil mixtures by means of laboratory test is difficult. Results from standard wet-dry test using brushed samples when compared to criteria developed for soil-cement mixtures, indicate that lime-soil mixtures have little resistance to weathering.

(e) It has been recommended that cement be used to stabilize those soils having a plasticity index of 15 or less and not more than 15% minus 0.074mm. Since the reactions proceeds slowly, the final mixing can be delayed for considerable time. Lime should be used where the plasticity index is greater than 15 and the minus 0.074mm proportion exceeds 15%. (USAID, 1971)

A decrease in compressive strength at higher lime contents as well as complete failures with high percentages of lime has been reported for lateritic soils by Winterkorn and Chandrasek han au (1951). Hayter and Cairns also reported little or no further gain in strength beyond a certain point, usually in the range of 4 -7 percent. There is also considerable difference between the strength developments for the lime stabilized soils from the laterite horizon and those from the mottled and pallid zones but the difference are less pronounced for the cement-stabilized soils.

The results discussed above are all based on laboratory results where conditions are easier to manipulate. In the field however it is very hard and expensive to dry and breakdown a plastic soil mechanically even with specialized machines. In a high rainfall area it is virtually impossible.

4.3.1.1. Cement Stabilization of Ghanaian Micaceous Soils and Decomposed Phyllites

The moisture-density relation for a typical Kumasi micaceous soil stabilized with various percentages of cement was investigated and the following results were established (Gidigasu and Mate-Korley, 1980). Insignificant increase in the maximum dry density with corresponding slight decrease in the optimum moisture content was generally noted with increasing cement content. Effect of cement stabilization in reducing the amount of swell was also established. At around 8% cement content the swell could drop from about 2% for the untreated soil to 0.5% for the stabilized soil. The bearing strength of some micaceous soils could be increased by 4 to 5 times with the addition of about 4% cement and by 2 to 4 times with the addition of the same amount of lime. Greyish and greenish Cape Coast micaceous soils when stabilized with 4% cement or lime might provide satisfactory sub-bases and the yellowish soil might even provide a base material for a lightly trafficked road. (Gidigasu, 1987)

It is also reported that CBR of typical Cape Coast micaceous soils increased 4 to 5 times with the addition of 4% cement and 2 to 4 times with the addition of 4% lime. This gain in strength was largely maintained after a total immersion in water for 7 days. It was concluded that the reddish, yellowish and greyish green varieties when stabilized with 4% cement might provide satisfactory sub-bases and the yellow soil stabilized with the same amount of cement might even provide a base material for a light trafficked road pavement.

Results of analysis of the laboratory and field determined geotechnical properties of the soil revealed that most Ghanaian lateritic gravels do not meet base material specifications; though in terms of Aggregate Impact Values (which were found to be generally below 30%): the coarse, particle satisfy surfacing and base material specifications. Because in most areas it is not possible to obtain alternative good quality gravels, the possibilities of improving the apparently sub-standard lateritic gravels in terms of CBR values was undertaken through cement stabilization. The conclusion available from these studies is that most Ghanaian gravels may be stabilized effectively with between 3-7% cement to meet the required specification for road construction. The magnitude of swell of the stabilized decomposed phyllites was found to be a function of the type of stabilizer and the horizon from which the material was sampled. For example lime-stabilized soils were from the pallid zone exhibited greater swells than soils from the mottled and laterite horizons.

4.3.1.2. Stabilization of Ghanaian Black Cotton Clays

Geotechnical studies on typical black cotton soils revealed clay size content of 50 to 60%, and cation exchange capacity of 50 to 60% mg/100gm. The liquid limit varies between 60 and 100% the plasticity index between 30 and 60% and the linear shrinkage between 13 and 16%. By the AASHO classification system they fall in A-7-5 or A-7-6 with group index ranging from 10 to 20. Though high CBR values of about 42% was obtain for the material compacted to modified AASHTO Specification, four days soaking reduced this value to about 2%. The use of high compactive effort appears to destroy the structure of the clay leading to considerable loss of strength. When treated with standard Portland cement, imported hydrated lime and locally produced lime, the tendency for the liquid limit to decrease was greatest for imported lime with the local lime being the least. All three stabilizers reduce the linear shrinkage.

Lime contents have given fairly high soaked CBR values of between 60% and 85% for the clay subjected to the modified AASHTO compaction. It was noted however that an increased in density might not necessarily be beneficial in terms of increase in the soaked CBR. This means that the moulding conditions have to be judiciously selected to achieve the desired optimum strength of the stabilized clay.

4.3.2. ***Bituminous stabilization-Local Experience***

As stated earlier there isn't much information on bituminous stabilization of lateritic soils in Ghana, even though a general statement has been made to the effect that almost all soils can be successfully stabilized and waterproofed with bituminous binders. Also soils with appreciable content of fines require special studies however, and as with all types stabilization, the type and amount of binders have to be established by means of laboratory tests involving actual project soils. (USAID, 1971)

4.3.3. ***Other Stabilization Methods-Local Experience***

4.3.3.1. Thermal of Black Cotton Clay

Results of studies have been reported on the thermal treatment of black cotton clays for engineering purposes. For example, it has been employed to stop slips and plastic f low of fat clays. Thermal treatment was also used to eliminate plasticity of black clays, as well as for producing low grade aggregates for low cost pavement. The principle underlying thermal stabilization of fat clays is that changes of the clay minerals at temperatures

exceeding 400 C produce modified soil texture and stability which do not greatly diminish even under adverse moisture condition. The linear shrinkage of the Dawhenya black clay was also reduced considerably through heat treatment. Note that generally thermal treatment of black clays has positive effect of reducing and sometimes completely eliminating the plasticity and shrinkage.

4.3.4. *Cost Comparison of the Common Stabilization Methods in Ghana*

4.3.4.1. Availability and Cost of Cement and Lime in Ghana

Ghacem Limited produces cement locally in Ghana. The company has two factories one in Tema and the other in Takoradi. Both produce Ordinary Portland Cement. The demand for cement is very high in Ghana and sometimes results in acute shortage leading to the importation of Cement from other countries. Prices are not constant as one travels across the country. Prices tend to increase from the southern parts to the northern parts of the country, i.e. as one move from away from the production areas. Prices change year after year and this has considerable effect on budgeting over a long period of time. In June 2000 a bag of 50kg cement was selling at twenty five thousand Cedis (¢25,000) while 1kg of lime is sold at one thousand Cedis (¢1,000).

4.3.4.2. Availability and Cost of Bituminous Product in Ghana

Bituminous products in Ghana are supplied by Shell Ghana Limited, Mobil oil Ghana Limited, Ghana Oil Company Limited, Unipetrol Ghana Limited, Elf Ghana limited, Total Ghana Limited, Ghana Emulsion Company Limited. Ghana Emulsion and Shell are the two companies that produce bitumen emulsion in Ghana. Ghana Emulsion produces the cationic type whilst Shell produces the anionic type under a trade name Colas. Ghana Emulsion has been operating since 1997 and the prices of the bitumen emulsion has been considerable stable since they started operation.

Table 4.6 Price of Bitumen Emulsion by Ghana Emulsion

PRODUCT	PRICE PER LITER (¢	
	1997	1999
GEL 50S PRIMER	782	770
GEL 60R TACKCOAT	736	800
GEL 65M COLD MIX	736	825
GEL 70R SURFACE DRESSING	736	845

Table 4.7 Cost Comparisons for Using the Various Stabilizers, June 2000

Stabilizer	% Required to effectively Stabilize Lateritic Soils	Cost of Stabilizer per kg (cedis)	Quantity required to Stabilize 100Kg	Total Cost for Effective Stabilization
Cement	4.5	440	4.5	1980
Lime	5	1000	5	5000
Bitumen Emulsion	2	770	2	1540

From the above table it can be concluded that with all things being equal, it will be more economical to use bitumen emulsion for stabilizing a road material that is to be left as the running surface.

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CHAPTER FIVE

5 LABORATORY TESTING

The laboratory work for this study consisted of two main components

1. The laboratory study of the pavement material, where selected engineering properties of the natural air-dried soil sample and the bitumen emulsion treated sample were investigated.
2. A laboratory model pavement study in which a model road pavement made of lateritic gravel material is exposed to simulated rainfall in the H313 hydrological chamber to evaluate the effect of bitumen emulsion treatment on erosion of gravel road pavement.

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5.1. PAVEMENT MATERIAL TESTING

The selected engineering properties that were investigated on the natural sample and also the sample treated with various percentages of bitumen emulsion include

1. Index properties; Grading and Atterberg limits
2. Compaction characteristics
3. The strength as measured by California Bearing Ratio (CBR)
4. Permeability and
5. Erodibility Test

The test methodology used for the laboratory investigations on the samples are described briefly below in the test procedures. The sample collection procedure were in accordance with BS 1924: 1975 (Stabilized Soils), which deals with the methods for testing of stabilised soils, sample collection, sample preparation etc. The procedure followed for the material testing was in accordance with BS 1377: 1990 with some adaptations as described in the various testing procedures. The Bitumen Emulsion used for the experiment was stored in 20litre containers and was stirred with a wooden rod each time it had to be used. The **GEL 50S PRIMER** (slow curing) bitumen emulsion was used for all the test experiments.

5.1.1. *Sample Acquisition and Preparation*

Samples were taken from a total of 5 borrow pits. At some of the gravel pits the material were already stockpiled and samples were taken in 50kg bags to the laboratory and were air-dried under room temperature. When the samples were sufficiently dried they were stored in wooden boxes and kept from excessive exposure to moisture. Varying amounts of the samples were taken from these storage boxes for the various test performed. In addition to the normal test listed above for sample K2 the effect of curing on the grading and Atterberg limits was also investigated.

The effect of curing on the engineering properties was investigated by initially mixing the sample with the various percentages of bitumen emulsion and leaving it to cure for four days before commencing the various testing procedures.

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5.1.2. *Index Properties*

5.1.2.1. Particle Size Distribution

The wet sieve analysis was used for the test samples, and the procedure can be summarised as follows:

(a) Natural Sample

(i) 1000g of the sample was used for each wet sieve analysis.

(ii) The sample was soaked overnight before washing. The deflocculating agent used was Sodium Hexametaphosphate

(iii) The sample after washing was oven dried at a temperature of 105^0C overnight before sieving.

(iv) The hydrometer test was performed to provide information on the distribution of the fine particles smaller than 75μm for the sample.

(b) Bitumen Emulsion Treated Sample

(i) 1500g of the sample was weighed and 15g of bitumen emulsion (1% by weight of the sample) was added and the two mixed thoroughly and left to air dry for 6 hours.

(ii) 1000g of the treated sample was weighed and soaked overnight before washing. The hydrometer test was not performed for the bitumen treated samples. No deflocculating agent was used in the case of the bitumen treated samples.

(iii) The steps (i) and (ii) above are repeated using 2%, 3%, 4%, 6% and 8% of the bitumen emulsion by weight of the sample weighed and mixing thoroughly before air-dying.

The hydrometer test was not performed on the bitumen treated samples because of the difficulty in loosening the material in the mortar using the pistil.

5.1.2.2. Liquid Limit

For the entire test performed the Casagrande apparatus was used. However, for sample K2, the cone penetrometer method for determining liquid limit was used. The testing procedure is described briefly below:

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(a) *Casagrande test method*

Natural Sample

(i) A portion of the soil sample was taken and loosened in the mortar using the pistil

(ii) The sample was sieved through BS sieve No. 36 i.e. 0.425mm

(iii) About 400g was taken and mixed with distilled water till it was uniformly soaked and plastic.

(iv) The test was performed using the Casagrande apparatus and the LL determined

Bitumen Emulsion Treated Sample

(i) 1000g of the sample was taken and mixed thoroughly with (10g) bitumen emulsion (i.e. 1% by weight of the sample weighed)

(ii) The sample was left to air dry overnight and then the steps (i) to (iv) as in the case of the natural sample was repeated

(iii) The steps (i) and (ii) above were repeated but using 2%, 3%, 4%, 6% and 8% bitumen emulsion by weight of the sample weighed before mixing thoroughly and air-drying

(b) *Cone penetrometer method*

This test was performed only on sample K2 in addition to the Casagrande method in order to provide a comparison between the results of the liquid limit obtained for the two methods.

(i) Steps (a)(i) to (a)(iii) in the Casagrande method for natural sample is repeated

(ii) The LL was determine using the Cone penetrometer apparatus

(iii) The bitumen emulsion sample preparation was as in the case of the Casagrande apparatus

(iv) The moisture content corresponding to 20mm penetration was taken as the liquid limit.

5.1.2.3. Plastic Limit

The sample preparation was as in the case of the LL and usually a part of the sample prepared for the plastic limit was set aside for the test.

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5.1.2.4. Linear Shrinkage

Soil samples were prepared as in the case of the liquid limit. The lengths of the sample before and after the test were measured and the average of the two taken as the linear shrinkage.

5.1.3. ***Compaction***

Natural Sample

A portion of the natural soil sample that had been air-dried and stored in the wooden boxes was sieved through the 20mm sieve and 7000g of the sieved sample weighed into the mixing tray for each compaction test. The compaction tests performed were in accordance with the modified AASHTO specification. The procedure was carried out using a 4.5 kg rammer dropping through a height of 457mm in a mould of 152mm diameter..

(i) 210cl of water (i.e. 3% by weight of the soil sample) was added to the sample and mixed thoroughly.

(ii) The sample was compacted in 5 layers applying 55 blows/layer

(iii) The top of the compacted sample was trimmed and weighed.

(iv) Some of trimmings were taken for moisture content determination.

(v) The steps (i) to (iii) were repeated reusing the sample but adding a further 210cl of water to the sample and mixing thoroughly before compacting.

Bitumen Emulsion Treated Sample

A portion of the sample was sieved through the 20mm sieve and 7000g of the sieved sample weighed into the mixing tray for each compaction test.

(i) 70g of bitumen emulsion (i.e. 1% of Bitumen emulsion by weight of the sample) was weighed and mixed thoroughly with the soil sample. The bitumen emulsion was added in small quantities at a time while mixing with the soil in the tray. This was to prevent setting of the emulsion as it got into contact with the laterite.

(ii) Steps (i) to (iv) in the test for the raw sample were repeated for the sample

(iii) Step (i) and (ii) above were repeated using 2%, 3%, 4%, 6% and 8% of bitumen emulsion by weight of the initial raw sample weighed and then mixed thoroughly.

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5.1.4. *California Bearing Ratio (CBR)*

Natural Sample

The sample were prepared in pairs.

(i) 12kg of the soil sample was weighed into the mixing tray for each pair of test

(ii) Water corresponding to the OMC determined from the compaction test for the natural material was measured and mixed thoroughly with the sample before compacting. The amount of water added in grams was calculated using the equation 1.

$$Water\ \text{Added} = \frac{(\text{OMC} - \text{NMC})}{(100 - NMC)} \times 12000 \quad \text{.....equation 1}$$

NMC = Natural Moisture Content of the Sample (1.3 – 4%)
OMC = Optimum Moisture content corresponding to the MDD for 0% Bitumen Emulsion Content compaction.

(iii) Two identical samples were prepared in 2 moulds, (Sample 01 and Sample 02) according to the modified AASHTO specifications

(iv) The first sample was subjected to the CBR test immediately after compaction and weighing with a surcharge placed on it.

(v) The second sample 02 was soaked in water for 96hrs (four days) with a surcharge placed on it during the soaking. The sample was removed from the water after 96hrs and allowed to drain for 30minutes before the test was carried out.

Bitumen Emulsion Treated Sample

12000g of the sample was weighed and 120g of bitumen emulsion (i.e. 1% by weight of the sample) was added to it and mixed thoroughly together.

(i) The appropriate quantity of water was added to the material weighed and mixed thoroughly. The amount of water added was calculated using the following relationship

$$Water\ \text{Added} = \left[\frac{(\text{OMC} - \text{NMC})}{(100 - NMC)} \times 12000\right] - F \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{equation 2}$$

NMC = Natural Moisture Content of the Sample (1.3 – 4%)
OMC = Optimum Moisture content corresponding to the MDD for the Bitumen Emulsion Content compaction.

where F= 42% of the weight of bitumen emulsion (i.e. 0.42 x 120 for 1%)

F represents the amount of water in the bitumen emulsion. This value was deducted from the total fluids content required to attain the MDD since the water from the emulsion phase also adds to the water added to give the total moisture content. It was determined that the emulsion contained 58% bitumen in suspension and about 42% of water plus a small amount of additives.

(ii) Steps (ii) and (iv) for the natural sample were followed

(iii) Steps (i) to (iii) above were repeated but in each case the soil was mixed with 2%, 3%, 4%, 6% and 8% bitumen emulsion contents respectively.

5.1.5. ***Permeability***

The Falling Head Permeability test was performed on the samples prepared by the proctor compaction specification, using the proctor mould of diameter 10.16cm and 2.5kg rammer compacting in three layers at 25 blows/layer.

Natural Sample

(i) Part of the bulk sample stored in the wooden boxes was sieved through the 4.75mm sieve (No 4) and 2500g of this taken.

(ii) This was thoroughly mixed with the quantity of water corresponding to the OMC (for the AASHTO compaction test) for the specific test sample i.e. using equation 1. Even though it is known that the use of different compactive effort give rise to different OMC the difference is not so much great hence the use of the AASHTO

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OMC.

(iii) The test sample was saturated with water using a vacuum pump. The saturation took about 30mins to complete.

(iv) The sample was setup in the falling head apparatus and the water was allowed to run through it for 30min to attain equilibrium before carrying out the test, in accordance with the specification.

Bitumen Emulsion Treated Sample

(i) 2500g of the sieved sample was taken

(ii) 25g of bitumen emulsion (1% by weight of the sample weighed) was mixed with the sample adding a little at a time and mixing.

(iii) The amount of water added was calculated using the equation 2

(iv) The steps (i) to (iii) as in the case of the natural sample were followed.

(v) The whole procedure was repeated but using different percentages of the bitumen emulsion.

5.1.6. *Crumb Test*

This test was performed to give a guide to the erodibility potential of the sample. The crumb test was performed on the sample K4 only. The testing procedure was as follows

(i) 250cl of distilled water was poured into a beaker and made to stand on a table

(ii) A lump of the soil sample about 1cm diameter was taken and gently place in the beaker of water by means of a thong

(iii) Then the sample was observed for the disintegration characteristics over a period of 24 hrs.

5.2. LABORATORY MODEL PAVEMENT STUDY

The effect of bitumen emulsion on the erosion resistance of the soil sample was studied in the H313 hydrological apparatus.

5.2.1. *Description of Test Apparatus*

5.2.1.1. The H313 Hydrological Apparatus

The H313 hydrological apparatus was used as the rainfall simulation chamber. The Photo 5.1 is a picture of the apparatus showing the experimental setup. The diagrammatic representation is shown in Fig 5.2 with the sample mounted on the wooden platform placed inside the chamber with the whole chamber and sample tilted as shown in the experimental setup. The overall dimensions are approximately 2.4m long x 1.0m wide x1.8m high.

Fig 5.1 General View of H313 Hydrological Apparatus

When valve 'B' is opened, water passes through the rotameter (range 0 to 22 l/min) to the overhead sprinklers and simulated rainfall will occur on the pavement. Adjustment of valve 'B' controls the quantity of rainfall simulated through the sprinklers. With valve 'E' open the water is uniformly distributed all over the catchment, closure of 'E' permits rainfall to occur only on the upper part of the catchment, and rainfall movement may be simulated by first having valve 'E' closed and subsequently opening it. A Perspex screen fits around the apparatus to limit the spray. A tilt mechanism allows the catchment slope to be varied. The runoff passes over the pavement and over a sharp edged rectangular weir for collection in the runoff collection chamber. The area of the model catchment itself is approximately 2m long x lm wide. When the test sample is assembled into the apparatus, it is mounted on a wooden platform placed in the rainfall chamber to support the model pavement. A 100mm diameter PVC pipe is connected under the runoff collection chamber and the runoff passes through it into the runoff collection containers.

The whole chamber is inclined at an angle of 1.8^0 to enable the water flow from the upper part of the pavement to the lower part into the collection chamber.

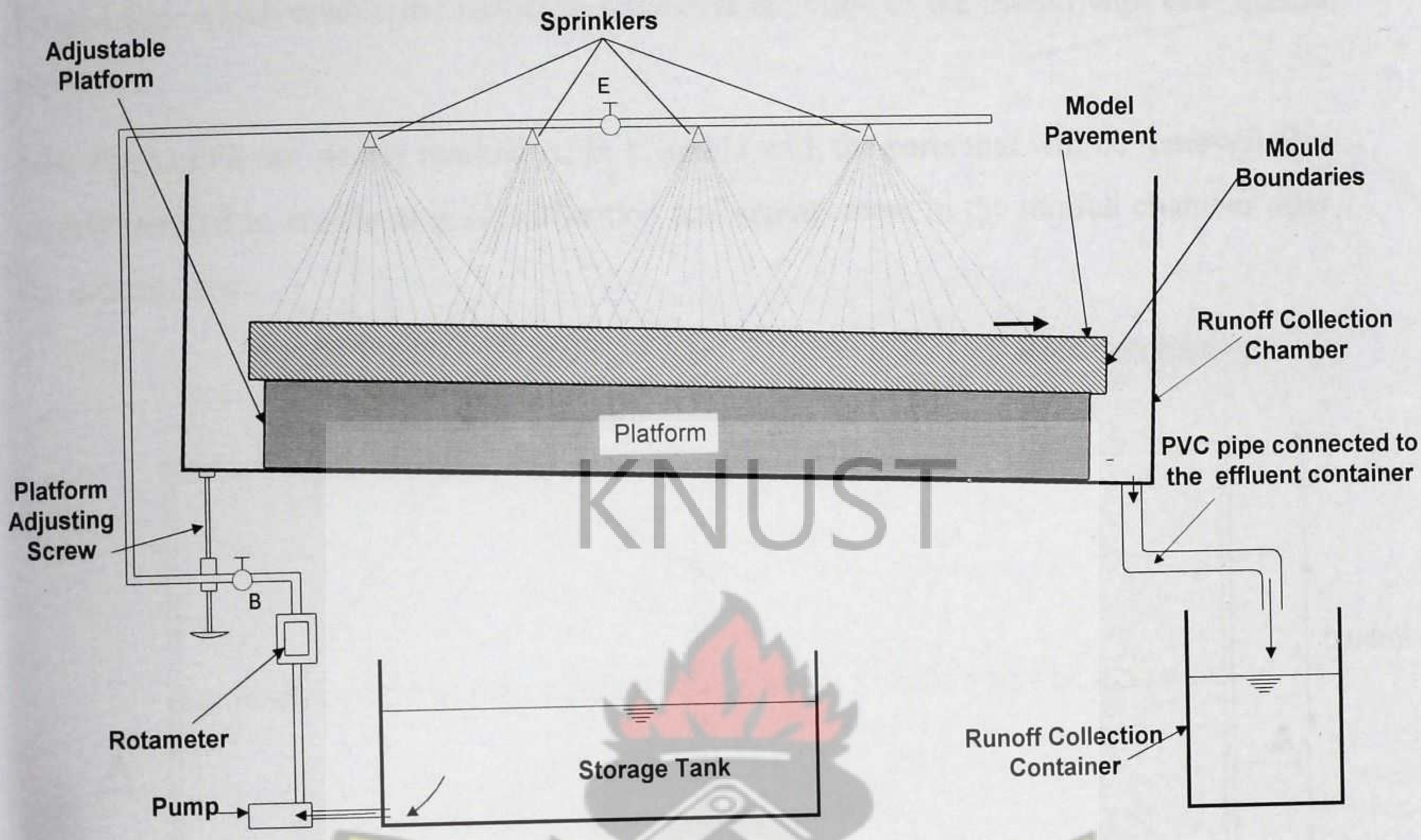

Fig 5.2 Simplified Illustrative Diagram of the H313 Hydrological Apparatus

5.2.1.2. Mould Construction

The mould consisted of four rectangular wooden trays, made of 2.54mm (1inch) thick timber boards. Each tray had the following dimensions; length 1.045m, breath 0.47m and height 0.135m which give a total length of 2.09m, total width of 0.94m and total volume of $0.265m^3$. The overall dimensions enable the mould to fits into the H313 Hydrology apparatus with a slight overhung on the platform to facilitate the runoff to collect into the collection chamber.

Two sides of each mould are removed after compaction for mounting in the chamber. For each unit tray of the mould the two edge sides that were removed after assembling the entire mould had additional timber reinforcement on the linings placed inside the moulds to prevent excess bulging during compaction. During compaction the mould is supported in a wooden bracket made of timber on the outside to restrain the sides of the timber from excessive bulging when the rammer impacts on it. After the compaction, the moulds are transported and mounted on the wooden platform inside the collection chamber. The two edges marked are removed when the moulds have been assembled on the platform in the

hydrological chamber. This is done with the least disturbance to the sides of the pavement material. The edges of the mould along the runoff collection chamber have a small 2.5cm hinged flap which enable the runoff to pass over the edge of the mould with ease during the test.

NB: The mould are clearly marked A, B, C and D with the parts that will be removed also clearly marked to enable easy identification and arrangement in the rainfall chamber after the compaction.

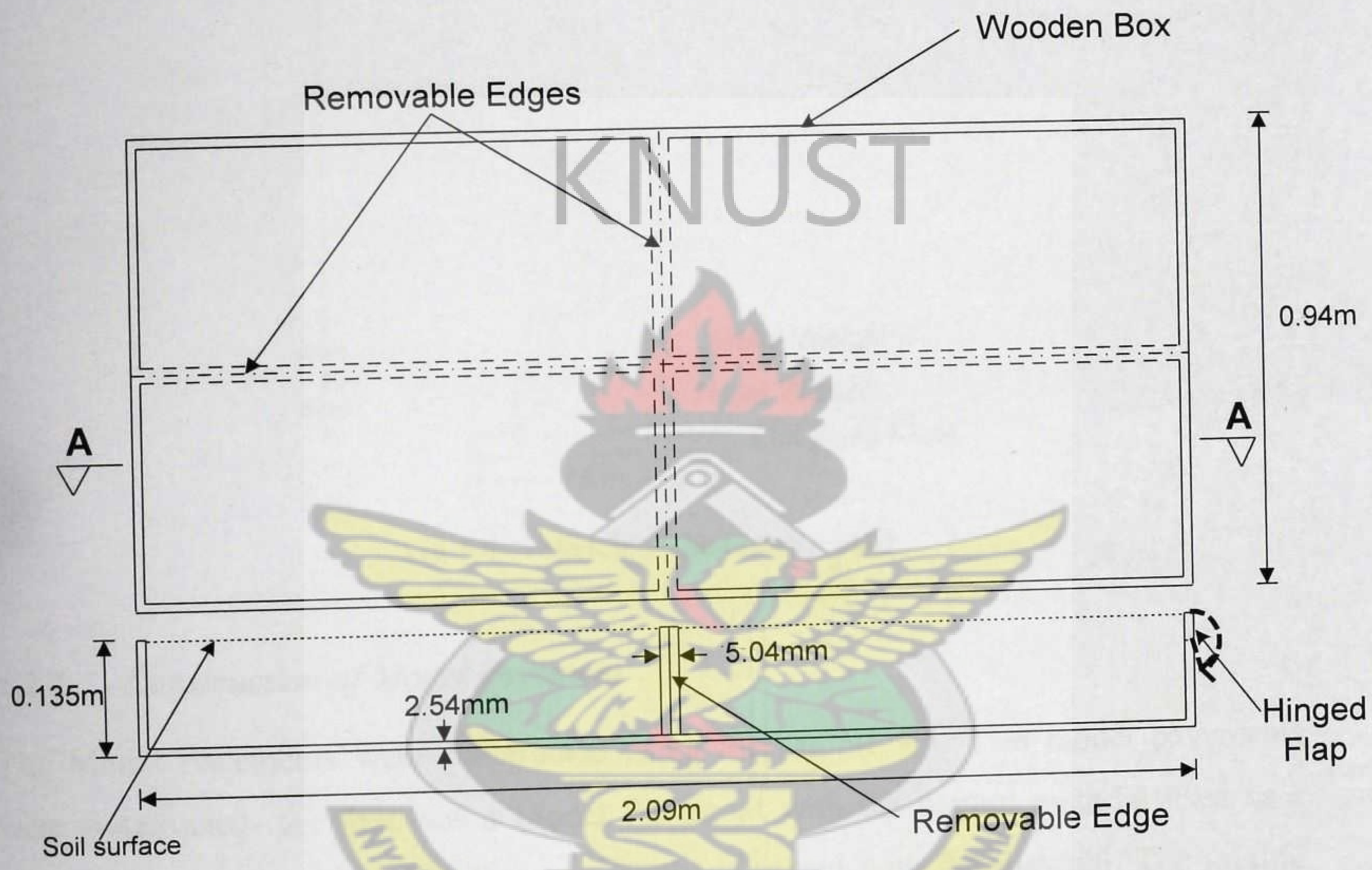

Fig 5.3 An Illustrative diagram of the Mould

5.2.1.3. Rammer Construction

The rammer is made of a square metal base plate with two cylindrical steel weights welded onto it and a metal handle welded on top of the weights. The total weight of the rammer including the handle was 21.8kg. The square base plate is to give an even distribution of the compactive effort during the compaction process. The total height of the rammer from the base plate to the top of the handle is 1.12m. Fig 5.4 is sketch of the rammer showing the dimensions

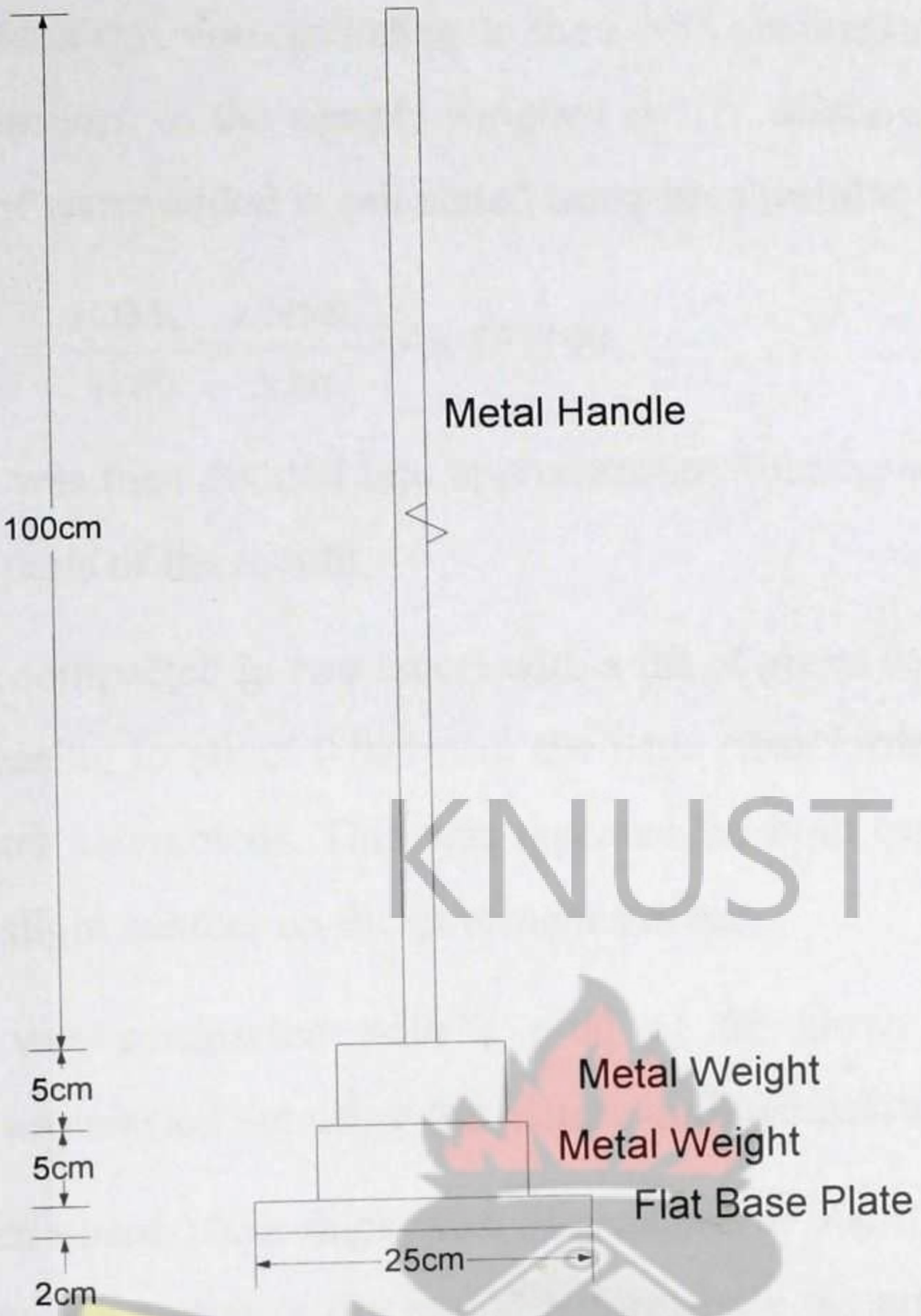

Fig 5.4 Sketch of the rammer used

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5.2.2. *Construction of Model Pavement*

The Model Pavements were constructed using the sample K4. Two model pavements were constructed- the first was a Model Pavement with the natural material used as a control and the other with 2% Bitumen emulsion mixed with the material. The mixing had to be done on the floor because of the volume of material being handled and in order to attain a uniform mix.

5.2.2.1. Untreated Material Model Pavement

(i) The mass of material required to fill the mould was calculated using the formulae

Mass = Density x Volume.....equation 3

= 2.14 x 0.265

=567.1kg

NB: The assumption here is that to attain the MDD obtained in the laboratory compaction then a specific mass of the material must fill the mould and since the volume of the wooden mould and the density required are known then the mass can be calculated

(ii) Water was added (i.e. corresponding to the OMC obtained at the MDD of natural sample compaction) to the sample weighed in '(i)' above and mixed thoroughly. The volume of water added is calculated using the formulae below

$$Water\ \text{Added} = \frac{(\text{OMC} - \text{NMC})}{(100 - NMC)} \times 567100 \quad \text{.....equation 4}$$

(iii) The material was then divided into approximately four equal parts for compaction into the four parts of the mould

(iv) The soil was compacted in two layers with a lift of about 0.080m at the outer edge slightly increasing to about 0.085m to the edge (that forms the centre line when the moulds are assembled). This was repeated for both compaction layers which gives a very slight camber on the pavement surface

(v) Each layer was compacted with a total of 60 blows of the rammer. The compaction was carried out using the pattern outlined below

a. A wooden board 10cm thick with dimensions of 30cm x 65cm was placed on the soil in one corner of the mould before apply the rammer onto it. 10 blows of the rammer are applied to the board. The wooden board was used because the sample was sticking to the base plate.

b. The board was moved to the other three corners and 10 blows were applied at each position of the board.

c. The board was moved round again but this time using 5 blows of the rammer for each position of the wooden board

(vi) The four moulds with the compacted sample was transported to the rainfall chamber. The moulds were lifted into the chamber carefully with the least twisting and were mounted on the stand in the rainfall chamber. The moulds were then pushed gently towards their final position but before they touch, the sides marked for removal as indicated in the Fig 5.3 are removed with the aid of a crowbar and pinches.

(vii) The spaces at the joints of the four moulds were filled with material left over. This filling is done in layers and carefully compacted with a small rammer and rod

5.2.2.2. *Bitumen Treated Material Model Pavement*

The volume of material was calculated as the case of the untreated material but using the MDD obtained for the 2% Bitumen Emulsion content laboratory compaction test for the K4 soil material. The amount of water added was also calculated using the formulae below

$$Water\ \text{Added} = \left[\frac{(\text{OMC} - \text{NMC})}{(100 - NMC)} \times 588300\right] - F \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{equation 5}$$

Where F = Amount of water equal to 42% of Bitumen Emulsion added

The experimental procedure was generally the same as was the case for the untreated material except that in the mixing of the material, bitumen emulsion is first added in small quantities while mixing until completely mixed. Then the volume of water calculated can also be added and mixed.

5.2.3. ***Measurement of Erosion***

(i) The rotameter reading was set to 4l/min and Tap B was then opened and the sprinkler made to run for about 1min to attain equilibrium, before timing the experiment for additional 15min. The time was chosen to allow accumulation of measurable quantities.

(ii) The runoff (containing the eroded material) was collected into the collection container.

(iii) The water collected was made to stand for about 30min to allow some of the particles in suspension to settle. Then some water is taken from the top and used to wash the runoff collection chamber to remove any excess particles that were left in it.

(iv) The water collected in the container was left to stand overnight to allow the solid particles to settle.

(v) The water was carefully decanted into another container and the residue soil material left behind was dried overnight in the oven at 105^0C to determine the total weight of material eroded from the pavement.

(vi) The water decanted was stirred and one litre taken and put in the oven. The water was allowed to evaporate and the amount of solid material that was left in

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suspension was determined. Since the total volume of decanted water is known the total volume of material in suspension can be computed.

(vii) The amount of material eroded is the addition of the soil residue [step (v)] and soil in suspension [step (vi)].

(viii) The pavement was left to dry overnight before another test was conducted

(ix) The rotameter flow rate was increased to 6L/min, 8L/min, and 9.75L/min and for each flow the whole test repeated.

The whole process was repeated for the soil material treated with 2% bitumen emulsion.

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5.2.3.1. Calibration of the Rainfall Chamber

The rainfall chamber (H313 Hydrological Apparatus) was calibrated before the tests were performed to determine the relationship between the actual measured rates of flow of water from the sprinklers and the flowmeter (Rotameter) readings. The calibration process is as described below.

(i) With no model in the chamber, the pump was started and the flow indicator adjusted to read 2L/min and allowed to run for about 1min to enable the pump flow to reach equilibrium.

(ii) A 34litres bucket was placed under each sprinkler simultaneously while at the same time starting a clock (one person per sprinkler). The quantity of water collected in 10minutes was recorded. The test was repeated four (4) times and the average taken.

(iii) The flow rate was increased to 4L/min, 6L/min, 8L/min and 9.75L/min respectively and the corresponding volume of water collected for each flow rate.

(iv) The actual flow measured was plotted against the rotameter readings and a relationship derived between the two. From the relationship derived the actual rate of flow of water can be calculated when the rotameter reads a specific value.

The pump was unable to deliver water beyond 9.75 L/min when all 8 sprinklers are opened. The calibration was conducted for the range available. The 2L/min rate of flow was not used for the erosion test because the spread of the showers was such that the coefficient of uniformity for such low flow rates was very low i.e. <15%.

NB: PICTURES OF EXPERIMENT ARE SHOWN IN THE APPENDICES

CHAPTER SIX

6 DISCUSSION OF RESULTS

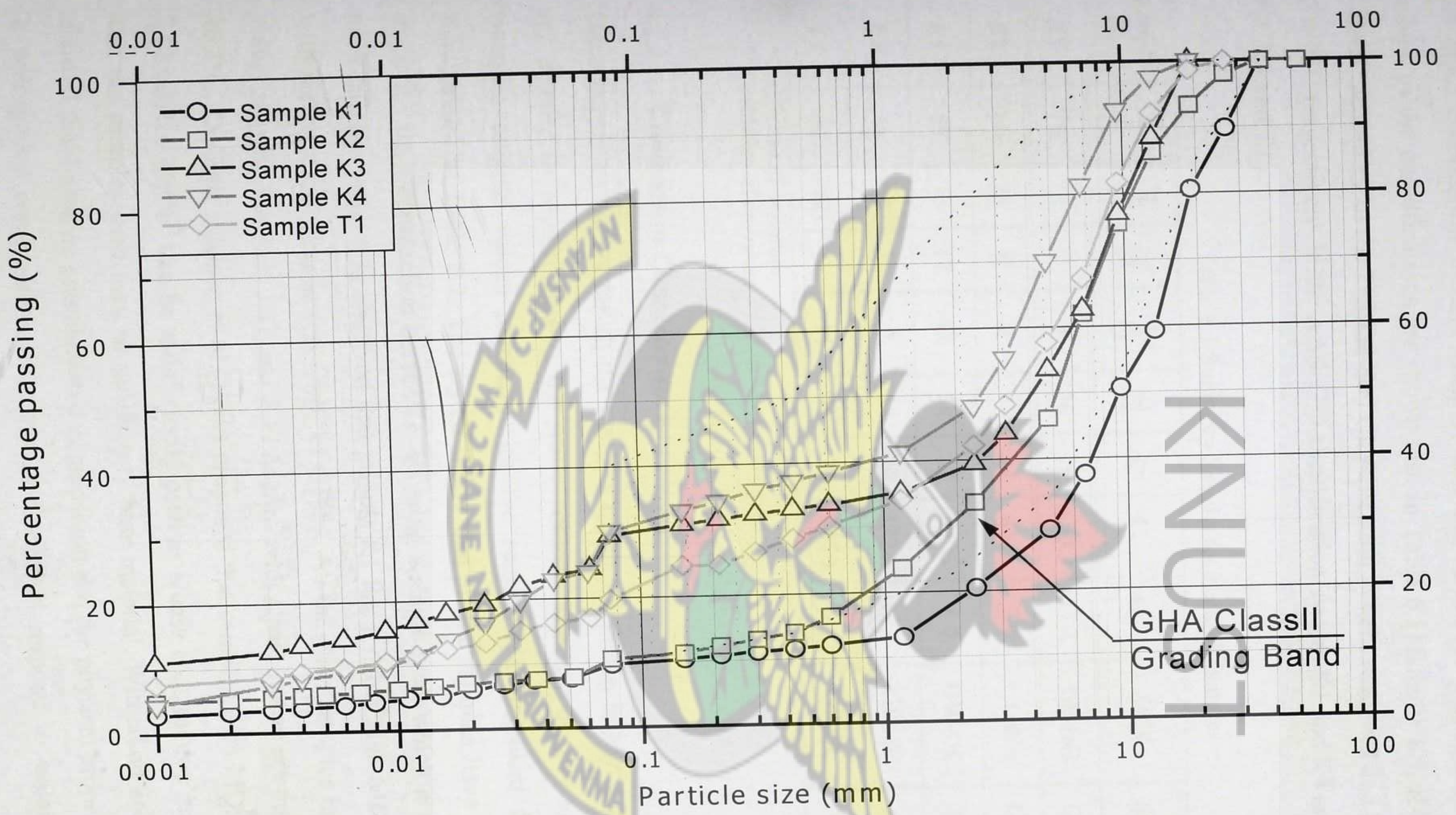
6.1. CHARACTERISTICS OF STUDY MATERIAL

Samples from agro-ecological zone 2 and zone 4 as discussed in Chapter 3 were used for this study. Four samples labelled K1, K2, K3, and K4 were taken from the Ashanti Region which forms part of the Zone 2 and one sample labelled T1 was taken from the Western Region in the Zone 3. The Ashanti Region was chosen due to proximity and therefore ease of accessibility to the site and the Western Region because of the peculiar nature of the climate i.e. the high rainfall characteristics.

In the Ashanti Region, the materials used were taken from four gravel pits in the same area off the Kumasi – Obuasi road near the Brofoyedu township. These gravel pits supply gravel for a number of projects in the Ashanti region. The site is about 17km from Kejetia in the Central business district of Kumasi. The material from these gravel pits is formed over Phyllites and it is nodular or concretional gravel. The material from the Western Region was taken from a gravel pit on the Takoradi - Agona Nkwanta road. The summary of the properties of the various samples investigated is given in the appendix.

6.1.1. *Index Properties of Study Material*

The grading characteristics of the five (5) samples studied are shown in the Fig 6.1. The MRT specification for naturally occurring gravel for Class II roads i.e. for low traffic volume roads (roads having less than 300veh/day ADT) is also superimposed on all the grading curves. It can be seen that with the exception of sample K1 all the other samples lie within the band. Sample K1 itself is only slightly outside the lower limit of the band. Thus by and large it may be said that the samples used for this study meet the grading requirement for gravel subbase material. The index properties are summarized in Table 6.1. It can be seen that the samples studied have high gravel content and low clay content, varying between 2% for K2 and 12% for sample K3. With the exception of K4 all the others have gravel fraction exceeding 50% with relatively small percentages of fines. All the samples have higher LL and PI values than the MRT Specifications shown in Table 2.2 (i.e. LL = 30% max, PI = 15% max). The results illustrate the often encountered difficulty of obtaining material with PI and LL values meeting the specification.



	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	
CLAY	**SILT**			**SAND**			**GRAVEL**		

Fig 6.1 Grading Curves for Soil Samples Investigated

The samples were classified using various the Unified Soil Classification System (USCS), the BS Classification System (BSCS) and the AASHTO Classification system. The results of the classifications are shown also in Table 6.1. Sample K1, K4 and T1 are all GP-GC according to the Unified Soil Classification system while K2 and K3 are GW and GW-GC respectively. In the AASHTO classification system K1 and K4 are A-2-6 and the K2, K3 and T1 are A-2-7.

Table 6.1 Summary Results for Natural Samples

Sample ID	*Gravel*	*Sand*	*Silt*	*Clay*	*LL*	*PI*	C_u^*	C_z^{**}	*UCS*	*BSCS*	*4ASHTO*
K1	79	11	7	3	36	18	130.3	17.2	GP-GC	GWM	A-2-6
K2	66	23	9	2	45	24	86.4	7.4	GW	GWM	A-2-7
K3	57	13	17	12	54	30	6306	4.0	GW-GC	GML	A-2-7
K4	45	22	26	7	38	20	332.3	17.2	GP-GC	GML	A-2-6
T1	52	28	9	11	41	25	574.3	6.5	GP-GC	GML	A-2-7

*Coefficient of uniformity
**Coefficient of curvature

6.1.2. *Compaction Characteristics*

The compaction curves for all the samples tested are shown in Fig. 6.2 which plots the dry density in Mg/m^3 against the water content. The dry density and the optimum moisture content values together with the soaked and unsoaked CBR values are summarized in Table 6.2. The figure shows that all the samples have almost the same shape for their compaction curves i.e. showing a single peak which is characteristics of most lateritic soils. It is observed that sample K1 has a rather high MDD of $2.29Mg/m^3$ with the corresponding lowest OMC of 4.75%. All the other samples have similar MDD values ranging between 2.12 and 2.17 Mg/m^3 with OMC values ranging between 7.7%-10.1%. DeGraft Johnson et al (1969) proposed that samples with MDD values between 2.082-2.210 Mg/m^3 can be satisfactorily used as a base construction material suggesting that the samples used may be satisfactory base material. Winterkon and Pamukcu, 1990 showed that based on granulometric composition and the physical properties, soils having a well-graded composition with enough fines will respond to waterproofed granular stabilization as shown in Table 4.5.

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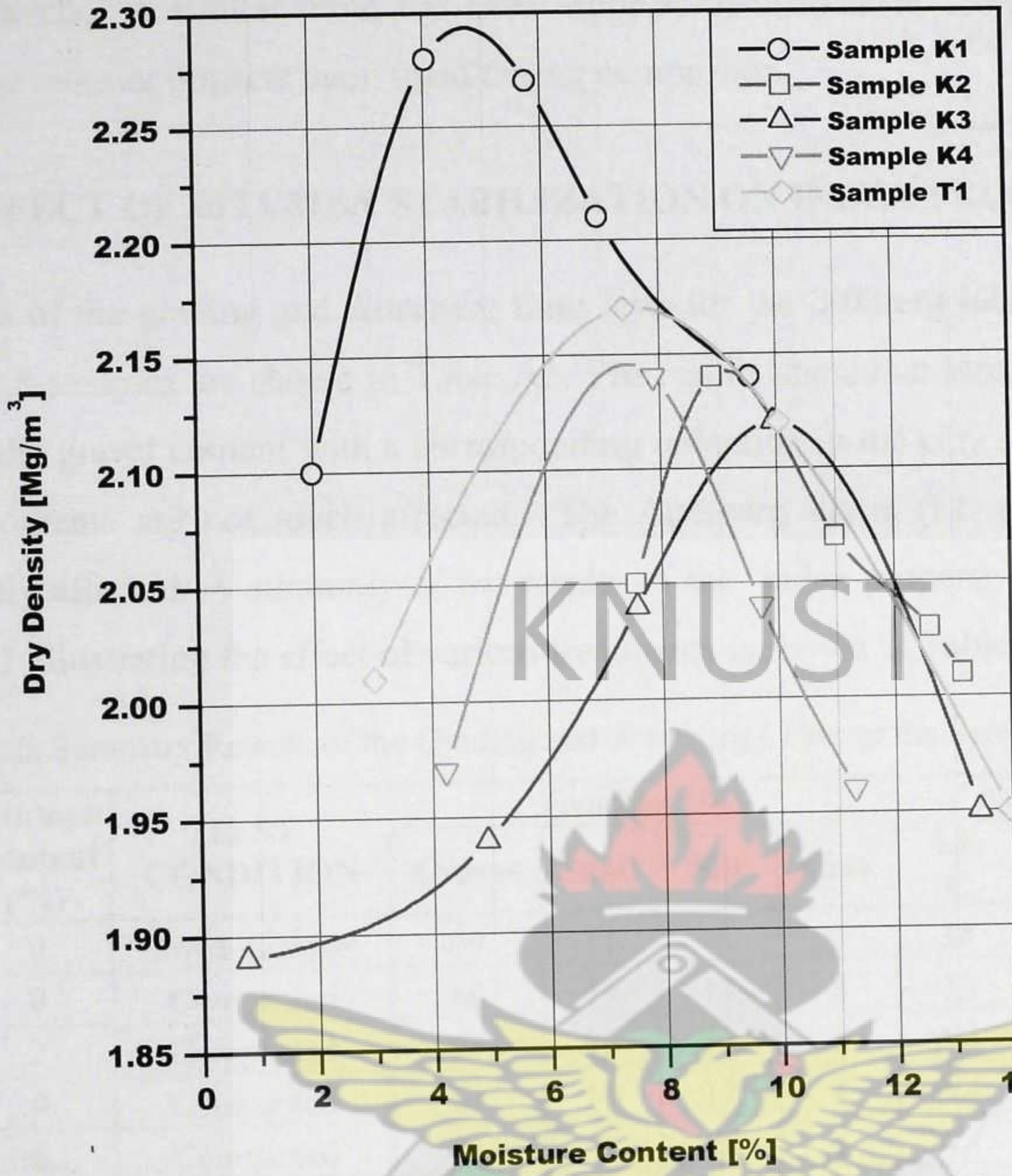

Fig 6.2 Compaction Characteristics Curves for Untreated Samples

Again as in the case of the MDD, sample K1 showed a relatively high CBR value of 128 while the remaining samples had CBR values ranging between 29 for K1 and 80 for T1. However, sample K1 also showed the largest percentage drop in CBR upon soaking of 72.7%. The smallest percentage drop of 13.8% was observed for sample K2.

Table 6.2 Summary Results for Natural Samples

Sample ID	*OMC*	*MDD*	*Unsoaked CBR*	*Soaked CBR*	*% Drop in CBR*
K1	4.75	2.29	128	35	72.7
K2	9.10	2.14	29	25	13.8
K3	10.05	2.12	30	18	40.0
K4	7.89	2.14	45	21	53.3
T1	7.68	2.17	80	50	37.5

For sample K1and K2, the grading after compaction was also performed. The results show that the there was a significant reduction in the gravel fraction while the fines

fraction percentage increased correspondingly. This phenomenon is characteristic of lateritic gravels. A similar trend has been reported by Ahiamadi, 1997. The particles break as the rammer impacts upon them during compaction.

6.2. EFFECT OF BITUMEN STABILIZATION ON INDEX PROPERTIES.

The results of the grading and Atterberg limit tests for the different bitumen content for the different samples are shown in Table A1. The results show that bitumen stabilization increases the gravel content with a corresponding reduction in the clay content. The sand and silt contents are not much affected. The Atterberg limits (LL and PI) were not significantly affected. A summary of the results of the index property tests for samples K1 and K2 illustrating the effect of various treatments is shown in Table 6.2(a.).

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Table 6.2a Summary Results of the Grading and Atterberg Limts of the Samples K1 and K2

Sample	Bitumen Content (%)	TEST CONDITION	Grading (%)				Atterberg Limits			
			Gravel	Sand	Silt	Clay	LL C	LL P	PI	LS
K1	0	Fresh Sample	79	11	7	3	38	36	18	9
	0	Compacted	60	19	12	8	32	31	14	10
	2	Compacted	65	12	18	5	*NA*	36	18	12
	4	Compacted	68	10	17	4	*NA*	45	22	14
	6	Compacted	81	9	9	1	*NA*	42	19	14
K2	0	Fresh Sample	86	13	0	1	*NA*	45	24	13
	0	Compacted	46	13	19	22	47	46	24	14
	1	Compacted	59	13	17	11	48	46	23	15
	2	Compacted	57	12	19	12	47	45	23	7
	3	Compacted	64	12	17	7	51	50	26	14
	4	Compacted	62	10	20	8	52	50	32	15
	6	Compacted	60	11	21	7	52	54	28	14
	8	Compacted	68	10	19	3	54	53	26	14
	10	Compacted	76	9	12	3	53	37	28	14
K2-cured	0	Compacted	44	17	24	15	45	42	25	14
	2	Compacted	45	17	22	16	43	41	24	11
	3	Compacted	63	13	15	9	45	45	25	12
	4	Compacted	61	14	16	9	50	45	30	15
	6	Compacted	76	12	8	4	39	44	21	13
K2-cured	0	OMC Compacted	52	14	21	13	42	*NA*	23	13
	2	OMC Compacted	58	17	17	8	42	*NA*	22	12
	3	OMC Compacted	59	16	16	9	44	*NA*	24	13
	4	OMC Compacted	68	17	11	5	43	*NA*	23	9
	6	OMC Compacted	59	15	25	1	42	*NA*	23	15

The effect of these treatments on the grading properties of sample K2 is shown with in Fig. 6.3(a). The figure compares the effect of compacting with gradually increasing water content while re-using the same sample for each increase with the effect of compacting once at the OMC. It also shows that there is a general increase in the gravel component with increasing bitumen content. The figure illustrates the tremendous reduction in gravel content on compaction

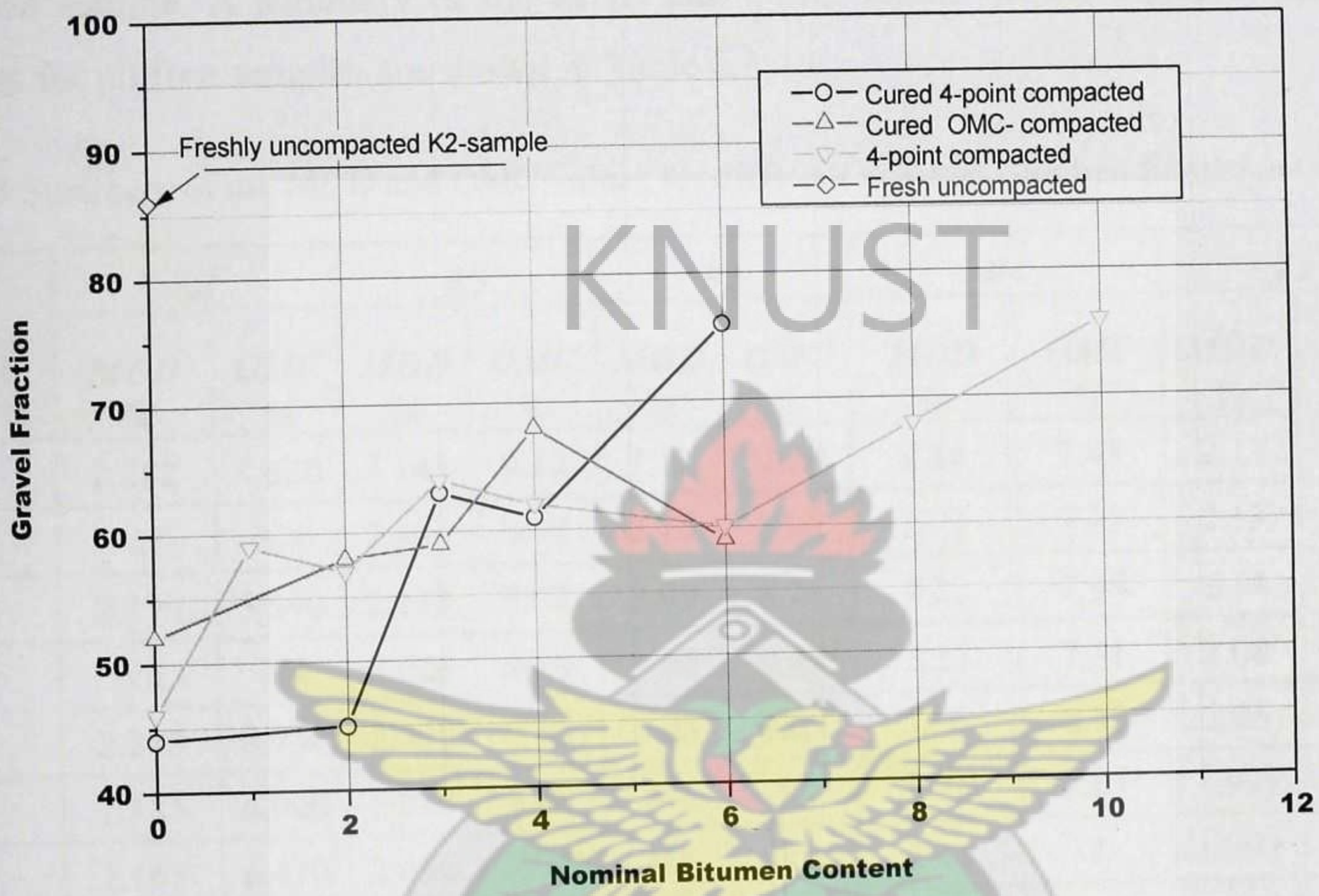

Fig. 6.3 Variation of Gravel fraction with nominal bitumen content for various treatments of sample K2
4-point compaction procedure is one in which the moisture content is increased while reusing the sample.
The OMC-compacted is a 1-point compaction test performed at the OMC of the sample already determined

For the Sample T1 the material was not compacted before carrying out the particle size test and the results did not indicate a significant change both in the grading characteristics and the Atterberg limits

Table 6.2b Summary Results of the Grading and Atterberg Limts of the Sample T1

Bitumen Content	Test Conditions	Grading			Atterberg Limits	
		Gravel	Sand	Fines	LL	PI
0	Uncompacted	52	28	20	42	26
1	Uncompacted	59	20	21	48	30
2	Uncompacted	56	23	21	44	27
3	Uncompacted	61	20	19	46	29
4	Uncompacted	69	16	14	46	28
6	Uncompacted	67	17	15	48	31
8	Uncompacted	56	23	21	45	27

6.3. EFFECT OF BITUMEN STABILIZATION ON COMPACTION CHARACTERISTICS

The compaction curves for the five samples stabilized with various percentages of bitumen-emulsion are shown in Fig. A1 to Fig. A5. The figures show an initial increase in dry density with increasing total moisture content up till optimum total moisture content beyond which the dry density begins to reduce. The trend is similar to the untreated sample. A summary of the MDD and OMC values for the different bitumen contents for all five samples are shown in Table 6.3

Table 6.3 Summary of the MDD and OMC values for different nominal Bitumen Emulsion Contents

Bit. Emul. Cont. %	*K1*		*K2*		*K3*		*K4*		*T1*	
	MDD %	*OMC %*	*MDD %*	*OMC %*	*MDD %*	*OMC %*	*MDD %*	*OMC %*	*MDD %*	*OMC %*
0	2.282	4.620	2.143	9.12	2.12	10.01	2.14	7.45	2.17	7.66
1	*NA*	*NA*	2.130	9.58	2.14	7.98	2.26	7.13	2.13	7.38
2	2.330	5.590	2.133	9.02	2.09	8.71	2.22	7.98	2.14	7.19
3	*NA*	*NA*	2.086	9.68	2.02	9.41	2.21	7.31	2.08	6.72
4	2.215	5.730	2.080	9.15	2.03	9.07	2.2	8.32	2.06	6.98
6	2.185	6.000	2.060	8.01	*NA*	*NA*	2.16	8.01	1.996	8.31
8	2.165	6.470	2.050	10.02	*NA*	*NA*	2.11	7	1.993	7.76
10	2.135	7.110	2.020	9.46	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

The MDD values for the different bitumen contents are plotted in Fig. 6.4 for all the five samples studied. The absolute bitumen content obtained by determining the actual water content of bitumen emulsion is also shown. Again as in the unstabilized samples, K1 showed relatively high MDD values for all bitumen contents followed by K4 while except at 1% bitumen content, K3 showed the lowest MDD values. It may be noted that both sample K1 and K4 belong to the A-2-6 AASHTO classification while the remaining 3 samples belonged to the A-2-7 class of soils. The figure also shows that for sample K1, K3 and K4 there is an initial increase in the MDD values attaining a maximum around 1-2% nominal bitumen emulsion content before decreasing as the bitumen emulsion content was increased further. For samples K2 and T1, however, there is an initial slight to insignificant decrease in the MDD value at around 1% nominal bitumen emulsion content, but beyond 2% there is a rapid reduction in MDD values with increasing bitumen emulsion content.

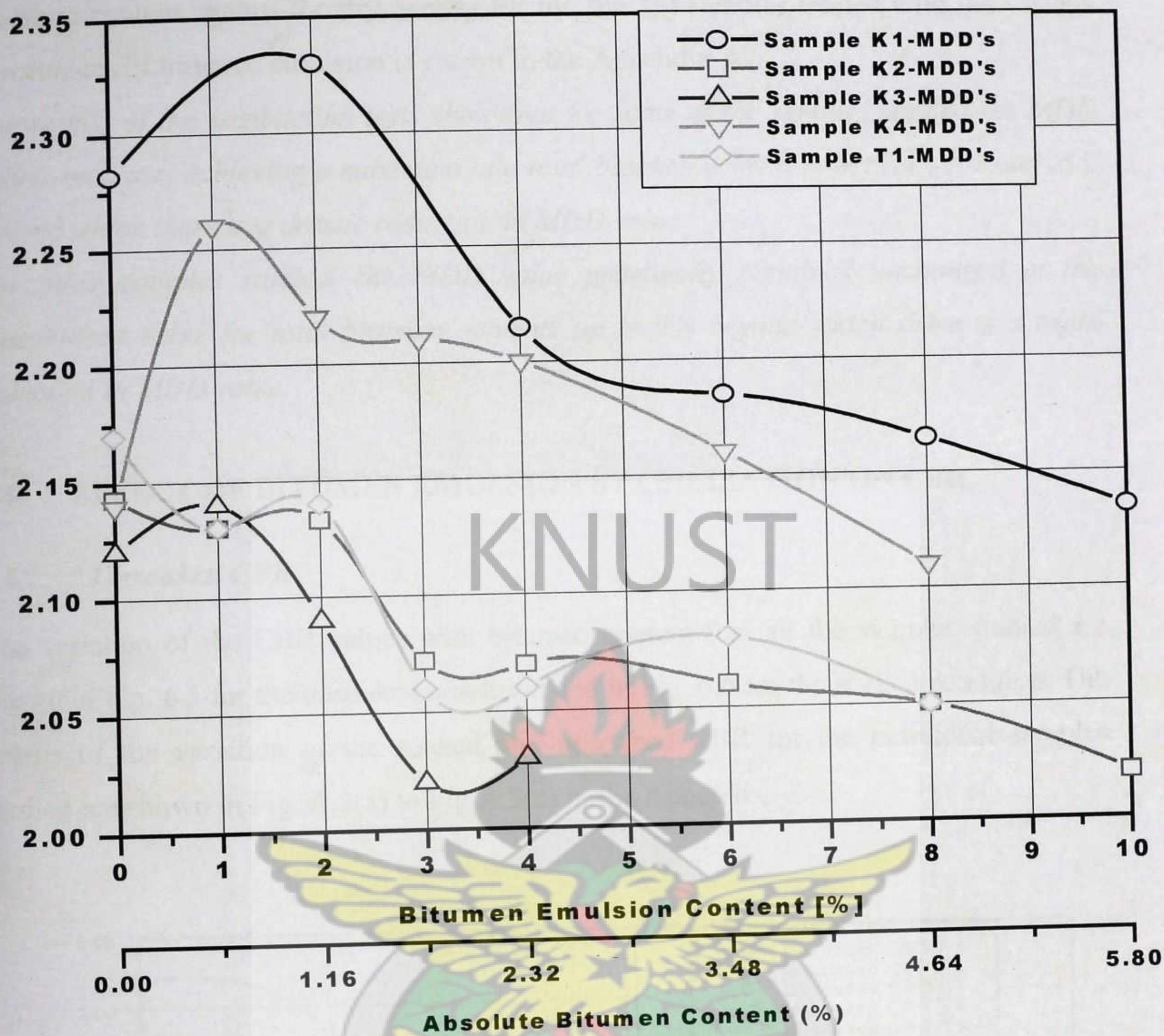

Fig 6.4 Variation of MDD's with Bitumen Emulsion Content for all samples studied

Winterkorn and Pamakcu, 1990 demonstrated similar results in which the unconfined compressive strength increases to a maximum at a certain bitumen content and then decrease with the continual increment in the bitumen emulsion content. Ingles and Metcalf 1972 also reported similar results as already discussed in chapter 4. The possible explanation to the general trend observed where the MDD's tend to increase and then decrease could be due to the fact that initially when the amount of bitumen is small it tent to increase the bond strength that exist between the particle and so generally help the compacted material to fit onto each other well however with further increase in the bitumen emulsion content the particles tend to slide over each other and so they are not able to bond well. Also since the unit weight of bitumen is lower that that of laterite the more of bitumen we incorporate into the laterite the overall unit weight is reduced and thus reducing the MDD as the bitumen emulsion content increases. The plots of the

moisture content against the dry density for the five (5) samples treated with the various percentages of bitumen emulsion is shown in the Appendix A.

The results of the compaction tests show that for some of the samples studied the MDD values increase, achieving a maximum at a total bitumen content of between 1% and 2%, beyond which there is a drastic reduction in MDD value

For other samples studied, the MDD value practically remained unchanged at the unstabilized value for total bitumen contents up to 2% beyond which there is a rapid reduction in MDD value.

6.4. EFFECT OF BITUMEN EMULSION STABILIZATION ON CBR

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6.4.1. *Unsoaked CBR*

The variation of the CBR values with bitumen content for all the samples studied are shown in Fig. 6.5 for the unsoaked condition and in Fig. 6.6 for the soaked condition. The details of the variation of the soaked and unsoaked CBR for the individual samples studied are shown in Fig. A.2(a) to Fig A.2(e) in the Appendix.

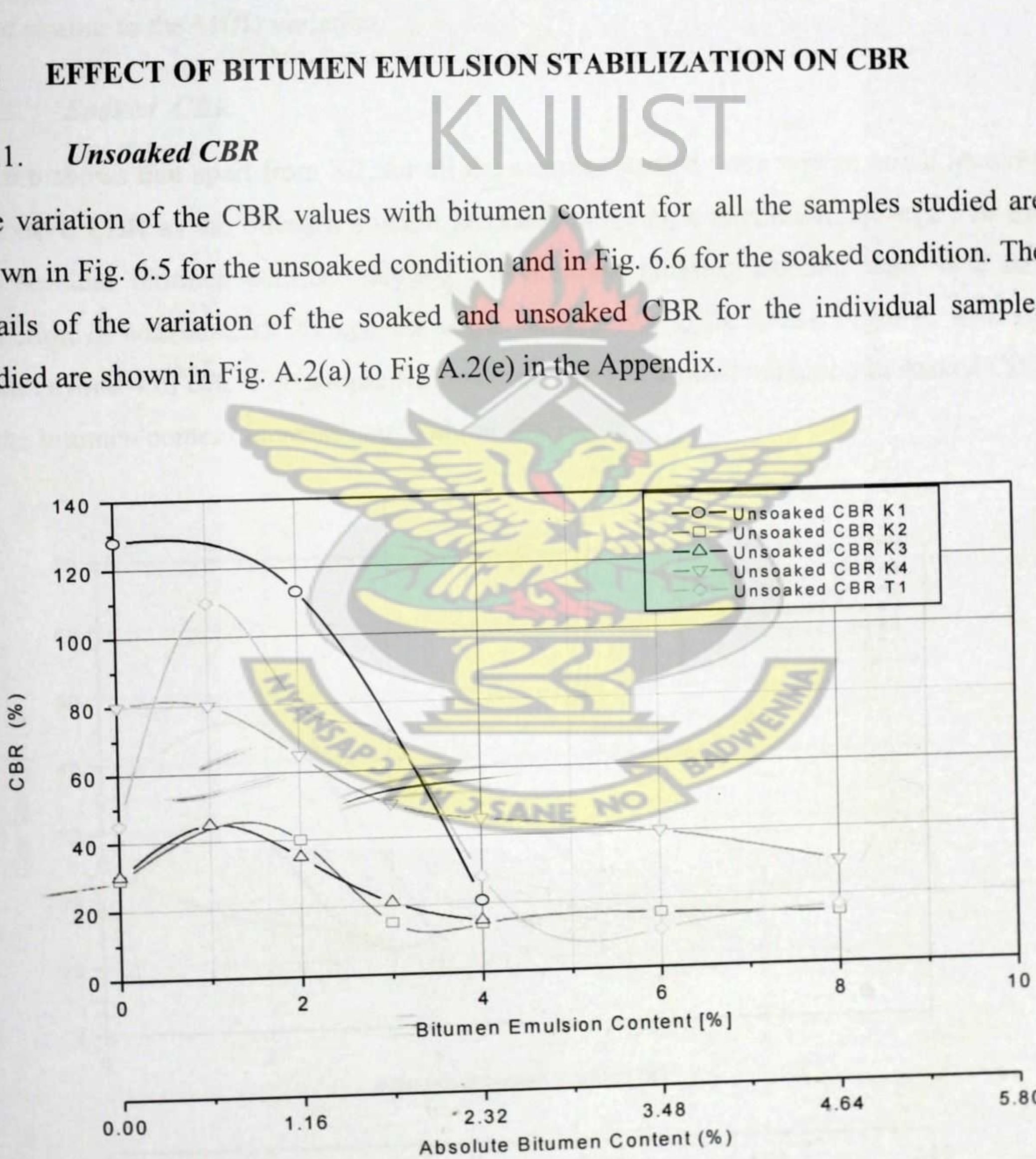

Fig 6.5 Variation of Unsoaked CBR Strength of Samples with Increasing Bitumen Emulsion Content

Again for nominal bitumen contents of up to about 3% sample K1 gave the highest values of unsoaked CBR while K2 and K3 gave the lowest values. The results also show that for K1 and T1, up to a bitumen content of about 2%, the reduction in unsoaked CBR is only slight, but beyond this bitumen content, there is a rapid reduction in unsoaked CBR with increasing bitumen content with K1 showing a faster rate of reduction. For samples K2, K3 and K4 on the other hand, the plots show an initial increase in CBR up to about 1% bitumen content followed by an initial gradual decrease such that beyond about 2-3% bitumen content the CBR values reduce below the untreated value. The results suggest a trend similar to the MDD variation.

6.4.2. *Soaked CBR*

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Fig 6.6 shows that apart from K2, for all the samples studied there was an initial increase in soaked CBR as the bitumen content increases attaining a maximum between 1% and 2% nominal bitumen content. Beyond 2% nominal bitumen content, there is a fast reduction in soaked CBR though for some samples the CBR values begin to increase again beyond 4 to 6%. For sample K2 however, there is a small reduction in soaked CBR as the bitumen content increases up to about 4%.

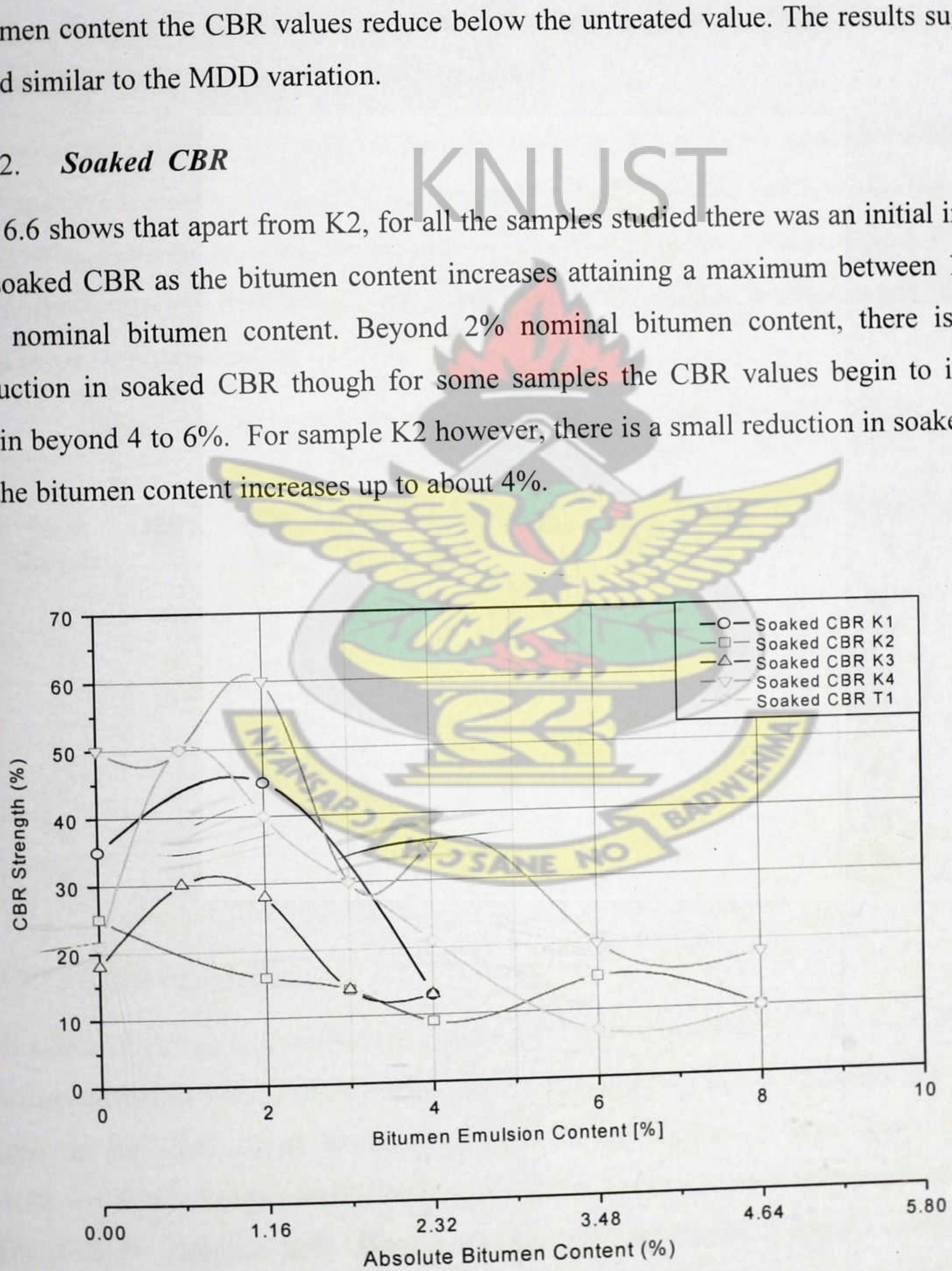

Fig. 6.6 Variation of Soaked CBR with bitumen Content for all samples studied

When the samples are soaked for 96hrs (4 days) before performing the CBR strength test as is required from the Ministry of Roads and Transport specification for natural occurring gravel material, the results obtained were generally lower than the comparative values obtained for the same sample when the CBR test is performed without soaking the sample. The results shown in Appendix A2 show a reduction in CBR values upon soaking, but the magnitude of the reduction depends on the bitumen content used for the stabilization. As previously discussed sample K1 showed the greatest reduction on soaking for the non-stabilized material. The CBR values for both the soaked and unsoaked condition are shown in Table 6.4 below.

The trend for the CBR is similar to the MDD values. Just as in the case of the MDD the bitumen content go in to increase the strength initially because the particles are able to bond strongly hence resisting any attempt to penetrate it, as the bitumen emulsion content increases the amount of force needed to penetrate decreases because the particle slide past each other with greater ease.

Table 6.4 Summary of CBR values for different Bitumen Emulsion Content

Bit. Emul. Cont. %	K1		K2		K3		K4		T1	
	CBR_U %	CBR_S (%)	CBR_U %	CBR_S (%)	CBR_U %	CBR_S (%)	CBR_U %	CBR_S (%)	CBR_U %	CBR_S (%)
0	128	35	29	25	30	18	45	21	80	50
1	*NA*	*NA*	*NA*	*NA*	45	30	110	50	80	50
2	113	45	40	16	35	28	80	40	65	60
3	*NA*	*NA*	15	14	21	14	70	30	50	30
4	21	13	14	9	15	13	28	21	45	35
6	*NA*	*NA*	16	15	*NA*	*NA*	11	7	40	20
8	*NA*	*NA*	15	10	*NA*	*NA*	17	10	30	18

6.4.3. *Effect of curing*

The effect of curing is important in deciding whether a waiting time after application of bitumen-emulsion will have any effect on the performance of the material. The effect of curing on the CBR values is shown in Fig. 6.7 for sample K2. The figure shows the results for ❶cured-compacted-CBR(i.e. unsoaked) samples, ❷cured-compacted-soaked CBR(soaked) samples and ❸cured-compacted-cured-CBR(unsoaked) samples. The numerical values are shown in Table 6.6. The result obtained for cured-unsoaked at 0% bitumen content is inconclusive. Though the results are inadequate and may be

inconclusive, overall they appear to suggest that curing does not have any significant effect on the CBR values.

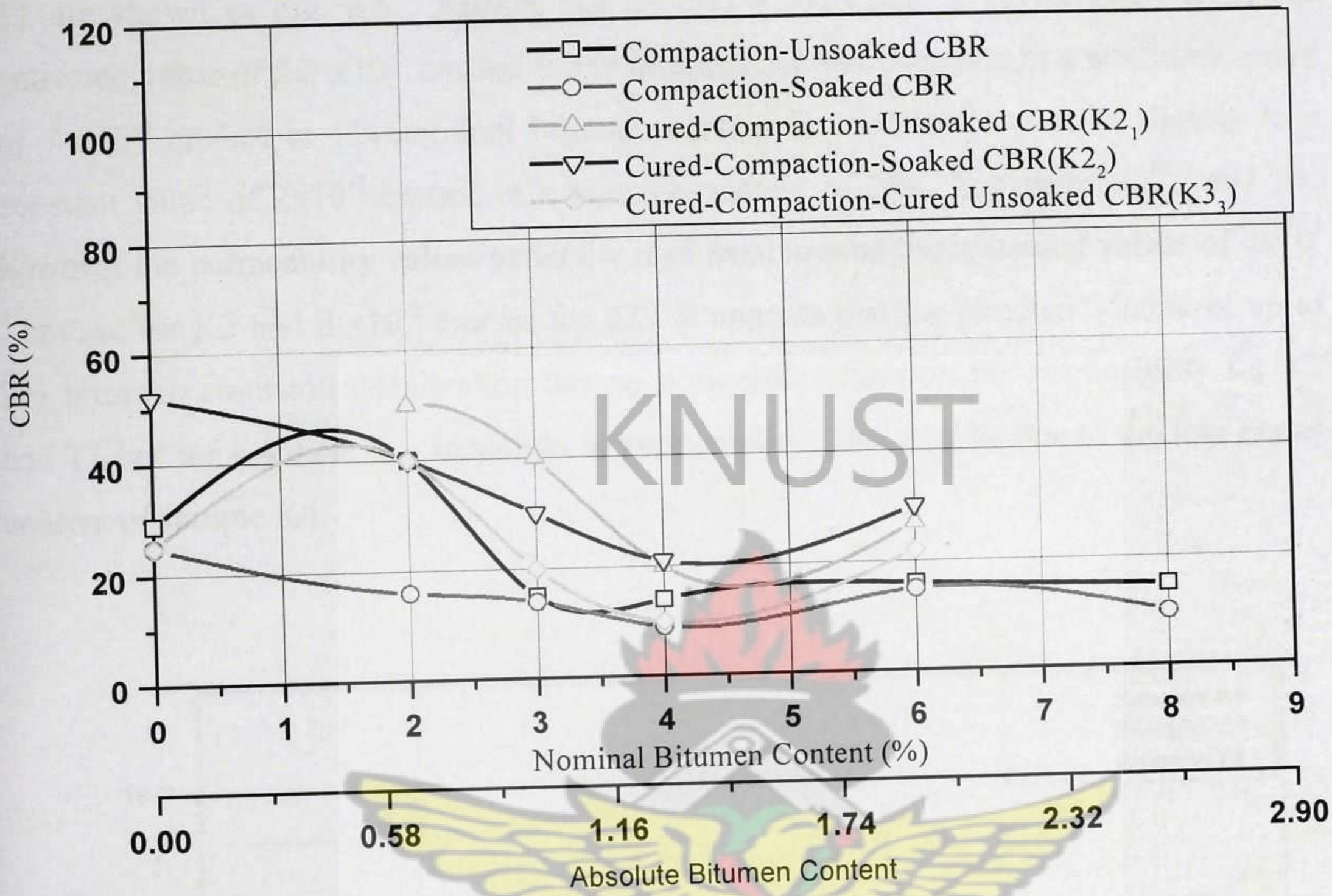

Fig 6.7 Effect of Curing on CBR values for various bitumen Content for Sample K2

Table 6.5 Summary of CBR values for K2 cured sample for different Bitumen Emulsion Content

Bit. Emul. Cont. %	Unsoaked CBR	Soaked CBR	$K2_1$	$K2_2$	$K2_3$
			CBR %	CBR %	CBR %
0		52	108	52	25
2	50	40	50	40	40
3	40	30	40	30	20
4	20	21	20	21	10
6	27	30	27	30	22

The plots of the stress against the strain curves for the five samples treated with different amount of bitumen emulsion have been shown in the Appendix C while the plots of the CBR values against the bitumen emulsion contents for the all the samples have been shown in the Appendix B.

6.5. EFFECT OF BITUMEN EMULSION STABILIZATION ON PERMEABILITY

The effect of bitumen emulsion stabilization on the permeability of samples K2, K4 and T1 are shown in Fig. 6.8. Sample K4 showed a reduction in permeability from the untreated value of 2.5 $x10^{-5}$ cm/sec as the bitumen content increases to a minimum value of 7 $x10^{-8}$ cm/sec at 1% nominal bitumen content beyond which it rises slightly to a constant value of $2x10^{-7}$ cm/sec at a bitumen content of 2%. For samples K2 and T1, however the permeability values generally oscillated around the untreated values of $4x10^{-4}$ cm/sec for K2 and 8 $x10^{-5}$ cm/sec for T1. It appears that for bitumen content of up to 2% bitumen emulsion stabilization has no noticeable effect on the permeability for K2 and T1 but for K4 there is a reduction in permeability. This may be due to the less gravel content of sample K4.

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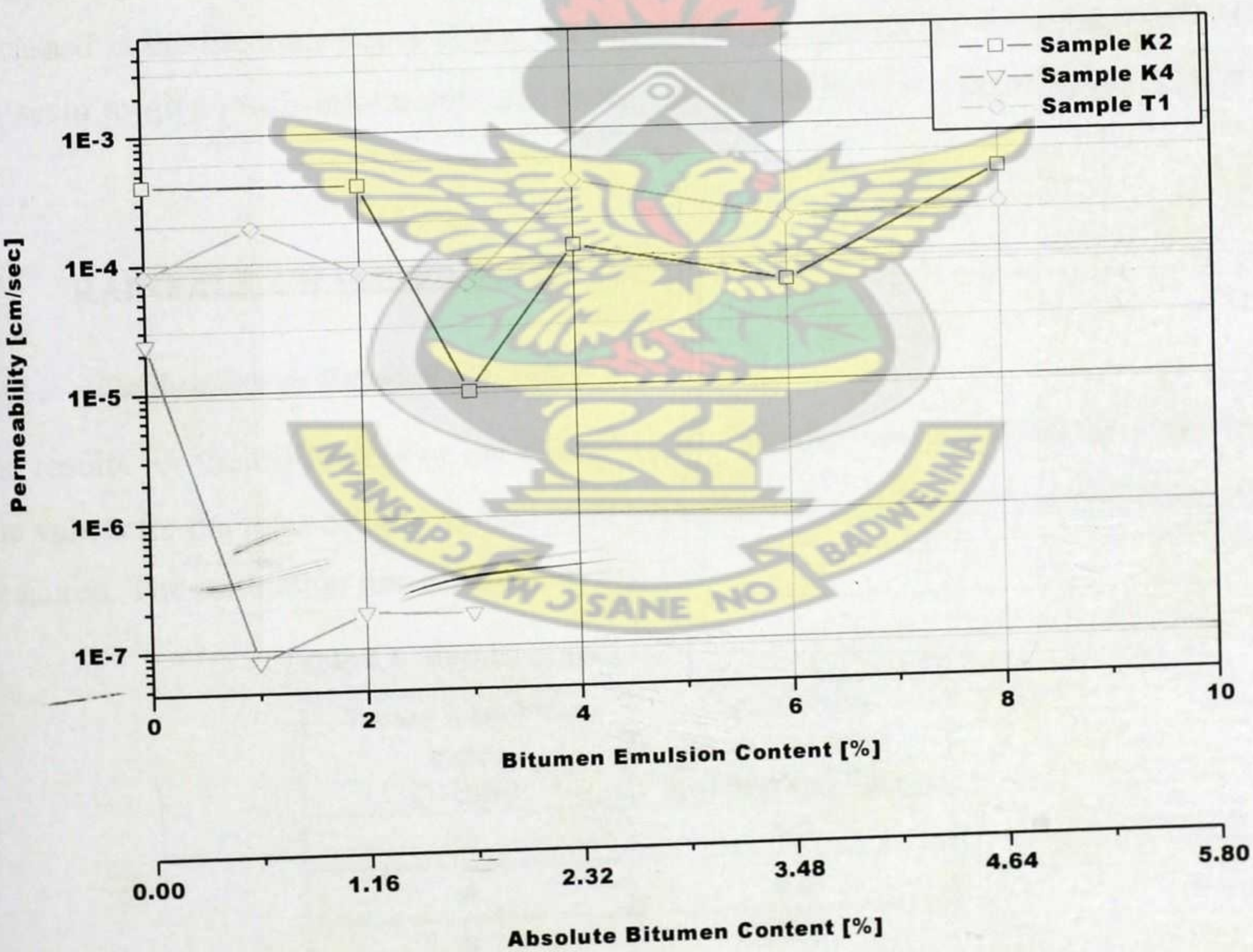

Fig 6.8 Variation of Permeability with Increasing Bitumen Emulsion Content

NB: The Total summary of all the test results for the five samples is shown in the Table 6.8.

6.6. ERODIBILITY POTENTIAL

Since the crumb test is an empirical test method the results is not very conclusive on its own. All the samples used were air-dried and stored. During the drying process the sample was pulverized so much that further thorough mixing with the bitumen broke down the lumped particles further.

The general observation was that the samples were stable in the distilled water with some of them disintegrating slowly immediately but there was no accompanying cloudiness. Since there is a lot of pulverization during the drying process, it was difficult to get a sample 1cm in diameter. Remoulding will change the properties of the sample as has been discussed in the literature hence it was not done. The test was halted since the results did not seem to give much information and there will be the need to maybe try the pinhole test.

6.7. RAINFALL CHAMBER TEST

6.7.1. *Calibration of Rainfall Chamber*

The results for the calibration of the rainfall in the chamber test are shown in Table 6.7. The values for the rates of flow as read from the rotameter is shown against the actual rate measured. The calibration line is shown in Fig. 6.9.

Table 6.6 Results of Rainfall Chamber Caliberation

Rating from Flow meter (L/min)	Actual Flow measured from sprinklers. (L/min)
2	5.6
4	8.0
6	10.8
8	13.3

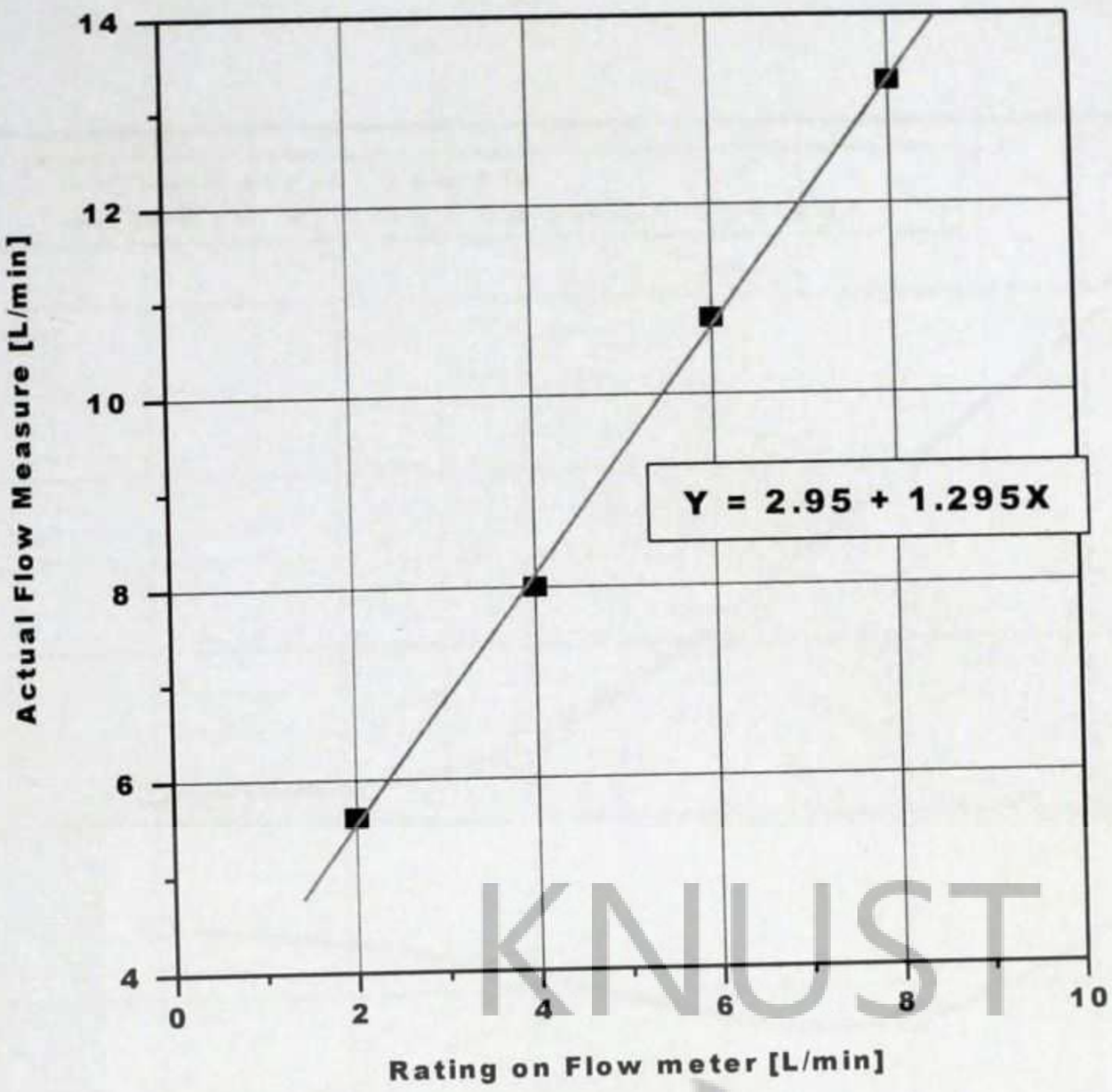

Fig 6.9 Calibration Curve for the Rainfall Chamber

The plot gave a linear relationship between the rotameter reading and the actual flow measured from the sprinklers and is represented by the equation given below

$Y = 2.95 + 1.295X$ ..... *Equation 6.1*

Where Y is the total volume of water flowing from the sprinklers and
X is the rotameter reading

NB the rotameter is unable to deliver water beyond the 9.75L/min when all the 8 sprinklers are in use. When the lower 4 sprinklers are shut then the pump can deliver up to about 18l/min of water from the reading on the rotameter

6.7.2. *Simulated Erosion*

The results of the erosion simulation on the model pavement in the rainfall chamber is shown in Fig. 6.10. The test was performed over a period of 15minutes. The numerical values are shown in Table 6. 8

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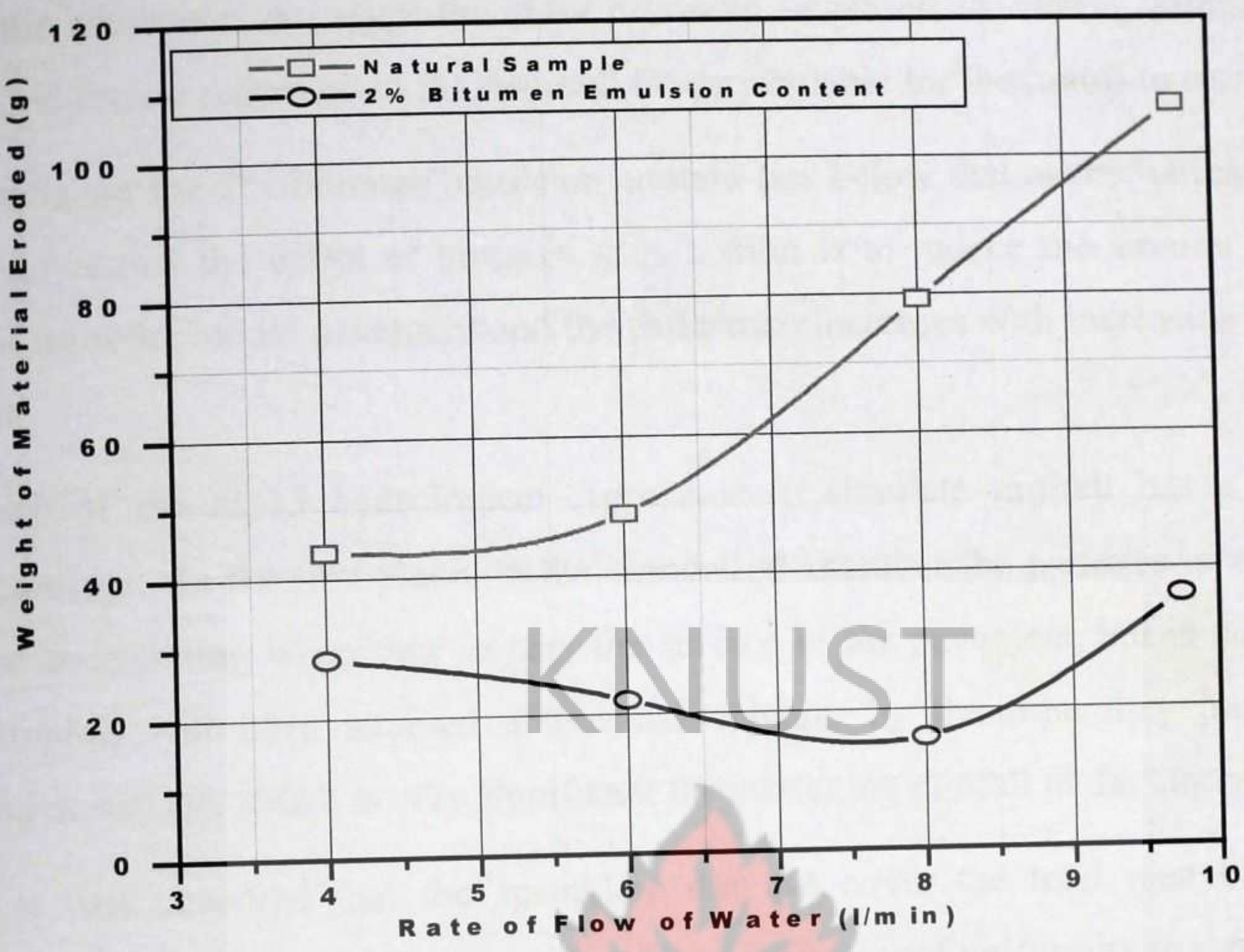

Fig 6.10 Plot of Material Loss Against Rate of Water Flow for the model pavement using material from sample K4

Table 6.7 Summary of results of simulated erosion in Rainfall Simulation Chamber

Rotameter Reading L/min	*Actual rate of flow of water L/min*	*Weight of Material Eroded (g)*	
		Natural material	*2% Bitumen Emulsion Sample*
4	8.1	43.795	28.464
6	10.7	48.825	21.982
8	13.3	79.24	15.95
9.75	15.6	107.45	36.28

The material loss curve for the untreated sample (0% bitumen emulsion content) showed increasing material loss with increasing flow rate. This is attributed to the fact that the more the volume of water that runs over the pavement surface the greater its ability to carry particles in suspension hence more particles are carried into the runoff chamber. The material loss curve for the 2% bitumen emulsion treated sample showed a slight initial decreases in material loss with increasing rate of flow up to 13l/min and then a slight increase beyond that. This may be attributed to the fact that it is possible that most

of the fines were washed off during the first trial using the 4l/min flow rate measured from the rotameter, so when the flow rate was increased to 6l/min, 8l/min and then 9.75l/min there a reduction in the material freely available for the runoff to carry.

The curve for the 2% bitumen emulsion content lies below that of the untreated sample. This shows that the effect of bitumen stabilization is to reduce the amount of material eroded from the model pavement and the difference increases with increasing intensity of rainfall.

The use of the H313 hydrological Apparatus to simulate rainfall has a number of shortcomings. In the first place, in the simulation chamber the particles or droplets will still be accelerating when they impact the surface of the pavement, but in actual rainfall the droplets will have attained a terminal velocity by the time they impact on the pavement surface, which is very significant for modelling rainfall in the laboratory.

Also it was observed that the sprinklers did not cover the total area of the model pavement. The results of the calculation of the coefficient of uniformity is shown below.

Total surface area of the impact of the pavement $= 2.09 \times 0.94 = 1.96\ m^2$

Actual area of pavement covered by Sprinkler $= 8 \times 3.14 \times 0.40^2 / 4 = 1.00\ m^2$

Coefficient of uniformity $= 1.00 \times 100 / 1.96 = 51\%$

The calculation shows that only about 50% of the total surface area of the pavement actually made contact with the simulated rainfall

6.7.3. *Estimation of the Actual Intensity of the Rainfall Event Simulated*

The amount of rainfall corresponding to the rates measured from the sprinklers can be compared to actual rainfall and the derivation is as follows

For the 4L/min rate of sprinkling measured from the rotameter the actual flow is given a

$= 8.1$ L/min

Total volume of rainwater generated during the single rainfall event of 15min duration simulated in the chamber is given as

Volume $= 8.1 \times 15$

Volume of rainfall in litres $= 121.5$ Litres

Volume in cubic meter $= 121.5 \times 0.001 m^3$

$= 0.1215 m^3$

Total rainwater per unit area is =0.1215/1.96

=0.06199m

=61.99mm

The intensity for 1hr per unit area =61.99 x 4

=247mm/hr

Comparing the rainfall intensity values obtained above with typical rainfall intensity values in Ghana it implies that the values are very high compared to real rainfall events in the country. The height of the H313 hydrological chamber is such that the sprinklers are just about 1m above the pavement surface hence it is not possible for the raindrops to attain terminal velocity within the chamber before impacting on the pavement. The clearance height of the rainfall chamber gives the situation where the particles are still accelerating when they impact on the pavement surface. It is thus not possible to relate the calculated values to real situations, but for the purpose of this experiment the range of values is all that was possible to use. Also wind effect is common in our part of the world and it was not possible to simulate the effect of wind on the falling raindrops.

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NB: The Graphs from the Laboratory Test and the Laboratory Test Results are all shown in the Appendices

CHAPTER SEVEN

7 CONCLUSION AND RECOMMENDATION

7.1. CONCLUSION

The following conclusions were arrived at based on the observations that were made during the experiments

1. The optimum value of bitumen for effective stabilization is about 2% of the bitumen emulsion content by weight of the material.
2. Increasing bitumen emulsion content causes the CBR and MDD values to increase to a maximum at around 2% bitumen emulsion content with further increase in the bitumen emulsion content causing a decrease in the CBR and MDD values. The resulting values becoming lower than that for the untreated material for bitumen emulsion contents about 8% and above.
3. On the whole the effect of curing is not significant on the investigated engineering properties of the materials
4. There is an increase in the larger particles and a degree in the smaller particles sizes when treated with bitumen emulsion
5. The Atterberg limits are not significantly affected by the addition of Bitumen
6. Permeability is not affected by the addition of bitumen emulsion to the soil material.
7. Erodibility Index (crumb test) results gave limited information in that the sample all stayed without much change during the 24 hour observation period
8. Bitumen Emulsion content of about 2% has the potential to reduce the rate of erosion of material from the pavement surface by about two to four fold as is shown in the Fig 6.18.

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7.2. RECOMMENDATIONS

Considering the situation that Ghana finds herself in terms of financing the maintenance of existing roads and the construction of a new ones the various test the following recommendation will be made

- Samples from other climatic areas in the country should be investigated to give further information on the behaviour of bitumen emulsion treated laterites especially in reducing the rate of erosion of pavement material.
- A field trial should be conducted on pavements to confirm the erosion results obtained in the laboratory when natural climatic factors are acting on the pavement

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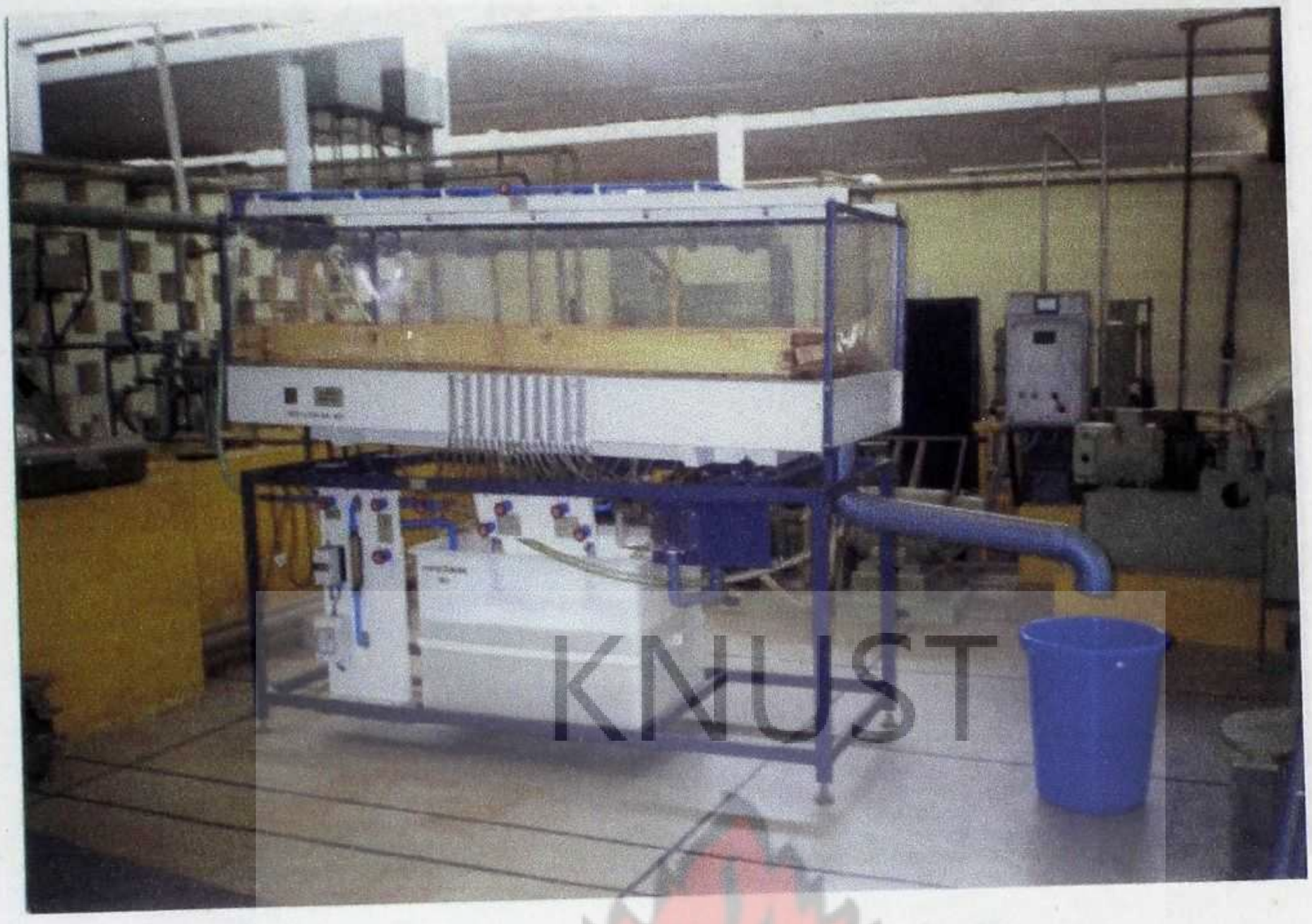
APPENDICES



Picture 1- Experimental Setup for the Erosion Chamber Test

Picture 2 – Showing the Runoff Collecting into the Bucket

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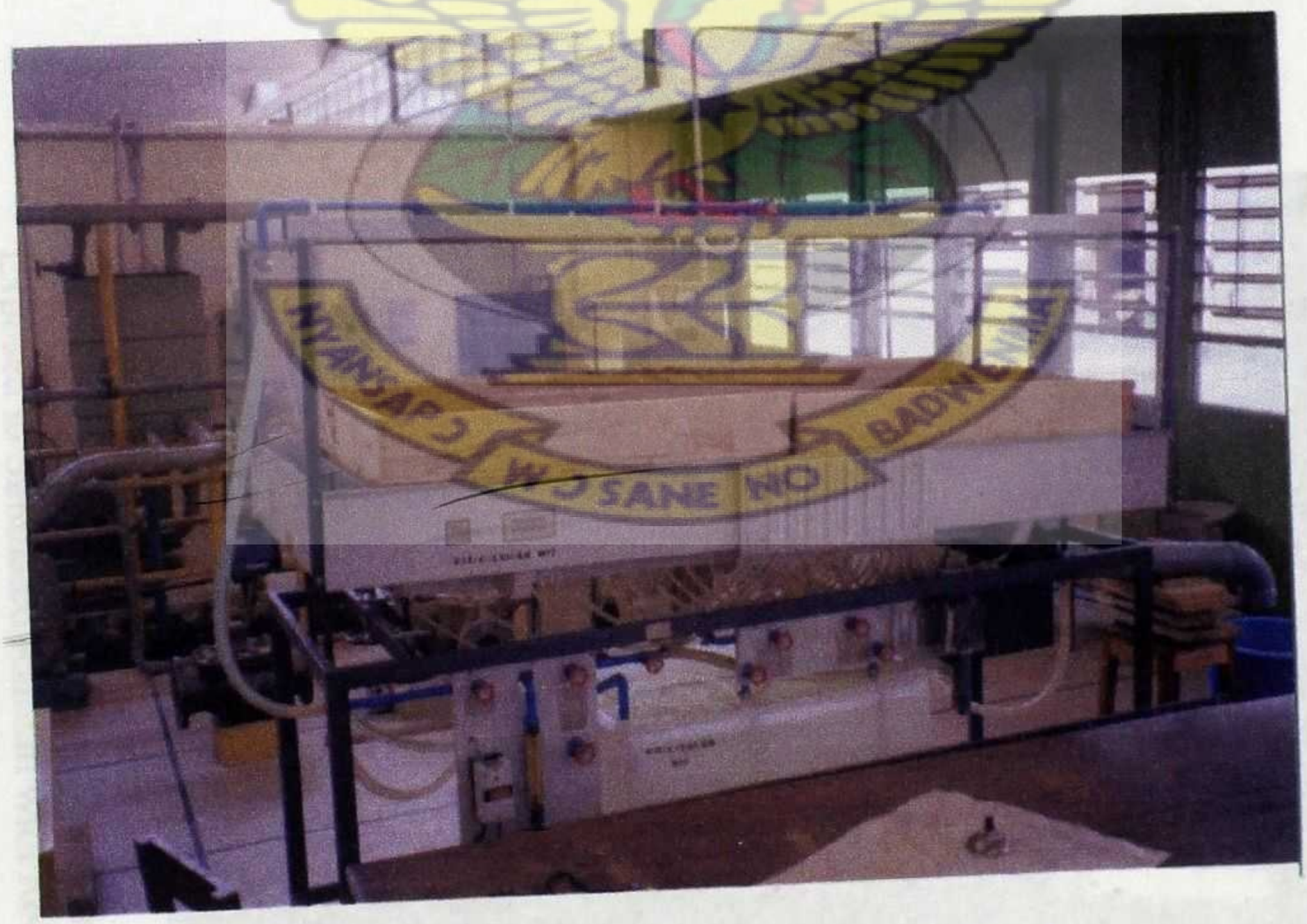
Picture 3 - Model Pavement Placed in the Erosion Chamber During the Experiment



Picture 4 - Model Pavement Placed in the Erosion Chamber During the Experiment with one Perspex Cover Removed

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Picture 5a – Showing the model Pavement Being Exposed to Simulated Rainfall with Rotameter Reading 6l/min

Picture 5b – Showing the model Pavement Being Exposed to Simulated Rainfall with Rotameter Reading 6l/min

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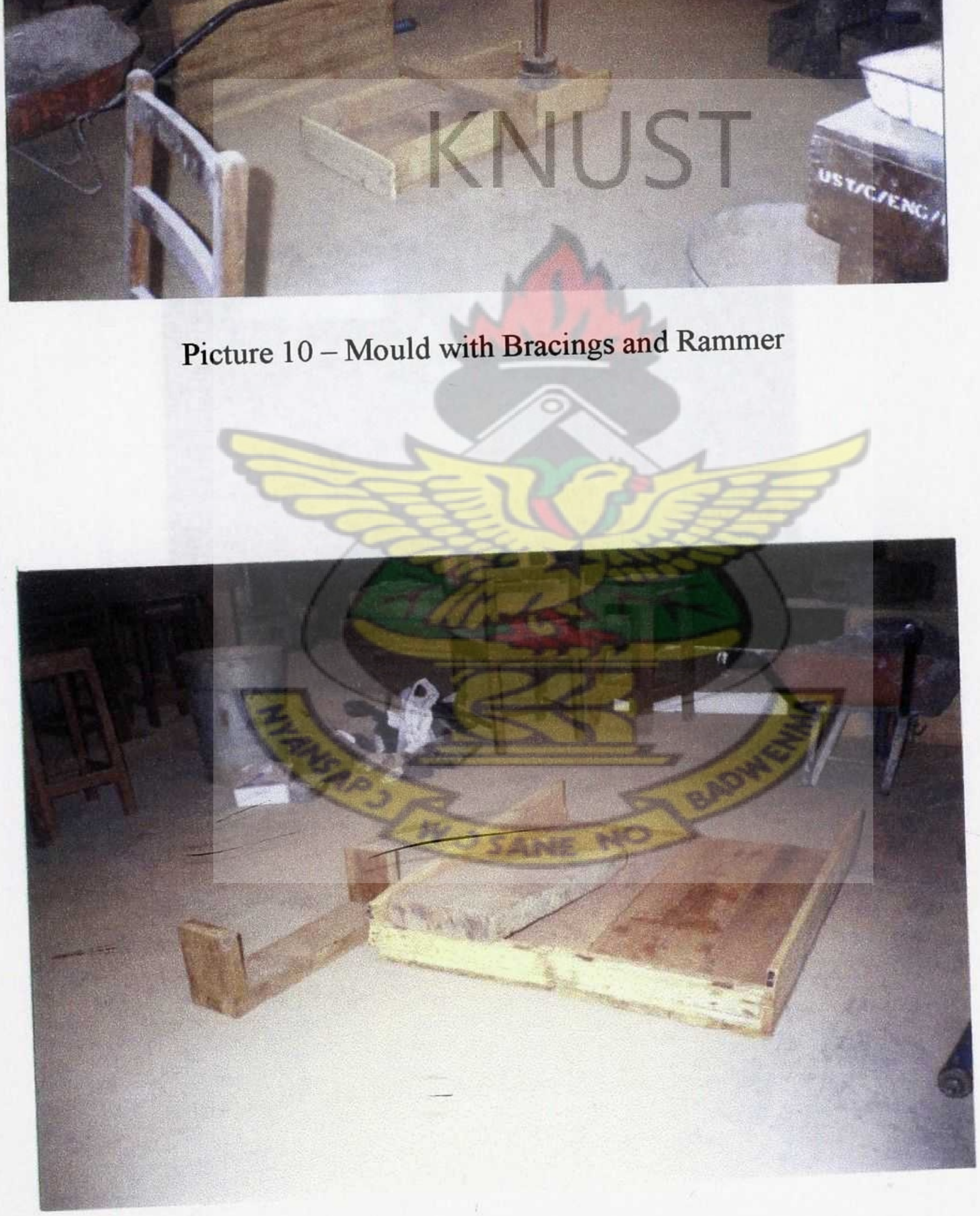
Picture 6 - Surface of the Model Pavement Before Simulating Rainfall

Picture 7 – Material being weighed on a Balance Scale before Mixing

Picture 8 – Mixing the Material with Water Prior to Compaction

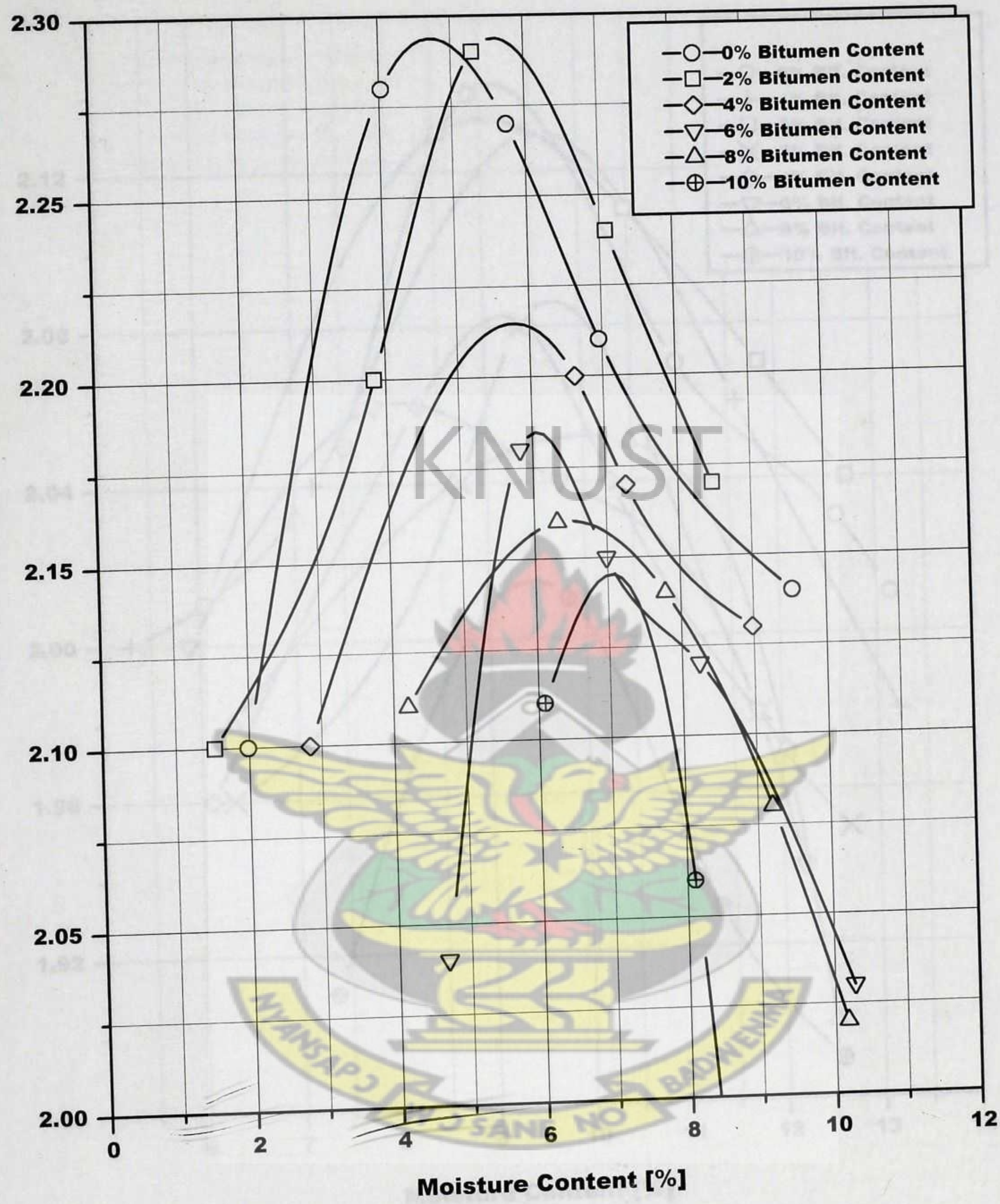
Picture 9 – Mould with the Bracing and Wooden Board for Compaction

Picture 10 – Mould with Bracings and Rammer



Picture 11 - Showing Two Moulds as Arranged in the Rainfall Chamber

Picture 12 - Rammer



Compaction Characteristics Curves for Sample K1

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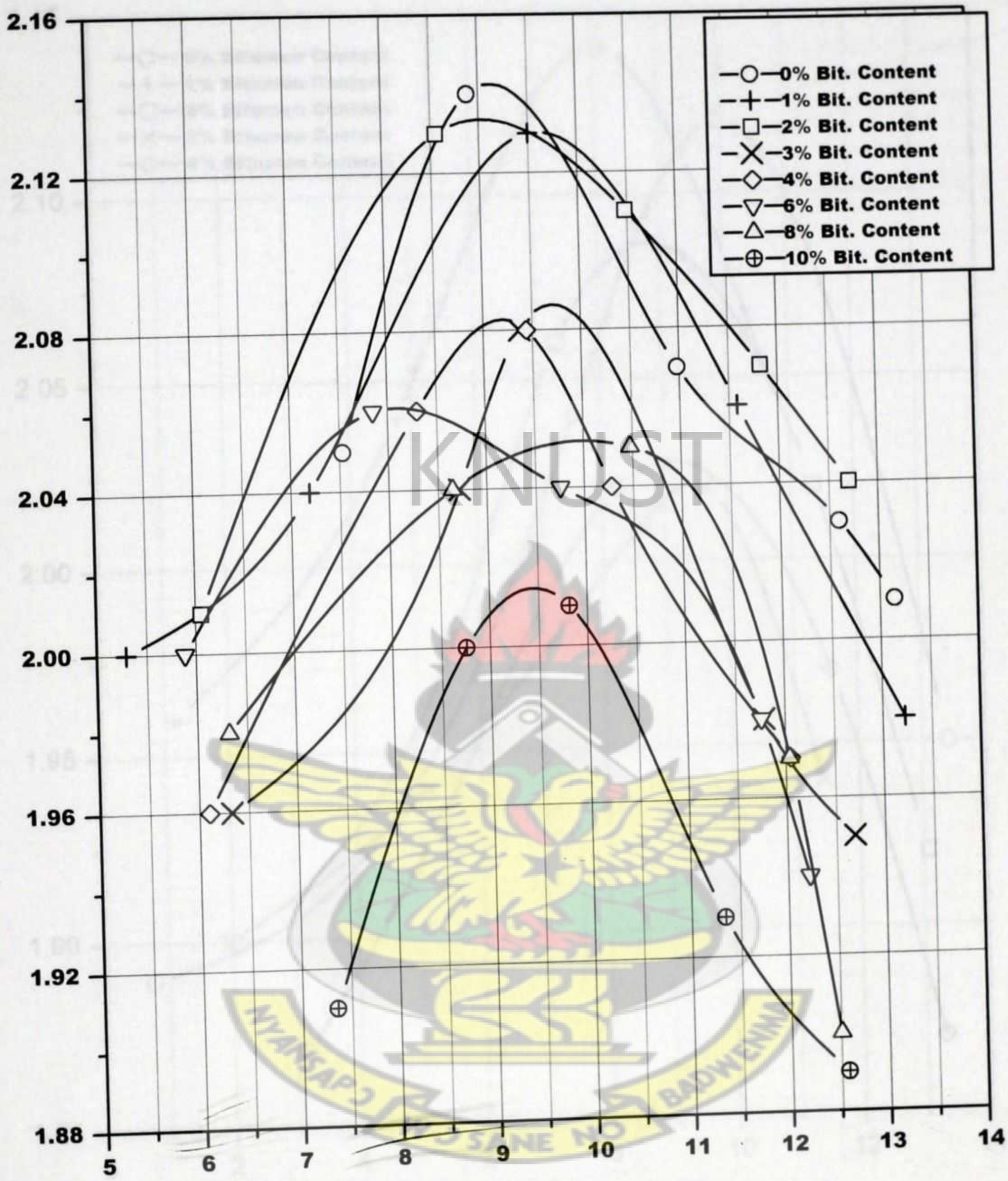
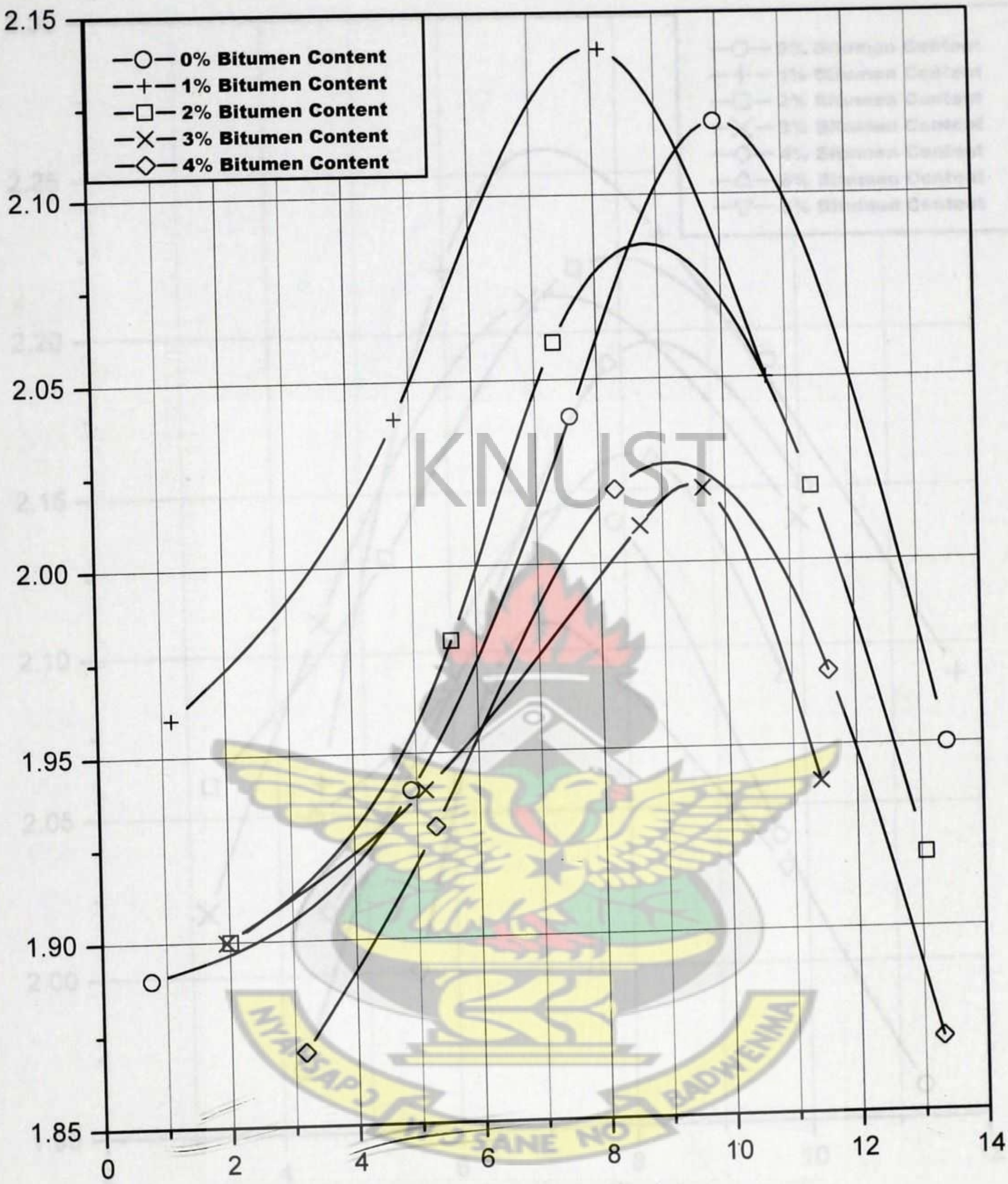


Compaction Characteristic Curves for Sample K2

Appendix A2



Compaction Characteristics Curves for Sample K3

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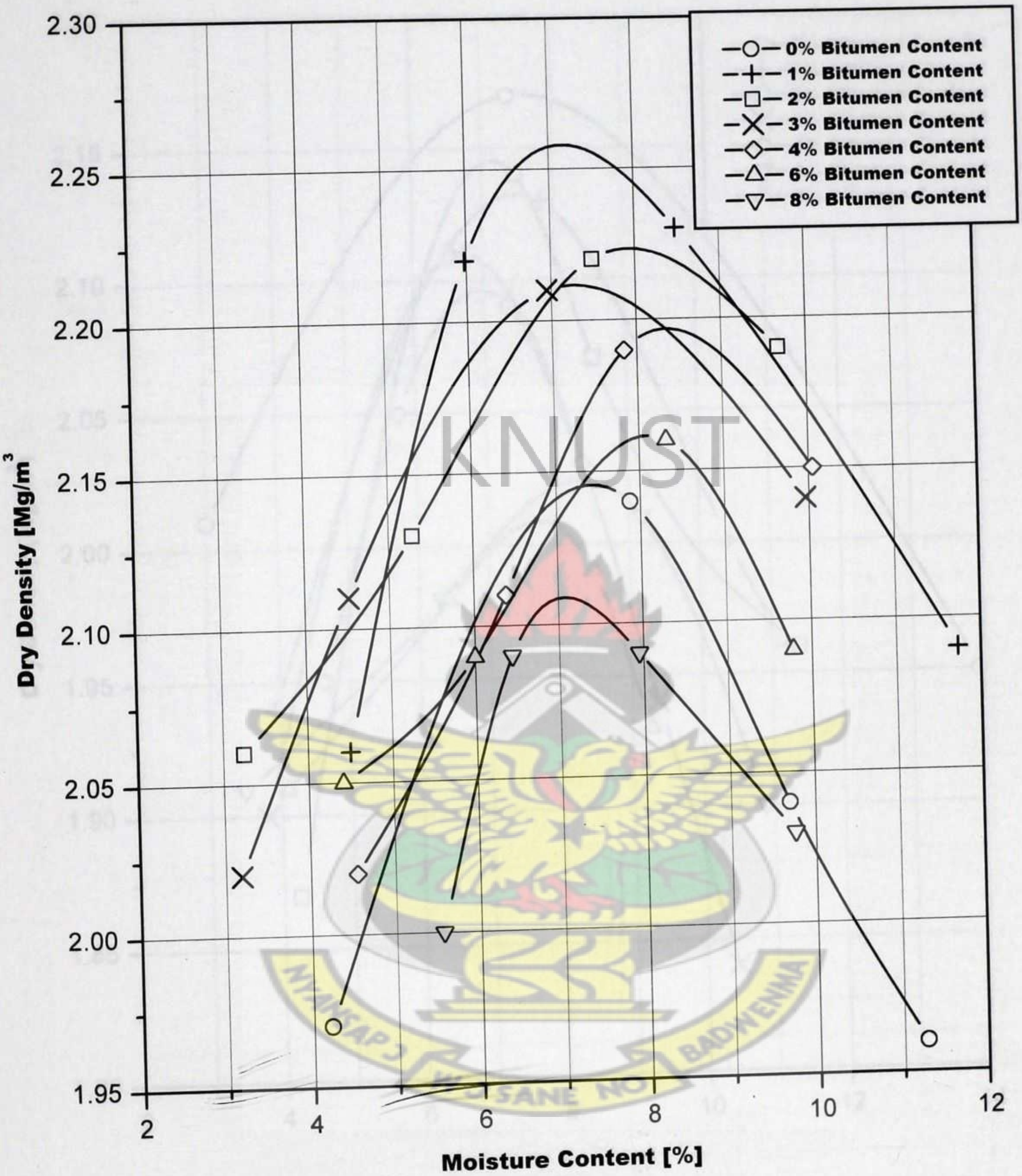
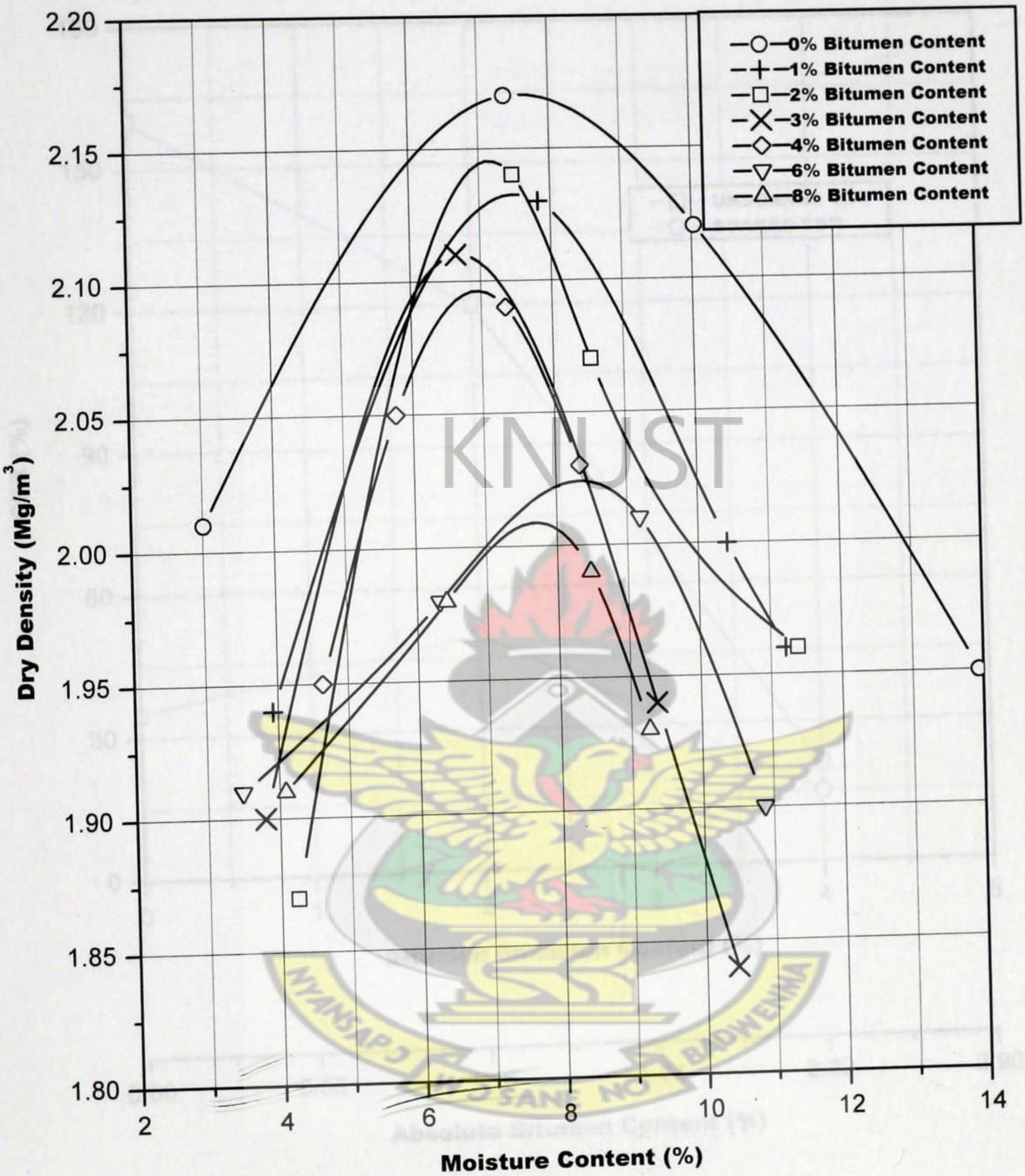
Appendix A3



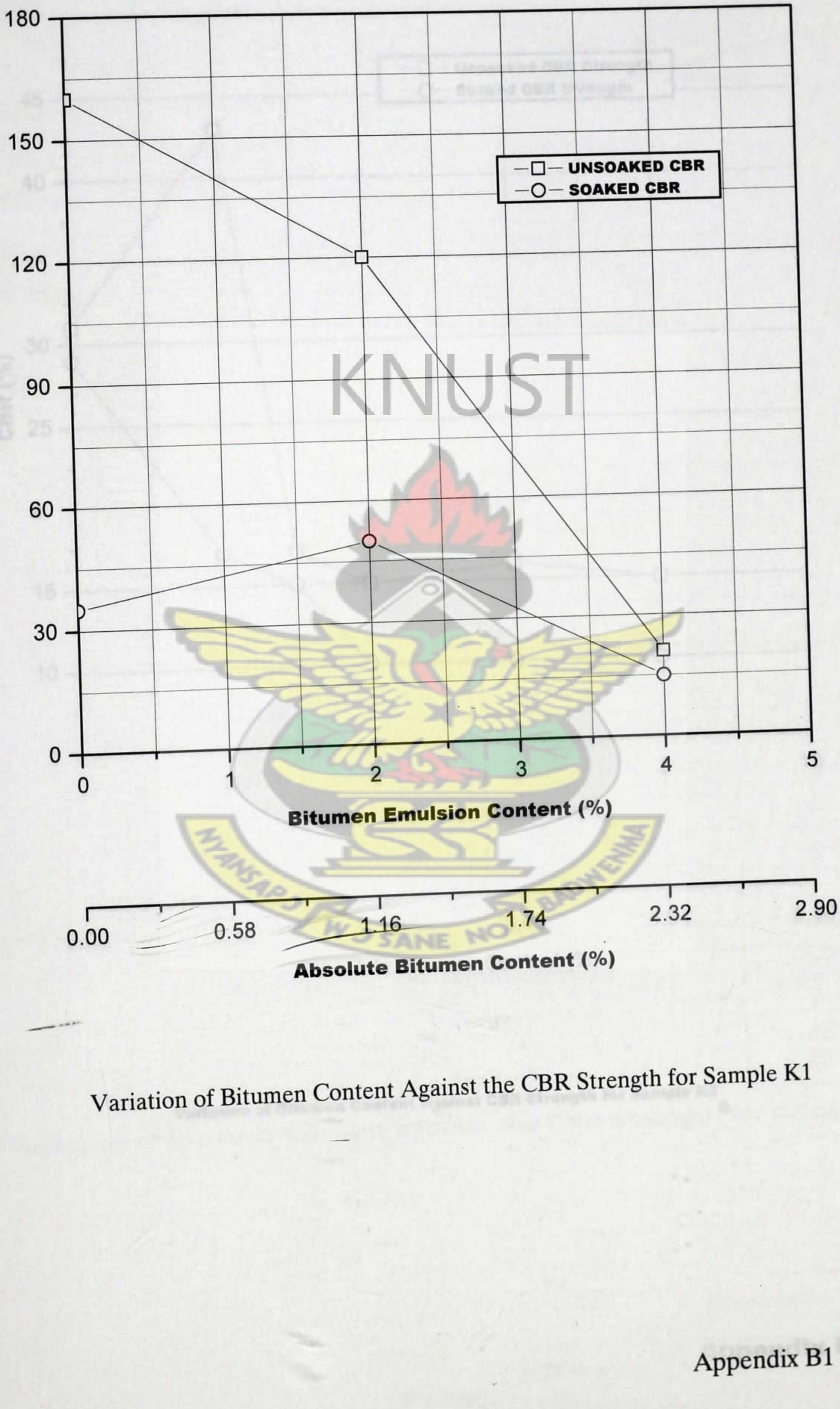
Compaction Characteristics Curves for Sample K4

Appendix A4

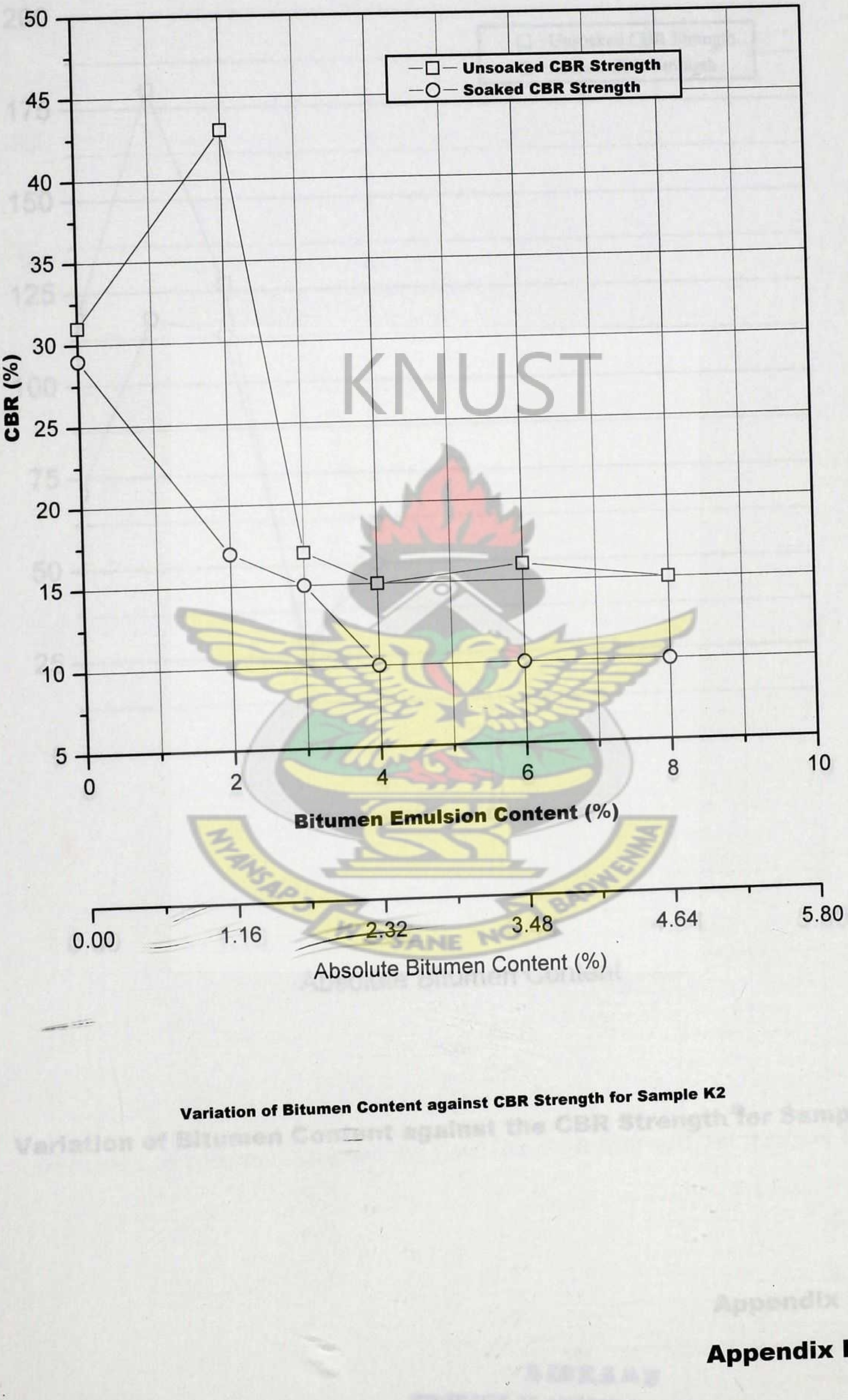


Compaction Characteristics Curves for Sample T1

Appendix A5



Variation of Bitumen Content Against the CBR Strength for Sample K1



Variation of Bitumen Content against CBR Strength for Sample K2

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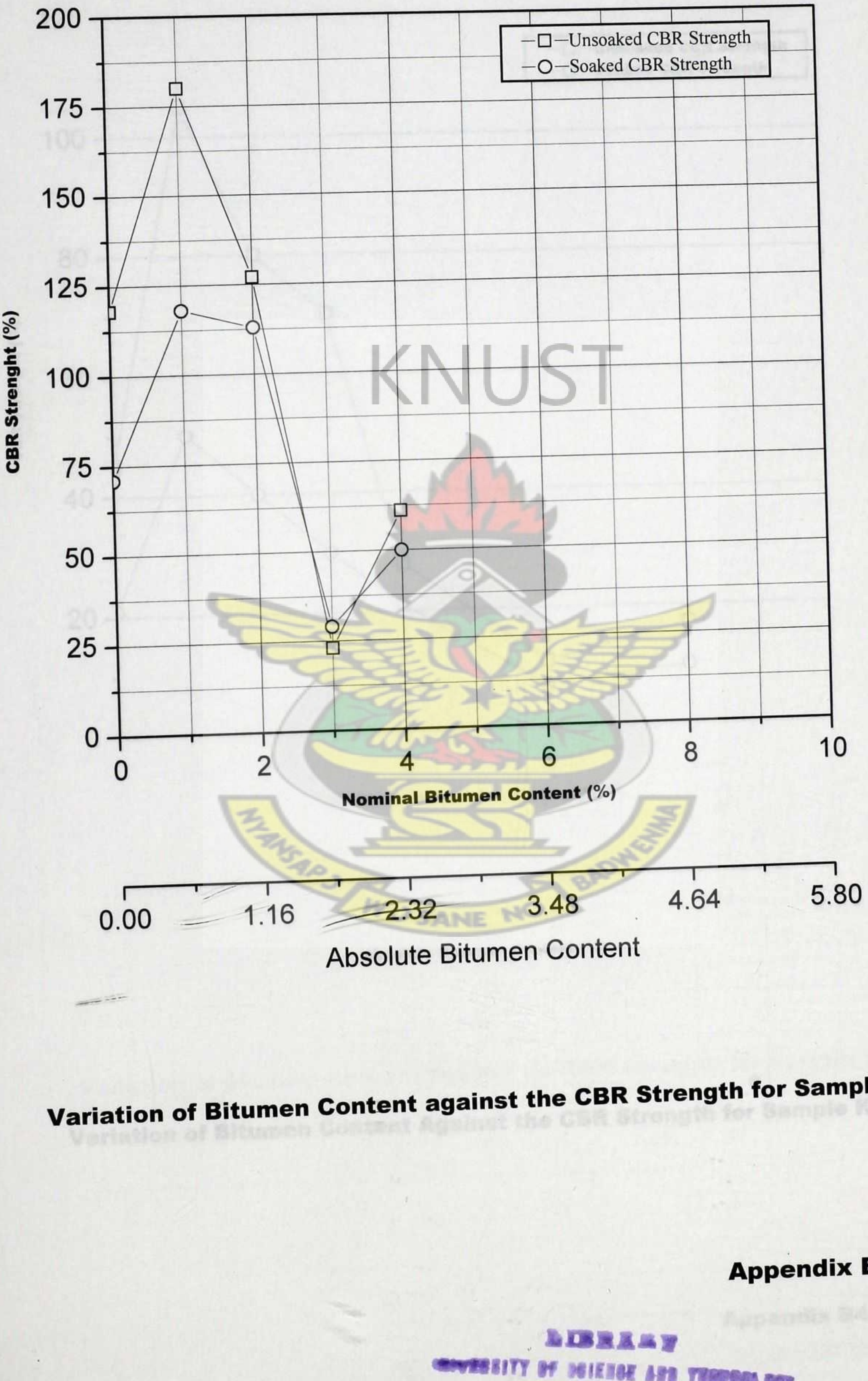
Appendix B2



Variation of Bitumen Content against the CBR Strength for Sample K3

Appendix B3

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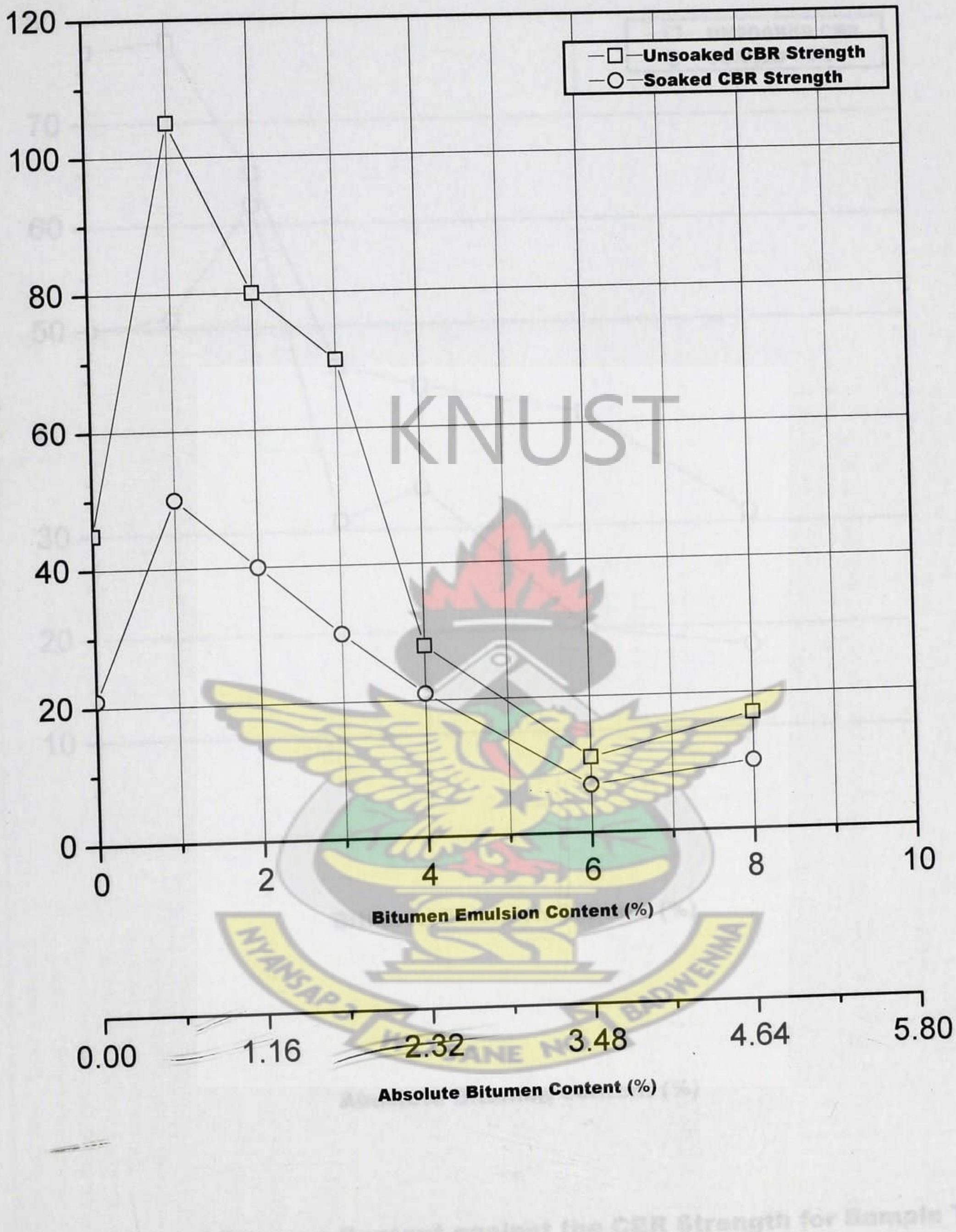

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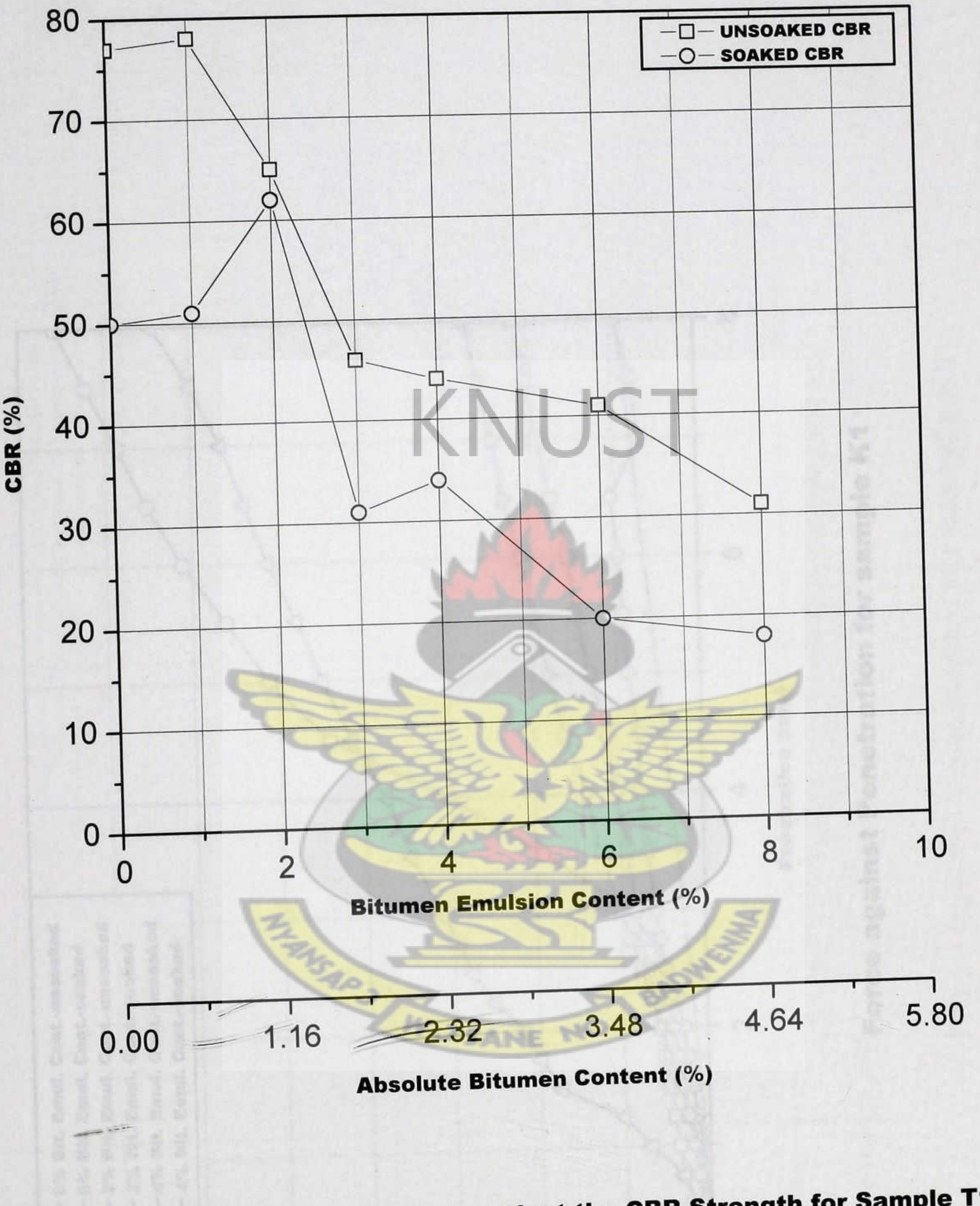
Variation of Bitumen Content Against the CBR Strength for Sample K4

Appendix B4



Variation of Bitumen Content against the CBR Strength for Sample T1

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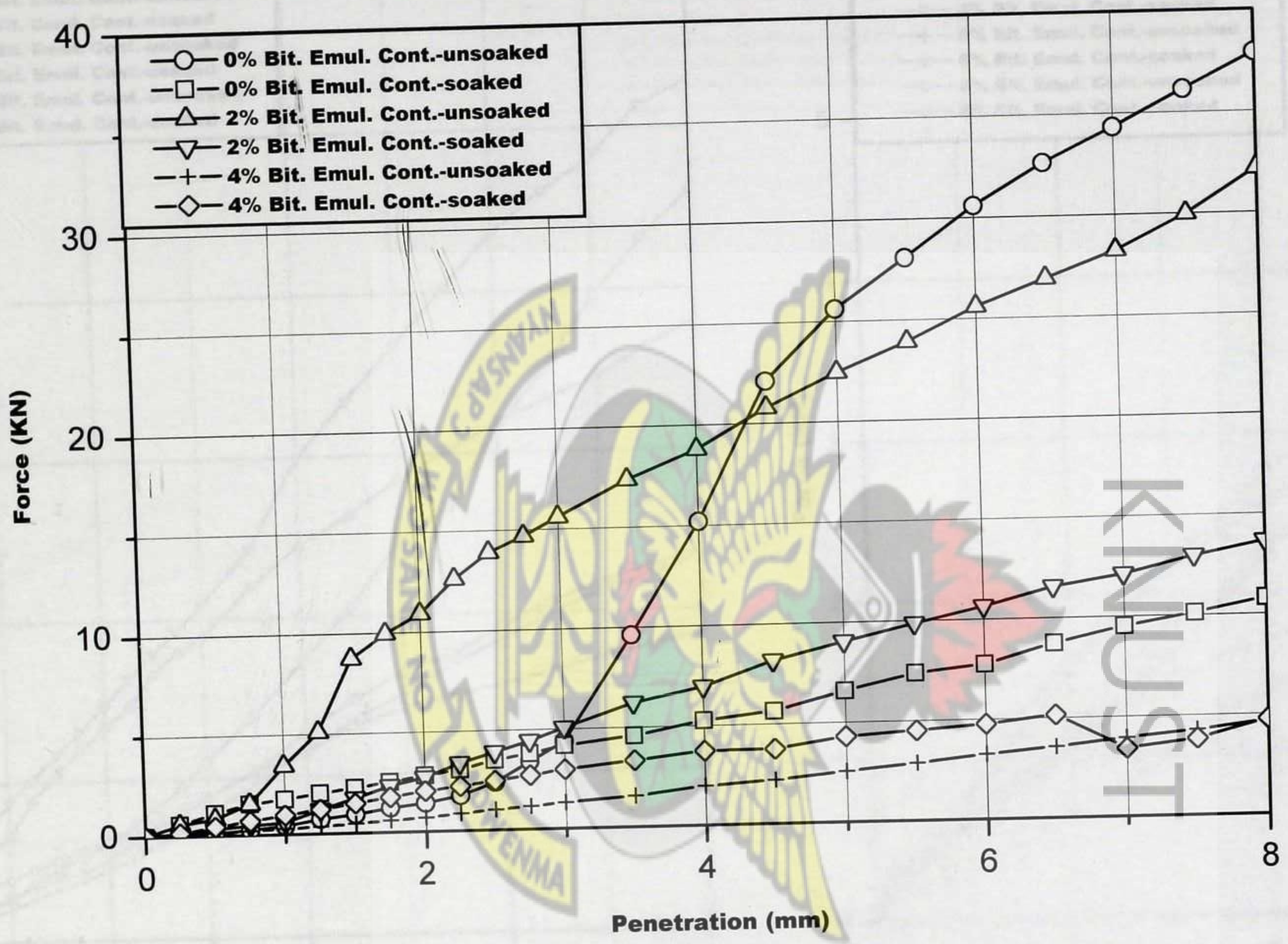
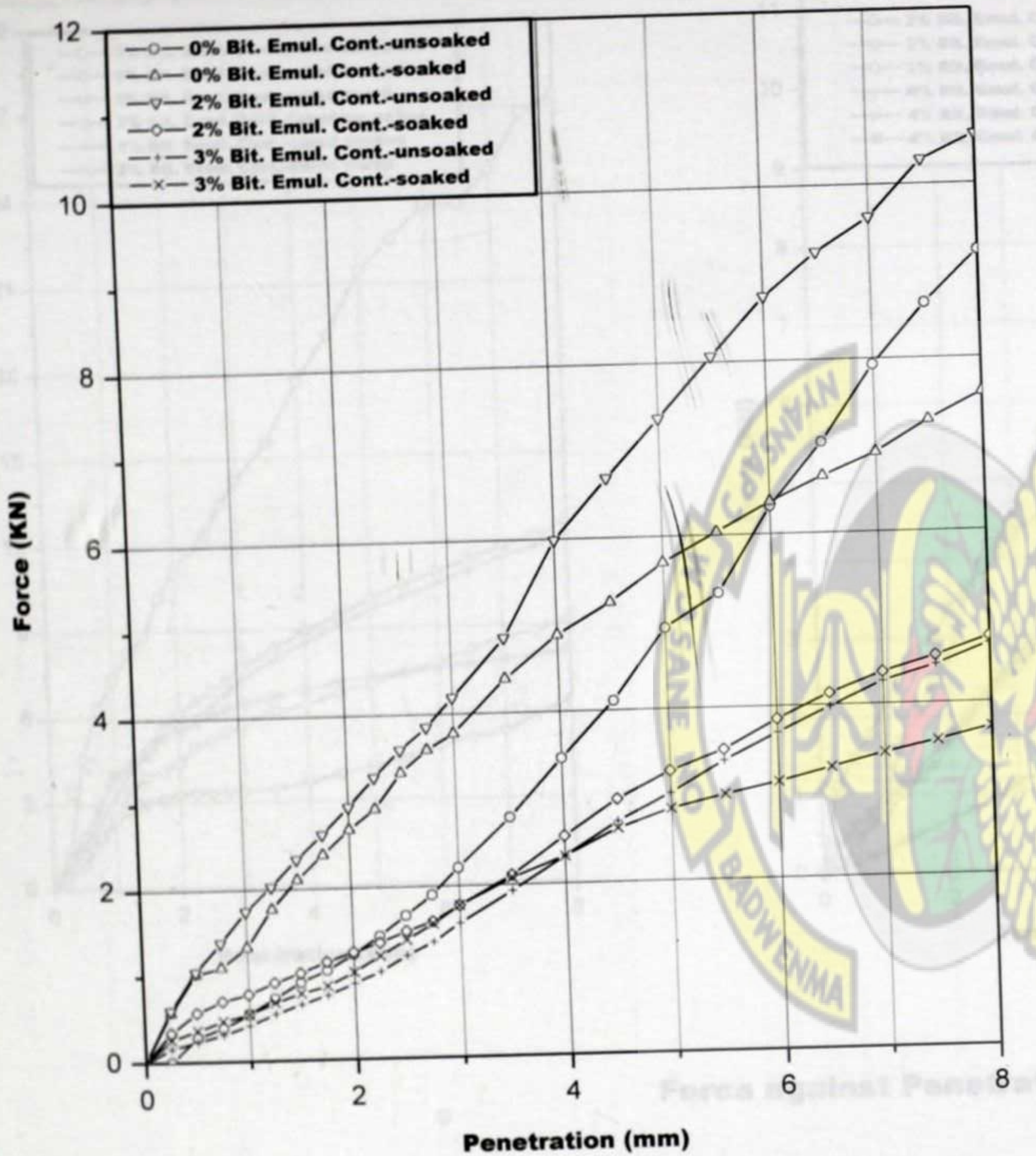
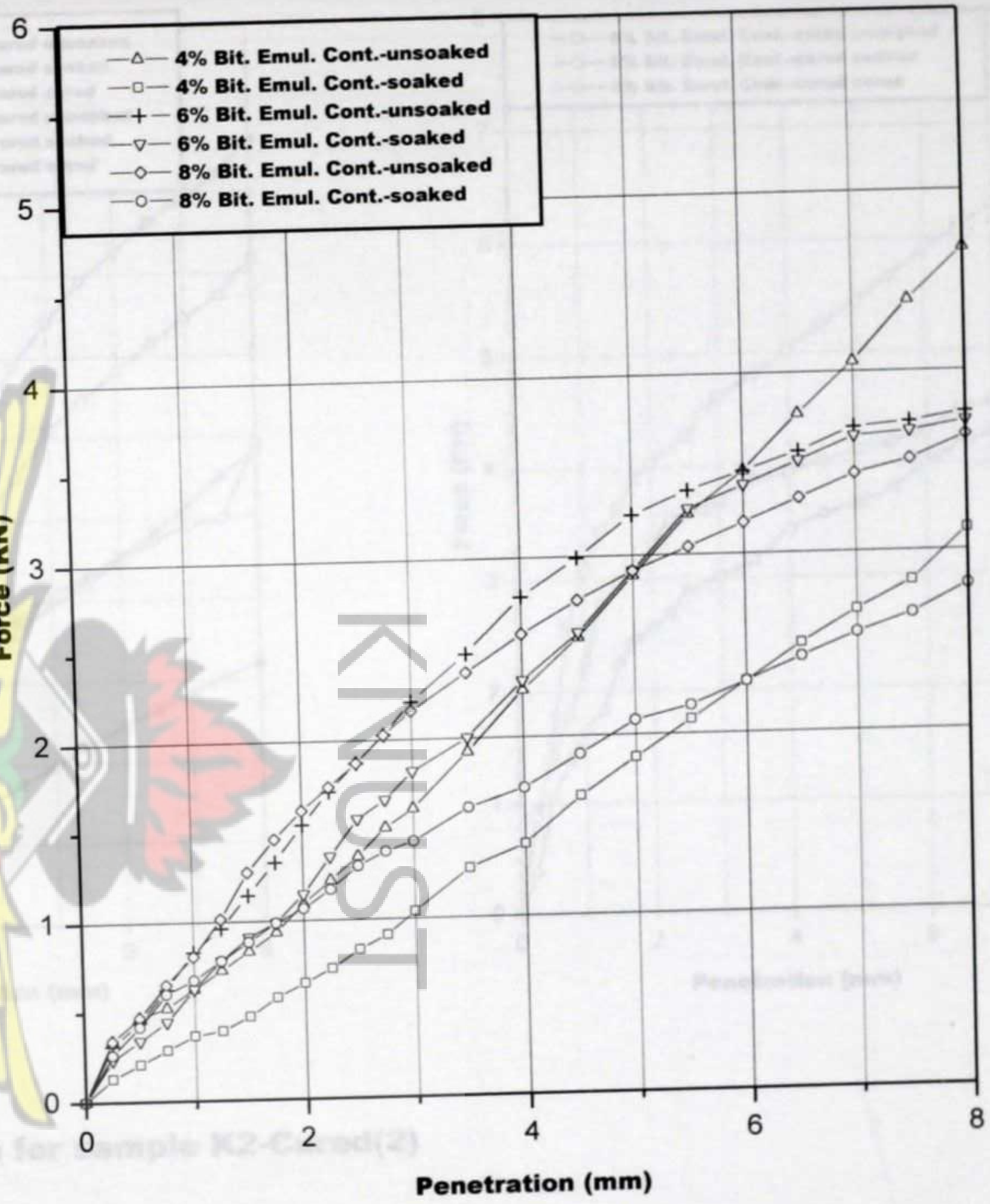


Force against Penetration for sample K1

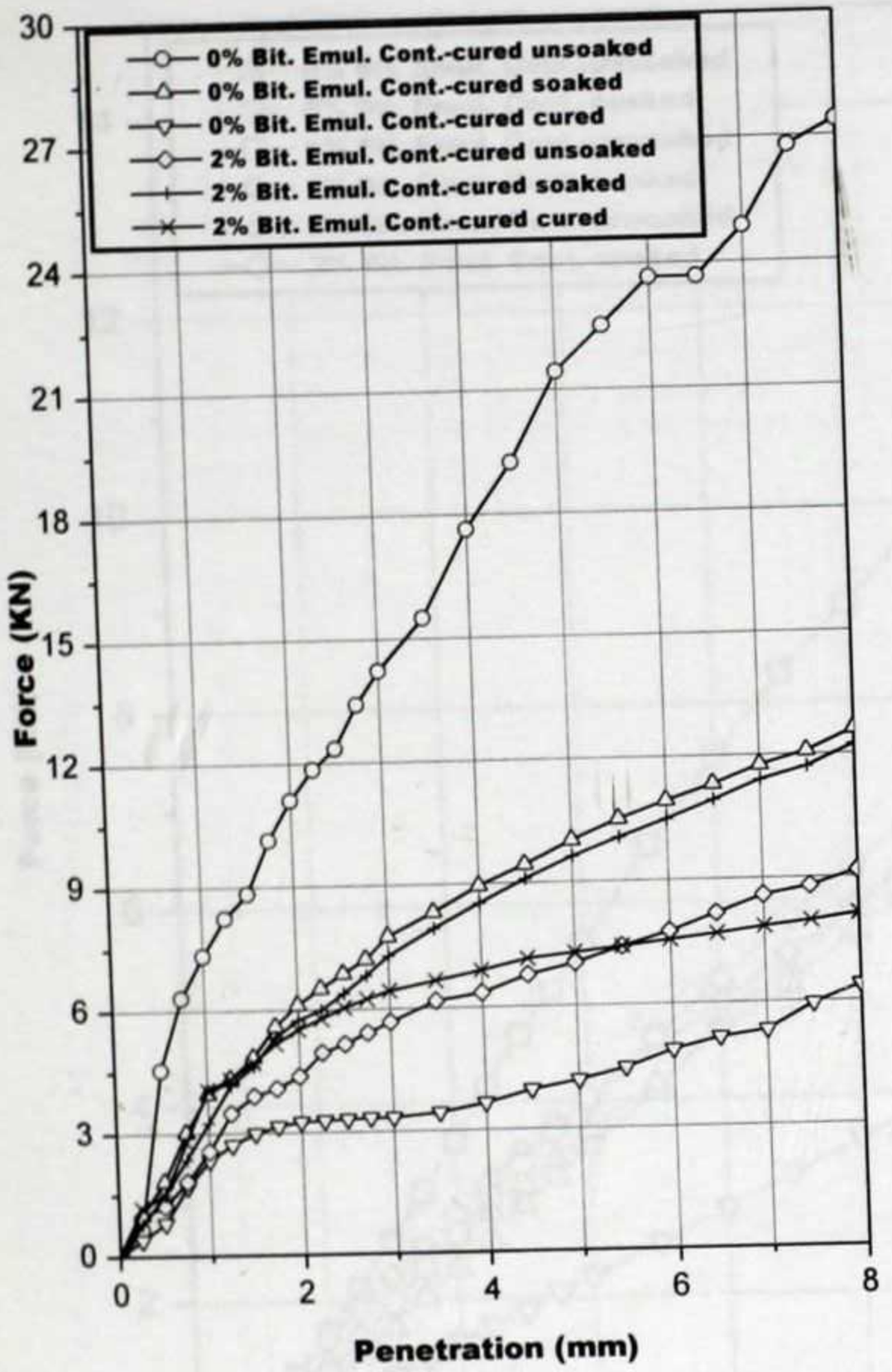
Appendix C1

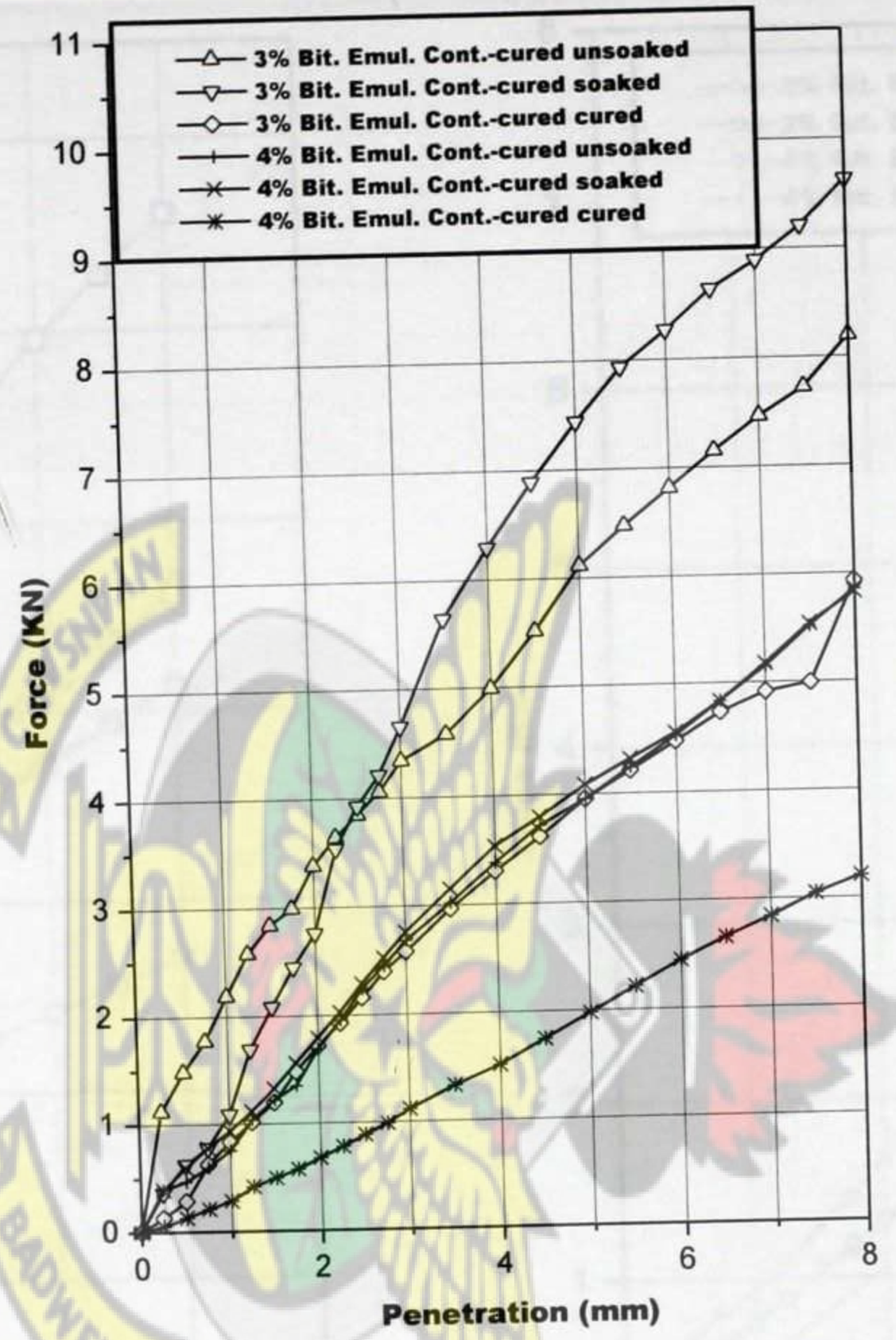


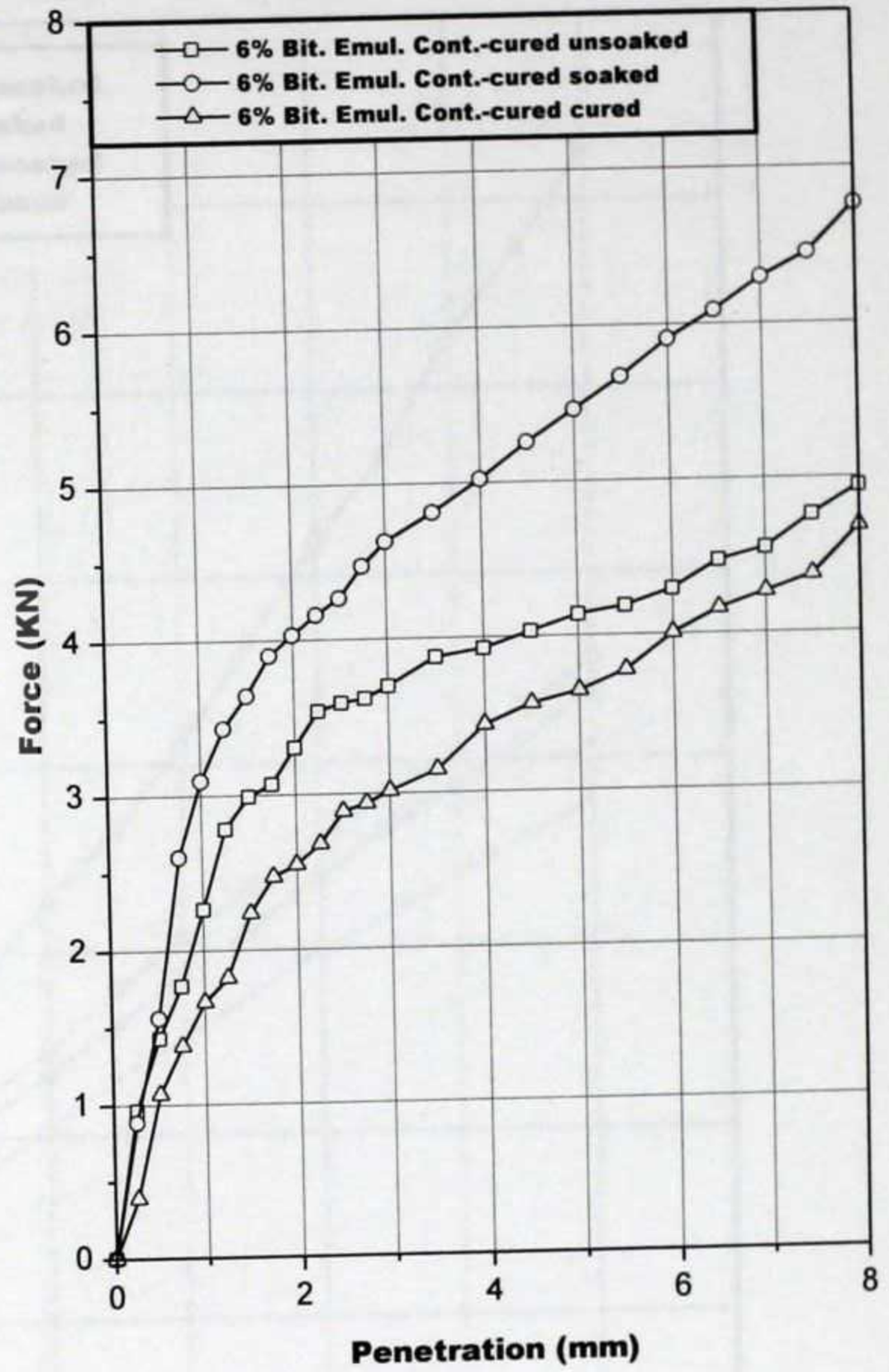


Force against Penetration for sample K2

Appendix C2

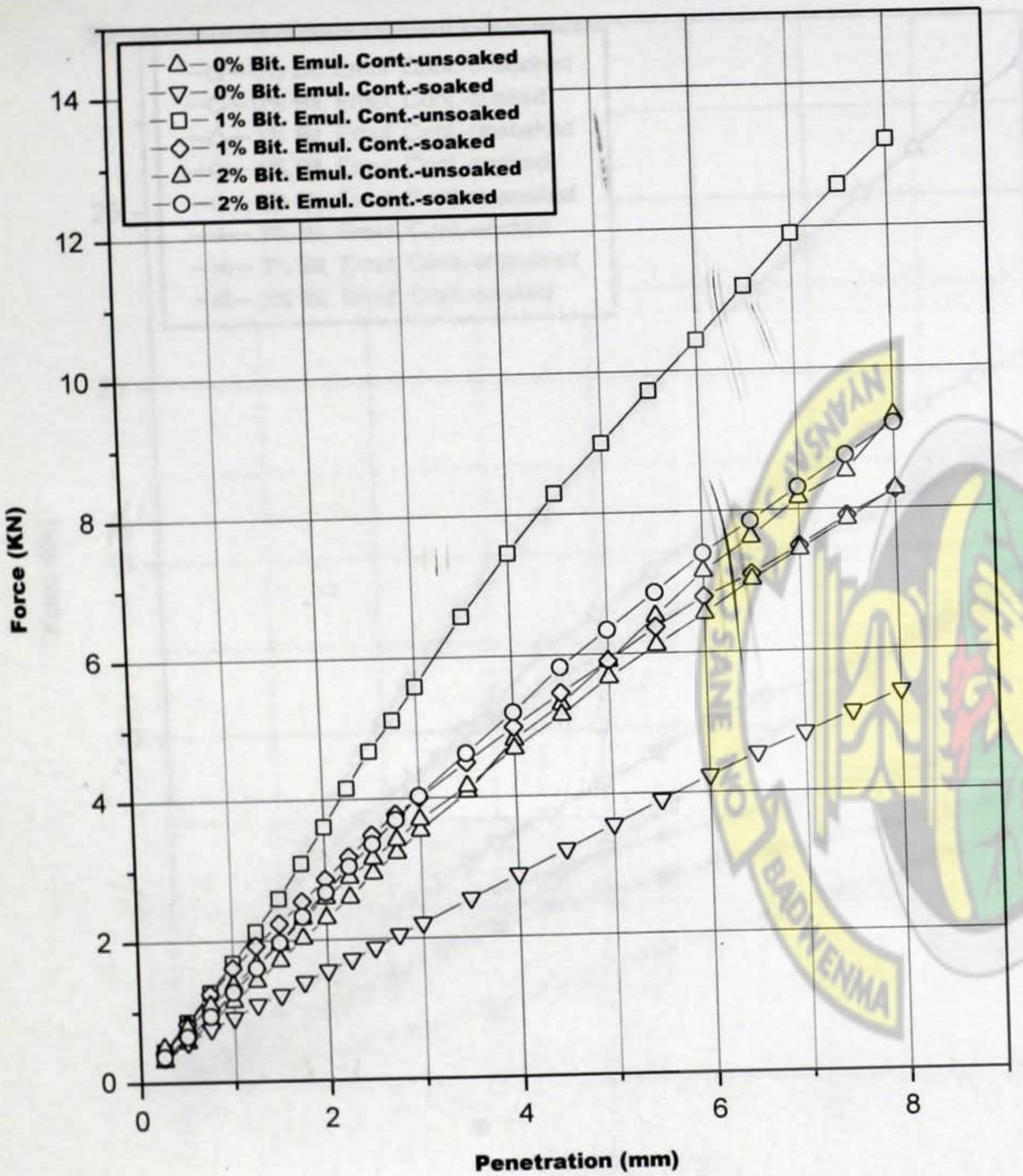


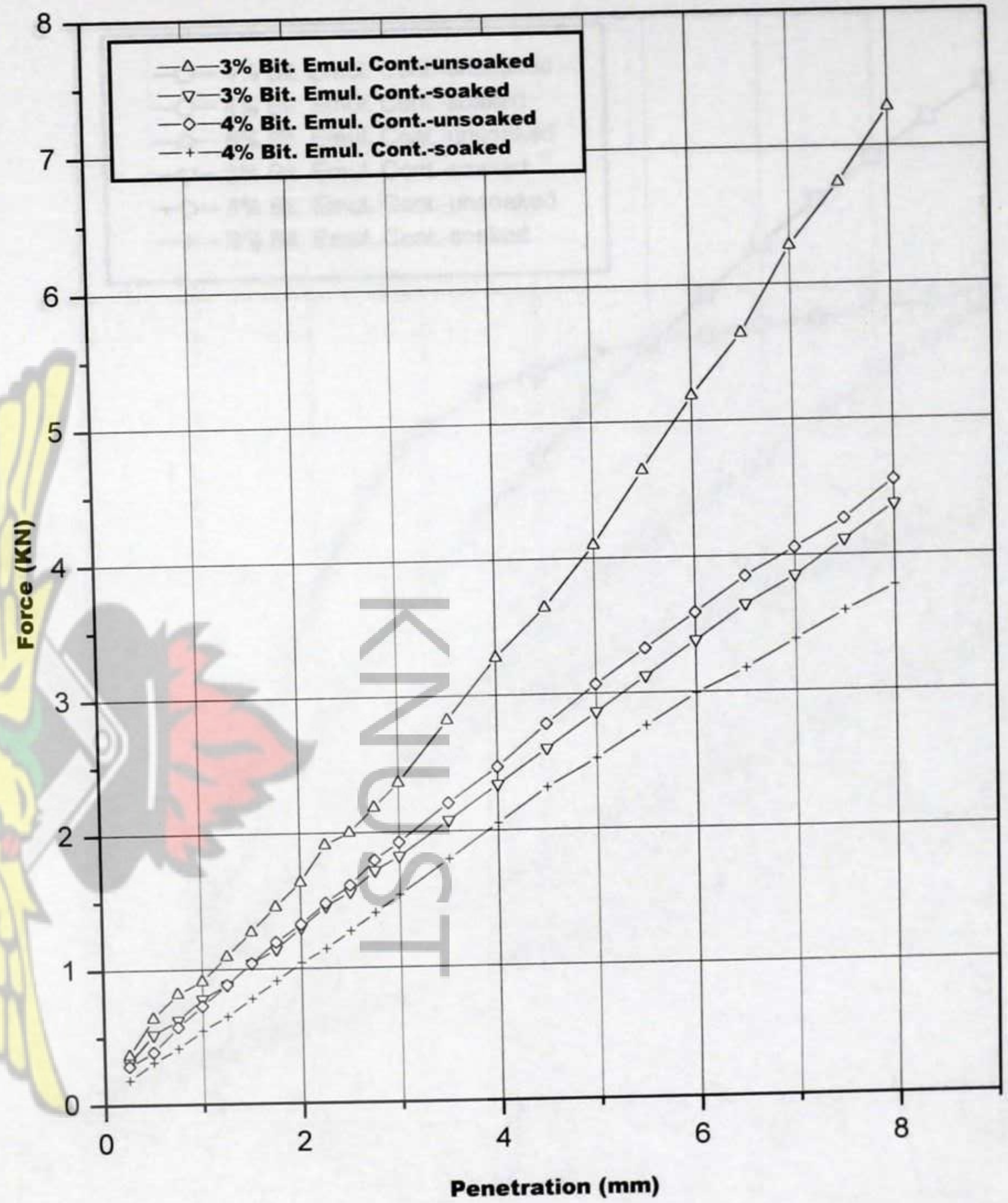




Force against Penetration for sample K2-Cured(2)

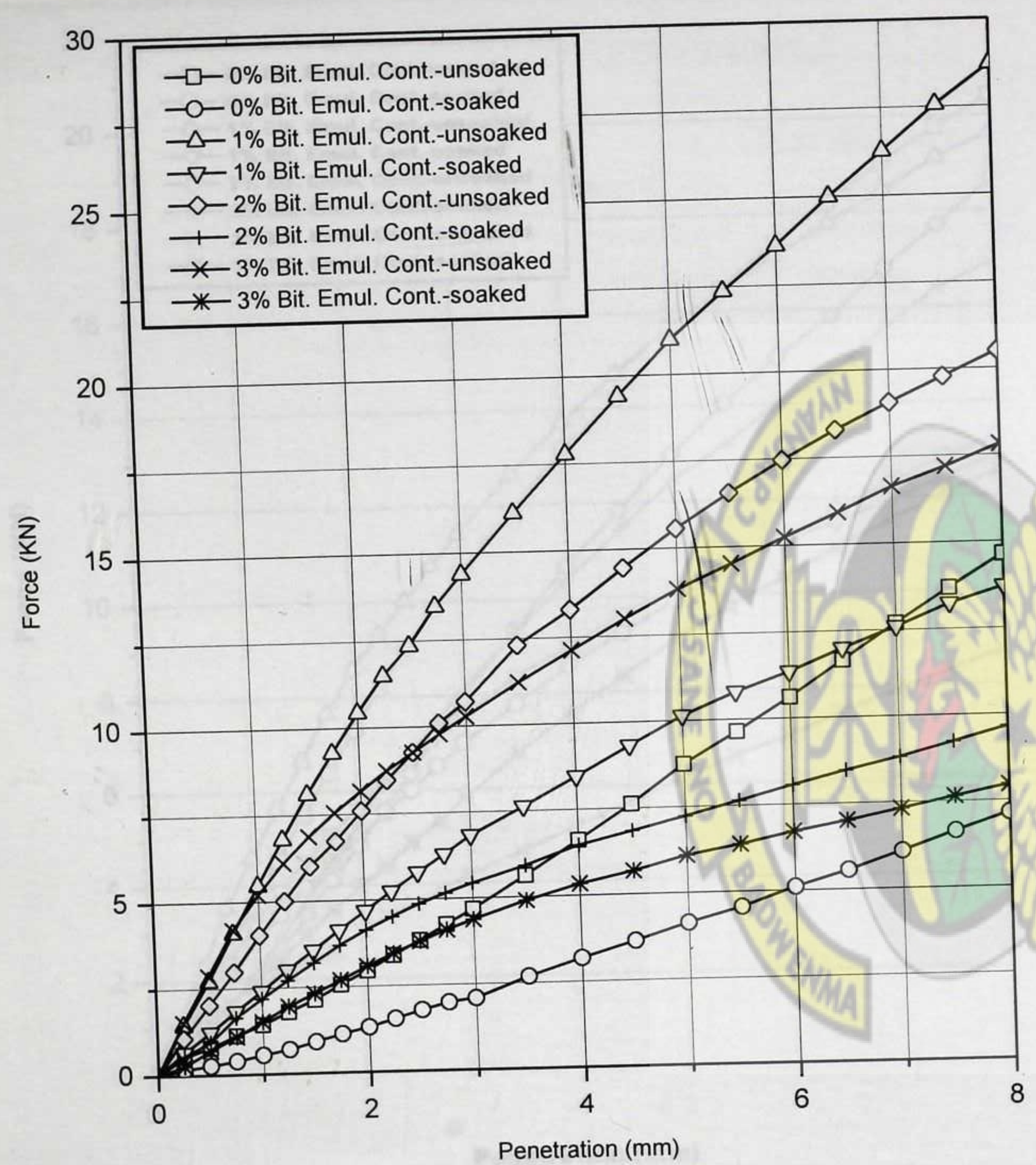
Appendix C3

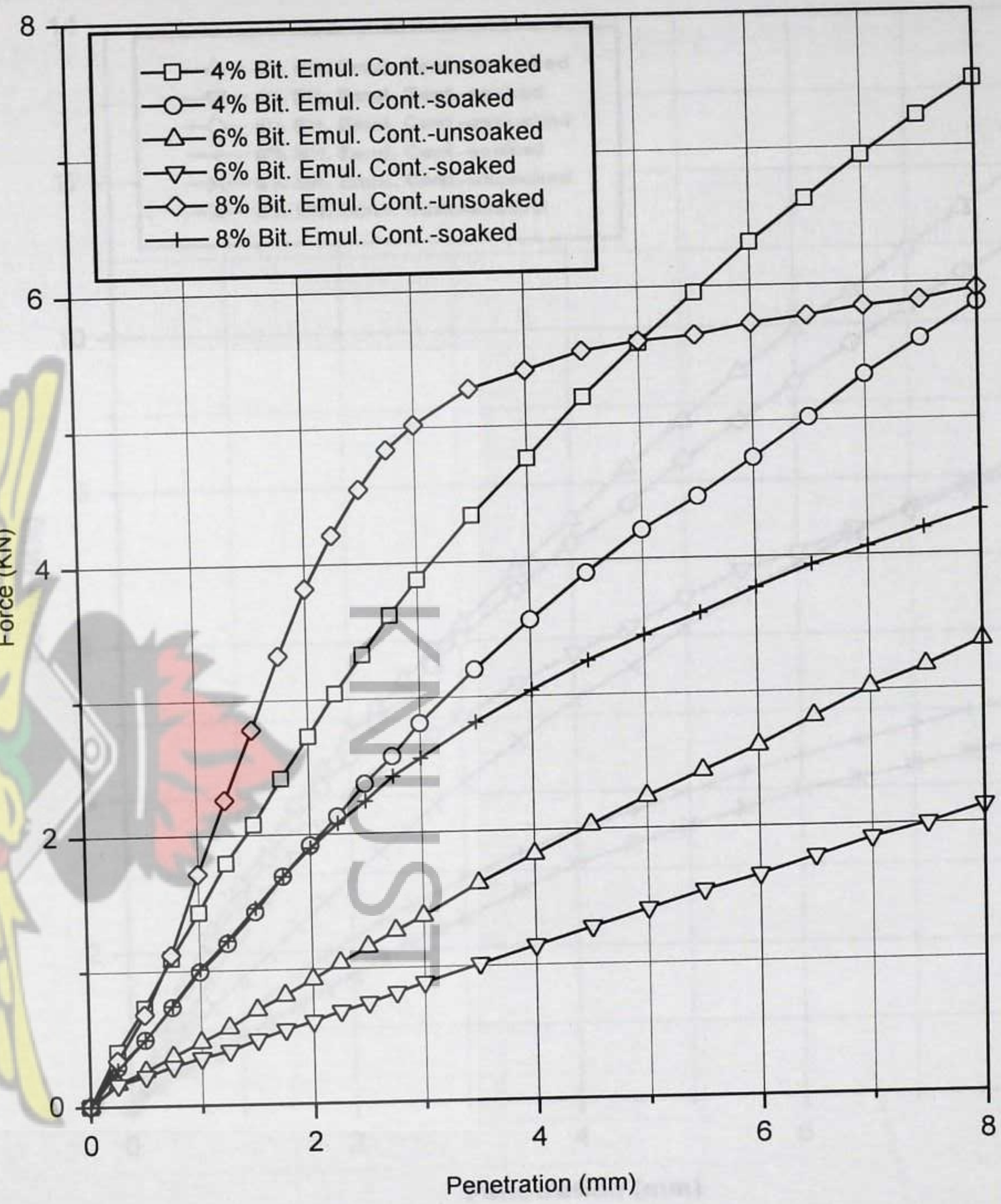




Force against Penetration for sample K3

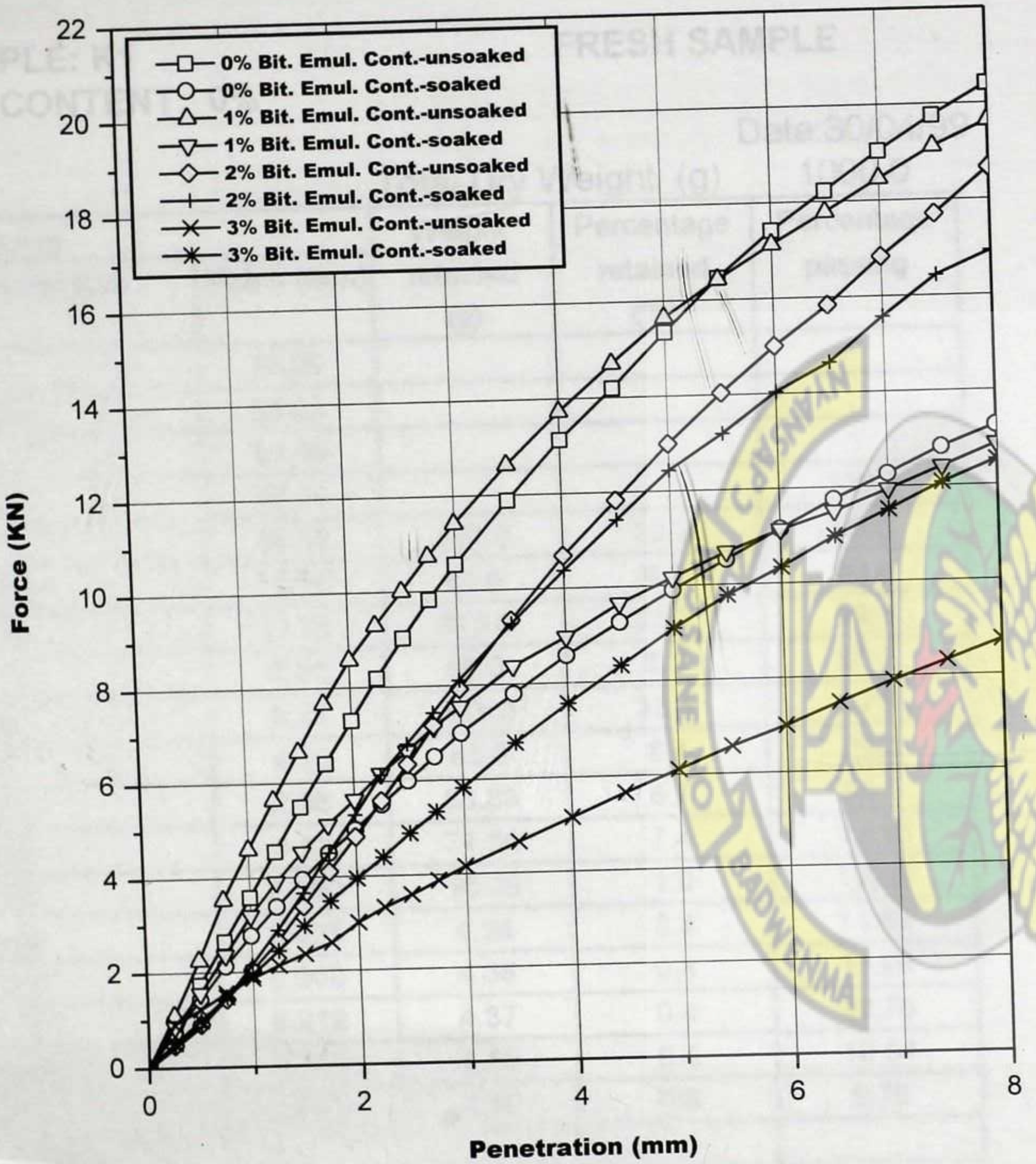
Appendix C4

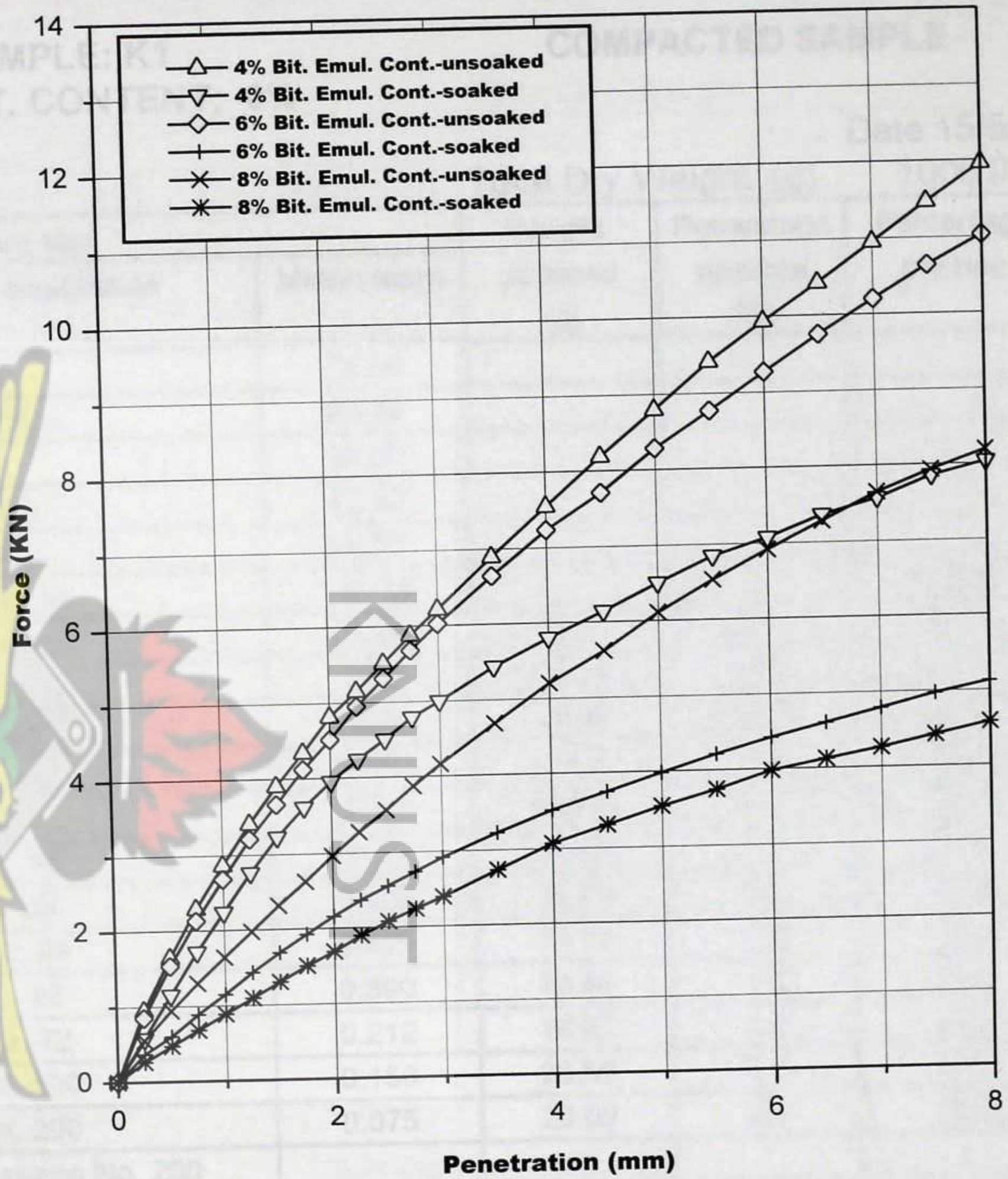




Force against Penetration for sample K4

Appendix C5





Force against Penetration for sample T1

Appendix C6

CIVIL ENGINEERING DEPARTMENT

GRADING ANALYSIS

SAMPLE: K1
BIT. CONTENT: 0%

FRESH SAMPLE

Date:30/04/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			100.0
1 in	26.50	102.0	10.2	89.8
¾ in	19.00	91.6	9.2	80.6
½ in	13.20	213.0	21.3	59.3
⅜ in	9.50	86.5	8.7	50.7
¼	6.70	131.0	13.1	37.6
3/16	4.75	83.6	8.4	29.2
No. 7	2.36	86.89	8.7	20.5
No. 14	1.18	74.31	7.4	13.10
No. 25	0.600	10.39	1.0	12.06
No. 36	0.425	4.24	0.4	11.63
No. 52	0.300	4.38	0.4	11.20
NO. 72	0.212	4.37	0.4	10.76
No. 100	0.150	4.15	0.4	10.34
No. 200	0.075	6.41	0.6	9.70
Passing No. 200				
Total		903.0		

Gravel	**79**
Sand	**11**
Silt	**7**

CIVIL ENGINEERING DEPARTMENT

GRADING ANALYSIS

SAMPLE: K1
BIT. CONTENT: 0%

COMPACTED SAMPLE

Date:15/5/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	85.3	8.5	91.5
⅜ in	9.50	115.5	11.5	79.9
¼	6.70	129.6	13.0	67.0
3/16	4.75	84.6	8.5	58.5
No. 7	2.36	189.91	19.0	39.5
No. 14	1.18	81.66	8.2	31.4
No. 25	0.600	35.49	3.5	27.8
No. 36	0.425	13.17	1.3	26.5
No. 52	0.300	12.44	1.2	25.2
NO. 72	0.212	10.27	1.0	24.2
No. 100	0.150	20.59	2.1	22.2
No. 200	0.075	20.00	2.0	20.2
Passing No. 200				
Total		798.4		

Gravel	**60**
Sand	**19**
Silt	**12**
Clay	**8**

SAMPLE: K1
BIT. CONTENT: 2%

COMPACTED SAMPLE

Date:11/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			100.0
¾ in	19.00	9.3	0.9	99.1
½ in	13.20	114.4	11.4	87.6
⅜ in	9.50	127.7	12.8	74.9
¼	6.70	134.9	13.5	61.4
3/16	4.75	60.3	6.0	55.3
No. 7	2.36	207.52	20.8	34.6
No. 14	1.18	77.54	7.8	26.8
No. 25	0.600	29.94	3.0	23.8
No. 36	0.425	7.63	0.8	23.1
No. 52	0.300	0.00	0.0	23.1
NO. 72	0.212	0.00	0.0	23.1
No. 100	0.150	0.00	0.0	23.1
No. 200	0.075	0.00	0.0	23.1
Passing No. 200				
Total		769.3		

Gravel	**65**
Sand	**12**
Silt	**18**
Clay	**5**

SAMPLE: K1
BIT. CONTENT: 4%

COMPACTED SAMPLE

Date:11/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	152.9	15.3	84.7
⅜ in	9.50	130.7	13.1	71.6
¼	6.70	147.5	14.7	56.9
3/16	4.75	95.1	9.5	47.4
No. 7	2.36	158.2	15.8	31.6
No. 14	1.18	65.41	6.5	25.0
No. 25	0.600	30.64	3.1	22.0
No. 36	0.425	7.83	0.8	21.2
No. 52	0.300	0.00	0.0	21.2
NO. 72	0.212	0.00	0.0	21.2
No. 100	0.150	0.00	0.0	21.2
No. 200	0.075	0.00	0.0	21.2
Passing No. 200				
Total		788.3		

Gravel	**68**
Sand	**10**
Silt	**17**
Clay	**4**

APPENDIX D2

SAMPLE: K1
BIT. CONTENT: 6%

COMPACTED SAMPLE

Date:15/5/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			100.0
¾ in	19.00	41.4	4.1	95.9
½ in	13.20	175.9	17.6	78.3
⅜ in	9.50	194.5	19.5	58.8
¼	6.70	159.3	15.9	42.9
3/16	4.75	75.1	7.5	35.4
No. 7	2.36	165.51	16.6	18.8
No. 14	1.18	53.03	5.3	13.5
No. 25	0.600	24.85	2.5	11.0
No. 36	0.425	7.37	0.7	10.3
No. 52	0.300	0.00	0.0	10.3
NO. 72	0.212	0.00	0.0	10.3
No. 100	0.150	0.00	0.0	10.3
No. 200	0.075	0.00	0.0	10.3
Passing No. 200				
Total		897.1		

Gravel	**81**
Sand	**9**
Silt	**9**
Clay	**1**

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APPENDIX D3

HYDROMETER ANALYSIS

SAMPLE: K1 **FRESH SAMPLE** Date:30/04/99

BIT. CONTENT: 0% Total Dry Weight (g) 50.0 **Gs=** 2.8

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K%
10:10	27.8	0.5	1.0270	27.0	27.5	91.98	0.832	0.0510	1.7341	25.13	7.58
	27.8	1.0	1.0265	26.5	27.0	93.95	0.832	0.0364	1.7341	24.63	7.43
	27.8	2.0	1.0245	24.5	25.0	101.85	0.832	0.0268	1.7341	22.63	6.83
	27.8	4.0	1.0220	22.0	22.5	111.73	0.83	0.0199	1.7341	20.13	6.08
	27.8	8.0	1.0190	19.0	19.5	123.58	0.83	0.0148	1.7341	17.13	5.17
	27.8	15.0	1.0180	18.0	18.5	127.53	0.83	0.0110	1.7341	16.13	4.87
	27.9	30.0	1.0165	16.5	17.0	133.45	0.83	0.0079	1.7606	14.66	4.42
	28.0	60.0	1.0150	15.0	15.5	139.38	0.83	0.0057	1.7872	13.19	3.98
	28.0	120	1.0140	14.0	14.5	143.33	0.83	0.0041	1.7872	12.19	3.68
	28.0	240	1.0135	13.5	14.0	145.30	0.83	0.0029	1.7872	11.69	3.53
	28.0	480	1.0125	12.5	13.0	149.25	0.83	0.0021	1.7872	10.69	3.23
	28.8	1440	1.0110	11.0	11.5	155.18	0.81	0.0012	2.0039	9.40	2.84

SAMPLE: K1 **COMPACTED SAMPLE** Date:15/5/99

BIT. CONTENT: 0% Total Dry Weight (g) 50.0 **Gs=** 2.8

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.0	0.5	1.0305	30.5	31.0	78.15	0.867	0.0480	1.2755	28.18	17.71
	26.0	1.0	1.0275	27.5	28.0	90.00	0.867	0.0364	1.2755	25.18	15.82
09:44	26.0	2.0	1.0250	25.0	25.5	99.88	0.867	0.0271	1.2755	22.68	14.25
09:46	26.0	4.0	1.0230	23.0	23.5	107.78	0.867	0.0199	1.2755	20.68	12.99
09:50	26.0	8.0	1.0216	21.6	22.1	113.31	0.867	0.0144	1.2755	19.28	12.11
09:57	26.4	15.0	1.0205	20.5	21.0	117.65	0.859	0.0107	1.3744	18.27	11.48
10:12	26.4	30.0	1.0185	18.5	19.0	125.55	0.859	0.0078	1.3744	16.27	10.23
10:42	26.8	60.0	1.0175	17.5	18.0	129.50	0.851	0.0056	1.4750	15.38	9.66
11:42	27.2	120	1.0165	16.5	17.0	133.45	0.843	0.0040	1.5774	14.48	9.10
13:42	28.0	240	1.0155	15.5	16.0	137.40	0.828	0.0028	1.7872	13.69	8.60
17:42	28.4	480	1.0150	15.0	15.5	139.38	0.820	0.0020	1.8947	13.29	8.35
09:42	29.8	1440	1.0132	13.2	13.7	146.49	0.795	0.0012	2.2844	11.88	7.47

SAMPLE: K1 **COMPACTED SAMPLE** Date:7/6/99

BIT. CONTENT: 2% Total Dry Weight (g) 50.0 **Gs=** **2.8**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.6	0.5	1.0220	22.0	22.5	111.73	0.836	0.0563	1.6814	20.08	14.43
	27.6	1.0	1.0205	20.5	21.0	117.65	0.836	0.0409	1.6814	18.58	13.35
09:44	27.6	2.0	1.0182	18.2	18.7	126.74	0.836	0.0300	1.6814	16.28	11.70
09:46	27.6	4.0	1.0175	17.5	18.0	129.50	0.836	0.0214	1.6814	15.58	11.20
09:50	27.6	8.0	1.0154	15.4	15.9	137.80	0.836	0.0156	1.6814	13.48	9.69
09:57	27.6	15.0	1.0140	14.0	14.5	143.33	0.836	0.0116	1.6814	12.08	8.68
10:12	27.6	30.0	1.0130	13.0	13.5	147.28	0.836	0.0083	1.6814	11.08	7.96
10:42	27.4	60.0	1.0118	11.8	12.3	152.02	0.839	0.0060	1.6292	9.83	7.06
11:42	27.4	120	1.0110	11.0	11.5	155.18	0.839	0.0043	1.6292	9.03	6.49
13:42	27.3	240	1.0100	10.0	10.5	159.13	0.841	0.0031	1.6032	8.00	5.75
17:42	27.4	480	1.0090	9.0	9.5	163.08	0.839	0.0022	1.6292	7.03	5.05
09:42	29.0	1440	1.0077	7.7	8.2	168.21	0.809	0.0013	2.0591	6.16	4.43

SAMPLE: K1 **COMPACTED SAMPLE** Date:9/6/99

BIT. CONTENT: 4% Total Dry Weight (g) 50.0 **Gs=** **2.8**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.5	0.5	1.0200	20.0	20.5	119.63	0.838	0.0584	1.6552	18.06	11.91
	27.5	1.0	1.0185	18.5	19.0	125.55	0.838	0.0423	1.6552	16.56	10.92
09:44	27.5	2.0	1.0176	17.6	18.1	129.11	0.838	0.0303	1.6552	15.66	10.33
09:46	27.5	4.0	1.0155	15.5	16.0	137.40	0.838	0.0221	1.6552	13.56	8.94
09:50	27.5	8.0	1.0140	14.0	14.5	143.33	0.838	0.0160	1.6552	12.06	7.95
09:57	27.4	15.0	1.0125	12.5	13.0	149.25	0.839	0.0119	1.6292	10.53	6.94
10:12	27.5	30.0	1.0113	11.3	11.8	153.99	0.838	0.0085	1.6552	9.36	6.17
10:42	27.3	60.0	1.0100	10.0	10.5	159.13	0.841	0.0062	1.6032	8.00	5.28
11:42	27.4	120	1.0090	9.0	9.5	163.08	0.839	0.0044	1.6292	7.03	4.64
13:42	27.4	240	1.0087	8.7	9.2	164.26	0.839	0.0031	1.6292	6.73	4.44
17:42	28.4	480	1.0074	7.4	7.9	169.40	0.820	0.0022	1.8947	5.69	3.76
09:42	29.0	1440	1.0070	7.0	7.5	170.98	0.809	0.0013	2.0591	5.46	3.60

APPENDIX D5

SAMPLE: K1 **COMPACTED SAMPLE** Date:15/5/99

BIT. CONTENT: 6% Total Dry Weight (g) 50.0 **Gs=** **2.8**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.0	0.5	1.0200	20.0	20.5	119.63	0.867	0.0594	1.2755	17.68	5.66
	26.0	1.0	1.0190	19.0	19.5	123.58	0.867	0.0427	1.2755	16.68	5.34
09:44	26.0	2.0	1.0175	17.5	18.0	129.50	0.867	0.0309	1.2755	15.18	4.86
09:46	26.0	4.0	1.0152	15.2	15.7	138.59	0.867	0.0226	1.2755	12.88	4.13
09:50	26.0	8.0	1.0135	13.5	14.0	145.30	0.867	0.0164	1.2755	11.18	3.58
09:57	26.0	15.0	1.0123	12.3	12.8	150.04	0.867	0.0121	1.2755	9.98	3.20
10:12	26.4	30.0	1.0110	11.0	11.5	155.18	0.859	0.0087	1.3744	8.77	2.81
10:42	26.6	60.0	1.0096	9.6	10.1	160.71	0.855	0.0062	1.4245	7.42	2.38
11:42	27.2	120	1.0085	8.5	9.0	165.05	0.843	0.0044	1.5774	6.48	2.08
13:42	28.0	240	1.0075	7.5	8.0	169.00	0.828	0.0031	1.7872	5.69	1.82
17:42	28.4	480	1.0070	7.0	7.5	170.98	0.820	0.0022	1.8947	5.29	1.70
09:42	29.7	1440	1.0050	5.0	5.5	178.88	0.797	0.0013	2.2559	3.66	1.17

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APPENDIX D6

SAMPLE: K1

Bit Content: 0%	1	2	3	4	5
CONTAINER NO.	C4	B9	B5	C14	A11
WEIGHT OF CONT.	3.7	3.6	3.7	3.7	3.8
NO. OF BLOWS	43	7	13	29	35
WET SAMPLE+CONT	31.8	27.7	30.9	26	23.9
DRY SAMPLE+CONT	24.6	20.2	23	19.9	18.6
WEIGHT OF WATER	7.2	7.5	7.9	6.1	5.3
WEIGHT OFDRY SAMPLE	20.9	16.6	19.3	16.2	14.8
W. CONT	34.4	45.18	40.93	37.65	35.81

plastic limit

CONTAINER NO.	C27	B25	B35	B36
WEIGHT OF CONT.	3.7	3.6	3.8	3.6
WET SAMPLE+CONT	5.6	6.3	5.7	5.8
DRY SAMPLE+CONT	5.3	5.9	5.4	5.5
WEIGHT OF WATER	0.3	0.4	0.3	0.3
WEIGHT OFDRY SAMPLE	1.6	2.3	1.6	1.9
W. CONT	18.75	17.4	18.75	15.79
AVERAGE OF TOTAL	17		17.27	

SAMPLE: K1

Bit Content: 0%	1	2	3	4
CONTAINER NO.	C35	A7	B42	C29
WEIGHT OF CONT.	3.67	3.75	3.7	3.67
WET SAMPLE+CONT	21.8	15.11	13.66	17.84
DRY SAMPLE+CONT	19.02	13.35	12.1	15.63
WEIGHT OF WATER	2.78	1.76	1.56	2.21
WEIGHT OFDRY SAMPLE	15.35	9.6	8.4	11.96
W. CONT	18.11	18.3	18.57	18.48
	18		**19**	

SAMPLE: K1

Bit Content: 0%	1	2	3	4
CONTAINER NO.	a	b	d1	32
WEIGHT OF CONT.	3.71	3.61	3.73	3.55
NO. OF BLOWS	35	29	20	17
WET SAMPLE+CONT	41.59	43.64	40.81	32.99
DRY SAMPLE+CONT	33.26	33.9	31.45	25.31
WEIGHT OF WATER	8.33	7.5	7.9	6.1
WEIGHT OFDRY SAMPLE	29.55	30.29	27.72	21.76
W. CONT	28.19	24.8	28.50	28.03

plastic limit

CONTAINER NO.	A3	A34
WEIGHT OF CONT.	3.69	3.73
WET SAMPLE+CONT	11.73	10.83
DRY SAMPLE+CONT	10.54	9.8
WEIGHT OF WATER	1.19	1.03
WEIGHT OFDRY SAMPLE	6.85	6.07
W. CONT	17.37	17.0
	17.17	

SAMPLE: K1

Bit Content: 0%	plastic limit			
CONTAINER NO.	C15	B14	C5	C34
WEIGHT OF CONT.	3.65	3.72	3.56	3.6
WET SAMPLE+CONT	23.68	19.45	12.29	16.03
DRY SAMPLE+CONT	20.16	16.56	10.7	13.77
WEIGHT OF WATER	3.52	2.89	1.59	2.26
WEIGHT OFDRY SAMPLE	16.51	12.84	7.14	10.17
W. CONT	21.32	22.5	22.27	22.22
	22		**22**	

SAMPLE: K1

Bit Content: 0%	1	2
	plastic limit	
CONTAINER NO.	A25	B29
WEIGHT OF CONT.	3.74	3.67
WET SAMPLE+CONT	10.88	8.13
DRY SAMPLE+CONT	9.52	7.34
WEIGHT OF WATER	1.36	0.79
WEIGHT OFDRY SAMPLE	5.78	3.67
W. CONT	23.53	21.5
	23	

SAMPLE: K2

Bit Content: 0%	plastic limit			
CONTAINER NO.	C39	B12	C32	A16
WEIGHT OF CONT.	3.72	3.63	3.65	3.72
WET SAMPLE+CONT	12.44	14.62	24.74	17.84
DRY SAMPLE+CONT	10.77	12.52	20.76	15.19
WEIGHT OF WATER	1.67	2.1	3.98	2.65
WEIGHT OFDRY SAMPLE	7.05	8.89	17.11	11.47
W. CONT	23.69	23.6	23.26	23.10
	23.65		23.18	

SAMPLE: K2

Bit Content: 0%	1	2	3	4
CONTAINER NO.	B25	A34	B21	A30
WEIGHT OF CONT.	3.62	3.73	3.59	3.6
WET SAMPLE+CONT	10.05	10.46	11.83	14.57
DRY SAMPLE+CONT	8.71	9.26	10.36	12.66
WEIGHT OF WATER	1.34	1.2	1.47	1.91
WEIGHT OFDRY SAMPLE	5.09	5.53	6.77	9.06
W. CONT	26.33	21.7	21.71	21.08
	24		21	

KNUST

APPENDIX D8

CIVIL ENGINEERING DEPARTMENT

GEOTECHNICAL ENGINEERING LABORATORY

SHRINKAGE ANALYSIS

SAMPLE K1
FRESH SAMPLE

DATE:7-5-99

BIT CONTENT: 0%

Test	1	2
Mould No.	A1	A2
Initial length	12.8	14.1
Length of oven dried sample	11.7	12.8
Linear shrinkage	8.594	9.091
Average		

SAMPLE K1
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 2%

Test	1	2
Mould No.	A	B
Initial length	12.7	12.8
Length of oven dried sample	11.4	11.1
Linear shrinkage	10.236	13.281
Average		

SAMPLE K1
COMPACTED SAMPLE

DATE:5-5-99

BIT CONTENT: 6%

Test	1	2
Mould No.	A4	A5
Initial length	14.1	14
Length of oven dried sample	12.2	12.1
Linear shrinkage	13.475	13.571
Average		

SAMPLE K1
COMPACTED SAMPLE

DATE:15-5-99

BIT CONTENT: 0%

Test	1	2
Mould No.	A10	A20
Initial length	12.8	12.9
Length of oven dried sample	11.5	11.75
Linear shrinkage	10.156	8.915
Average		

SAMPLE K1
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 4%

Test	1	2
Mould No.	P	K
Initial length	13.95	14
Length of oven dried sample	12.05	12.05
Linear shrinkage	13.620	13.929
Average		

APPENDIX D9

LIQUID LIMITS USING THE CONE PENETROMETER

Sample:K1

Date 16-06-99

Fresh Sample
Bit Content: 0%

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	24.34	26.59	25.36	25.5	25.64
Final dial gauge reading (mm)	10.67	7.75	6.83	6.45	4.14
Cone penetration (mm)	13.67	18.84	18.53	19.1	21.5
Container No.	A38	A6	A39	B1	A37
Mass of wet soil+container (g)	60.31	66.84	64.61	53.6	81.35
Mass of dried soil+container (g)	47.51	51.37	49.23	41.2	60.43
Mass of container (g)	14.26	14.2	14.26	14.6	15.63
Mass of moisture (g)	12.8	15.47	15.38	12.4	20.92
Mass of dry soil (g)	33.25	37.17	34.97	26.6	44.8
Moisture content (%)	38.50	41.62	43.98	46.51	46.70

Sample:K1

Date 16-06-99

Compacted Sample
Bit Content: 0%

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	27.76	23.8	29.76	26	25.06
Final dial gauge reading (mm)	14.26	12.52	14.26	9.22	5.4
Cone penetration (mm)	13.5	11.28	15.5	16.7	19.66
Container No.	A17	A18	A12	A10	A14
Mass of wet soil+container (g)	47.8	64.69	61.23	53	58.9
Mass of dried soil+container (g)	39.65	50.92	48.16	41.8	45.23
Mass of container (g)	17.05	14.38	14.24	14.4	15
Mass of moisture (g)	8.15	13.77	13.07	11.2	13.67
Mass of dry soil (g)	22.6	36.54	33.92	27.4	30.23
Moisture content (%)	36.06	37.68	38.53	40.73	45.22

Sample:K1

Date 16-06-99

Compacted Sample
Bit Content: 1%

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	21.9	23.01	23.44	27.5	21.69
Final dial gauge reading (mm)	12.4	9.09	6.57	5.52	1.31
Cone penetration (mm)	9.5	13.92	16.87	22	20.38
Container No.	A11	A22	A40	A16	A50
Mass of wet soil+container (g)	54.65	57.76	68.28	42.3	53.03
Mass of dried soil+container (g)	43.65	44.3	51.22	33.3	43.5
Mass of container (g)	14.98	14.76	14.36	14.2	14.31
Mass of moisture (g)	11	13.46	17.06	9.02	9.53
Mass of dry soil (g)	28.67	29.54	36.86	19.1	29.19
Moisture content (%)	38.37	45.57	46.28	47.23	32.65

Sample:K1

Date 16-06-99

Compacted Sample
Bit Content: 2%

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	19.14	19.32	23.24	19.2	16.96
Final dial gauge reading (mm)	10.43	7.65	5.64	5.56	2.95
Cone penetration (mm)	8.71	11.67	17.6	13.6	14.01
Container No.	A12	A14	A39	A33	A11
Mass of wet soil+container (g)	58.24	43.68	42.41	43.4	48.65
Mass of dried soil+container (g)	45.98	35.46	33.72	34.7	38.79
Mass of container (g)	14.26	15.02	14.28	14.5	14.99
Mass of moisture (g)	12.26	8.22	8.69	8.69	9.86
Mass of dry soil (g)	31.72	20.44	19.44	20.2	23.8
Moisture content (%)	38.65	40.22	44.70	42.96	41.43

Sample: K1

Compacted Sample

Bit Content: 3%

Date 16-06-99

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	21.8	20.88	21.7	22.9	24.47
Final dial gauge reading (mm)	10.59	8.13	7.96	3.94	2.59
Cone penetration (mm)	11.21	12.75	13.74	19	21.88
Container No.	A24	A38	A37	A42	A2
Mass of wet soil+container (g)	49.89	47.66	48.45	54.6	52.28
Mass of dried soil+container (g)	39.94	37.66	38.2	41.3	39.37
Mass of container (g)	14.51	14.27	15.68	14.7	14.32
Mass of moisture (g)	9.95	10	10.25	13.3	12.91
Mass of dry soil (g)	25.43	23.39	22.52	26.6	25.05
Moisture content (%)	39.13	42.75	45.52	49.96	51.54

Sample: K1

Compacted Sample

Bit Content: 4%

Date 16-06-99

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	21.65	21.81	21.72	21.9	21.7
Final dial gauge reading (mm)	8.97	8.04	5.21	3.11	0.46
Cone penetration (mm)	12.68	13.77	16.51	18.8	21.24
Container No.	A50	A23	A18	A5	A22
Mass of wet soil+container (g)	47.92	66.13	54.44	61.4	56.77
Mass of dried soil+container (g)	38.12	50.73	41.91	46.1	42.42
Mass of container (g)	14.32	15.39	14.4	14.8	14.76
Mass of moisture (g)	9.8	15.4	12.53	15.3	14.35
Mass of dry soil (g)	23.8	35.34	27.51	31.3	27.66
Moisture content (%)	41.18	43.58	45.55	48.71	51.88

Sample: K1

Compacted Sample

Bit Content: 6%

Date 16-06-99

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	19.65	20.45	20.84	20.3	20.37
Final dial gauge reading (mm)	11.86	9.46	8.95	5.66	4.17
Cone penetration (mm)	7.79	10.99	11.89	14.7	16.2
Container No.	A6	A17	B1	A40	A27
Mass of wet soil+container (g)	45.69	55.03	48.63	47.9	88.41
Mass of dried soil+container (g)	37.12	44.09	38.6	37.6	64.2
Mass of container (g)	14.32	17.09	14.61	14.5	12.85
Mass of moisture (g)	8.57	10.94	10.03	10.4	24.21
Mass of dry soil (g)	22.8	27	23.99	23.1	51.35
Moisture content (%)	37.59	40.52	41.81	44.84	47.15

Sample: K1

Compacted Sample

Bit Content: 8%

Date 16-06-99

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	19.52	19.32	19.05	19.6	19.62
Final dial gauge reading (mm)	11.44	10.52	6.82	5.31	4.38
Cone penetration (mm)	8.08	8.8	12.23	14.3	15.24
Container No.	A10	B2	A16	A8	B6
Mass of wet soil+container (g)	55.54	51.99	63.48	61.7	77.79
Mass of dried soil+container (g)	44.05	41.08	48.31	46.7	56.62
Mass of container (g)	14.43	14.93	14.31	14.3	14.27
Mass of moisture (g)	11.49	10.91	15.17	15	21.17
Mass of dry soil (g)	29.62	26.15	34	32.4	42.35
Moisture content (%)	38.79	41.72	44.62	46.25	49.99

APPENDIX D11

Sample: K1
Compacted Sample
Bit Content: 10%

Date 16-06-99

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	19.42	19.62	19.46	19.3	19.09
Final dial gauge reading (mm)	11.47	9.02	6.35	2.79	1.56
Cone penetration (mm)	7.95	10.6	13.11	16.6	17.53
Container No.	N5	N14	N18	N1	A36
Mass of wet soil+container (g)	44.28	38.34	41.93	35.7	37.98
Mass of dried soil+container (g)	35.24	30.44	32.44	27.9	30.09
Mass of container (g)	11.19	11.14	11.14	11.1	14.79
Mass of moisture (g)	9.04	7.9	9.49	7.85	7.89
Mass of dry soil (g)	24.05	19.3	21.3	16.8	15.3
Moisture content (%)	37.59	40.93	44.55	46.70	51.57

KNUST

COMPACTION TEST RESULTS- MODIFIED PROCTOR

SAMPLE: K1 Date:

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 0% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	11931	12422	12491	12404	12383
Mass of cylinder (gm)	7390	7390	7390	7390	7390
Mass of wet sample (gm)	4541	5032	5101	5014	4993
Bulk density (Mg/m^3)	2.14	2.37	2.40	2.36	2.35

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	D14	D7	O4	A6	Q	D4	D6	O3	P2	107
Mass of container+Wet soil (gm)	131.74	139.37	112.27	98.01	117.15	118.11	106.84	116.16	114.72	117.64
Mass of container+Dry soil (gm)	129.49	137.05	109.04	94.57	111.73	112.73	101.46	109.37	106.23	109.07
Mass of container (gm)	18.25	18.11	18.66	17.84	18.29	18.21	18.68	17.76	18.06	18.40
Mass of water (gm)	2.25	2.32	3.23	3.44	5.42	5.38	5.38	6.79	8.49	8.57
Mass of dry soil (gm)	111.24	118.94	90.38	76.73	93.44	94.52	82.78	91.61	88.17	90.67
Water content (%)	2.02	1.95	3.57	4.48	5.80	5.69	6.50	7.41	9.63	9.45
Average water content	1.99		4.03		5.75		6.96		9.54	
Dry density (Mg/m^3)	2.10		2.28		2.27		2.21		2.14	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

KNUST

Date:

SAMPLE: K1

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 2% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	11915	12300	12501	12485	12411
Mass of cylinder (gm)	7390	7390	7390	7390	7390
Mass of wet sample (gm)	4525	4910	5111	5095	5021
Bulk density (Mg/m^3)	2.13	2.31	2.41	2.40	2.36

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	D16	D8	D3	D7	D17	D20	C18	D13	C10	A7
Mass of container+Wet soil (gm)	137.19	147.02	98.84	95.53	115.38	120.88	116.10	119.32	119.86	128.71
Mass of container+Dry soil (gm)	135.47	144.98	95.18	91.89	110.33	115.9	109.61	112.62	111.72	120.3
Mass of container (gm)	17.81	18.01	18.24	17.84	18.30	18.05	17.67	18.38	18.55	17.82
Mass of water (gm)	1.72	2.04	3.66	3.64	5.05	4.98	6.49	6.70	8.14	8.41
Mass of dry soil (gm)	117.66	126.97	76.94	74.05	92.03	97.85	91.94	94.24	93.17	102.48
Water content (%)	1.46	1.61	4.76	4.92	5.49	5.09	7.06	7.11	8.74	8.21
Average water content	1.53		4.84		5.29		7.08		8.47	
Dry density (Mg/m^3)	2.10		2.20		2.29		2.24		2.17	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

SAMPLE: K1 Date:

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 4% bitumen content**

Sample preparation	1		2		3		4			
Mass of cylinder + Wet sample (gm	11972		12378		12330		12312			
Mass of cylinder (gm)	7390		7390		7390		7390			
Mass of wet sample (gm)	4582		4988		4940		4922			
Bulk density (Mg/m^3)	2.16		2.35		2.33		2.32			

Water Content Determination

Test No.	1		2		3		4			
Container No.	A16	A50	A39	A28	A30	B3	B1	A5		
Mass of container+Wet soil (gm)	112.28	114.35	101.78	108.02	101.02	113.72	119.88	108.25		
Mass of container+Dry soil (gm)	109.87	111.28	96.15	102.42	95.05	107.19	111.40	100.45		
Mass of container (gm)	14.21	14.31	14.26	14.24	15.00	15.29	15.58	14.80		
Mass of water (gm)	2.41	3.07	5.63	5.60	5.97	6.53	8.48	7.80		
Mass of dry soil (gm)	95.66	96.97	81.89	88.18	80.05	91.90	95.82	85.65		
Water content (%)	2.52	3.17	6.88	6.35	7.46	7.11	8.85	9.11		
Average water content	2.84		6.61		7.28		8.98			
Dry density (Mg/m^3)	2.10		2.20		2.17		2.13			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

KNUST

Date:

SAMPLE: K1

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 6% bitumen content**

Sample preparation	1		2		3		4		5	
Mass of cylinder + Wet sample (gm	11931		12283		12288		12266		12138	
Mass of cylinder (gm)	7390		7390		7390		7390		7390	
Mass of wet sample (gm)	4541		4893		4898		4876		4748	
Bulk density (Mg/m^3)	2.14		2.30		2.31		2.30		2.24	

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	D9	D10	D1	D5	C3	C4	C11	C14	A10	A35
Mass of container+Wet soil (gm)	144.60	143.62	140.61	149.15	157.9	161.44	153.53	122.97	116.94	129.82
Mass of container+Dry soil (gm)	138.85	138.11	133.4	142.42	148.95	151.94	143.59	114.7	107.38	119.04
Mass of container (gm)	18.10	18.09	18.01	17.97	18.81	18.24	18.12	18.01	14.39	14.27
Mass of water (gm)	5.75	5.51	7.21	6.73	8.95	9.50	9.94	8.27	9.56	10.78
Mass of dry soil (gm)	120.75	120.02	115.39	124.45	130.14	133.70	125.47	96.69	92.99	104.77
Water content (%)	4.76	4.59	6.25	5.41	6.88	7.11	7.92	8.55	10.28	10.29
Average water content	4.68		5.83		6.99		8.24		10.28	
Dry density (Mg/m^3)	2.04		2.18		2.15		2.12		2.03	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

APPENDIX D14

SAMPLE: K1 Date:

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 8% bitumen content**

Sample preparation	1		2		3		4		5	
Mass of cylinder + Wet sample (gm	12069		12259		12286		12217		12119	
Mass of cylinder (gm)	7390		7390		7390		7390		7390	
Mass of wet sample (gm)	4679		4869		4896		4827		4729	
Bulk density (Mg/m^3)	2.20		2.29		2.30		2.27		2.23	

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	D4	P2	D14	D6	P4	D7	Q	107	3	A6
Mass of container+Wet soil (gm)	96.15	93.80	98.44	108.63	121.37	122.87	151.09	139.27	128.59	128.94
Mass of container+Dry soil (gm)	93.12	90.64	93.46	103.53	113.62	115.64	140.37	128.66	118.48	118.55
Mass of container (gm)	18.21	18.03	18.27	18.69	18.66	18.13	18.28	18.41	17.79	17.84
Mass of water (gm)	3.03	3.16	4.98	5.10	7.75	7.23	10.72	10.61	10.11	10.39
Mass of dry soil (gm)	74.91	72.61	75.19	84.84	94.96	97.51	122.09	110.25	100.69	100.71
Water content (%)	4.04	4.35	6.62	6.01	8.16	7.41	8.78	9.62	10.04	10.32
Average water content	4.20		6.32		7.79		9.20		10.18	
Dry density (Mg/m^3)	2.11		2.16		2.14		2.08		2.02	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

KNUST

SAMPLE: K1 Date:

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 10% bitumen content**

Sample preparation	1		2		3		4		5	
Mass of cylinder + Wet sample (gm	12151		12121		11286					
Mass of cylinder (gm)	7390		7390		7390					
Mass of wet sample (gm)	4761		4731		3896					
Bulk density (Mg/m^3)	2.24		2.23		1.83					

Water Content Determination

Test No.	1		2		3					
Container No.	C8	C7	C12	C17	S	D11				
Mass of container+Wet soil (gm)	121.74	141.17	137.89	131.25	144.16	150.56				
Mass of container+Dry soil (gm)	115.45	134.5	128.61	123	133.24	139.17				
Mass of container (gm)	18.04	18.14	17.75	17.81	18.00	17.87				
Mass of water (gm)	6.29	6.67	9.28	8.25	10.92	11.39				
Mass of dry soil (gm)	97.41	116.36	110.86	105.19	115.24	121.30				
Water content (%)	6.46	5.73	8.37	7.84	9.48	9.39				
Average water content	6.09		8.11		9.43					
Dry density (Mg/m^3)	2.11		2.06		1.68					

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

APPENDIX D15

GEOTECHNICAL ENGINEERING LABORATORY
CBR TEST RECORDING SHEET

DATE: 10/5/99

SAMPLE : K1

SAMPLE DESCRIPTION: 0% Bitumen Content

Mould No.			
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,118	12,118	
Mass of Mould	7,427	7,427	
Mass of wet sample	4,691	4,691	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.209	2.209	

WATER CONTENT OF TRIMMINGS

	TOP	BOT				
Container No.	D8	C11				
Wet sample + container (g)	114.0	134.2				
Dry sample + container (g)	110.9	128.9				
Mass of container	18.02	18.14				
Mass of water	3.07	5.33				
Mass of dry sample	92.91	110.7				
Water content	3.30	4.81				
Average Water content	4.06					
Dry density	2.12					

AFTER SOAKING

Wet sample + Mould (g)			
Mass of wet sample	-7390		
Bulk density (g/cc)	-3.479		

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.						
Wet sample + container (g)						
Dry sample + container (g)						
Mass of container						
Mass of water	0.00	0.00				
Mass of dry sample	0.00	0.00				
Water content	#####	#####				
Average Water content	#DIV/0!					
Dry density	#DIV/0!					

Proving Ring constant:kN/div **0.026**

Penetration	Unsoaked			Soaked					
	Load		CBR	Load		CBR	Load		CBR
(mm)	(div)	(kN)		div	kN		div	kN	
0.25	2.2	0.0572		22	0.572				
0.50	4.5	0.117		43	1.118				
0.75	9.8	0.2548		60	1.56				
1.00	16	0.416		68	1.768				
1.25	28	0.728		78	2.028				
1.50	36	0.936		87	2.262				
1.75	47	1.222		97	2.522				
2.00	55	1.43		108	2.808				
2.25	68	1.768		118	3.068				
2.50	92	2.392	**18**	135	3.51	**27**			
2.75	130	3.38		146	3.796				
3.00	168	4.368		160	4.16				
3.50	370	9.62		176	4.576				
4.00	585	15.21		202	5.252				
4.50	850	22.1		217	5.642				
5.00	985	25.61	**128**	253	6.578	**33**			
5.50	1080	28.08		284	7.384				
6.00	1176	30.576		298	7.748				
6.50	1255	32.63		336	8.736				
7.00	1320	34.32		366	9.516				
7.50	1390	36.14		389	10.114				
8.00	1458	37.908		416	10.816				

SWELL DATA

Date	Time	Gauge(di	Date	Time	Gauge	Date	Time	Gaug

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			0			0
		0			0			0
		0			0			0
		0			0			0

DATE: 10/5/99

SAMPLE : K1

SAMPLE DESCRIPTION: 2% Bitumen Content

Proving Ring constant **0.026**

Mould No.	L1-A2-01		
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,342	12,316	
Mass of Mould	7,427	7,489	
Mass of wet sample	4,915	4,827	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.314	2.273	

WATER CONTENT OF TRIMMINGS

	TOP	BOT				
Container No.	D5	C11	D7	D10		
Wet sample + container (g)	106.6	134.2	93.0	111.3		
Dry sample + container (g)	101.4	128.9	85.6	103.9		
Mass of container	17.96	18.14	17.87	18.09		
Mass of water	5.20	5.33	7.43	7.44		
Mass of dry sample	83.5	110.7	67.7	85.8		
Water content	6.23	4.81	10.97	8.67		
Average Water content	5.52		9.82			
Dry density	2.19		2.07			

AFTER SOAKING

Mould No.	L1-A2-02		
Wet sample + Mould (g)	12234		
Mass of wet sample	4844		
Bulk density (g/cc)	2.281		

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	D8	10	D8	10		
Wet sample + container (g)	82.97	79.44	82.97	79.44		
Dry sample + container (g)	78.45	72.52	78.45	72.52		
Mass of container	17.99	6.92	17.99	6.92		
Mass of water	4.52	6.92	4.52	6.92		
Mass of dry sample	60.46	65.60	60.46	65.60		
Water content	7.48	10.55	7.48	10.55		
Average Water content	9.01		9.01			
Dry density	2.12		2.08			

Penetration	Unsoaked			Soaked					
	Load		CBR	Load		CBR	Load		CBR
(mm)	(div)	(kN)		div	kN		div	kN	
0.25	21.5	0.559		5	0.13				
0.50	32	0.832		12.5	0.325				
0.75	60	1.56		18	0.468				
1.00	132	3.432		23	0.598				
1.25	196	5.096		46	1.196				
1.50	336	8.736		67	1.742				
1.75	383	9.958		89	2.314				
2.00	420	10.92		104	2.704				
2.25	485	12.61		130	3.38				
2.50	535	13.91	**105**	149.5	3.887	**29**			
2.75	565	14.69		170	4.42				
3.00	600	15.6		194	5.044				
3.50	668	17.368		239	6.214				
4.00	723	18.798		267	6.942				
4.50	799	20.774		314	8.164				
5.00	864	22.464	**113**	347	9.022	**45**			
5.50	920	23.92		379	9.854				
6.00	984	25.584		409	10.634				
6.50	1035	26.91		444	11.544				
7.00	1086	28.236		466	12.116				
7.50	1153	29.978		498	12.948				
8.00	1238	32.188		525	13.65				

SWELL DA **1238**

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gaug

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			0			0
		0			0			0
		0			0			0
		0			0			0

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UNIVERSITY OF SCIENCE AND TECHNOLOGY

DATE: 10/5/99

SAMPLE : K1

Proving Ring constant 0.026

SAMPLE DESCRIPTION: 4% Bitumen Content

Mould No.	L1-A4-01		
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,344	12,118	
Mass of Mould	7,454	7,427	
Mass of wet sample	4,890	4,691	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.302	2.209	

WATER CONTENT OF TRIMMINGS

	TOP	BOT				
Container No.	D8	C11	D8	C11		
Wet sample + container (g)	110.0	134.2	114.0	134.2		
Dry sample + container (g)	104.5	128.9	110.9	128.9		
Mass of container	18.02	18.14	18.02	18.14		
Mass of water	5.54	5.33	3.07	5.33		
Mass of dry sample	86.45	110.7	92.9	110.7		
Water content	6.41	4.81	3.30	4.81		
Average Water content	5.61		4.06			
Dry density	2.18		2.12			

AFTER SOAKING	L1-A4-02		
Wet sample + Mould (g)	12254	12356	
Mass of wet sample	4864	4929	
Bulk density (g/cc)	2.290107553	2130	

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	D8	10				
Wet sample + container (g)	82.97	79.44				
Dry sample + container (g)	78.45	72.52				
Mass of container	17.99	6.92				
Mass of water	4.52	6.92				
Mass of dry sample	60.46	65.60				
Water content	7.48	10.55				
Average Water content	9.01					
Dry density	2.11					

Penetration	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	4	0.104		6	0.156				
0.50	5.5	0.143		17	0.442				
0.75	8	0.208		27	0.702				
1.00	11	0.286		37	0.962				
1.25	14	0.364		47	1.222				
1.50	18	0.468		57	1.482				
1.75	23	0.598		68	1.768				
2.00	27	0.702		78	2.028				
2.25	33	0.858		86	2.236				
2.50	39	1.014	**8**	95	2.47	**19**			
2.75	44	1.144		104	2.704				
3.00	50	1.3		114	2.964				
3.50	60	1.56		128	3.328				
4.00	75.5	1.963		143	3.718				
4.50	84	2.184		144	3.744				
5.00	98	2.548	**13**	165	4.29	**21**			
5.50	111	2.886		173	4.498				
6.00	125	3.25		183	4.758				
6.50	137	3.562		198	5.148				
7.00	151	3.926		131	3.406				
7.50	164	4.264		147	3.822				
8.00	180	4.68		183	4.758				

SWELL DATA

Date	Time	Gauge (div)	Date	Time	Gauge (div)	Date	Time	Gauge (div)

ΔT	Δh	ΔT	Δh	ΔT	Δh
	0		0		0
	0		0		0
	0		0		0
	0		0		0
	0		0		0

KNUST
NYANSAPƆW ƆSANE NO BADWENIMA

CIVIL ENGINEERING DEPARTMENT

GRADING ANALYSIS

SAMPLE: K2 **FRESH SAMPLE**

BIT. CONTENT: 0%

Date:11/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			100.0
1 in	26.50	20.2	2.0	98.0
¾ in	19.00	47.1	4.7	93.3
½ in	13.20	70.2	7.0	86.3
⅜ in	9.50	106.5	10.6	75.6
¼	6.70	136.8	13.7	61.9
3/16	4.75	158.3	15.8	46.1
No. 7	2.36	125.9	12.6	33.5
No. 14	1.18	98.83	9.9	23.6
No. 25	0.600	71.61	7.2	16.5
No. 36	0.425	24.17	2.4	14.1
No. 52	0.300	9.44	0.9	13.1
NO. 72	0.212	9.27	0.9	12.2
No. 100	0.150	9.24	0.9	11.3
No. 200	0.075	7.36	0.7	10.5
Passing No. 200				
Total		894.8		

Gravel	**66**
Sand	**23**
Silt	**9**
Clay	**2**

APPENDIX E1

SAMPLE: K2
BIT. CONTENT: 0%

COMPACTED SAMPLE

Date:11/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 1/2 in	63.00			
2 in	53.00			
1 1/2 in	37.10			
1 in	26.50			
3/4 in	19.00			100.0
1/2 in	13.20	31.7	3.2	96.8
3/8 in	9.50	90.0	9.0	87.8
1/4	6.70	102.4	10.2	77.6
3/16	4.75	78.8	7.9	69.7
No. 7	2.36	153.29	15.3	54.4
No. 14	1.18	63.71	6.4	48.0
No. 25	0.600	32.34	3.2	44.8
No. 36	0.425	11.30	1.1	43.6
No. 52	0.300	9.02	0.9	42.7
NO. 72	0.212	7.61	0.8	42.0
No. 100	0.150	5.54	0.6	41.4
No. 200	0.075	0.00	0.0	41.4
Passing No. 200				
Total		585.8		

Gravel	**46**
Sand	**13**
Silt	**19**
Clay	**22**

SAMPLE: K2
BIT. CONTENT: 1%

COMPACTED SAMPLE

Date:18/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 1/2 in	63.00			
2 in	53.00			
1 1/2 in	37.10			
1 in	26.50			
3/4 in	19.00			100.0
1/2 in	13.20	144.8	14.5	85.5
3/8 in	9.50	104.4	10.4	75.1
1/4	6.70	117.5	11.7	63.3
3/16	4.75	77.8	7.8	55.5
No. 7	2.36	145.97	14.6	40.9
No. 14	1.18	60.29	6.0	34.9
No. 25	0.600	31.79	3.2	31.7
No. 36	0.425	10.90	1.1	30.7
No. 52	0.300	10.71	1.1	29.6
NO. 72	0.212	9.40	0.9	28.6
No. 100	0.150	6.34	0.6	28.0
No. 200	0.075	0.00	0.0	28.0
Passing No. 200				
Total		720.0		

Gravel	**59**
Sand	**13**
Silt	**17**
Clay	**11**

APPENDIX E2

SAMPLE: K2
BIT. CONTENT: 2%

COMPACTED SAMPLE

Date:18/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	78.7	7.9	92.1
⅜ in	9.50	83.0	8.3	83.8
¼	6.70	144.6	14.5	69.4
3/16	4.75	90.5	9.1	60.3
No. 7	2.36	173.47	17.3	43.0
No. 14	1.18	58.84	5.9	37.1
No. 25	0.600	30.38	3.0	34.0
No. 36	0.425	10.44	1.0	33.0
No. 52	0.300	9.25	0.9	32.1
NO. 72	0.212	7.97	0.8	31.3
No. 100	0.150	4.68	0.5	30.8
No. 200	0.075	0.00	0.0	30.8
Passing No. 200				
Total		691.9		

Gravel	**57**
Sand	**12**
Silt	**19**
Clay	**12**

SAMPLE: K2
BIT. CONTENT: 3%

COMPACTED SAMPLE

Date:18/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	100.3	10.0	90.0
⅜ in	9.50	123.7	12.4	77.6
¼	6.70	162.1	16.2	61.4
3/16	4.75	95.6	9.6	51.8
No. 7	2.36	162.25	16.2	35.6
No. 14	1.18	55.71	5.6	30.0
No. 25	0.600	29.96	3.0	27.0
No. 36	0.425	10.76	1.1	26.0
No. 52	0.300	9.32	0.9	25.0
NO. 72	0.212	8.62	0.9	24.2
No. 100	0.150	5.50	0.6	23.6
No. 200	0.075	0.00	0.0	23.6
Passing No. 200				
Total		763.8		

Gravel	**64**
Sand	**12**
Silt	**17**
Clay	**7**

SAMPLE: K2
BIT. CONTENT: 4%

COMPACTED SAMPLE

Date:19/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	125.9	12.6	87.4
⅜ in	9.50	102.5	10.3	77.2
¼	6.70	142.7	14.3	62.9
3/16	4.75	98.2	9.8	53.1
No. 7	2.36	151.81	15.2	37.9
No. 14	1.18	60.20	6.0	31.9
No. 25	0.600	29.37	2.9	28.9
No. 36	0.425	7.81	0.8	28.2
No. 52	0.300	0.00	0.0	28.2
NO. 72	0.212	0.00	0.0	28.2
No. 100	0.150	0.00	0.0	28.2
No. 200	0.075	0.00	0.0	28.2
Passing No. 200				
Total		718.5		

Gravel	**62**
Sand	**10**
Silt	**20**
Clay	**8**

SAMPLE: K2
BIT. CONTENT: 6%

COMPACTED SAMPLE

Date:19/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			100.0
¾ in	19.00	5.9	0.6	99.4
½ in	13.20	72.1	7.2	92.2
⅜ in	9.50	105.2	10.5	81.7
¼	6.70	143.8	14.4	67.3
3/16	4.75	108.0	10.8	56.5
No. 7	2.36	168.89	16.9	39.6
No. 14	1.18	69.54	7.0	32.7
No. 25	0.600	35.57	3.6	29.1
No. 36	0.425	9.26	0.9	28.2
No. 52	0.300	0.00	0.0	28.2
NO. 72	0.212	0.00	0.0	28.2
No. 100	0.150	0.00	0.0	28.2
No. 200	0.075	0.00	0.0	28.2
Passing No. 200				
Total		718.3		

Gravel	**60**
Sand	**11**
Silt	**21**
Clay	**7**

APPENDIX E4

SAMPLE: K2
BIT. CONTENT: 8%

COMPACTED SAMPLE

Date:19/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			100.0
¾ in	19.00	40.4	4.0	96.0
½ in	13.20	101.6	10.2	85.8
⅜ in	9.50	123.3	12.3	73.5
¼	6.70	158.2	15.8	57.6
3/16	4.75	103.0	10.3	47.4
No. 7	2.36	154.20	15.4	31.9
No. 14	1.18	62.50	6.3	25.7
No. 25	0.600	32.08	3.2	22.5
No. 36	0.425	8.43	0.8	21.6
No. 52	0.300	0.00	0.0	21.6
NO. 72	0.212	0.00	0.0	21.6
No. 100	0.150	0.00	0.0	21.6
No. 200	0.075	0.00	0.0	21.6
Passing No. 200				
Total		783.7		

Gravel	**68**
Sand	**10**
Silt	**19**
Clay	**3**

SAMPLE: K2
BIT. CONTENT: 10%

COMPACTED SAMPLE

Date:19/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			100.0
1 in	26.50	78.1	7.8	92.2
¾ in	19.00	53.8	5.4	86.8
½ in	13.20	144.6	14.5	72.3
⅜ in	9.50	118.9	11.9	60.5
¼	6.70	137.8	13.8	46.7
3/16	4.75	88.9	8.9	37.8
No. 7	2.36	137.0	13.7	24.1
No. 14	1.18	56.64	5.7	18.4
No. 25	0.600	26.61	2.7	15.8
No. 36	0.425	4.66	0.5	15.3
No. 52	0.300	0.00	0.0	15.3
NO. 72	0.212	0.00	0.0	15.3
No. 100	0.150	0.00	0.0	15.3
No. 200	0.075	0.00	0.0	15.3
Passing No. 200				
Total		847.1		

Gravel	**76**
Sand	**9**
Silt	**12**
Clay	**3**

APPENDIX E5

SAMPLE: K2-CURED
BIT. CONTENT: 0%

COMPACTED SAMPLE

Date:11/8/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	29.2	2.9	97.1
⅜ in	9.50	47.4	4.7	92.3
¼	6.70	114.9	11.5	80.9
3/16	4.75	89.9	9.0	71.9
No. 7	2.36	162.4	16.2	55.6
No. 14	1.18	80.10	8.0	47.6
No. 25	0.600	40.80	4.1	43.5
No. 36	0.425	15.40	1.5	42.0
No. 52	0.300	12.10	1.2	40.8
NO. 72	0.212	10.60	1.1	39.7
No. 100	0.150	10.60	1.1	38.7
No. 200	0.075	0.00	0.0	38.7
Passing No. 200				
Total		613.4		

Gravel	**44**
Sand	**17**
Silt	**24**
Clay	**15**

SAMPLE: K2-CURED
BIT. CONTENT: 2%

Date:11/8/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	43.8	4.4	95.6
⅜ in	9.50	52.0	5.2	90.4
¼	6.70	90.4	9.0	81.4
3/16	4.75	87.6	8.8	72.6
No. 7	2.36	174.7	17.5	55.1
No. 14	1.18	80.00	8.0	47.1
No. 25	0.600	40.95	4.1	43.1
No. 36	0.425	14.98	1.5	41.6
No. 52	0.300	16.70	1.7	39.9
NO. 72	0.212	11.24	1.1	38.8
No. 100	0.150	6.77	0.7	38.1
No. 200	0.075	0.00	0.0	38.1
Passing No. 200				
Total		619.2		

Gravel	**45**
Sand	**17**
Silt	**22**
Clay	**16**

APPENDIX E6

SAMPLE: K2-CURED
BIT. CONTENT: 3%

COMPACTED SAMPLE

Date:11/8/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 1/2 in	63.00			
2 in	53.00			
1 1/2 in	37.10			
1 in	26.50			100.0
3/4 in	19.00	10.4	1.0	99.0
1/2 in	13.20	128.9	12.9	86.1
3/8 in	9.50	105.0	10.5	75.6
1/4	6.70	132.4	13.2	62.3
3/16	4.75	87.1	8.7	53.6
No. 7	2.36	169.6	17.0	36.7
No. 14	1.18	67.40	6.7	29.9
No. 25	0.600	32.01	3.2	26.7
No. 36	0.425	10.16	1.0	25.7
No. 52	0.300	8.07	0.8	24.9
NO. 72	0.212	8.40	0.8	24.1
No. 100	0.150	2.80	0.3	23.8
No. 200	0.075	0.00	0.0	23.8
Passing No. 200				
Total		762.2		

Gravel	**63**
Sand	**13**
Silt	**15**
Clay	**9**

SAMPLE: K2-CURED
BIT. CONTENT: 4%

COMPACTED SAMPLE

Date:11/8/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 1/2 in	63.00			
2 in	53.00			
1 1/2 in	37.10			
1 in	26.50			
3/4 in	19.00			100.0
1/2 in	13.20	113.3	11.3	88.7
3/8 in	9.50	60.4	6.0	82.6
1/4	6.70	129.7	13.0	69.7
3/16	4.75	104.7	10.5	59.2
No. 7	2.36	199.3	19.9	39.3
No. 14	1.18	74.96	7.5	31.8
No. 25	0.600	32.30	3.2	28.5
No. 36	0.425	9.86	1.0	27.5
No. 52	0.300	9.41	0.9	26.6
NO. 72	0.212	8.85	0.9	25.7
No. 100	0.150	3.54	0.4	25.4
No. 200	0.075	0.00	0.0	25.4
Passing No. 200				
Total		746.4		

Gravel	**61**
Sand	**14**
Silt	**16**
Clay	**9**

APPENDIX E7

SAMPLE: K2-CURED
BIT. CONTENT: 6%

COMPACTED SAMPLE

Date:11/8/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			100.0
¾ in	19.00	54.1	5.4	94.6
½ in	13.20	174.3	17.4	77.2
⅜ in	9.50	140.9	14.1	63.1
¼	6.70	136.0	13.6	49.5
3/16	4.75	97.7	9.8	39.7
No. 7	2.36	154.2	15.4	24.3
No. 14	1.18	65.03	6.5	17.8
No. 25	0.600	30.31	3.0	14.7
No. 36	0.425	9.71	1.0	13.8
No. 52	0.300	7.85	0.8	13.0
NO. 72	0.212	5.39	0.5	12.5
No. 100	0.150	3.32	0.3	12.1
No. 200	0.075	0.00	0.0	12.1
Passing No. 200				
Total		878.8		

Gravel	**76**
Sand	**12**
Silt	**8**
Clay	**4**

SAMPLE: K2-CURED
BIT. CONTENT: 0%

COMPACTED SAMPLE-CURED

Date:12/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	33.4	3.3	96.7
⅜ in	9.50	74.2	7.4	89.2
¼	6.70	148.2	14.8	74.4
3/16	4.75	103.4	10.3	64.1
No. 7	2.36	159.8	16.0	48.1
No. 14	1.18	65.10	6.5	41.6
No. 25	0.600	34.80	3.5	38.1
No. 36	0.425	11.90	1.2	36.9
No. 52	0.300	10.40	1.0	35.9
NO. 72	0.212	9.70	1.0	34.9
No. 100	0.150	5.20	0.5	34.4
No. 200	0.075	0.00	0.0	34.4
Passing No. 200				
Total		656.1		

Gravel	**52**
Sand	**14**
Silt	**21**
Clay	**13**

APPENDIX E8

SAMPLE: K2-CURED
BIT. CONTENT: 2%

COMPACTED SAMPLE-CURED

Date:12/8/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	66.6	6.7	93.3
⅜ in	9.50	72.7	7.3	86.1
¼	6.70	139.8	14.0	72.1
3/16	4.75	109.2	10.9	61.2
No. 7	2.36	196.4	19.6	41.5
No. 14	1.18	86.10	8.6	32.9
No. 25	0.600	44.10	4.4	28.5
No. 36	0.425	14.90	1.5	27.0
No. 52	0.300	10.30	1.0	26.0
NO. 72	0.212	10.00	1.0	25.0
No. 100	0.150	2.70	0.3	24.7
No. 200	0.075	0.00	0.0	24.7
Passing No. 200				
Total		752.8		

Gravel	**58**
Sand	**17**
Silt	**17**
Clay	**8**

SAMPLE: K2-CURED
BIT. CONTENT: 3%

COMPACTED SAMPLE-CURED

Date:12/6/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			100.0
¾ in	19.00	9.4	0.9	99.1
½ in	13.20	78.0	7.8	91.3
⅜ in	9.50	109.4	10.9	80.3
¼	6.70	113.6	11.4	69.0
3/16	4.75	102.1	10.2	58.8
No. 7	2.36	182.0	18.2	40.6
No. 14	1.18	83.56	8.4	32.2
No. 25	0.600	37.79	3.8	28.4
No. 36	0.425	11.91	1.2	27.2
No. 52	0.300	10.19	1.0	26.2
NO. 72	0.212	8.49	0.8	25.4
No. 100	0.150	4.28	0.4	24.9
No. 200	0.075	0.00	0.0	24.9
Passing No. 200				
Total		750.7		

Gravel	**59**
Sand	**16**
Silt	**16**
Clay	**9**

APPENDIX E9

SAMPLE: K2-CURED
BIT. CONTENT: 4%

COMPACTED SAMPLE-CURED

Date:12/8/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			100.0
¾ in	19.00	86.0	8.6	91.4
½ in	13.20	67.9	6.8	84.6
⅜ in	9.50	103.2	10.3	74.3
¼	6.70	117.0	11.7	62.6
3/16	4.75	104.3	10.4	52.2
No. 7	2.36	199.8	20.0	32.2
No. 14	1.18	84.20	8.4	23.8
No. 25	0.600	44.10	4.4	19.4
No. 36	0.425	11.30	1.1	18.2
No. 52	0.300	11.30	1.1	17.1
NO. 72	0.212	9.60	1.0	16.1
No. 100	0.150	4.98	0.5	15.6
No. 200	0.075	0.00	0.0	15.6
Passing No. 200				
Total		843.7		

Gravel	**68**
Sand	**17**
Silt	**11**
Clay	**5**

SAMPLE: K2-CURED
BIT. CONTENT: 6%

COMPACTED SAMPLE-CURED

Date:12/8/99

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			100.0
¾ in	19.00	20.1	2.0	98.0
½ in	13.20	65.6	6.6	91.4
⅜ in	9.50	86.5	8.7	82.8
¼	6.70	127.5	12.8	70.0
3/16	4.75	95.2	9.5	60.5
No. 7	2.36	198.7	19.9	40.6
No. 14	1.18	80.80	8.1	32.6
No. 25	0.600	38.60	3.9	28.7
No. 36	0.425	11.40	1.1	27.6
No. 52	0.300	10.70	1.1	26.5
NO. 72	0.212	7.10	0.7	25.8
No. 100	0.150	5.00	0.5	25.3
No. 200	0.075	0.00	0.0	25.3
Passing No. 200				
Total		747.2		

Gravel	**59**
Sand	**15**
Silt	**24**
Clay	**1**

APPENDIX E10

CIVIL ENGINEERING DEPARTMENT

HYDROMETER ANALYSIS

SAMPLE: K2 **FRESH SAMPLE** Date:9/6/99

BIT. CONTENT: 0% Total Dry Weight (g) 50.0 **Gs=** **2.8**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	28.0	0.5	1.0260	26.0	26.5	95.92	0.828	0.0520	1.7872	24.19	0.38
	28.0	1.0	1.0250	25.0	25.5	99.88	0.828	0.0375	1.7872	23.19	0.36
09:44	28.0	2.0	1.0242	24.2	24.7	103.04	0.828	0.0269	1.7872	22.39	0.35
09:46	28.0	4.0	1.0235	23.5	24.0	105.80	0.828	0.0193	1.7872	21.69	0.34
09:50	28.0	8.0	1.0222	22.2	22.7	110.94	0.828	0.0140	1.7872	20.39	0.32
09:57	27.7	15.0	1.0215	21.5	22.0	113.70	0.834	0.0104	1.7077	19.61	0.31
10:12	27.5	30.0	1.0205	20.5	21.0	117.65	0.838	0.0075	1.6552	18.56	0.29
10:42	27.4	60.0	1.0197	19.7	20.2	120.81	0.839	0.0054	1.6292	17.73	0.28
11:42	27.4	120	1.0193	19.3	19.8	122.39	0.839	0.0038	1.6292	17.33	0.27
13:42	27.3	240	1.0185	18.5	19.0	125.55	0.841	0.0027	1.6032	16.50	0.26
17:42	27.3	480	1.0178	17.8	18.3	128.32	0.841	0.0020	1.6032	15.80	0.25
09:42	29.0	1440	1.0165	16.5	17.0	133.45	0.809	0.0011	2.0591	14.96	0.23

APPENDIX E11

SAMPLE: K2 **COMPACTED SAMPLE** Date:9/6/99

BIT. CONTENT: 0% Total Dry Weight (g) 50.0 **Gs=** **2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	28.0	0.5	1.0280	28.0	28.5	88.02	0.828	0.0498	1.7872	26.19	33.47
	28.0	1.0	1.0270	27.0	27.5	91.98	0.828	0.0360	1.7872	25.19	32.19
09:44	28.0	2.0	1.0250	25.0	25.5	99.88	0.828	0.0265	1.7872	23.19	29.63
09:46	28.0	4.0	1.0245	24.5	25.0	101.85	0.828	0.0189	1.7872	22.69	28.99
09:50	28.0	8.0	1.0235	23.5	24.0	105.80	0.828	0.0136	1.7872	21.69	27.72
09:57	27.7	15.0	1.0226	22.6	23.1	109.36	0.834	0.0102	1.7077	20.71	26.46
10:12	27.6	30.0	1.0220	22.0	22.5	111.73	0.836	0.0073	1.6814	20.08	25.66
10:42	27.4	60.0	1.0210	21.0	21.5	115.68	0.839	0.0052	1.6292	19.03	24.32
11:42	27.4	120	1.0205	20.5	21.0	117.65	0.839	0.0037	1.6292	18.53	23.68
13:42	27.4	240	1.0200	20.0	20.5	119.63	0.839	0.0027	1.6292	18.03	23.04
17:42	28.3	480	1.0195	19.5	20.0	121.60	0.822	0.0019	1.8676	17.77	22.71
09:42	29.0	1440	1.0180	18.0	18.5	127.53	0.809	0.0011	2.0591	16.46	21.03

SAMPLE: K2 **COMPACTED SAMPLE** Date:9/6/99

BIT. CONTENT: 1% Total Dry Weight (g) 50.0 **Gs=** **2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.8	0.5	1.0255	25.5	26.0	97.90	0.832	0.0526	1.7341	23.63	20.43
	27.8	1.0	1.0240	24.0	24.5	103.83	0.832	0.0383	1.7341	22.13	19.13
09:44	27.8	2.0	1.0230	23.0	23.5	107.78	0.832	0.0276	1.7341	21.13	18.27
09:46	27.8	4.0	1.0215	21.5	22.0	113.70	0.832	0.0200	1.7341	19.63	16.97
09:50	27.8	8.0	1.0200	20.0	20.5	119.63	0.832	0.0145	1.7341	18.13	15.67
09:57	27.8	15.0	1.0195	19.5	20.0	121.60	0.832	0.0107	1.7341	17.63	15.24
10:12	27.8	30.0	1.0185	18.5	19.0	125.55	0.832	0.0077	1.7341	16.63	14.38
10:42	27.7	60.0	1.0175	17.5	18.0	129.50	0.834	0.0055	1.7077	15.61	13.49
11:42	27.6	120	1.0165	16.5	17.0	133.45	0.836	0.0040	1.6814	14.58	12.60
13:42	28.5	240	1.0150	15.0	15.5	139.38	0.819	0.0028	1.9218	13.32	11.51
09:42	28.0	1440	1.0135	13.5	14.0	145.30	0.828	0.0012	1.7872	11.69	10.10

APPENDIX E12

SAMPLE: K2 **COMPACTED SAMPLE** Date:9/6/99

BIT. CONTENT: 2% Total Dry Weight (g) 50.0 **Gs=** **2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.6	0.5	1.0255	25.5	26.0	97.90	0.836	0.0527	1.6814	23.58	22.42
	27.6	1.0	1.0245	24.5	25.0	101.85	0.836	0.0380	1.6814	22.58	21.47
09:44	27.6	2.0	1.0230	23.0	23.5	107.78	0.836	0.0277	1.6814	21.08	20.04
09:46	27.6	4.0	1.0215	21.5	22.0	113.70	0.836	0.0201	1.6814	19.58	18.62
09:50	27.6	8.0	1.0200	20.0	20.5	119.63	0.836	0.0146	1.6814	18.08	17.19
09:57	27.6	15.0	1.0190	19.0	19.5	123.58	0.836	0.0108	1.6814	17.08	16.24
10:12	27.6	30.0	1.0175	17.5	18.0	129.50	0.836	0.0078	1.6814	15.58	14.81
10:42	27.6	60.0	1.0170	17.0	17.5	131.48	0.836	0.0056	1.6814	15.08	14.34
11:42	27.6	120	1.0160	16.0	16.5	135.43	0.836	0.0040	1.6814	14.08	13.39
13:42	28.7	240	1.0150	15.0	15.5	139.38	0.815	0.0028	1.9764	13.38	12.72
09:42	28.0	1440	1.0130	13.0	13.5	147.28	0.828	0.0012	1.7872	11.19	10.64

SAMPLE: K2 **COMPACTED SAMPLE** Date:9/6/99

BIT. CONTENT: 3% Total Dry Weight (g) 50.0 **Gs=** **2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.7	0.5	1.0255	25.5	26.0	97.90	0.834	0.0527	1.7077	23.61	17.20
	27.7	1.0	1.0245	24.5	25.0	101.85	0.834	0.0380	1.7077	22.61	16.47
09:44	27.7	2.0	1.0230	23.0	23.5	107.78	0.834	0.0276	1.7077	21.11	15.38
09:46	27.7	4.0	1.0210	21.0	21.5	115.68	0.834	0.0202	1.7077	19.11	13.92
09:50	27.7	8.0	1.0193	19.3	19.8	122.39	0.834	0.0147	1.7077	17.41	12.68
09:57	27.7	15.0	1.0180	18.0	18.5	127.53	0.834	0.0110	1.7077	16.11	11.73
10:12	27.7	30.0	1.0167	16.7	17.2	132.66	0.834	0.0079	1.7077	14.81	10.79
10:42	27.7	60.0	1.0155	15.5	16.0	137.40	0.834	0.0057	1.7077	13.61	9.91
11:42	27.6	120	1.0144	14.4	14.9	141.75	0.836	0.0041	1.6814	12.48	9.09
13:42	28.3	240	1.0130	13.0	13.5	147.28	0.822	0.0029	1.8676	11.27	8.21
09:42	28.0	1440	1.0100	10.0	10.5	159.13	0.828	0.0012	1.7872	8.19	5.96

APPENDIX E13

SAMPLE: K2 **COMPACTED SAMPLE** Date:9/6/99

BIT. CONTENT: 4% Total Dry Weight (g) 50.0 **Gs=** **2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.8	0.5	1.0250	25.0	25.5	99.88	0.832	0.0531	1.7341	23.13	20.14
	27.8	1.0	1.0226	22.6	23.1	109.36	0.832	0.0393	1.7341	20.73	18.05
09:44	27.8	2.0	1.0210	21.0	21.5	115.68	0.832	0.0286	1.7341	19.13	16.66
09:46	27.8	4.0	1.0195	19.5	20.0	121.60	0.832	0.0207	1.7341	17.63	15.35
09:50	27.8	8.0	1.0177	17.7	18.2	128.71	0.832	0.0151	1.7341	15.83	13.78
09:57	27.7	15.0	1.0165	16.5	17.0	133.45	0.834	0.0112	1.7077	14.61	12.72
10:12	27.6	30.0	1.0160	16.0	16.5	135.43	0.836	0.0080	1.6814	14.08	12.26
10:42	27.6	60.0	1.0140	14.0	14.5	143.33	0.836	0.0058	1.6814	12.08	10.52
11:42	27.6	120	1.0127	12.7	13.2	148.46	0.836	0.0042	1.6814	10.78	9.39
13:42	27.9	240	1.0120	12.0	12.5	151.23	0.830	0.0030	1.7606	10.16	8.85
09:42	27.4	1440	1.0100	10.0	10.5	159.13	0.839	0.0013	1.6292	8.03	6.99

SAMPLE: K2 **COMPACTED SAMPLE** Date:9/6/99

BIT. CONTENT: 6% Total Dry Weight (g) 50.0 **Gs=** **2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.6	0.5	1.0220	22.0	22.5	111.73	0.836	0.0563	1.6814	20.08	17.48
	27.6	1.0	1.0200	20.0	20.5	119.63	0.836	0.0412	1.6814	18.08	15.74
09:44	27.6	2.0	1.0185	18.5	19.0	125.55	0.836	0.0299	1.6814	16.58	14.43
09:46	27.6	4.0	1.0177	17.7	18.2	128.71	0.836	0.0214	1.6814	15.78	13.74
09:50	27.6	8.0	1.0165	16.5	17.0	133.45	0.836	0.0154	1.6814	14.58	12.69
09:57	27.6	15.0	1.0155	15.5	16.0	137.40	0.836	0.0114	1.6814	13.58	11.82
10:12	27.6	30.0	1.0140	14.0	14.5	143.33	0.836	0.0082	1.6814	12.08	10.52
10:42	27.6	60.0	1.0125	12.5	13.0	149.25	0.836	0.0059	1.6814	10.58	9.21
11:42	27.6	120	1.0119	11.9	12.4	151.62	0.836	0.0042	1.6814	9.98	8.69
13:42	27.4	240	1.0105	10.5	11.0	157.15	0.839	0.0031	1.6292	8.53	7.42
09:42	27.5	1440	1.0090	9.0	9.5	163.08	0.838	0.0013	1.6552	7.06	6.14

APPENDIX E14

SAMPLE: K2 **COMPACTED SAMPLE** Date:9/6/99

BIT. CONTENT: 8% Total Dry Weight (g) 50.0 **Gs=** **2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.6	0.5	1.0210	21.0	21.5	115.68	0.836	0.0573	1.6814	19.08	12.72
	27.6	1.0	1.0180	18.0	18.5	127.53	0.836	0.0426	1.6814	16.08	10.72
09:44	27.6	2.0	1.0169	16.9	17.4	131.87	0.836	0.0306	1.6814	14.98	9.99
09:46	27.6	4.0	1.0150	15.0	15.5	139.38	0.836	0.0222	1.6814	13.08	8.72
09:50	27.6	8.0	1.0133	13.3	13.8	146.09	0.836	0.0161	1.6814	11.38	7.59
09:57	27.6	15.0	1.0125	12.5	13.0	149.25	0.836	0.0119	1.6814	10.58	7.06
10:12	27.6	30.0	1.0105	10.5	11.0	157.15	0.836	0.0086	1.6814	8.58	5.72
10:42	27.6	60.0	1.0100	10.0	10.5	159.13	0.836	0.0061	1.6814	8.08	5.39
11:42	27.6	120	1.0085	8.5	9.0	165.05	0.836	0.0044	1.6814	6.58	4.39
13:42	27.5	240	1.0075	7.5	8.0	169.00	0.838	0.0032	1.6552	5.56	3.70
09:42	27.5	1440	1.0070	7.0	7.5	170.98	0.838	0.0013	1.6552	5.06	3.37

SAMPLE: K2 **COMPACTED SAMPLE** Date:9/6/99

BIT. CONTENT: 10% Total Dry Weight (g) 50.0 **Gs=** **2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.6	0.5	1.0200	20.0	20.5	119.63	0.836	0.0583	1.6814	18.08	8.54
	27.6	1.0	1.0177	17.7	18.2	128.71	0.836	0.0428	1.6814	15.78	7.45
09:44	27.6	2.0	1.0160	16.0	16.5	135.43	0.836	0.0310	1.6814	14.08	6.65
09:46	27.6	4.0	1.0150	15.0	15.5	139.38	0.836	0.0222	1.6814	13.08	6.18
09:50	27.6	8.0	1.0135	13.5	14.0	145.30	0.836	0.0161	1.6814	11.58	5.47
09:57	27.6	15.0	1.0125	12.5	13.0	149.25	0.836	0.0119	1.6814	10.58	5.00
10:12	27.6	30.0	1.0120	12.0	12.5	151.23	0.836	0.0085	1.6814	10.08	4.76
10:42	27.6	60.0	1.0100	10.0	10.5	159.13	0.836	0.0061	1.6814	8.08	3.82
11:42	27.6	120	1.0095	9.5	10.0	161.10	0.836	0.0044	1.6814	7.58	3.58
10:04	27.3	240	1.0086	8.6	9.1	164.66	0.841	0.0031	1.6032	6.60	3.12
09:42	27.5	1440	1.0070	7.0	7.5	170.98	0.838	0.0013	1.6552	5.06	2.39

APPENDIX E15

SAMPLE: K2-CURED **COMPACTED SAMPLE** Date:7/8/99

BIT. CONTENT: 0% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.6	0.5	1.0330	33.0	33.5	68.28	0.855	0.0446	1.4245	30.82	36.82
	26.6	1.0	1.0250	25.0	25.5	99.88	0.855	0.0381	1.4245	22.82	27.27
09:44	26.6	2.0	1.0235	23.5	24.0	105.80	0.855	0.0277	1.4245	21.32	25.48
09:46	26.6	4.0	1.0225	22.5	23.0	109.75	0.855	0.0200	1.4245	20.32	24.28
09:50	26.6	8.0	1.0210	21.0	21.5	115.68	0.855	0.0145	1.4245	18.82	22.49
09:57	26.7	15.0	1.0205	20.5	21.0	117.65	0.853	0.0107	1.4497	18.35	21.92
10:12	27.0	30.0	1.0201	20.1	20.6	119.23	0.847	0.0076	1.5260	18.03	21.53
10:42	26.5	60.0	1.0185	18.5	19.0	125.55	0.857	0.0055	1.3994	16.30	19.47
11:42	25.8	120	1.0175	17.5	18.0	129.50	0.871	0.0040	1.2267	15.13	18.07
10:04	25.4	240	1.0165	16.5	17.0	133.45	0.880	0.0029	1.1304	14.03	16.76
10:04	26.0	480	1.0155	15.5	16.0	137.40	0.867	0.0021	1.2755	13.18	15.74
09:42	27.1	1440	1.0145	14.5	15.0	141.35	0.845	0.0012	1.5516	12.45	14.88

SAMPLE: K2-CURED **COMPACTED SAMPLE** Date:7/8/99

BIT. CONTENT: 2% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	25.7	0.5	1.0255	25.5	26.0	97.90	0.873	0.0539	1.2025	23.10	27.17
	25.7	1.0	1.0253	25.3	25.8	98.69	0.873	0.0383	1.2025	22.90	26.94
09:44	25.7	2.0	1.0251	25.1	25.6	99.48	0.873	0.0272	1.2025	22.70	26.70
09:46	25.7	4.0	1.0235	23.5	24.0	105.80	0.873	0.0198	1.2025	21.10	24.82
09:50	27.4	8.0	1.0220	22.0	22.5	111.73	0.839	0.0141	1.6292	20.03	23.56
09:57	27.2	15.0	1.0210	21.0	21.5	115.68	0.843	0.0105	1.5774	18.98	22.32
10:12	26.8	30.0	1.0205	20.5	21.0	117.65	0.851	0.0075	1.4750	18.38	21.61
10:42	26.5	60.0	1.0193	19.3	19.8	122.39	0.857	0.0055	1.3994	17.10	20.11
11:42	25.8	120	1.0180	18.0	18.5	127.53	0.871	0.0040	1.2267	15.63	18.38
10:04	25.4	240	1.0170	17.0	17.5	131.48	0.880	0.0029	1.1304	14.53	17.09
10:04	26.0	480	1.0160	16.0	16.5	135.43	0.867	0.0020	1.2755	13.68	16.08
09:42	27.1	1440	1.0150	15.0	15.5	139.38	0.845	0.0012	1.5516	12.95	15.23

APPENDIX E16

SAMPLE: K2-CURED **COMPACTED SAMPLE** Date:7/8/99

BIT. CONTENT: 3% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	27.3	0.5	1.0265	26.5	27.0	93.95	0.841	0.0518	1.6032	24.50	18.00
	27.3	1.0	1.0250	25.0	25.5	99.88	0.841	0.0378	1.6032	23.00	16.90
09:44	27.3	2.0	1.0230	23.0	23.5	107.78	0.841	0.0278	1.6032	21.00	15.43
09:46	27.2	4.0	1.0220	22.0	22.5	111.73	0.843	0.0200	1.5774	19.98	14.68
09:50	27.0	8.0	1.0205	20.5	21.0	117.65	0.847	0.0146	1.5260	18.43	13.54
09:57	26.5	15.0	1.0195	19.5	20.0	121.60	0.857	0.0109	1.3994	17.30	12.71
10:12	26.5	30.0	1.0185	18.5	19.0	125.55	0.857	0.0078	1.3994	16.30	11.98
10:42	26.2	60.0	1.0177	17.7	18.2	128.71	0.863	0.0056	1.3248	15.42	11.33
11:42	25.8	120	1.0170	17.0	17.5	131.48	0.871	0.0040	1.2267	14.63	10.75
10:04	25.4	240	1.0155	15.5	16.0	137.40	0.880	0.0029	1.1304	13.03	9.57
10:04	26.0	480	1.0150	15.0	15.5	139.38	0.867	0.0021	1.2755	12.68	9.31
09:42	27.1	1440	1.0140	14.0	14.5	143.33	0.845	0.0012	1.5516	11.95	8.78

SAMPLE: K2-CURED **COMPACTED SAMPLE** Date:7/8/99

BIT. CONTENT: 4% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.8	0.5	1.0260	26.0	26.5	95.92	0.851	0.0527	1.4750	23.88	18.72
	26.8	1.0	1.0240	24.0	24.5	103.83	0.851	0.0388	1.4750	21.88	17.15
09:44	26.8	2.0	1.0215	21.5	22.0	113.70	0.851	0.0287	1.4750	19.38	15.19
09:46	26.8	4.0	1.0203	20.3	20.8	118.44	0.851	0.0207	1.4750	18.18	14.25
09:50	26.8	8.0	1.0193	19.3	19.8	122.39	0.851	0.0149	1.4750	17.18	13.47
09:57	26.7	15.0	1.0185	18.5	19.0	125.55	0.853	0.0110	1.4497	16.35	12.82
10:12	26.5	30.0	1.0183	18.3	18.8	126.34	0.857	0.0078	1.3994	16.10	12.62
10:42	26.1	60.0	1.0175	17.5	18.0	129.50	0.865	0.0056	1.3001	15.20	11.92
11:42	25.6	120	1.0166	16.6	17.1	133.06	0.875	0.0041	1.1784	14.18	11.12
10:04	25.5	240	1.0159	15.9	16.4	135.82	0.878	0.0029	1.1543	13.45	10.55
10:04	26.0	480	1.0150	15.0	15.5	139.38	0.867	0.0021	1.2755	12.68	9.94
09:42	27.1	1440	1.0136	13.6	14.1	144.91	0.845	0.0012	1.5516	11.55	9.06

SAMPLE: K2-CURED **COMPACTED SAMPLE** Date:7/8/99

BIT. CONTENT: 6% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.8	0.5	1.0255	25.5	26.0	97.90	0.851	0.0532	1.4750	23.38	8.73
	26.8	1.0	1.0233	23.3	23.8	106.59	0.851	0.0393	1.4750	21.18	7.91
09:44	26.8	2.0	1.0215	21.5	22.0	113.70	0.851	0.0287	1.4750	19.38	7.24
09:46	26.7	4.0	1.0200	20.0	20.5	119.63	0.853	0.0208	1.4497	17.85	6.67
09:50	26.7	8.0	1.0190	19.0	19.5	123.58	0.853	0.0150	1.4497	16.85	6.29
09:57	26.5	15.0	1.0175	17.5	18.0	129.50	0.857	0.0112	1.3994	15.30	5.71
10:12	26.5	30.0	1.0160	16.0	16.5	135.43	0.857	0.0081	1.3994	13.80	5.15
10:42	26.0	60.0	1.0145	14.5	15.0	141.35	0.867	0.0059	1.2755	12.18	4.55
11:42	25.6	120	1.0140	14.0	14.5	143.33	0.875	0.0042	1.1784	11.58	4.32
10:04	25.5	240	1.0125	12.5	13.0	149.25	0.878	0.0030	1.1543	10.05	3.76
10:04	26.0	480	1.0150	15.0	15.5	139.38	0.867	0.0021	1.2755	12.68	4.73
09:42	27.1	1440	1.0110	11.0	11.5	155.18	0.845	0.0012	1.5516	8.95	3.34

SAMPLE: K2-CURED **COMPACTED SAMPLE-CURED** Date:7/8/99

BIT. CONTENT: 0% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.5	0.5	1.0260	26.0	26.5	95.92	0.857	0.0529	1.3994	23.80	25.27
	26.6	1.0	1.0240	24.0	24.5	103.83	0.855	0.0388	1.4245	21.82	23.18
09:44	26.6	2.0	1.0225	22.5	23.0	109.75	0.855	0.0282	1.4245	20.32	21.58
09:46	26.6	4.0	1.0200	20.0	20.5	119.63	0.855	0.0208	1.4245	17.82	18.93
09:50	26.5	8.0	1.0198	19.8	20.3	120.42	0.857	0.0148	1.3994	17.60	18.69
09:57	26.4	15.0	1.0195	19.5	20.0	121.60	0.859	0.0109	1.3744	17.27	18.34
10:12	25.8	30.0	1.0190	19.0	19.5	123.58	0.871	0.0078	1.2267	16.63	17.66
10:42	25.6	60.0	1.0180	18.0	18.5	127.53	0.875	0.0056	1.1784	15.58	16.54
11:42	25.6	120	1.0175	17.5	18.0	129.50	0.875	0.0040	1.1784	15.08	16.01
10:04	26.0	240	1.0164	16.4	16.9	133.85	0.867	0.0029	1.2755	14.08	14.95
10:04	26.0	480	1.0150	15.0	15.5	139.38	0.867	0.0021	1.2755	12.68	13.46
09:42	25.0	1440	1.0142	14.2	14.7	142.54	0.888	0.0012	1.0358	11.64	12.36

SAMPLE: K2-CURED **COMPACTED SAMPLE-CURED** Date:7/8/99

BIT. CONTENT: 2% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.4	0.5	1.0260	26.0	26.5	95.92	0.859	0.0529	1.3744	23.77	18.13
	26.4	1.0	1.0234	23.4	23.9	106.20	0.859	0.0394	1.3744	21.17	16.15
09:44	26.4	2.0	1.0215	21.5	22.0	113.70	0.859	0.0288	1.3744	19.27	14.70
09:46	26.4	4.0	1.0203	20.3	20.8	118.44	0.859	0.0208	1.3744	18.07	13.78
09:50	26.4	8.0	1.0189	18.9	19.4	123.97	0.859	0.0150	1.3744	16.67	12.71
09:57	26.1	15.0	1.0185	18.5	19.0	125.55	0.865	0.0111	1.3001	16.20	12.35
10:12	26.0	30.0	1.0170	17.0	17.5	131.48	0.867	0.0080	1.2755	14.68	11.19
10:42	25.8	60.0	1.0162	16.2	16.7	134.64	0.871	0.0058	1.2267	13.83	10.54
11:42	25.4	120	1.0150	15.0	15.5	139.38	0.880	0.0042	1.1304	12.53	9.55
10:04	25.6	240	1.0143	14.3	14.8	142.14	0.875	0.0030	1.1784	11.88	9.06
10:04	26.0	480	1.0135	13.5	14.0	145.30	0.867	0.0021	1.2755	11.18	8.52
09:42	25.0	1440	1.0125	12.5	13.0	149.25	0.888	0.0013	1.0358	9.94	7.58

SAMPLE: K2-CURED **COMPACTED SAMPLE-CURED** Date:7/8/99

BIT. CONTENT: 3% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.0	0.5	1.0340	34.0	34.5	64.32	0.867	0.0435	1.2755	31.68	24.35
	26.0	1.0	1.0240	24.0	24.5	103.83	0.867	0.0391	1.2755	21.68	16.66
09:44	26.0	2.0	1.0220	22.0	22.5	111.73	0.867	0.0287	1.2755	19.68	15.12
09:46	26.0	4.0	1.0205	20.5	21.0	117.65	0.867	0.0208	1.2755	18.18	13.97
09:50	26.0	8.0	1.0195	19.5	20.0	121.60	0.867	0.0150	1.2755	17.18	13.20
09:57	25.8	15.0	1.0187	18.7	19.2	124.76	0.871	0.0111	1.2267	16.33	12.55
10:12	25.8	30.0	1.0182	18.2	18.7	126.74	0.871	0.0079	1.2267	15.83	12.17
10:42	25.6	60.0	1.0176	17.6	18.1	129.11	0.875	0.0057	1.1784	15.18	11.67
11:42	25.2	120	1.0165	16.5	17.0	133.45	0.884	0.0041	1.0829	13.98	10.75
10:04	25.5	240	1.0155	15.5	16.0	137.40	0.878	0.0029	1.1543	13.05	10.03
10:04	26.0	480	1.0150	15.0	15.5	139.38	0.867	0.0021	1.2755	12.68	9.74
09:42	24.8	1440	1.0140	14.0	14.5	143.33	0.892	0.0012	0.9892	11.39	8.75

SAMPLE: K2-CURED **COMPACTED SAMPLE-CURED** Date:7/8/99

BIT. CONTENT: 4% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.0	0.5	1.0250	25.0	25.5	99.88	0.867	0.0543	1.2755	22.68	10.92
	26.0	1.0	1.0240	24.0	24.5	103.83	0.867	0.0391	1.2755	21.68	10.44
09:44	26.0	2.0	1.0225	22.5	23.0	109.75	0.867	0.0284	1.2755	20.18	9.72
09:46	26.0	4.0	1.0205	20.5	21.0	117.65	0.867	0.0208	1.2755	18.18	8.75
09:50	26.0	8.0	1.0186	18.6	19.1	125.16	0.867	0.0152	1.2755	16.28	7.84
09:57	26.0	15.0	1.0175	17.5	18.0	129.50	0.867	0.0113	1.2755	15.18	7.31
10:12	25.9	30.0	1.0165	16.5	17.0	133.45	0.869	0.0081	1.2511	14.15	6.81
10:42	25.6	60.0	1.0155	15.5	16.0	137.40	0.875	0.0058	1.1784	13.08	6.30
11:42	25.0	120	1.0146	14.6	15.1	140.96	0.888	0.0042	1.0358	12.04	5.80
10:04	24.4	240	1.0140	14.0	14.5	143.33	0.901	0.0030	0.8972	11.30	5.44
10:04	26.5	480	1.0127	12.7	13.2	148.46	0.857	0.0021	1.3994	10.50	5.06
09:42	25.0	1440	1.0125	12.5	13.0	149.25	0.888	0.0013	1.0358	9.94	4.78

SAMPLE: K2-CURED **COMPACTED SAMPLE-CURED** Date:7/8/99

BIT. CONTENT: 6% Total Dry Weight (g) 50.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
09:42	26.0	0.5	1.0200	20.0	20.5	119.63	0.867	0.0594	1.2755	17.68	13.80
	26.0	1.0	1.0160	16.0	16.5	135.43	0.867	0.0447	1.2755	13.68	10.68
09:44	26.0	2.0	1.0130	13.0	13.5	147.28	0.867	0.0329	1.2755	10.68	8.34
09:46	26.0	4.0	1.0110	11.0	11.5	155.18	0.867	0.0239	1.2755	8.68	6.78
09:50	26.0	8.0	1.0075	7.5	8.0	169.00	0.867	0.0176	1.2755	5.18	4.04
09:57	25.9	15.0	1.0050	5.0	5.5	178.88	0.869	0.0133	1.2511	2.65	2.07
10:12	25.8	30.0	1.0030	3.0	3.5	186.78	0.871	0.0096	1.2267	0.63	0.49
10:42	25.6	60.0	1.0030	3.0	3.5	186.78	0.875	0.0068	1.1784	0.58	0.45
11:42	25.0	120	1.0030	3.0	3.5	186.78	0.888	0.0048	1.0358	0.44	0.34
10:04	25.0	240	1.0030	3.0	3.5	186.78	0.888	0.0034	1.0358	0.44	0.34
10:04	25.0	480	1.0030	3.0	3.5	186.78	0.888	0.0024	1.0358	0.44	0.34
09:42	25.0	1440	1.0030	3.0	3.5	186.78	0.888	0.0014	1.0358	0.44	0.34

APPENDIX E20

SAMPLE: K2

Bit Content: 0%	1	2	3	4	
CONTAINER NO.	B25	A34	B21	A30	
WEIGHT OF CONT.	3.62	3.73	3.59	3.6	
WET SAMPLE+CONT	10.05	10.46	11.83	14.57	
DRY SAMPLE+CONT	8.71	9.26	10.36	12.66	
WEIGHT OF WATER	1.34	1.2	1.47	1.91	
WEIGHT OFDRY SAMPLE	5.09	5.53	6.77	9.06	
W. CONT	26.33	21.7	21.71	21.08	
	24		21		

SAMPLE: K2

Bit Content: 0%	plastic limit				
CONTAINER NO.	C39	B12	C32	A16	
WEIGHT OF CONT.	3.72	3.63	3.65	3.72	
WET SAMPLE+CONT	12.44	14.62	24.74	17.84	
DRY SAMPLE+CONT	10.77	12.52	20.76	15.19	
WEIGHT OF WATER	1.67	2.1	3.98	2.65	
WEIGHT OFDRY SAMPLE	7.05	8.89	17.11	11.47	
W. CONT	23.69	23.6	23.26	23.10	
	23.65		23.18		

SAMPLE: K2

Bit Content: 2%	1	2	3	4	
CONTAINER NO.	C35	A7	C36	C21	
WEIGHT OF CONT.	3.67	3.75	3.75	3.72	
WET SAMPLE+CONT	11.53	13.4	12.4	12.62	
DRY SAMPLE+CONT	10.07	11.4	10.74	10.9	
WEIGHT OF WATER	1.46	2	1.66	1.72	
WEIGHT OFDRY SAMPLE	6.4	7.65	6.99	7.18	
W. CONT	22.81	26.1	23.75	23.96	
	24.48		23.85		

SAMPLE: K2

Bit Content: 1%	1	2	3	4	
CONTAINER NO.	C36	C21	C37	B9	
WEIGHT OF CONT.	3.75	3.72	3.7	3.68	
WET SAMPLE+CONT	9.18	25.48	19.24	21.01	
DRY SAMPLE+CONT	8.07	21.2	16.16	17.64	
WEIGHT OF WATER	1.11	4.28	3.08	3.37	
WEIGHT OFDRY SAMPLE	4.32	17.48	12.46	13.96	
W. CONT	25.69	24.5	24.72	24.14	
	25.09		24.43		

SAMPLE: K2

Bit Content: 3%	1	2	3	4	
CONTAINER NO.	A5	A36	A32	B29	
WEIGHT OF CONT.	3.8	3.75	3.68	3.77	
WET SAMPLE+CONT	10.96	12.88	13.99	14.5	
DRY SAMPLE+CONT	9.49	11.09	11.93	12.33	
WEIGHT OF WATER	1.47	1.79	2.06	2.17	
WEIGHT OFDRY SAMPLE	5.69	7.34	8.25	8.56	
W. CONT	25.83	24.4	24.97	25.35	
	25.11		25.16		

SAMPLE: K2

Bit Content: 4%	1	2	3	4	
CONTAINER NO.	C37	A34	C34	B14	
WEIGHT OF CONT.	3.7	3.73	3.6	3.72	
WET SAMPLE+CONT	11.58	10.9	13.12	11.39	
DRY SAMPLE+CONT	10.01	9.46	11.27	9.9	
WEIGHT OF WATER	1.57	1.44	1.85	1.49	
WEIGHT OFDRY SAMPLE	6.31	5.73	7.67	6.18	
W. CONT	24.88	25.1	24.12	24.11	
	25.01		24.11		

SAMPLE: K2

Bit Content: 8%	1	2	3	4	
CONTAINER NO.	B12	B42	C15	B25	
WEIGHT OF CONT.	3.63	3.71	3.64	3.62	
WET SAMPLE+CONT	13.25	12.74	13.07	11.35	
DRY SAMPLE+CONT	11.13	10.83	11	9.7	
WEIGHT OF WATER	2.12	1.91	2.07	1.65	
WEIGHT OFDRY SAMPLE	7.5	7.12	7.36	6.08	
W. CONT	28.27	26.8	28.13	27.14	
	27.55		27.63		

SAMPLE: K2

Bit Content: 0%	1	2	3	4	
CONTAINER NO.					
WEIGHT OF CONT.	3.6	4.9	6.5	6.3	
NO. OF BLOWS	36	7	13	10	
WET SAMPLE+CONT	34.7	37.6	28.2	32.6	
DRY SAMPLE+CONT	25.5	24.8	20.7	22.7	
WEIGHT OF WATER	9.2	7.5	7.9	6.1	
WEIGHT OFDRY SAMPLE	21.9	19.9	14.2	16.4	
W. CONT	42.01	37.7	55.63	37.20	

SAMPLE: K2

Bit Content: 6%	1	2	3	4	
CONTAINER NO.	A30	C5	C39	C29	
WEIGHT OF CONT.	3.6	3.54	3.72	3.68	
WET SAMPLE+CONT	15.26	13.86	13.2	14.77	
DRY SAMPLE+CONT	12.85	11.75	11.3	12.54	
WEIGHT OF WATER	2.41	2.11	1.9	2.23	
WEIGHT OFDRY SAMPLE	9.25	8.21	7.58	8.86	
W. CONT	26.05	25.7	25.07	25.17	
	25.88		25.12		

SAMPLE: K2

Bit Content: 10%	1	2	3	4	
CONTAINER NO.	C32	B21	B9	A16	
WEIGHT OF CONT.	3.65	3.59	3.67	3.71	
NO. OF BLOWS	9.02	8.58	8.84	10.66	
WET SAMPLE+CONT	7.95	7.41	7.82	9.25	
DRY SAMPLE+CONT	1.07	1.17	1.02	1.41	
WEIGHT OF WATER	4.3	3.82	4.15	5.54	
WEIGHT OFDRY SAMPLE	24.88	30.6	24.58	25.45	
W. CONT	27.76		25.01		

SAMPLE: K2

Bit Content: 1%	1	2	3	4	
CONTAINER NO.	3.6	3.4	3.4	9.7	
WEIGHT OF CONT.	35	12	15	8	
WET SAMPLE+CONT	27.2	25.1	23.1	29.3	
DRY SAMPLE+CONT	19.8	17.5	16.3	19.6	
WEIGHT OF WATER	7.4	7.5	7.9	6.1	
WEIGHT OFDRY SAMPLE	16.2	14.1	12.9	9.9	
W. CONT	45.68	53.2	61.24	61.62	

APPENDIX E22

SAMPLE: K2

Bit Content: 2%	1	2	3	4	
CONTAINER NO.					
WEIGHT OF CONT.	3.6	3.4	3.4	3.4	
NO. OF BLOWS	32	23	16	12	
WET SAMPLE+CONT	25.4	20.7	26.1	27.3	
DRY SAMPLE+CONT	18.8	14.3	18.3	18.8	
WEIGHT OF WATER	6.6	7.5	7.9	6.1	
WEIGHT OFDRY SAMPLE	15.2	10.9	14.9	15.4	
W. CONT	43.42	68.8	53.02	39.61	

SAMPLE: K2

Bit Content: 4%	1	2	3	4	
CONTAINER NO.					
WEIGHT OF CONT.	16.8	16.2	16.3	17	
NO. OF BLOWS	10	14	24	35	
WET SAMPLE+CONT	40.7	41.7	45.5	49.4	
DRY SAMPLE+CONT	32.9	33.1	35	37.4	
WEIGHT OF WATER	7.8	7.5	7.9	6.1	
WEIGHT OFDRY SAMPLE	16.1	16.9	18.7	20.4	
W. CONT	48.45	44.4	42.25	29.90	

SAMPLE: K2

Bit Content: 8%	1	2	3	4	
CONTAINER NO.					
WEIGHT OF CONT.	16.8	16.7	16.5	16.5	
NO. OF BLOWS	7	12	23	37	
WET SAMPLE+CONT	39.5	34.9	45	45.7	
DRY SAMPLE+CONT	31.7	28.3	35.1	34.8	
WEIGHT OF WATER	7.8	7.5	7.9	6.1	
WEIGHT OFDRY SAMPLE	14.9	11.6	18.6	18.3	
W. CONT	52.35	64.7	42.47	33.33	

SAMPLE: K2-Cured

SAMPLE: K2

Bit Content: 3%	1	2	3	4	
CONTAINER NO.					
WEIGHT OF CONT.	8.8	9.2	8.9	9.4	
NO. OF BLOWS	10	20	31	45	
WET SAMPLE+CONT	22.4	29.2	30.5	31.8	
DRY SAMPLE+CONT	18.1	22.4	23.2	23.3	
WEIGHT OF WATER	4.3	7.5	7.9	6.1	
WEIGHT OFDRY SAMPLE	9.3	13.2	14.3	13.9	
W. CONT	46.24	56.8	55.24	43.88	

SAMPLE: K2

Bit Content: 6%	1	2	3	4	
CONTAINER NO.					
WEIGHT OF CONT.	16.9	16.4	16.2	16.9	
NO. OF BLOWS	7	11	19	31	
WET SAMPLE+CONT	38	40.4	44.3	46.4	
DRY SAMPLE+CONT	30.9	32.2	34.1	35.4	
WEIGHT OF WATER	7.1	7.5	7.9	6.1	
WEIGHT OFDRY SAMPLE	14	15.8	17.9	18.5	
W. CONT	50.71	47.5	44.13	32.97	

SAMPLE: K2

Bit Content: 10%	1	2	3	4	
CONTAINER NO.					
WEIGHT OF CONT.	16.8	17.1	16.7	16.9	
NO. OF BLOWS	9	15	23	40	
WET SAMPLE+CONT	38	42.5	45.8	48.5	
DRY SAMPLE+CONT	30.9	33.6	35.3	36.2	
WEIGHT OF WATER	7.1	7.5	7.9	6.1	
WEIGHT OFDRY SAMPLE	14.1	16.5	18.6	19.3	
W. CONT	50.35	45.5	42.47	31.61	

SAMPLE: K2-Cured

APPENDIX E23

Bit Content: 0%	1	2	3	4	5
CONTAINER NO.					
WEIGHT OF CONT.	3.66	3.69	3.8	3.76	3.71
NO. OF BLOWS	46	33	29	26	20
WET SAMPLE+CONT	20.15	16.67	16.32	15.18	32.67
DRY SAMPLE+CONT	15.21	12.76	12.54	11.68	23.55
WEIGHT OF WATER	4.94	7.5	7.9	6.1	6.1
WEIGHT OFDRY SAMPLE	11.55	9.07	8.74	7.92	19.84
W. CONT	42.77	82.7	90.39	77.02	30.75

SAMPLE: K2-Cured

Bit Content: 3%	1	2	3	4	
CONTAINER NO.					
WEIGHT OF CONT.	3.76	3.71	3.71	3.75	
NO. OF BLOWS	24	25	32	27	
WET SAMPLE+CONT	13.09	24.7	31.29	38.77	
DRY SAMPLE+CONT	10.2	18.22	22.78	27.96	
WEIGHT OF WATER	2.89	7.5	7.9	6.1	
WEIGHT OFDRY SAMPLE	6.44	14.51	19.07	24.21	
W. CONT	44.88	51.7	41.43	25.20	

SAMPLE: K2-Cured

Bit Content: 6%	1	2	3	4	5
CONTAINER NO.					
WEIGHT OF CONT.	3.78	3.7	3.62	3.64	3.77
NO. OF BLOWS	21	37	31	26	16
WET SAMPLE+CONT	17.17	28.43	30.82	31.8	42.35
DRY SAMPLE+CONT	13.09	21.29	22.85	23.44	30.38
WEIGHT OF WATER	4.08	7.5	7.9	6.1	6.1
WEIGHT OFDRY SAMPLE	9.31	17.59	19.23	19.8	26.61
W. CONT	43.82	42.6	41.08	30.81	22.92

SAMPLE: Cured-K2-Cured

Bit Content: 2%	1	2	3	4	5
CONTAINER NO.					
WEIGHT OF CONT.	3.75	3.64	3.61	3.81	3.71
NO. OF BLOWS	49	40	29	27	24
WET SAMPLE+CONT	36.26	41.07	35.26	34.43	49.29
DRY SAMPLE+CONT	26.81	30.05	25.88	25.22	35.2
WEIGHT OF WATER	9.45	7.5	7.9	6.1	6.1
WEIGHT OFDRY SAMPLE	23.06	26.41	22.27	21.41	31.49
W. CONT	40.98	28.4	35.47	28.49	19.37

SAMPLE: K2-Cured

Bit Content: 4%	1	2	3	4	5
CONTAINER NO.					
WEIGHT OF CONT.	3.67	3.76	3.72	3.62	3.79
NO. OF BLOWS	49	45	41	23	19
WET SAMPLE+CONT	14.06	18.33	20.57	21.41	41.84
DRY SAMPLE+CONT	10.81	13.68	15.12	15.47	29.07
WEIGHT OF WATER	3.25	7.5	7.9	6.1	6.1
WEIGHT OFDRY SAMPLE	7.14	9.92	11.4	11.85	25.28
W. CONT	45.52	75.6	69.30	51.48	24.13

SAMPLE: Cured-K2-Cured

Bit Content: 0%	1	2	3	4	5
CONTAINER NO.					
WEIGHT OF CONT.	3.5	3.68	3.51	3.57	3.75
NO. OF BLOWS	14	19	24	30	36
WET SAMPLE+CONT	19.47	29.11	31.64	28.91	43.83
DRY SAMPLE+CONT	14.84	21.65	23.23	21.31	31.46
WEIGHT OF WATER	4.63	7.5	7.9	6.1	6.1
WEIGHT OFDRY SAMPLE	11.34	17.97	19.72	17.74	27.71
W. CONT	40.83	41.7	40.06	34.39	22.01

SAMPLE: Cured-K2-Cured

APPENDIX E24

Bit Content: 2%	1	2	3	4	5
CONTAINER NO.					
WEIGHT OF CONT.	3.69	3.7	3.71	3.69	3.65
NO. OF BLOWS	34	30	21	18	15
WET SAMPLE+CONT	22.3	18.06	25.06	26.03	19.71
DRY SAMPLE+CONT	16.74	14.37	18.45	19.05	14.63
WEIGHT OF WATER	5.56	7.5	7.9	6.1	6.1
WEIGHT OFDRY SAMPLE	13.05	10.67	14.74	15.36	10.98
W. CONT	42.61	70.3	53.60	39.71	55.56

SAMPLE: Cured-K2-Cured

Bit Content: 4%	1	2	3	4	5
CONTAINER NO.					
WEIGHT OF CONT.	3.73	3.96	3.8	3.86	3.55
NO. OF BLOWS	49	40	20	29	19
WET SAMPLE+CONT	25.45	27.58	25.06	32.51	33.11
DRY SAMPLE+CONT	19.32	20.76	18.76	23.95	24.03
WEIGHT OF WATER	6.13	7.5	7.9	6.1	6.1
WEIGHT OFDRY SAMPLE	15.59	16.8	14.96	20.09	20.48
W. CONT	39.32	44.6	52.81	30.36	29.79

Bit Content: 3%	1	2	3	4	5
CONTAINER NO.					
WEIGHT OF CONT.	3.7	3.82	3.74	3.62	3.67
NO. OF BLOWS	41	24	20	15	12
WET SAMPLE+CONT	26.91	33.49	20.7	27.62	28.81
DRY SAMPLE+CONT	19.99	24.47	15.48	20.08	20.78
WEIGHT OF WATER	6.92	7.5	7.9	6.1	6.1
WEIGHT OFDRY SAMPLE	16.29	20.65	11.74	16.46	17.11
W. CONT	42.48	36.3	67.29	37.06	35.65

SAMPLE: Cured-K2-Cured

Bit Content: 6%	1	2	3	4	5
CONTAINER NO.					
WEIGHT OF CONT.	3.61	3.6	3.71	3.58	3.77
NO. OF BLOWS	49	26	24	16	10
WET SAMPLE+CONT	20.05	18.6	22.93	23.92	30.46
DRY SAMPLE+CONT	15.47	14.17	17.21	17.74	22.28
WEIGHT OF WATER	4.58	7.5	7.9	6.1	6.1
WEIGHT OFDRY SAMPLE	11.86	10.57	13.5	14.16	18.51
W. CONT	38.62	71.0	58.52	43.08	32.96

CIVIL ENGINEERING DEPARTMENT

GEOTECHNICAL ENGINEERING LABORATORY

SHRINKAGE ANALYSIS

SAMPLE K2
FRESH SAMPLE

DATE:16-6-99

BIT CONTENT: 0%

Test	1	2
Mould No.	A	C
Initial length	12.7	12.8
Length of oven dried sample	11.1	11.2
Linear shrinkage	12.598	12.500
Average		

SAMPLE K2
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 0%

Test	1	2
Mould No.	E	C
Initial length	12.7	12.8
Length of oven dried sample	10.85	11.2
Linear shrinkage	14.567	12.500
Average		

SAMPLE K2
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 2%

Test	1	2
Mould No.	E	A
Initial length	12.7	12.8
Length of oven dried sample	11.9	11.9
Linear shrinkage	6.299	7.031
Average		

SAMPLE K2
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 1%

Test	1	2
Mould No.	I	M
Initial length	12.7	14
Length of oven dried sample	10.7	12
Linear shrinkage	15.748	14.286
Average		

SAMPLE K2
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 3%

Test	1	2
Mould No.	B	C
Initial length	12.85	12.85
Length of oven dried sample	11.05	11.05
Linear shrinkage	14.008	14.008
Average		

SAMPLE K2
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 4%

Test	1	2
Mould No.	P	K
Initial length	14	14
Length of oven dried sample	11.95	11.95
Linear shrinkage	14.643	14.643
Average		

SAMPLE K2
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 8%

Test	1	2
Mould No.	B	C
Initial length	12.8	12.85
Length of oven dried sample	11.05	11.1
Linear shrinkage	13.672	13.619
Average		

SAMPLE K2
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 6%

Test	1	2
Mould No.	M	I
Initial length	14	12.8
Length of oven dried sample	12.05	11
Linear shrinkage	13.929	14.063
Average		

SAMPLE K2
COMPACTED SAMPLE

DATE:16-6-99

BIT CONTENT: 10%

Test	1	2
Mould No.	A	C
Initial length	12.75	12.7
Length of oven dried sample	11	11
Linear shrinkage	13.725	13.386
Average		

LIQUID LIMITS USING THE CONE PENETROMETER

Sample: K2-Cured

Date 11-08-99

Bit Content: 0%

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	22.1	22.91	22.87	19.5	23.11
Final dial gauge reading (mm)	11.75	11.71	11.57	7.79	6.55
Cone penetration (mm)	10.35	11.2	11.3	11.7	16.56
Container No.	A15	A12	A6	B23	C7
Mass of wet soil+container (g)	14.01	14.6	14.32	24.2	16.8
Mass of dried soil+container (g)	11.39	11.76	11.53	18.5	13.09
Mass of container (g)	3.75	3.68	3.73	3.74	3.66
Mass of moisture (g)	2.62	2.84	2.79	5.69	3.71
Mass of dry soil (g)	7.64	8.08	7.8	14.7	9.43
Moisture content (%)	34.29	35.15	35.77	38.63	39.34

Sample: K2-Cured

Date 11-08-99

Bit Content: 2%

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	23.2	20.85	22.9	20.6	23.38
Final dial gauge reading (mm)	13	9.25	6.92	5.49	6.4
Cone penetration (mm)	10.2	11.6	15.98	15.2	16.98
Container No.	A5	A7	A1	A9	B14
Mass of wet soil+container (g)	26.1	35.78	36.85	36.6	38.25
Mass of dried soil+container (g)	20.41	27.19	27.65	27.3	28.43
Mass of container (g)	3.79	3.74	3.74	3.79	3.72
Mass of moisture (g)	5.69	8.59	9.2	9.32	9.82
Mass of dry soil (g)	16.62	23.45	23.91	23.5	24.71
Moisture content (%)	34.24	36.63	38.48	39.68	39.74

Sample: K2-Cured

Date 11-08-99

Bit Content: 3%

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	23.38	22.86	23.28	24.1	23.08
Final dial gauge reading (mm)	10.76	10.2	6.78	6.44	2.83
Cone penetration (mm)	12.62	12.66	16.5	17.7	20.25
Container No.	B38	C39	C23	B35	B4
Mass of wet soil+container (g)	13.64	16.93	14.42	14.6	16.45
Mass of dried soil+container (g)	11.04	13.33	11.41	11.5	12.66
Mass of container (g)	3.81	3.72	3.77	3.79	3.63
Mass of moisture (g)	2.6	3.6	3.01	3.1	3.79
Mass of dry soil (g)	7.23	9.61	7.64	7.72	9.03
Moisture content (%)	35.96	37.46	39.40	40.16	41.97

Sample: K2-Cured

Date 11-08-99

Bit Content: 4%

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	24.37	23.42	22.12	21.6	22.91
Final dial gauge reading (mm)	12.94	11.67	6.35	6.38	5.31
Cone penetration (mm)	11.43	11.75	15.77	15.2	17.6
Container No.	A30	B22	B25	A34	B39
Mass of wet soil+container (g)	19.47	23.49	16.56	22	24.99
Mass of dried soil+container (g)	15.32	18.16	12.78	16.5	18.46
Mass of container (g)	3.6	3.71	3.61	3.74	3.67
Mass of moisture (g)	4.15	5.33	3.78	5.51	6.53
Mass of dry soil (g)	11.72	14.45	9.17	12.7	14.79
Moisture content (%)	35.41	36.89	41.22	43.25	44.15

Sample: K2-Cured

Date 11-08-99

Bit Content: 6%

Test No.	1	2	3	4	5
Initial dial gauge reading (mm)	22.94	22.2	23.29	21.8	20.38
Final dial gauge reading (mm)	10.49	9.12	6.35	3.96	0.29
Cone penetration (mm)	12.45	13.08	16.94	17.9	20.09
Container No.	A16	C35	B3	B21	A41
Mass of wet soil+container (g)	21.03	19.13	20.54	21.8	17.88
Mass of dried soil+container (g)	16.49	14.95	15.7	16.4	13.51
Mass of container (g)	3.71	3.66	3.48	3.59	3.7
Mass of moisture (g)	4.54	4.18	4.84	5.35	4.37
Mass of dry soil (g)	12.78	11.29	12.22	12.8	9.81
Moisture content (%)	35.52	37.02	39.61	41.73	44.55

KNUST

COMPACTION TEST RESULTS- MODIFIED AASHTO

SAMPLE: K2

Date:27/5/99

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 0% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	12132	12398	12340	12298	12293
Mass of cylinder (gm)	7454	7454	7454	7454	7454
Mass of wet sample (gm)	4678	4944	4886	4844	4839
Bulk density (Mg/m^3)	2.20	2.33	2.30	2.28	2.28

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	D9	D8	D2	D20	D16	107	C8	C3	S	112
Mass of container+Wet soil (gm)	108.28	111.21	81.28	88.11	91.11	92.07	92.30	97.42	95.42	84.46
Mass of container+Dry soil (gm)	101.91	104.73	76.52	81.95	83.85	84.78	83.84	88.78	86.58	76.58
Mass of container (gm)	18.13	17.99	18.02	18.03	17.81	18.33	18.04	18.79	18.82	17.12
Mass of water (gm)	6.37	6.48	4.76	6.16	7.26	7.29	8.46	8.64	8.84	7.88
Mass of dry soil (gm)	83.78	86.74	58.50	63.92	66.04	66.45	65.80	69.99	67.76	59.46
Water content (%)	7.60	7.47	8.14	9.64	10.99	10.97	12.86	12.34	13.05	13.25
Average water content	7.54		8.89		10.98		12.60		13.15	
Dry density (Mg/m^3)	2.05		2.14		2.07		2.03		2.01	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Date:

SAMPLE: K2

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 1% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	11921	12106	12403	12341	12214
Mass of cylinder (gm)	7454	7454	7454	7454	7454
Mass of wet sample (gm)	4467	4652	4949	4887	4760
Bulk density (Mg/m^3)	2.10	2.19	2.33	2.30	2.24

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	A27	A12	A100	A17	A88	A24	B5	A36	A42	A14
Mass of container+Wet soil (gm)	75.63	81.88	71.60	79.88	66.69	72.65	70.98	73.38	74.21	74.03
Mass of container+Dry soil (gm)	72.34	78.62	67.83	75.59	61.98	67.78	65.08	67.3	67.27	67.1
Mass of container (gm)	12.82	14.24	14.36	17.09	14.23	14.48	14.22	14.76	14.67	14.85
Mass of water (gm)	3.29	3.26	3.77	4.29	4.71	4.87	5.90	6.08	6.94	6.93
Mass of dry soil (gm)	59.52	64.38	53.47	58.50	47.75	53.30	50.86	52.54	52.60	52.25
Water content (%)	5.53	5.06	7.05	7.33	9.86	9.14	11.60	11.57	13.19	13.26
Average water content	5.30		7.19		9.50		11.59		13.23	
Dry density (Mg/m^3)	2.00		2.04		2.13		2.06		1.98	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

SAMPLE: K2 Date: 27/5/99

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 2% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	11979	12364	12408	12370	12316
Mass of cylinder (gm)	7454	7454	7454	7454	7454
Mass of wet sample (gm)	4525	4910	4954	4916	4862
Bulk density (Mg/m^3)	2.13	2.31	2.33	2.31	2.29

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	A6	A7	A2	A3	P4	P5	D17	D3	C4	G5
Mass of container+Wet soil (gm)	95.21	87.44	89.06	85.08	83.14	87.82	77.13	83.5	82.45	82.71
Mass of container+Dry soil (gm)	90.63	83.64	83.45	79.85	75.88	82.43	70.77	76.71	75.39	75.21
Mass of container (gm)	18.13	18.08	18.08	18.54	18.45	17.66	18.36	17.77	18.23	17.78
Mass of water (gm)	4.58	3.80	5.61	5.23	7.26	5.39	6.36	6.79	7.06	7.50
Mass of dry soil (gm)	72.50	65.56	65.37	61.31	57.43	64.77	52.41	58.94	57.16	57.43
Water content (%)	6.32	5.80	8.58	8.53	12.64	8.32	12.14	11.52	12.35	13.06
Average water content	6.06		8.56		10.48		11.83		12.71	
Dry density (Mg/m^3)	2.01		2.13		2.11		2.07		2.04	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

KNUST

SAMPLE: K2 Date:

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 3% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	11889	12172	12294	12154	12126
Mass of cylinder (gm)	7454	7454	7454	7454	7454
Mass of wet sample (gm)	4435	4718	4840	4700	4672
Bulk density (Mg/m^3)	2.09	2.22	2.28	2.21	2.20

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	D17	C4	A2	G5	A7	A3	P4	A6	D3	P5
Mass of container+Wet soil (gm)	98.29	89.94	94.02	90.08	80.72	86.28	87.83	87.3	85.16	86.76
Mass of container+Dry soil (gm)	93.07	86.09	87.94	84.28	74.97	80.89	80.54	79.98	77.47	79.08
Mass of container (gm)	18.36	18.24	18.21	17.78	18.01	18.53	18.41	18.15	17.77	17.66
Mass of water (gm)	5.22	3.85	6.08	5.80	5.75	5.39	7.29	7.32	7.69	7.68
Mass of dry soil (gm)	74.71	67.85	69.73	66.50	56.96	62.36	62.13	61.83	59.70	61.42
Water content (%)	6.99	5.67	8.72	8.72	10.09	8.64	11.73	11.84	12.88	12.50
Average water content	6.33		8.72		9.37		11.79		12.69	
Dry density (Mg/m^3)	1.96		2.04		2.083		1.98		1.95	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

SAMPLE: K2 Date:27/5/99

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 4% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	11882	12200	12283	12234	12152
Mass of cylinder (gm)	7454	7454	7454	7454	7454
Mass of wet sample (gm)	4428	4746	4829	4780	4698
Bulk density (Mg/m^3)	2.08	2.23	2.27	2.25	2.21

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	C8	C3	D8	D2	D16	D9	107	112	S	D20
Mass of container+Wet soil (gm)	101.55	90.51	92.52	85.55	76.06	85.71	82.61	87.72	83.68	82.34
Mass of container+Dry soil (gm)	97.03	86.14	86.88	80.31	71.11	79.79	76.60	81.23	76.59	75.45
Mass of container (gm)	18.04	18.79	17.99	18.03	17.80	18.13	18.32	17.92	18.02	18.04
Mass of water (gm)	4.52	4.37	5.64	5.24	4.95	5.92	6.01	6.49	7.09	6.89
Mass of dry soil (gm)	78.99	67.35	68.89	62.28	53.31	61.66	58.28	63.31	58.57	57.41
Water content (%)	5.72	6.49	8.19	8.41	9.29	9.60	10.31	10.25	12.11	12.00
Average water content	6.11		8.30		9.44		10.28		12.05	
Dry density (Mg/m^3)	1.96		2.06		2.08		2.04		1.97	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

KNUST

SAMPLE: K2 Date:

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 6% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	11950	12167	12210	12144	12095
Mass of cylinder (gm)	7454	7454	7454	7454	7454
Mass of wet sample (gm)	4496	4713	4756	4690	4641
Bulk density (Mg/m^3)	2.12	2.22	2.24	2.21	2.18

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	A32	A29	A15	A39	A5	A34	C17	C12	C7	C11
Mass of container+Wet soil (gm)	70.56	77.65	71.40	75.20	63.46	69.63	85.19	80.12	90.8	85.76
Mass of container+Dry soil (gm)	67.15	74.88	66.84	71.3	59	64.85	78.07	73.59	82.69	78.58
Mass of container (gm)	14.81	22.24	15.38	14.26	14.81	14.10	17.83	17.78	18.15	18.15
Mass of water (gm)	3.41	2.77	4.56	3.90	4.46	4.78	7.12	6.53	8.11	7.18
Mass of dry soil (gm)	52.34	52.64	51.46	57.04	44.19	50.75	60.24	55.81	64.54	60.43
Water content (%)	6.52	5.26	8.86	6.84	10.09	9.42	11.82	11.70	12.57	11.88
Average water content	5.89		7.85		9.76		11.76		12.22	
Dry density (Mg/m^3)	2.00		2.06		2.04		1.98		1.94	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

SAMPLE: K2 Date:27/5/99

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 8% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	11928	12162	12259	12137	11998
Mass of cylinder (gm)	7454	7454	7454	7454	7454
Mass of wet sample (gm)	4474	4708	4805	4683	4544
Bulk density (Mg/m^3)	2.11	2.22	2.26	2.20	2.14

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	D16	D2	C8	C3	112	107	D9	D8	D20	S
Mass of container+Wet soil (gm)	84.48	82.78	77.57	77.71	72.88	71.42	76.67	75.19	72.56	74.32
Mass of container+Dry soil (gm)	80.38	79.07	72.87	72.98	67.58	66.47	70.74	68.7	66.39	68.17
Mass of container (gm)	17.81	18.03	18.05	18.77	17.92	18.32	18.13	18.00	18.04	18.03
Mass of water (gm)	4.10	3.71	4.70	4.73	5.30	4.95	5.93	6.49	6.17	6.15
Mass of dry soil (gm)	62.57	61.04	54.82	54.21	49.66	48.15	52.61	50.70	48.35	50.14
Water content (%)	6.55	6.08	8.57	8.73	10.67	10.28	11.27	12.80	12.76	12.27
Average water content	6.32		8.65		10.48		12.04		12.51	
Dry density (Mg/m^3)	1.98		2.04		2.05		1.97		1.90	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

SAMPLE: K2 Date:

SITE: BROFOYEDU **SAMPLE DESCRIPTION: 10% bitumen content**

Sample preparation	1	2	3	4	5
Mass of cylinder + Wet sample (gm	11814	12071	12142	11998	11982
Mass of cylinder (gm)	7454	7454	7454	7454	7454
Mass of wet sample (gm)	4360	4617	4688	4544	4528
Bulk density (Mg/m^3)	2.05	2.17	2.21	2.14	2.13

Water Content Determination

Test No.	1		2		3		4		5	
Container No.	C3	C17	D2	D4	D11	D3	C7	D14	P4	C2
Mass of container+Wet soil (gm)	82.49	77.69	70.32	85.40	78.67	92.01	93.29	88.55	89.55	95.42
Mass of container+Dry soil (gm)	78.15	73.56	65.98	80.16	73.03	85.67	85.92	81.69	81.56	86.82
Mass of container (gm)	18.82	17.83	18.04	18.21	17.89	18.24	18.15	18.26	18.62	17.79
Mass of water (gm)	4.34	4.13	4.34	5.24	5.64	6.34	7.37	6.86	7.99	8.60
Mass of dry soil (gm)	59.33	55.73	47.94	61.95	55.14	67.43	67.77	63.43	62.94	69.03
Water content (%)	7.32	7.41	9.05	8.46	10.23	9.40	10.88	10.82	12.69	12.46
Average water content	7.36		8.76		9.82		10.85		12.58	
Dry density (Mg/m^3)	1.91		2.00		2.01		1.93		1.89	

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

KNUST

GEOTECHNICAL ENGINEERING LABORATORY
CBR TEST RECORDING SHEET

DATE: 6/6/99

SAMPLE : K2

SAMPLE DESCRIPTION: 0% Bitumen Content

Proving Ring constant: 0.026

Mould No.	L2-A0-01		
No. of blows per layer	55		
Wet sample + Mould (g)	12,382		
Mass of Mould	7,363		
Mass of wet sample	5,019		
Volume of mould	2124		
Bulk density (g/cc)	2.363		

WATER CONTENT OF TRIMMINGS

	TOP	BOT				
Container No.	D3	C2				
Wet sample + container (g)	90.95	74.52				
Dry sample + container (g)	84.88	68.98				
Mass of container	18.24	17.80				
Mass of water	6.07	5.54				
Mass of dry sample	66.64	51.18				
Water content	9.11	10.82				
Average Water content	9.97					
Dry density	2.15					

AFTER SOAKING	L2-A0-02		
Wet sample + Mould (g)	12339		
Mass of mould	7398		
Mass of wet sample	4941		
Bulk density (g/cc)	2.33		

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	A7	C4				
Wet sample + container (g)	75.54	80.68				
Dry sample + container (g)	67.92	71.59				
Mass of container	17.87	18.3				
Mass of water	7.62	9.09				
Mass of dry sample	50.05	53.33				
Water content	15.22	17.04				
Average Water content	16.13					
Dry density	2.03					

Penetration	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	0	0.00		22	0.57				
0.50	11	0.29		39	1.01				
0.75	15	0.39		42	1.09				
1.00	21	0.55		51	1.33				
1.25	28	0.73		68	1.77				
1.50	35	0.91		81	2.11				
1.75	40	1.04		92	2.39				
2.00	47	1.22		103	2.68				
2.25	55	1.43		112	2.91				
2.50	64	1.66	**13**	128	3.33	**25**			
2.75	73	1.90		138	3.59				
3.00	85	2.21		145	3.77				
3.50	107	2.78		169	4.39				
4.00	133	3.46		188	4.89				
4.50	158	4.11		202	5.25				
5.00	190	4.94	**25**	219	5.69	**29**			
5.50	205	5.33		232	6.03				
6.00	243	6.32		245	6.37				
6.50	271	7.05		256	6.66				
7.00	305	7.93		266	6.92				
7.50	332	8.63		280	7.28				
8.00	355	9.23		292	7.59				

KNUST

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					1			
					16			
					16			
					16			
					16			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			15			0
		0			0			0
		0			0			0
		0			0			0

B

GEOTECHNICAL ENGINEERING LABORATORY
CBR TEST RECORDING SHEET

DATE: 6/6/99

SAMPLE : K2

SAMPLE DESCRIPTION: 2% Bitumen Content

Proving Ring constant: 0.026kN/div

Mould No.	L2-A2-01		
No. of blows per layer	55		
Wet sample + Mould (g)	12,460		
Mass of Mould	7,538		
Mass of wet sample	4,922		
Volume of mould	2124		
Bulk density (g/cc)	2.317		

WATER CONTENT OF TRIMMINGS

	TOP	BOT				
Container No.	C3	D9				
Wet sample + container (g)	75.22	86.17				
Dry sample + container (g)	69.72	80.40				
Mass of container	18.69	18.22				
Mass of water	5.50	5.77				
Mass of dry sample	51.03	62.18				
Water content	10.78	9.28				
Average Water content	10.03					
Dry density	2.11					

AFTER SOAKING	L2-A2-02		
Wet sample + Mould (g)	12271		
Mass of mould	7412		
Mass of wet sample	4859		
Bulk density (g/cc)	2.28775341		

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	D6	10				
Wet sample + container (g)	77.08	79.44				
Dry sample + container (g)	18.00	72.52				
Mass of container	17.99	6.92				
Mass of water	59.08	6.92				
Mass of dry sample	0.01	65.60				
Water content	####	10.55				
Average Water content	295405.27					
Dry density	0.00					

Penetration	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	23	0.60		13	0.34				
0.50	40	1.04		22	0.57				
0.75	53	1.38		27	0.70				
1.00	67	1.74		30	0.78				
1.25	78	2.03		35	0.91				
1.50	90	2.34		39	1.01				
1.75	101	2.63		44	1.14				
2.00	113	2.94		48	1.25				
2.25	126	3.28		52	1.35				
2.50	138	3.59	**27**	57	1.48	**11**			
2.75	148	3.85		61	1.59				
3.00	161	4.19		68	1.77				
3.50	187	4.86		81	2.11				
4.00	230	5.98		98	2.55				
4.50	257	6.68		114	2.96				
5.00	283	7.36	**37**	126	3.28	**16**			
5.50	310	8.06		135	3.51				
6.00	336	8.74		148	3.85				
6.50	355	9.23		159	4.13				
7.00	370	9.62		168	4.37				
7.50	395	10.27		175	4.55				
8.00	406	10.56		183	4.76				

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					282			
					287			
					289			
					289			
					289			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			5			0
		0			2			0
		0			0			0
		0			0			0

B

6/6/99

LE : K2

E DESCRIPTION: 3% Bitumen Content

lo.	L2-A3-01		
lows per layer	55		
mple + Mould (g)	12,258		
Mould	7,493		
wet sample	4,765		
of mould	2124		
nsity (g/cc)	2.243		

R CONTENT OF TRIMMINGS

	TOP	BOT				
er No.	D14	D11				
mple + container (g)	69.97	63.27				
mple + container (g)	65.23	59.27				
f container	18.27	18.22				
f water	4.74	4.00				
f dry sample	46.96	41.05				
content	10.09	9.74				
e Water content	9.92					
nsity	2.04					
SOAKING	L2-A3-02					
mple + Mould (g)	12313					
f mould	7440					
f wet sample	4873					
nsity (g/cc)	2.29434501					

INGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
ner No.	D3	D7				
mple + container (g)	65.59	67.47				
mple + container (g)	59.38	60.70				
f container	18.24	17.9				
f water	6.21	6.77				
f dry sample	41.14	42.81				
content	15.09	15.81				
e Water content	15.45					
nsity	1.94					

Proving Ring constant: 0.026kN/div

Penetration	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	6	0.16		10	0.26				
0.50	9	0.23		14	0.36				
0.75	12	0.31		18	0.47				
1.00	16	0.42		21	0.55				
1.25	21	0.55		26	0.68				
1.50	25	0.65		30	0.78				
1.75	29	0.75		33	0.86				
2.00	34	0.88		39	1.01				
2.25	39	1.01		46	1.20				
2.50	46	1.20	**9**	53	1.38	**10**			
2.75	52	1.35		60	1.56				
3.00	60	1.56		68	1.77				
3.50	74	1.92		80	2.08				
4.00	89	2.31		89	2.31				
4.50	104	2.70		101	2.63				
5.00	116	3.02	**15**	109	2.83	**14**			
5.50	130	3.38		115	2.99				
6.00	142	3.69		120	3.12				
6.50	153	3.98		126	3.28				
7.00	164	4.26		132	3.43				
7.50	171	4.45		137	3.56				
8.00	180	4.68		143	3.72				

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					283			
					287			
					289			
					289			
					289			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0						
		0						
		0						
		0						

B

6/6/99

SA LE : K2

SA LE DESCRIPTION: 4% Bitumen Content

Mo No.	L2-A4-01		
No blows per layer	55		
We mple + Mould (g)	12,254		
Ma of Mould	7,493		
Ma of wet sample	4,761		
Vo e of mould	2124		
Bu ensity (g/cc)	2.242		

WA R CONTENT OF TRIMMINGS

	TOP	BOT				
Co ner No.	107	C4				
We mple + container (g)	84.93	78.17				
Dr mple + container (g)	79.03	72.31				
Ma of container	18.24	18.27				
Ma of water	5.90	5.86				
Ma of dry sample	60.79	54.04				
W- content	9.71	10.84				
Av ge Water content	10.27					
Dr nsity	2.03					
AF R SOAKING	L2-A4-02					
W mple + Mould (g)	12334					
Ma of mould	7572					
Ma of wet sample	4762					
Bu ensity (g/cc)	2.24208309					

TR MINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Co iner No.	C3	C18				
W mple + container (g)	71.99	64.99				
Dr mple + container (g)	62.48	57.89				
M- of container	18.68	17.7				
M of water	9.51	7.10				
M of dry sample	43.80	40.22				
W content	21.71	17.65				
Av ge Water content	19.68					
D ensity	1.87					

Proving Ring constant: 0.026kN/div

Penetration	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	13	0.34		5	0.13				
0.50	18	0.47		8	0.21				
0.75	20	0.52		11	0.29				
1.00	24	0.62		14	0.36				
1.25	28	0.73		15	0.39				
1.50	32	0.83		18	0.47				
1.75	36	0.94		22	0.57				
2.00	42	1.09		25	0.65				
2.25	47	1.22		28	0.73				
2.50	52	1.35	**10**	32	0.83	**6**			
2.75	58	1.51		35	0.91				
3.00	62	1.61		40	1.04				
3.50	74	1.92		49	1.27				
4.00	87	2.26		54	1.40				
4.50	98	2.55		64	1.66				
5.00	111	2.89	**14**	72	1.87	**9**			
5.50	124	3.22		80	2.08				
6.00	133	3.46		88	2.29				
6.50	145	3.77		96	2.50				
7.00	156	4.06		103	2.68				
7.50	169	4.39		109	2.83				
8.00	180	4.68		120	3.12				

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					288			
					293			
					293			
					293			
					293			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0						
		0						
		0						
		0						

D : 6/6/99

APPENDIX E35

KNUST

SAMPLE : K2

SAMPLE DESCRIPTION: 6% Bitumen Content

Mould No.	L2-A6-01		
No. of blows per layer	55		
Wet sample + Mould (g)	12,217		
Mass of Mould	7,575		
Mass of wet sample	4,642		
Volume of mould	2124		
Bulk density (g/cc)	2.186		

WATER CONTENT OF TRIMMINGS

	TOP	BOT				
Container No.	C7	C4				
Wet sample + container (g)	74.13	65.90				
Dry sample + container (g)	68.94	61.34				
Mass of container	18.15	18.14				
Mass of water	5.19	4.56				
Mass of dry sample	50.79	43.20				
Water content	10.22	10.56				
Average Water content	10.39					
Dry density	1.98					
AFTER SOAKING	L2-A6-02					
Wet sample + Mould (g)	12032					
Mass of mould	7362					
Mass of wet sample	4670					
Bulk density (g/cc)	2.19876691					

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	C2	A10				
Wet sample + container (g)	64.24	67.01				
Dry sample + container (g)	57.91	59.62				
Mass of container	17.79	17.9				
Mass of water	6.33	7.39				
Mass of dry sample	40.12	41.71				
Water content	15.78	17.72				
Average Water content	16.75					
Dry density	1.88					

Proving Ring constant: 0.026kN/div

Penetration	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	12	0.31		9	0.23				
0.50	17	0.44		13	0.34				
0.75	24	0.62		17	0.44				
1.00	32	0.83		24	0.62				
1.25	37	0.96		30	0.78				
1.50	44	1.14		35	0.91				
1.75	51	1.33		38	0.99				
2.00	59	1.53		44	1.14				
2.25	66	1.72		52	1.35				
2.50	72	1.87	**14**	60	1.56	**12**			
2.75	78	2.03		64	1.66				
3.00	85	2.21		70	1.82				
3.50	95	2.47		77	2.00				
4.00	107	2.78		89	2.31				
4.50	115	2.99		99	2.57				
5.00	124	3.22	**16**	112	2.91	**15**			
5.50	129	3.35		125	3.25				
6.00	133	3.46		130	3.38				
6.50	137	3.56		135	3.51				
7.00	142	3.69		140	3.64				
7.50	143	3.72		141	3.67				
8.00	145	3.77		143	3.72				

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					123			
					128			
					128			
					128			
					128			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
					5			0
					0			0
					0			0
					0			0

B

DATE: 6/6/99

SAMPLE : K2

SAMPLE DESCRIPTION: 8% Bitumen Content

Mould No.	L2-A8-01		
No. of blows per layer	55		
Wet sample + Mould (g)	11,995		
Mass of Mould	7,364		
Mass of wet sample	4,631		
Volume of mould	2124		
Bulk density (g/cc)	2.180		

WATER CONTENT OF TRIMMINGS

	TOP	BOT				
Container No.	D7	D9				
Wet sample + container (g)	68.29	58.13				
Dry sample + container (g)	62.89	53.90				
Mass of container	17.88	18.15				
Mass of water	5.40	4.23				
Mass of dry sample	45.01	35.75				
Water content	12.00	11.83				
Average Water content	11.91					
Dry density	1.95					
AFTER SOAKING	L2-A8-02					
Wet sample + Mould (g)	12329					
Mass of mould	7656					
Mass of wet sample	4673					
Bulk density (g/cc)	2.2001794					

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	D9	D14				
Wet sample + container (g)	58.07	64.15				
Dry sample + container (g)	52.48	58.05				
Mass of container	18.09	18.3				
Mass of water	5.59	6.10				
Mass of dry sample	34.39	39.80				
Water content	16.25	15.33				
Average Water content	15.79					
Dry density	1.90					

Proving Ring constant: 0.026kN/div

Penetration	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	13	0.34		10	0.26				
0.50	18	0.47		16	0.42				
0.75	25	0.65		23	0.60				
1.00	31	0.81		26	0.68				
1.25	39	1.01		30	0.78				
1.50	49	1.27		34	0.88				
1.75	56	1.46		38	0.99				
2.00	62	1.61		41	1.07				
2.25	67	1.74		45	1.17				
2.50	72	1.87	**14**	50	1.30	**10**			
2.75	78	2.03		53	1.38				
3.00	83	2.16		55	1.43				
3.50	91	2.37		62	1.61				
4.00	99	2.57		66	1.72				
4.50	106	2.76		73	1.90				
5.00	112	2.91	**15**	80	2.08	**10**			
5.50	117	3.04		83	2.16				
6.00	122	3.17		88	2.29				
6.50	127	3.30		93	2.42				
7.00	132	3.43		98	2.55				
7.50	135	3.51		102	2.65				
8.00	140	3.64		108	2.81				

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					135			1
					139			5
					139			5
					139			5
					139			5

	ΔT	Δh		ΔT	Δh		ΔT	Δh
					4			4
					0			0
					0			0
					0			0

GEOTECHNICAL ENGINEERING LABORATORY
CBR TEST RECORDING SHEET

DATE: 6/6/99

SAMPLE : K2-Cured

SAMPLE DESCRIPTION: 0% Bitumen Content

Proving Ring constant: 0.026 kN/div

Mould No.	L2-B0-01		L2-B0-03
No. of blows per layer	55		55
Wet sample + Mould (g)	12,145		12,223
Mass of Mould	7,464		7,447
Mass of wet sample	4,681		4,776
Volume of mould	2124		2124
Bulk density (g/cc)	2.204		2.249

WATER CONTENT OF TRIMMINGS

	TOP	BOT			TOP	BOT
Container No.	C7	C12			D3	A1
Wet sample + container (g)	61.35	71.70			68.08	60.18
Dry sample + container (g)	57.00	67.65			63.72	55.91
Mass of container	18.15	17.81			18.24	17.89
Mass of water	4.35	4.05			4.36	4.27
Mass of dry sample	38.85	49.84			45.48	38.02
Water content	11.20	8.13			9.59	11.23
Average Water content	9.66				10.41	
Dry density	2.01				2.04	

AFTER SOAKING	L2-B0-02		
Wet sample + Mould (g)	12129		
Mass of mould	7371		
Mass of wet sample	4758		
Bulk density (g/cc)	2.24		

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	A9	112				
Wet sample + container (g)	70.12	85.45				
Dry sample + container (g)	63.89	74.15				
Mass of container	18.00	17.89				
Mass of water	6.23	11.30				
Mass of dry sample	45.89	56.26				
Water content	13.58	20.09				
Average Water content	16.83					
Dry density	1.92					

Penetration	Unsoaked			Soaked			Cured		
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	25	0.65		38	0.99		15	0.39	
0.50	175	4.55		70	1.82		31	0.81	
0.75	243	6.32		116	3.02		65	1.69	
1.00	282	7.33		152	3.95		90	2.34	
1.25	317	8.24		166	4.32		104	2.70	
1.50	340	8.84		186	4.84		115	2.99	
1.75	390	10.14		215	5.59		121	3.15	
2.00	427	11.10		235	6.11		125	3.25	
2.25	456	11.86		250	6.50		126	3.28	
2.50	475	12.35	**93**	264	6.86	**52**	127	3.30	**25**
2.75	516	13.42		277	7.20		128	3.33	
3.00	547	14.22		298	7.75		128	3.33	
3.50	596	15.50		320	8.32		132	3.43	
4.00	678	17.63		344	8.94		140	3.64	
4.50	740	19.24		363	9.44		152	3.95	
5.00	824	21.42	**107**	385	10.01	**50**	160	4.16	**21**
5.50	866	22.52		404	10.50		171	4.45	
6.00	910	23.66		420	10.92		187	4.86	
6.50	910	23.66		435	11.31		198	5.15	
7.00	956	24.86		452	11.75		204	5.30	
7.50	1030	26.78		464	12.06		228	5.93	
8.00	1053	27.38		484	12.58		245	6.37	

SWELL DA 1082 484

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
							14:00	80
							14:00	86
							14:00	87
							14:00	87
							14:00	87

				ΔT			ΔT	Δh
							24hour	6
							24hour	1
							24hour	0
							24hour	0

DATE: 6/6/99

SAMPLE : K2-Cured

SAMPLE DESCRIPTION: 2% Bitumen Content

Proving Ring constant: 0.026kN/div

Mould No.	L2-B2-01		L2-B2-03
No. of blows per layer	55		55
Wet sample + Mould (g)	12,168		12,177
Mass of Mould	7,483		7,433
Mass of wet sample	4,685		4,744
Volume of mould	2124		2124
Bulk density (g/cc)	2.206		2.234

WATER CONTENT OF TRIMMINGS

	TOP	BOT			TOP	BOT
Container No.	D4	D9			D6	A1
Wet sample + container (g)	73.02	61.48			61.69	68.36
Dry sample + container (g)	68.08	57.01			57.17	62.68
Mass of container	18.20	18.10			18.69	18.91
Mass of water	4.94	4.47			4.52	5.68
Mass of dry sample	49.88	38.91			38.48	43.77
Water content	9.90	11.49			11.75	12.98
Average Water content	10.70				12.36	
Dry density	1.99				1.99	

AFTER SOAKING	L2-B2-02		
Wet sample + Mould (g)	12317		
Mass of mould	7549		
Mass of wet sample	4768		
Bulk density (g/cc)	2.24		

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	A9	112				
Wet sample + container (g)	70.12	85.45				
Dry sample + container (g)	63.89	74.15				
Mass of container	18.00	17.89				
Mass of water	6.23	11.30				
Mass of dry sample	45.89	56.26				
Water content	13.58	20.09				
Average Water content	16.83					
Dry density	1.92					

Penetration	Unsoaked			Soaked			Cured		
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	37	0.96		30	0.78		45	1.17	
0.50	47	1.22		57	1.48		57	1.48	
0.75	70	1.82		91	2.37		107	2.78	
1.00	98	2.55		125	3.25		156	4.06	
1.25	134	3.48		160	4.16		166	4.32	
1.50	150	3.90		178	4.63		181	4.71	
1.75	157	4.08		205	5.33		199	5.17	
2.00	168	4.37		221	5.75		212	5.51	
2.25	190	4.94		230	5.98		222	5.77	
2.50	198	5.15	**39**	245	6.37	**48**	232	6.03	**46**
2.75	208	5.41		262	6.81		240	6.24	
3.00	218	5.67		280	7.28		247	6.42	
3.50	237	6.16		305	7.93		256	6.66	
4.00	244	6.34		328	8.53		265	6.89	
4.50	260	6.76		350	9.10		275	7.15	
5.00	270	7.02	**35**	370	9.62	**48**	280	7.28	**36**
5.50	285	7.41		387	10.06		285	7.41	
6.00	298	7.75		403	10.48		290	7.54	
6.50	314	8.16		420	10.92		295	7.67	
7.00	330	8.58		438	11.39		301	7.83	
7.50	338	8.79		450	11.70		306	7.96	
8.00	352	9.15		470	12.22		312	8.11	

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					1		14:00	70
					16		14:00	74
					16		14:00	75
					16		14:00	75
					16		14:00	75

				ΔT	Δh		ΔT	Δh
					15			4
					0			1
					0			0
					0			0

DATE: 6/6/99

SAMPLE : K2-Cured

SAMPLE DESCRIPTION: 3% Bitumen Content

Mould No.	L2-B3-01		L2-B3-03
No. of blows per layer	55		55
Wet sample + Mould (g)	12,145		12,223
Mass of Mould	7,464		7,447
Mass of wet sample	4,681		4,776
Volume of mould	2124		2124
Bulk density (g/cc)	2.204		2.249

WATER CONTENT OF TRIMMINGS

	TOP	BOT			TOP	BOT
Container No.	107	D14			D6	D13
Wet sample + container (g)	65.64	73.37			65.44	60.75
Dry sample + container (g)	61.66	68.96			61.22	56.40
Mass of container	18.23	18.28			18.69	18.26
Mass of water	3.98	4.41			4.22	4.35
Mass of dry sample	43.43	50.68			42.53	38.14
Water content	9.16	8.70			9.92	11.41
Average Water content	8.93				10.66	
Dry density	2.02				2.03	

AFTER SOAKING	L2-B3-02		
Wet sample + Mould (g)	12215		
Mass of mould	7439		
Mass of wet sample	4776		
Bulk density (g/cc)	2.25		

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	C11	C18				
Wet sample + container (g)	68.55	64.64				
Dry sample + container (g)	61.29	58.47				
Mass of container	18.13	17.71				
Mass of water	7.26	6.17				
Mass of dry sample	43.16	40.76				
Water content	16.82	15.14				
Average Water content	15.98					
Dry density	1.94					

Proving Ring constant: 0.026kN/div

Penetration	Unsoaked			Soaked			Cured		
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	43	1.12		14	0.36		5	0.13	
0.50	57	1.48		24	0.62		11	0.29	
0.75	68	1.77		30	0.78		24	0.62	
1.00	84	2.18		42	1.09		32	0.83	
1.25	99	2.57		65	1.69		39	1.01	
1.50	109	2.83		80	2.08		46	1.20	
1.75	115	2.99		94	2.44		57	1.48	
2.00	130	3.38		106	2.76		66	1.72	
2.25	140	3.64		136	3.54		74	1.92	
2.50	148	3.85	**29**	151	3.93	**30**	83	2.16	**16**
2.75	156	4.06		162	4.21		92	2.39	
3.00	167	4.34		179	4.65		99	2.57	
3.50	176	4.58		217	5.64		114	2.96	
4.00	192	4.99		242	6.29		127	3.30	
4.50	212	5.51		265	6.89		139	3.61	
5.00	235	6.11	**31**	286	7.44	**37**	152	3.95	**20**
5.50	249	6.47		305	7.93		162	4.21	
6.00	262	6.81		318	8.27		172	4.47	
6.50	275	7.15		332	8.63		182	4.73	
7.00	287	7.46		342	8.89		189	4.91	
7.50	297	7.72		354	9.20		192	4.99	
8.00	315	8.19		370	9.62		228	5.93	

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					1		14:00	70
					16		14:00	74
					16		14:00	74
					16		14:00	74
					16		14:00	74

				ΔT	Δh		ΔT	Δh
					15			4
					0			0
					0			0
					0			0

DATE: 6/6/99

SAMPLE : K2-Cured

SAMPLE DESCRIPTION: 3% Bitumen Content

Mould No.	L2-B4-01		L2-B4-03
No. of blows per layer	55		55
Wet sample + Mould (g)	12,197		12,132
Mass of Mould	7,531		7,438
Mass of wet sample	4,666		4,694
Volume of mould	2124		2124
Bulk density (g/cc)	2.197		2.210

WATER CONTENT OF TRIMMINGS

	TOP	BOT			TOP	BOT
Container No.	C11	C18			C8	C7
Wet sample + container (g)	58.55	67.38			58.63	57.29
Dry sample + container (g)	54.44	63.06			54.00	52.75
Mass of container	18.13	17.71			18.07	18.15
Mass of water	4.11	4.32			4.63	4.54
Mass of dry sample	36.31	45.35			35.93	34.60
Water content	11.32	9.53			12.89	13.12
Average Water content	10.42				13.00	
Dry density	1.99				1.96	

AFTER SOAKING	L2-B4-02		
Wet sample + Mould (g)	12303		
Mass of mould	7574		
Mass of wet sample	4729		
Bulk density (g/cc)	2.23		

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	107	112				
Wet sample + container (g)	75.08	66.49				
Dry sample + container (g)	67.59	59.17				
Mass of container	18.23	17.92				
Mass of water	7.49	7.32				
Mass of dry sample	49.36	41.25				
Water content	15.18	17.75				
Average Water content	16.46					
Dry density	1.91					

Proving Ring constant: 0.026kN/div

Penetration	Unsoaked			Soaked			Cured		
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	15	0.39		15	0.39		2	0.05	
0.50	18	0.47		23	0.60		5	0.13	
0.75	23	0.60		30	0.78		8	0.21	
1.00	29	0.75		36	0.94		11	0.29	
1.25	40	1.04		43	1.12		16	0.42	
1.50	47	1.22		51	1.33		19	0.49	
1.75	52	1.35		60	1.56		22	0.57	
2.00	65	1.69		69	1.79		26	0.68	
2.25	75	1.95		78	2.03		30	0.78	
2.50	86	2.24	**17**	88	2.29	**17**	34	0.88	**7**
2.75	94	2.44		97	2.52		38	0.99	
3.00	103	2.68		106	2.76		43	1.12	
3.50	116	3.02		121	3.15		51	1.33	
4.00	130	3.38		136	3.54		58	1.51	
4.50	143	3.72		146	3.80		67	1.74	
5.00	152	3.95	**20**	157	4.08	**20**	76	1.98	**10**
5.50	163	4.24		166	4.32		85	2.21	
6.00	174	4.52		175	4.55		94	2.44	
6.50	186	4.84		186	4.84		102	2.65	
7.00	198	5.15		199	5.17		109	2.83	
7.50	212	5.51		213	5.54		117	3.04	
8.00	225	5.85		224	5.82		123	3.20	

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
							14:00	631
							14:00	633
							14:00	635
							14:00	635
							14:00	635

				ΔT	Δh		ΔT	Δh
					0			2
					0			2
					0			0
					0			0

DATE: 6/6/99

SAMPLE : K2-Cured

Proving Ring constant: 0.026kN/div

SAMPLE DESCRIPTION: 6% Bitumen Content

Mould No.	L2-B6-01		L2-B6-03
No. of blows per layer	55		55
Wet sample + Mould (g)	11,907		12,034
Mass of Mould	7,352		7,480
Mass of wet sample	4,555		4,554
Volume of mould	2124		2124
Bulk density (g/cc)	2.145		2.144

WATER CONTENT OF TRIMMINGS

	TOP	BOT			TOP	BOT
Container No.	C12	D9			D2	D8
Wet sample + container (g)	65.58	73.89			62.07	51.05
Dry sample + container (g)	61.12	68.72			58.13	48.06
Mass of container	17.80	18.12			18.01	17.99
Mass of water	4.46	5.17			3.94	2.99
Mass of dry sample	43.32	50.60			40.12	30.07
Water content	10.30	10.22			9.82	9.94
Average Water content	10.26				9.88	
Dry density	1.95				1.95	

AFTER SOAKING	L2-B6-02		
Wet sample + Mould (g)	12215		
Mass of mould	7396		
Mass of wet sample	4819		
Bulk density (g/cc)	2.27		

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	C7	D5				
Wet sample + container (g)	73.90	65.55				
Dry sample + container (g)	67.00	58.13				
Mass of container	18.13	17.96				
Mass of water	6.90	7.42				
Mass of dry sample	48.87	40.17				
Water content	14.12	18.47				
Average Water content	16.30					
Dry density	1.95					

Penetration	Unsoaked			Soaked			Cured		
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	37	0.96		34	0.88		15	0.39	
0.50	55	1.43		60	1.56		41	1.07	
0.75	68	1.77		100	2.60		53	1.38	
1.00	87	2.26		119	3.09		64	1.66	
1.25	107	2.78		132	3.43		70	1.82	
1.50	115	2.99		140	3.64		86	2.24	
1.75	118	3.07		150	3.90		95	2.47	
2.00	127	3.30		155	4.03		98	2.55	
2.25	136	3.54		160	4.16		103	2.68	
2.50	138	3.59	**27**	164	4.26	**32**	111	2.89	**22**
2.75	139	3.61		172	4.47		113	2.94	
3.00	142	3.69		178	4.63		116	3.02	
3.50	149	3.87		185	4.81		121	3.15	
4.00	151	3.93		193	5.02		132	3.43	
4.50	155	4.03		202	5.25		137	3.56	
5.00	159	4.13	**21**	210	5.46	**27**	140	3.64	**18**
5.50	161	4.19		218	5.67		145	3.77	
6.00	165	4.29		227	5.90		154	4.00	
6.50	172	4.47		234	6.08		160	4.16	
7.00	175	4.55		242	6.29		164	4.26	
7.50	183	4.76		248	6.45		168	4.37	
8.00	190	4.94		260	6.76		180	4.68	

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					1		14:30	22
					16		14:30	24
					16		14:30	25
					16		14:30	25
					16		14:30	25

				ΔT	Δh		ΔT	Δh
					15			2
					0			1
					0			0
					0			0

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GEOTECHNICAL ENGINEERING LABORATORY
GRADING ANALYSIS AND ATTERBERG LIMITS

K3

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 2 ½ in	63.00			
2 in	53.00			
11 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	115.7	11.6	88.4
⅜ in	9.50	114.7	11.5	77.0
1/4	6.70	143.3	14.3	62.6
3/16	4.75	91.9	9.2	53.5
1/8	3.18	94.69	9.5	44.0
No. 7	2.36	45.60	4.6	39.4
No. 14	1.18	42.58	4.3	35.2
No. 25	0.600	15.74	1.6	33.6
No. 36	0.425	6.08	0.6	33.0
No. 52	0.300	6.37	0.6	32.3
NO. 72	0.212	6.71	0.7	31.7
No. 100	0.150	6.57	0.7	31.0
No. 200	0.075	14.91	1.5	29.5
Passing No. 200				
Total		704.7		

Gravel	**61**
Sand	**10**
Silt	**18**
Clay	**12**

K3

O% Bit Cont.

Liquid Limit

Container No.	A35	B29	A9	B15	X12
Weight of Container	3.67	3.74	3.48	3.71	3.70
No. of Blows	49	32	22	18	10
Weight of cont. + Wet Sample	18.85	18.87	17.68	18.09	19.82
Weight of cont. + Dry Sample	13.76	13.67	12.71	13.00	13.87
Weight of Water	5.09	5.2	4.97	5.09	5.95
Weight of Dry Sample	10.09	9.93	9.23	9.29	10.17
Moisture Content	50.45	52.37	53.85	54.79	58.51

plastic limit

Container No.	A28	X15
Weight of Container	3.75	3.72
Weight of cont. + Wet Sample	18.92	19.17
Weight of cont. + Dry Sample	15.97	16.16
Weight of Water	2.95	3.01
Weight of Dry Sample	12.22	12.44
Moisture Content	24.14	24.20
	24	

APPENDIX F1

GEOTECHNICAL ENGINEERING LABORATORY
HYDROMETER ANALYSIS

K3

Total Dry Weight (g) 25.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
11:34	26.8	0.5	1.0165	16.5	17.0	133.45	0.851	0.0615	1.4750	14.38	26.18
	26.8	1.0	1.0156	15.6	16.1	137.01	0.851	0.0440	1.4750	13.48	24.54
	26.8	2.0	1.0145	14.5	15.0	141.35	0.851	0.0316	1.4750	12.38	22.54
	26.8	4.0	1.0130	13.0	13.5	147.28	0.85	0.0228	1.4750	10.88	19.81
	26.8	8.0	1.0124	12.4	12.9	149.65	0.85	0.0163	1.4750	10.28	18.71
	26.8	15.0	1.0117	11.7	12.2	152.41	0.85	0.0120	1.4750	9.58	17.44
	26.4	30.0	1.0110	11.0	11.5	155.18	0.86	0.0086	1.3744	8.77	15.98
	26.0	60.0	1.0105	10.5	11.0	157.15	0.87	0.0061	1.2755	8.18	14.89
	25.6	120	1.0100	10.0	10.5	159.13	0.88	0.0044	1.1784	7.58	13.80
	25.0	240	1.0096	9.6	10.1	160.71	0.89	0.0031	1.0358	7.04	12.81
	26.4	1440	1.0085	8.5	9.0	165.05	0.86	0.0013	1.3744	6.27	11.43

KNUST

APPENDIX F2

Date: 16/2/00

Sample K3

2% NOMINAL BITUMEN CONTENT

GRAVEL PIT 1

No of Blows/layer

	1	2	3	4	5	6	
Sample preparation							
Mass of cylinder + Wet sample (gm)	11670	11980	12283	12357	12235		
Mass of cylinder (gm)	7616	7616	7616	7616	7616		
Mass of wet sample (gm)	4054	4364	4667	4741	4619		
Bulk density (Mg/m^3)	1.91	2.05	2.20	2.23	2.17		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	A43	C29	A22	C36	A10	C3	X1	100	113	170		
Mass of container+Wet soil (gm)	38.23	36.13	41.01	45.41	47.42	48.93	59.35	57.51	67.58	78.02		
Mass of container+Dry soil (gm)	37.41	35.36	38.78	43.05	44.22	45.79	54.06	52.55	59.99	69.18		
Mass of container (gm)	3.79	3.67	3.67	3.73	3.77	3.70	3.62	3.72	3.78	3.71		
Mass of water (gm)	0.82	0.77	2.23	2.36	3.20	3.14	5.29	4.96	7.59	8.84		
Mass of dry soil (gm)	33.62	31.69	35.11	39.32	40.45	42.09	50.44	48.83	56.21	65.47		
Water content (%)	2.44	2.43	6.35	6.00	7.91	7.46	10.49	10.16	13.50	13.50		
Average water content	2.43		6.18		7.69		10.32		13.50			
Dry density (Mg/m^3)	1.86		1.93		2.04		2.02		1.92			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Date: 15/2/00

Sample K3

No of Blows/layer

3% NOMINAL BITUMEN CONTENT.

	1	2	3	4				
Sample preparation								
Mass of cylinder + Wet sample (gm)	11525	12058	12264	12127				
Mass of cylinder (gm)	7345	7345	7345	7345				
Mass of wet sample (gm)	4180	4713	4919	4782				
Bulk density (Mg/m^3)	1.97	2.22	2.32	2.25				

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B				
Container No.	B25	A2	A39	B18	A21	G4	B8	B19				
Mass of container+Wet soil (gm)	45.70	49.95	47.04	47.41	48.25	52.36	81.14	87.70				
Mass of container+Dry soil (gm)	43.86	48.24	44.43	44.72	44.9	48.61	74.89	81.39				
Mass of container (gm)	3.62	3.72	3.70	3.73	3.64	3.74	11.06	11.00				
Mass of water (gm)	1.84	1.71	2.61	2.69	3.35	3.75	6.25	6.31				
Mass of dry soil (gm)	40.24	44.52	40.73	40.99	41.26	44.87	63.83	70.39				
Water content (%)	4.57	3.84	6.41	6.56	8.12	8.36	9.79	8.96				
Average water content	4.21		6.49		8.24		9.38					
Dry density (Mg/m^3)	1.89		2.08		2.14		2.06					

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

APPENDIX F4

Date: 17/2/00

Sample K3

4% NOMINAL BITUMEN CONTENT

No of Blows/layer

	1	2	3	4	5		
Sample preparation							
Mass of cylinder + Wet sample (gm)	11700	11948	12248	12273	12118		
Mass of cylinder (gm)	7609	7609	7609	7609	7609		
Mass of wet sample (gm)	4091	4339	4639	4664	4509		
Bulk density (Mg/m^3)	1.93	2.04	2.18	2.20	2.12		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	78	47	AB	30	73	59	20	40	34	41		
Mass of container+Wet soil (gm)	90.23	79.10	95.42	103.84	102.64	96.34	97.79	95.91	114.06	111.65		
Mass of container+Dry soil (gm)	87.83	77.11	90.83	98.62	95.96	89.89	88.80	87.5	102.16	100.15		
Mass of container (gm)	13.27	13.21	12.95	13.09	13.30	13.28	13.03	13.00	13.27	13.17		
Mass of water (gm)	2.40	1.99	4.59	5.22	6.68	6.45	8.99	8.41	11.90	11.50		
Mass of dry soil (gm)	74.56	63.90	77.88	85.53	82.66	76.61	75.77	74.50	88.89	86.98		
Water content (%)	3.22	3.11	5.89	6.10	8.08	8.42	11.86	11.29	13.39	13.22		
Average water content	3.17		6.00		8.25		11.58		13.30			
Dry density (Mg/m^3)	1.87		1.93		2.02		1.97		1.87			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Date: 19/2/00

Sample K3

2% NOMINAL BITUMEN CONTENT (repeated)

No of Blows/layer

	1	2	3	4	5		
Sample preparation							
Mass of cylinder + Wet sample (gm)	11469	11751	12034	12122	11932		
Mass of cylinder (gm)	7344	7344	7344	7344	7344		
Mass of wet sample (gm)	4125	4407	4690	4778	4588		
Bulk density (Mg/m^3)	1.94	2.07	2.21	2.25	2.16		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	40	78	41	59	20	73	AB	52	68	30		
Mass of container+Wet soil (gm)	75.88	77.42	84.29	82.81	93.97	92.83	89.35	88.86	118.54	126.7		
Mass of container+Dry soil (gm)	74.70	76.1	81.47	79.12	88.53	87.33	81.89	80.8	106.84	113.05		
Mass of container (gm)	13.00	13.26	13.16	13.28	13.03	13.30	12.94	13.03	13.10	13.09		
Mass of water (gm)	1.18	1.32	2.82	3.69	5.44	5.50	7.46	8.06	11.70	13.65		
Mass of dry soil (gm)	61.70	62.84	68.31	65.84	75.50	74.03	68.95	67.77	93.74	99.96		
Water content (%)	1.91	2.10	4.13	5.60	7.21	7.43	10.82	11.89	12.48	13.66		
Average water content	2.01		4.87		7.32		11.36		13.07			
Dry density (Mg/m^3)	1.90		1.98		2.06		2.02		1.92			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

APPENDIX F5

Date: 21/2/00

Sample K3

3% NOMINAL BITUMEN CONTENT (repeated)

No of Blows/layer

Sample preparation	1		2		3		4	5		
Mass of cylinder + Wet sample (gm)	11456		11669		11993		12058	11968		
Mass of cylinder (gm)	7344		7344		7344		7344	7344		
Mass of wet sample (gm)	4112		4325		4649		4714	4624		
Bulk density (Mg/m^3)	1.94		2.04		2.19		2.22	2.18		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	X15	B38	X5	A35	X4	X24	X7	A4	A12	A24		
Mass of container+Wet soil (gm)	41.50	40.41	34.56	38.31	39.56	37.94	38.51	39.6	51.15	53.73		
Mass of container+Dry soil (gm)	40.79	39.7	33.07	36.59	36.43	35.47	35.47	36.41	45.95	48.95		
Mass of container (gm)	3.72	3.79	3.61	3.67	3.56	3.61	3.61	3.75	3.68	3.70		
Mass of water (gm)	0.71	0.71	1.49	1.72	3.13	2.47	3.04	3.19	5.20	4.78		
Mass of dry soil (gm)	37.07	35.91	29.46	32.92	32.87	31.86	31.86	32.66	42.27	45.25		
Water content (%)	1.92	1.98	5.06	5.22	9.52	7.75	9.54	9.77	12.30	10.56		
Average water content	1.95		5.14		8.64		9.65		11.43			
Dry density (Mg/m^3)	1.90		1.94		2.01		2.02		1.94			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

KNUST

GEOTECHNICAL ENGINEERING LABORATORY
CBR TEST RECORDING SHEET

DATE: 10/5/99
OPERATOR: MM
Sample K3

SAMPLE DESCRIPTION: **0%BIT**
Proving Ring constant:kN 0.026

Mould No.	L1-A-00-01	L1-A-00-02	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,571	12,736	
Mass of Mould	7,421	7,484	
Mass of wet sample	5,150	5,252	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.425	2.473	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	B18	B19	B2	B9		
Wet sample + container (g)	64.24	56.82	59.17	55.50		
Dry sample + container (g)	59.75	52.98	55.91	52.05		
Mass of container	11.08	11.00	11.12	11.04		
Mass of water	4.49	3.84	3.26	3.45		
Mass of dry sample	48.67	41.98	44.79	41.01		
Water content	9.23	9.15	7.28	8.41		
Average Water content	9.19		7.85			
Dry density	2.22		2.29			
AFTER SOAKING			L1-A0-02			
Wet sample + Mould (g)			12605			
Mass of wet sample			5215			
Bulk density (g/cc)			2.455			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			B18	B20		
Wet sample + container (g)			58.11	51.46		
Dry sample + container (g)			53.54	48.20		
Mass of container			11.08	11.2		
Mass of water	0.00	0.00	4.57	3.26		
Mass of dry sample	0.00	0.00	42.46	37.01		
Water content	####	####	10.76	8.81		
Average Water content	#DIV/0!		9.79			
Dry density	#DIV/0!		2.24			

Penetration	Unsoaked			Soaked					
	Load		CBR	Load		CBR	Load		CBR
(mm)	(div)	(kN)		div	kN		div	kN	
0.25	12	0.312		14	0.364				
0.50	22	0.572		22	0.572				
0.75	33	0.858		29	0.754				
1.00	44	1.144		35	0.91				
1.25	55	1.43		42	1.092				
1.50	66	1.716		47	1.222				
1.75	78	2.028		54	1.404				
2.00	89	2.314		60	1.56				
2.25	100	2.6		66	1.716				
2.50	113	2.938	22	72	1.872	14			
2.75	124	3.224		79	2.054				
3.00	136	3.536		85	2.21				
3.50	157	4.082		98	2.548				
4.00	185	4.81		111	2.886				
4.50	204	5.304		124	3.224				
5.00	227	5.902	30	137	3.562	18			
5.50	251	6.526		150	3.9				
6.00	275	7.15		163	4.238				
6.50	293	7.618		175	4.55				
7.00	314	8.164		186	4.836				
7.50	328	8.528		197	5.122				
8.00	358	9.308		208	5.408				

SWELL DATA

Date	Time	Gauge(d	Date	Time	Gauge	Date	Time	Gauge(d
					0			
					3			
					7.5			
					8			
					10			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			3			0
		0			4.5			0
		0			0.5			0
		0			2			0

DATE: 10/5/99
OPERATOR: MM
Sample K3

SAMPLE DESCRIPTIC **1% BIT**
Proving Ring constant: 0.026

Mould No.	L1-A-01-01	L1-A-01-02	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,506	12,754	
Mass of Mould	7,385	7,595	
Mass of wet sample	5,121	5,159	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.411	2.429	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	~~A39~~	A31	K1	~~K4~~		
Wet sample + container (g)	89.39	97.98	88.73	86.57		
Dry sample + container (g)	84.40	91.25	83.40	79.77		
Mass of container	14.28	14.34	16.27	15.62		
Mass of water	4.99	6.73	5.33	6.80		
Mass of dry sample	70.12	76.91	67.13	64.15		
Water content	7.12	8.75	7.94	10.60		
Average Water content	7.93		9.27			
Dry density	2.23		2.22			
AFTER SOAKING			L1-A-01-02			
Wet sample + Mould (g)			12558			
Mass of wet sample			5168			
Bulk density (g/cc)			2.433			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			A31	A39		
Wet sample + container (g)			76.60	96.56		
Dry sample + container (g)			70.75	88.17		
Mass of container			14.34	14.3		
Mass of water	0.00	0.00	5.85	8.39		
Mass of dry sample	0.00	0.00	56.41	73.89		
Water content	####	####	10.37	11.35		
Average Water content	#DIV/0!		10.86			
Dry density	#DIV/0!		2.19			

Penetration	Unsoaked			Soaked					
	Load		CBR	Load		CBR	Load		CBR
(mm)	(div)	(kN)		div	kN		div	kN	
0.25	17	0.442		16	0.416				
0.50	33	0.858		32	0.832				
0.75	49	1.274		48	1.248				
1.00	65	1.69		62	1.612				
1.25	82	2.132		74	1.924				
1.50	100	2.6		86	2.236				
1.75	119	3.094		98	2.548				
2.00	139	3.614		110	2.86				
2.25	160	4.16		122	3.172				
2.50	180	4.68	35	134	3.484	26			
2.75	197	5.122		145	3.77				
3.00	215	5.59		154	4.004				
3.50	253	6.578		173	4.498				
4.00	287	7.462		192	4.992				
4.50	319	8.294		210	5.46				
5.00	346	8.996	45	227	5.902	30			
5.50	374	9.724		245	6.37				
6.00	401	10.43		261	6.786				
6.50	430	11.18		273	7.098				
7.00	458	11.91		288	7.488				
7.50	484	12.58		304	7.904				
8.00	508	13.21		318	8.268				

SWELL 1238

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
					1			
					16			
					16			
					16			
					16			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			15			0
		0			0			0
		0			0			0
		0			0			0

DATE: 10/5/99
OPERATOR: MM
Sample K3

SAMPLE DESCRIPTIC **2% BIT**
Proving Ring constant: 0.026

Mould No.	L1-A-02-01	L1-A-02-02	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,553	12,619	
Mass of Mould	7,437	7,505	
Mass of wet sample	5,116	5,114	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.409	2.408	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	B7	B11	B15	B20		
Wet sample + container (g)	60.37	54.23	56.98	61.15		
Dry sample + container (g)	56.70	50.97	53.37	57.34		
Mass of container	11.14	12.13	11.09	11.19		
Mass of water	3.67	3.26	3.61	3.81		
Mass of dry sample	45.56	38.84	42.28	46.15		
Water content	8.06	8.39	8.54	8.26		
Average Water content	8.22		8.40			
Dry density	2.23		2.22			

AFTER SOAKING	L1-A-02-01	L1-A-02-02	
Wet sample + Mould (g)	12606		
Mass of wet sample	5216	-7390	
Bulk density (g/cc)	2.46	-3.48	

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.	B19	B11				
Wet sample + container (g)	54.52	60.71				
Dry sample + container (g)	50.60	55.88				
Mass of container	11.00	12.1				
Mass of water	3.92	4.83	0.00	0.00		
Mass of dry sample	39.60	43.75	0.00	0.00		
Water content	9.90	11.04	####	####		
Average Water content	10.47		#DIV/0!			
Dry density	2.18		#DIV/0!			

Penetration	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	19	0.494		14	0.364				
0.50	30	0.78		25	0.65				
0.75	42	1.092		36	0.936				
1.00	53	1.378		49	1.274				
1.25	64	1.664		62	1.612				
1.50	75	1.95		76	1.976				
1.75	89	2.314		90	2.34				
2.00	100	2.6		103	2.678				
2.25	111	2.886		117	3.042				
2.50	121	3.146	24	129	3.354	25			
2.75	131	3.406		142	3.692				
3.00	142	3.692		155	4.03				
3.50	160	4.16		178	4.628				
4.00	180	4.68		200	5.2				
4.50	198	5.148		224	5.824				
5.00	218	5.668	28	244	6.344	32			
5.50	235	6.11		264	6.864				
6.00	252	6.552		285	7.41				
6.50	270	7.02		302	7.852				
7.00	286	7.436		320	8.32				
7.50	302	7.852		337	8.762				
8.00	318	8.268		354	9.204				

SWELL DATA

Date	Time	Gauge	Date	Time	Gauge	Date	Time	Gauge
		0						1
		4						5
		9.5						5
		10						5
		12						5

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		4			0			4
		5.5			0			0
		0.5			0			0
		2			0			0

DATE: 10/5/99
OPERATOR: MM
Sample K3

SAMPLE DESCRIPTION: **3%BIT**
Proving Ring constant:kN 0.026

Mould No.	L4-A-03-01	L4-A-03-02	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,485	12,548	
Mass of Mould	7,434	7,539	
Mass of wet sample	5,051	5,009	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.378	2.358	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	A38	A39	A27	E2		
Wet sample + container (g)	91.00	87.57	####	97.26		
Dry sample + container (g)	84.56	82.13	97.42	91.56		
Mass of container	14.26	14.28	12.84	14.76		
Mass of water	6.44	5.44	6.84	5.70		
Mass of dry sample	70.30	67.85	84.58	76.80		
Water content	9.16	8.02	8.09	7.42		
Average Water content	8.59		7.75			
Dry density	2.19		2.19			

AFTER SOAKING		L4-A-03-02	
Wet sample + Mould (g)		12584	
Mass of wet sample		5194	
Bulk density (g/cc)		2.445	

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			A31	A39		
Wet sample + container (g)			90.03	94.26		
Dry sample + container (g)			84.42	87.49		
Mass of container			14.34	14.3		
Mass of water	0.00	0.00	5.61	6.77		
Mass of dry sample	0.00	0.00	70.08	73.21		
Water content	####	####	8.01	9.25		
Average Water content	#DIV/0!		8.63			
Dry density	#DIV/0!		2.25			

Penetration	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	14	0.364		12	0.312				
0.50	24.5	0.637		20	0.52				
0.75	31.5	0.819		24	0.624				
1.00	35	0.91		30	0.78				
1.25	42	1.092		34	0.884				
1.50	49	1.274		40	1.04				
1.75	56	1.456		44	1.144				
2.00	63	1.638		50	1.3				
2.25	73.5	1.911		56	1.456				
2.50	77	2.002	15	60	1.56	12			
2.75	84	2.184		66	1.716				
3.00	91	2.366		70	1.82				
3.50	108.5	2.821		80	2.08				
4.00	126	3.276		90	2.34				
4.50	140	3.64		100	2.6				
5.00	157.5	4.095	21	110	2.86	14			
5.50	178.5	4.641		120	3.12				
6.00	199.5	5.187		130	3.38				
6.50	217	5.642		140	3.64				
7.00	241.5	6.279		148	3.848				
7.50	259	6.734		158	4.108				
8.00	280	7.28		168	4.368				

SWELL DATA

Date	Time	Gauge(d	Date	Time	Gauge	Date	Time	Gauge(d
					0			1
					2.5			5
					8			5
					17			5
					17			5

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			2.5			4
		0			5.5			0
		0			9			0
		0			0			0

DATE: 10/5/99

OPERATOR: MM

SAMPLE DESCRIPTIC **4% BIT**

Proving Ring constant: 0.026

Sample K3

Mould No.	L4-A-04-01	L4-A-04-02	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,575	12,468	
Mass of Mould	7,549	7,434	
Mass of wet sample	5,026	5,034	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.366	2.370	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	A31	A14	K1	K4		
Wet sample + container (g)	71.54	87.42	91.43	86.65		
Dry sample + container (g)	67.50	82.28	86.76	81.49		
Mass of container	14.34	14.98	16.27	15.62		
Mass of water	4.04	5.14	4.67	5.16		
Mass of dry sample	53.16	67.30	70.49	65.87		
Water content	7.60	7.64	6.63	7.83		
Average Water content	7.62		7.23			
Dry density	2.20		2.21			
AFTER SOAKING	L4-A-04-01		L4-A-04-02			
Wet sample + Mould (g)			12503			
Mass of wet sample	-7390		5113			
Bulk density (g/cc)	-3.479		2.407			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			K1	K4		
Wet sample + container (g)			97.79	87.54		
Dry sample + container (g)			89.68	81.84		
Mass of container			16.27	15.6		
Mass of water	0.00	0.00	8.11	5.70		
Mass of dry sample	0.00	0.00	73.41	66.22		
Water content	####	####	11.05	8.61		
Average Water content	#DIV/0!		9.83			
Dry density	#DIV/0!		2.16			

Penetration	Unsoaked			Soaked					
	Load		CBR	Load		CBR	Load		CBR
(mm)	(div)	(kN)		div	kN		div	kN	
0.25	11	0.286		7	0.182				
0.50	15	0.39		12	0.312				
0.75	22	0.572		16	0.416				
1.00	28	0.728		21	0.546				
1.25	34	0.884		25	0.65				
1.50	40	1.04		30	0.78				
1.75	46	1.196		35	0.91				
2.00	51	1.326		40	1.04				
2.25	57	1.482		44	1.144				
2.50	62	1.612	12	49	1.274	10			
2.75	69	1.794		54	1.404				
3.00	74	1.924		59	1.534				
3.50	85	2.21		69	1.794				
4.00	95	2.47		79	2.054				
4.50	107	2.782		89	2.314				
5.00	118	3.068	15	97	2.522	13			
5.50	128	3.328		106	2.756				
6.00	138	3.588		115	2.99				
6.50	148	3.848		122	3.172				
7.00	156	4.056		130	3.38				
7.50	164	4.264		138	3.588				
8.00	175	4.55		145	3.77				

SWELI 1238

Date	Time	Gauge (div)	Date	Time	Gauge (div)	Date	Time	Gauge (div)
					0			1
					7			5
					10			5
					20			5
					20			5

ΔT	Δh	ΔT	Δh		ΔT	Δh
	0		7			4
	0		3			0
	0		10			0
	0		0			0

KNUST
NYANSAPƆ WƆSANE NO BADWENIMA

FALLLING HEAD PERMEABILITY TEST

PROJECT : 0% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c0 (cm)	adjusted initial water level in standpipe, h0=b+c0 (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c1 (cm)	adjusted final water level in standpipe, h1=b+c1 (cm)	h0/h1	2.3 *log(h0/h1)	K
1	11.58	102.9	81	183.9	138	75	177.9	1.034	0.033	2.531E-05
2	11.58	102.9	73.5	176.4	152	67.5	170.4	1.035	0.035	2.397E-05
3	11.58	102.9	87	189.9	160	80	182.9	1.038	0.038	2.472E-05
4	11.58	102.9	79	181.9	224	70	172.9	1.052	0.051	2.385E-05
4	11.58	102.9	90	192.9	136	84.5	187.4	1.029	0.029	2.240E-05
4	11.58	102.9	84.5	187.4	494	70.2	173.1	1.083	0.079	1.692E-05

2.40E-05

Diameter of sample	10.481
Diameter of pipe	1
Cross sectional area of sample	86.288
Cross sectional area of pipe	0.786

PROJECT : 1% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c0 (cm)	adjusted initial water level in standpipe, h0=b+c0 (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c1 (cm)	adjusted final water level in standpipe, h1=b+c1 (cm)	h0/h1	2.3 *log(h0/h1)	K
1	11.648	102.9	97.9	200.8	6186	96.9	199.8	1.00501	0.00499	9.17E-08
2	11.648	102.9	96.9	199.8	4113	96.3	199.2	1.00301	0.00300	8.31E-08
3	11.648	102.9	96.3	199.2	3750	95.35	198.25	1.00479	0.00478	1.45E-07
4	11.648	102.9	95.3	198.2	3951	94.75	197.65	1.00278	0.00278	7.99E-08

8.15E-08

Diameter of sample	10.12
Diameter of pipe	1
Cross sectional area of sample	80.447
Cross sectional area of pipe	0.786

PROJECT : 2% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c0 (cm)	adjusted initial water level in standpipe, h0=b+c0 (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c1 (cm)	adjusted final water level in standpipe, h1=b+c1 (cm)	h0/h1	2.3 *log(h0/h1)	K
1	11.648	102.9	95	197.9	1558	94.2	197.1	1.00406	0.00405	2.95E-07
2	11.648	102.9	94.2	197.1	921	93.9	196.8	1.00152	0.00152	1.88E-07
3	11.648	102.9	93.9	196.8	924	93.55	196.45	1.00178	0.00178	2.19E-07
4	11.648	102.9	93.5	196.4	919	93.2	196.1	1.00153	0.00153	1.89E-07
										1.88E-07

Diameter of sample	10.12
Diameter of pipe	1
Cross sectional area of sample	80.447
Cross sectional area of pipe	0.786

PROJECT : 3% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c0 (cm)	adjusted initial water level in standpipe, h0=b+c0 (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c1 (cm)	adjusted final water level in standpipe, h1=b+c1 (cm)	h0/h1	2.3 *log(h0/h1)	K
1	11.648	102.9	92.6	195.5	1606	92	194.9	1.00308	0.003070	2.17E-07
2	11.648	102.9	95	197.9	2112	94.6	197.5	1.00203	0.002021	1.09E-07
3	11.648	102.9	96.9	199.8	1411	96.45	199.35	1.00226	0.002252	1.82E-07
4	11.648	102.9	96.4	199.3	2522	95.6	198.5	1.00403	0.004018	1.81E-07
										1.81E-07

Diameter of sample	10.12
Diameter of pipe	1
Cross sectional area of sample	80.447
Cross sectional area of pipe	0.786

K4

Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	6.9	0.7	99.3
⅜ in	9.50	57.6	5.8	93.5
¼	6.70	96.5	9.6	83.9
3/16	4.75	104.1	10.4	73.5
1/8	3.18	129.2	12.9	60.6
No. 7	2.36	73.6	7.4	53.2
No. 14	1.18	74.5	7.4	45.8
No. 25	0.600	31.5	3.1	42.6
No. 36	0.425	12.5	1.3	41.4
No. 52	0.300	14.4	1.4	39.9
NO. 72	0.212	15.4	1.5	38.4
No. 100	0.150	14.3	1.4	37.0
No. 200	0.075	29.7	3.0	34.0
Passing No. 200				
Total		660.2		

Gravel	**47**
Sand	**19**
Silt	**21**
Clay	**13**

K4

0% Bit Cont.

Liquid Limit

Container No.	A9	A17	A16	B4	B36
Weight of Container	3.48	3.7	3.72	3.63	3.61
No. of Blows	50	41	22	19	12
Weight of cont. + Wet Sample	16.01	19.9	18.45	16.02	17.57
Weight of cont. + Dry Sample	12.73	15.58	14.39	12.57	13.58
Weight of Water	3.28	4.32	4.06	3.45	3.99
Weight of Dry Sample	9.25	11.88	10.67	8.94	9.97
Moisture Content	35.46	36.36	38.05	38.59	40.02

plastic limit

Container No.	B2	C11
Weight of Container	3.73	3.61
Weight of cont. + Wet Sample	9.6	9.48
Weight of cont. + Dry Sample	8.68	8.57
Weight of Water	0.92	0.91
Weight of Dry Sample	4.95	4.96
Moisture Content	18.59	18.35
	18	

GEOTECHNICAL ENGINEERING LABORATORY
HYDROMETER ANALYSIS

K4

Total Dry Weight (g) 25.0 **Gs= 2.84**

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
11:34	26.8	0.5	1.0165	16.5	17.0	133.45	0.851	0.0615	1.4750	14.38	30.18
	26.8	1.0	1.0156	15.6	16.1	137.01	0.851	0.0440	1.4750	13.48	28.29
	26.8	2.0	1.0145	14.5	15.0	141.35	0.851	0.0316	1.4750	12.38	25.98
	26.8	4.0	1.0130	13.0	13.5	147.28	0.85	0.0228	1.4750	10.88	22.83
	26.8	8.0	1.0124	12.4	12.9	149.65	0.85	0.0163	1.4750	10.28	21.57
	26.8	15.0	1.0117	11.7	12.2	152.41	0.85	0.0120	1.4750	9.58	20.10
	26.4	30.0	1.0110	11.0	11.5	155.18	0.86	0.0086	1.3744	8.77	18.42
	26.0	60.0	1.0105	10.5	11.0	157.15	0.87	0.0061	1.2755	8.18	17.16
	25.6	120	1.0100	10.0	10.5	159.13	0.88	0.0044	1.1784	7.58	15.91
	25.0	240	1.0096	9.6	10.1	160.71	0.89	0.0031	1.0358	7.04	14.77
	26.4	1440	1.0085	8.5	9.0	165.05	0.86	0.0013	1.3744	6.27	13.17

KNUST

CIVIL ENGINEERING DEPARTMENT

GEOTECHNICAL ENGINEERING LABORATORY

COMPACTION TEST

Date: 15/2/00

O% NOMINAL BITUMEN CONTENT

No of Blows/layer

Sample preparation	1	2	3	4	5	
Mass of cylinder + Wet sample (gm)	11953	12499	12359	12230		
Mass of cylinder (gm)	7594	7594	7594	7594		
Mass of wet sample (gm)	4359	4905	4765	4636		
Bulk density (Mg/m^3)	2.05	2.31	2.24	2.18		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B		
Container No.	A21	A15	A3	B5	A26	A37	A2	A50		
Mass of container+Wet soil (gm)	73.85	68.44	58.68	56.11	88.82	90.04	89.62	79.04		
Mass of container+Dry soil (gm)	71.46	66.26	55.62	52.96	81.89	83.7	82.27	72.24		
Mass of container (gm)	14.06	15.34	15.48	14.23	13.20	15.63	14.34	14.31		
Mass of water (gm)	2.39	2.18	3.06	3.15	6.93	6.34	7.35	6.80		
Mass of dry soil (gm)	57.40	50.92	40.14	38.73	68.69	68.07	67.93	57.93		
Water content (%)	4.16	4.28	7.62	8.13	10.09	9.31	10.82	11.74		
Average water content	4.22		7.88		9.70		11.28			
Dry density (Mg/m^3)	1.97		2.14		2.04		1.96			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Date: 15/2/00

1% NOMINAL BITUMEN CONTENT

No of Blows/layer

Sample preparation	1	2	3	4	5	
Mass of cylinder + Wet sample (gm)	12005	12437	12579	12400		
Mass of cylinder (gm)	7437	7437	7437	7437		
Mass of wet sample (gm)	4568	5000	5142	4963		
Bulk density (Mg/m^3)	2.15	2.35	2.42	2.34		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B		
Container No.	C2	C4	C6	C8	C14	D10	D4	D9		
Mass of container+Wet soil (gm)	98.47	92.14	87.42	87.80	82.09	76.67	104.43	106.84		
Mass of container+Dry soil (gm)	95.19	88.82	83.61	83.74	77.56	71.66	95.51	97.4		
Mass of container (gm)	18.76	18.41	17.78	18.04	17.92	18.12	18.21	18.15		
Mass of water (gm)	3.28	3.32	3.81	4.06	4.53	5.01	8.92	9.44		
Mass of dry soil (gm)	76.43	70.41	65.83	65.70	59.64	53.54	77.30	79.25		
Water content (%)	4.29	4.72	5.79	6.18	7.60	9.36	11.54	11.91		
Average water content	4.50		5.98		8.48		11.73			
Dry density (Mg/m^3)	2.06		2.22		2.23		2.09			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

APPENDIX G3

Date: 16/2/00

No of Blows/layer

2% NOMINAL BITUMEN CONTENT

Sample preparation	1	2	3	4		
Mass of cylinder + Wet sample (gm)	11958	12206	12520	12548		
Mass of cylinder (gm)	7443	7443	7443	7443		
Mass of wet sample (gm)	4515	4763	5077	5105		
Bulk density (Mg/m^3)	2.13	2.24	2.39	2.40		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B		
Container No.	X4	X13	C4	C18	D2	D10	C2	C14		
Mass of container+Wet soil (gm)	99.26	98.29	95.12	97.61	83.87	92.37	92.82	100.57		
Mass of container+Dry soil (gm)	96.98	95.5	91.35	93.53	79.36	87.1	86.19	93.3		
Mass of container (gm)	18.14	17.70	18.48	17.67	17.99	18.11	17.77	17.92		
Mass of water (gm)	2.28	2.79	3.77	4.08	4.51	5.27	6.63	7.27		
Mass of dry soil (gm)	78.84	77.80	72.87	75.86	61.37	68.99	68.42	75.38		
Water content (%)	2.89	3.59	5.17	5.38	7.35	7.64	9.69	9.64		
Average water content	3.24		5.28		7.49		9.67			
Dry density (Mg/m^3)	2.06		2.13		2.22		2.19			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Date: 15/2/00

No of Blows/layer

3% NOMINAL BITUMEN CONTENT.

Sample preparation	1	2	3	4		
Mass of cylinder + Wet sample (gm)	11867	12124	12447	12433		
Mass of cylinder (gm)	7434	7434	7434	7434		
Mass of wet sample (gm)	4433	4690	5013	4999		
Bulk density (Mg/m^3)	2.09	2.21	2.36	2.35		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B		
Container No.	C2	C4	C6	C8	C14	D4	D9	D10		
Mass of container+Wet soil (gm)	86.47	88.08	91.79	95.95	95.82	84.47	84.01	93.22		
Mass of container+Dry soil (gm)	84.65	85.62	88.64	92.53	91	79.96	78.09	86.36		
Mass of container (gm)	17.76	18.36	17.76	18.04	17.93	18.21	18.11	18.10		
Mass of water (gm)	1.82	2.46	3.15	3.42	4.82	4.51	5.92	6.86		
Mass of dry soil (gm)	66.89	67.26	70.88	74.49	73.07	61.75	59.98	68.26		
Water content (%)	2.72	3.66	4.44	4.59	6.60	7.30	9.87	10.05		
Average water content	3.19		4.52		6.95		9.96			
Dry density (Mg/m^3)	2.02		2.11		2.21		2.14			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

APPENDIX G4

Date: 17/2/00

No of Blows/layer

4% NOMINAL BITUMEN CONTENT

Sample preparation	1	2	3	4	5	
Mass of cylinder + Wet sample (gm)	12000	12281	12521	12531		
Mass of cylinder (gm)	7509	7509	7509	7509		
Mass of wet sample (gm)	4491	4772	5012	5022		
Bulk density (Mg/m^3)	2.11	2.25	2.36	2.36		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B		
Container No.	A27	A28	A26	A50	A3	A16	B1	E6		
Mass of container+Wet soil (gm)	68.92	71.77	68.75	74.86	74.51	70.69	81.05	75.1		
Mass of container+Dry soil (gm)	66.40	69.35	65.35	71.31	70.17	66.62	74.86	69.68		
Mass of container (gm)	12.84	14.23	13.21	14.33	15.48	14.22	14.59	14.50		
Mass of water (gm)	2.52	2.42	3.40	3.55	4.34	4.07	6.19	5.42		
Mass of dry soil (gm)	53.56	55.12	52.14	56.98	54.69	52.40	60.27	55.18		
Water content (%)	4.71	4.39	6.52	6.23	7.94	7.77	10.27	9.82		
Average water content	4.55		6.38		7.85		10.05			
Dry density (Mg/m^3)	2.02		2.11		2.19		2.15			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Date: 19/2/00

No of Blows/layer

6% NOMINAL BITUMEN CONTENT

Sample preparation	1	2	3	4	5	
Mass of cylinder + Wet sample (gm)	12051	12297	12483	12372		
Mass of cylinder (gm)	7508	7508	7508	7508		
Mass of wet sample (gm)	4543	4789	4975	4864		
Bulk density (Mg/m^3)	2.14	2.25	2.34	2.29		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B		
Container No.	C2	C4	C6	C8	C14	D4	D9	D10		
Mass of container+Wet soil (gm)	81.37	79.58	83.38	84.47	85.95	83.95	83.81	83.79		
Mass of container+Dry soil (gm)	78.59	77.08	78.74	79.46	80.87	78.76	78.01	77.88		
Mass of container (gm)	17.76	18.32	17.79	18.04	17.92	18.20	18.10	18.10		
Mass of water (gm)	2.78	2.50	4.64	5.01	5.08	5.19	5.80	5.91		
Mass of dry soil (gm)	60.83	58.76	60.95	61.42	62.95	60.56	59.91	59.78		
Water content (%)	4.57	4.25	7.61	8.16	8.07	8.57	9.68	9.89		
Average water content	4.41		7.88		8.32		9.78			
Dry density (Mg/m^3)	2.05		2.09		2.16		2.09			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

APPENDIX G5

Date: 21/2/00

No of Blows/layer

3% NOMINAL BITUMEN CONTENT (repeated)

	1	2	3	4		
Sample preparation						
Mass of cylinder + Wet sample (gm)	11885	12118	12184	12123		
Mass of cylinder (gm)	7396	7396	7396	7396		
Mass of wet sample (gm)	4489	4722	4788	4727		
Bulk density (Mg/m^3)	2.11	2.22	2.25	2.23		

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B		
Container No.	A21	B2	A15	A39	E3	Z1	A2	A38		
Mass of container+Wet soil (gm)	72.22	75.15	65.47	71.87	76.44	71.9	80.26	78.1		
Mass of container+Dry soil (gm)	68.99	72.15	62.23	68.63	72.28	67.36	74.56	72.27		
Mass of container (gm)	14.05	14.90	15.35	14.29	15.69	14.24	14.34	14.26		
Mass of water (gm)	3.23	3.00	3.24	3.24	4.16	4.54	5.70	5.83		
Mass of dry soil (gm)	54.94	57.25	46.88	54.34	56.59	53.12	60.22	58.01		
Water content (%)	5.88	5.24	6.91	5.96	7.35	8.55	9.47	10.05		
Average water content	5.56		6.44		7.95		9.76			
Dry density (Mg/m^3)	2.00		2.09		2.09		2.03			

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

KNUST

CBR TEST RECORDING SHEET

DATE: 10/5/99

SAMPLE DESCRIPTION: **0%BIT**

Proving Ring constant:kN 0.026

Sample K4

Mould No.	A5	A2	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,574	12,514	
Mass of Mould	7,421	7,377	
Mass of wet sample	5,153	5,137	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.426	2.419	

WATER CONTENT OF TRIMMINGS

	TOP	BOT				
Container No.	E4	B5	100	A42		
Wet sample + container (g)	82.46	81.08	77.77	79.73		
Dry sample + container (g)	77.06	76.09	73.53	74.79		
Mass of container	14.45	14.24	14.39	14.68		
Mass of water	5.40	4.99	4.24	4.94		
Mass of dry sample	62.61	61.85	59.14	60.11		
Water content	8.62	8.07	7.17	8.22		
Average Water content	8.35		7.69			
Dry density	2.24		2.25			
AFTER SOAKING						
Wet sample + Mould (g)			12578			
Mass of wet sample			5188			
Bulk density (g/cc)			2.443			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			A	A14		
Wet sample + container (g)			83.12	81.10		
Dry sample + container (g)			75.69	75.01		
Mass of container			14.86	14.2		
Mass of water			7.43	6.09		
Mass of dry sample			60.83	60.78		
Water content			12.21	10.02		
Average Water content			11.12			
Dry density			2.20			

Penetr	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	20	0.52		6	0.16				
0.50	30	0.78		10	0.26				
0.75	43	1.12		15	0.39				
1.00	55	1.43		21	0.55				
1.25	69	1.79		27	0.70				
1.50	82	2.13		35	0.91				
1.75	98	2.55		43	1.12				
2.00	113	2.94		50	1.30				
2.25	130	3.38		59	1.53				
2.50	146	3.80	29	68	1.77	13			
2.75	163	4.24		76	1.98				
3.00	180	4.68		80	2.08				
3.50	216	5.62		103	2.68				
4.00	254	6.60		122	3.17				
4.50	293	7.62		140	3.64				
5.00	336	8.74	44	159	4.13	21			
5.50	371	9.65		175	4.55				
6.00	408	10.61		196	5.10				
6.50	448	11.65		214	5.56				
7.00	488	12.69		234	6.08				
7.50	526	13.68		255	6.63				
8.00	563	14.64		275	7.15				

SWELL DATA

Date	Time	Gauge(d	Date	Time	Gauge	Date	Time	Gauge(d
					0			
					6			

				ΔT	Δh			
					0			
					0			
					0			
					6			

DATE: 10/5/99

SAMPLE DESCRIPTION: 1%BIT

Proving Ring constant:kN 0.026

Sample K4

Mould No.	A6	A1	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,537	12,547	
Mass of Mould	7,471	7,485	
Mass of wet sample	5,066	5,062	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.385	2.383	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	E5	A30	B3	A5		
Wet sample + container (g)	93.57	82.67	70.35	85.12		
Dry sample + container (g)	~~88.60~~	78.18	66.92	~~80.81~~		
Mass of container	15.19	15.02	15.31	14.21		
Mass of water	4.97	4.49	3.43	4.31		
Mass of dry sample	73.41	63.16	51.61	66.60		
Water content	6.77	7.11	6.65	6.47		
Average Water content	6.94		6.56			
Dry density	2.23		2.24			
AFTER SOAKING						
Wet sample + Mould (g)			12624			
Mass of wet sample			5234			
Bulk density (g/cc)			2.464			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			A16	E2		
Wet sample + container (g)			80.43	84.25		
Dry sample + container (g)			74.32	81.40		
Mass of container			14.25	14.8		
Mass of water			6.11	2.85		
Mass of dry sample			60.07	66.63		
Water content			10.17	4.28		
Average Water content			7.22			
Dry density			2.30			

Penetr	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	55	1.43		25	0.65				
0.50	104	2.70		47	1.22				
0.75	157	4.08		70	1.82				
1.00	210	5.46		92	2.39				
1.25	261	6.79		115	2.99				
1.50	311	8.09		137	3.56				
1.75	357	9.28		159	4.13				
2.00	401	10.43		180	4.68				
2.25	442	11.49		201	5.23				
2.50	475	12.35	93	222	5.77	44			
2.75	518	13.47		241	6.27				
3.00	553	14.38		262	6.81				
3.50	620	16.12		293	7.62				
4.00	684	17.78		325	8.45				
4.50	747	19.42		358	9.31				
5.00	808	21.01	105	390	10.14	51			
5.50	860	22.36		415	10.79				
6.00	909	23.63		436	11.34				
6.50	961	24.99		461	11.99				
7.00	1010	26.26		484	12.58				
7.50	1060	27.56		509	13.23				
8.00	1104	28.70		527	13.70				

SWELL DATA

Date	Time	Gauge(d	Date	Time	Gauge	Date	Time	Gauge(d
					0			
					17			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			0			0
		0			0			0
		0			0			0
		0			17			

KNUST

DATE: 10/5/99

SAMPLE DESCRIPTION: **2%BIT**

Proving Ring constant:kN 0.026

Sample K4

Mould No.	B2	A3	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,617	12,566	
Mass of Mould	7,519	7,489	
Mass of wet sample	5,098	5,077	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.400	2.390	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	B6	A14	A38	E3		
Wet sample + container (g)	68.51	69.90	73.94	75.72		
Dry sample + container (g)	65.05	65.70	69.69	71.38		
Mass of container	14.29	14.98	14.30	15.69		
Mass of water	3.46	4.20	4.25	4.34		
Mass of dry sample	50.76	50.72	55.39	55.69		
Water content	6.82	8.28	7.67	7.79		
Average Water content	7.55		7.73			
Dry density	2.23		2.22			
AFTER SOAKING						
Wet sample + Mould (g)			12663			
Mass of wet sample			5273			
Bulk density (g/cc)			2.483			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			K4	A2		
Wet sample + container (g)			73.95	74.82		
Dry sample + container (g)			64.40	69.01		
Mass of container			15.62	14.4		
Mass of water			9.55	5.81		
Mass of dry sample			48.78	54.62		
Water content			19.58	10.64		
Average Water content			15.11			
Dry density			2.16			

Penetr	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	41	1.06		21	0.55				
0.50	77	2.01		36	0.94				
0.75	114	2.96		63	1.64				
1.00	155	4.02		84	2.18				
1.25	193	5.01		104	2.70				
1.50	231	6.00		123	3.20				
1.75	258	6.72		142	3.69				
2.00	292	7.59		159	4.13				
2.25	326	8.47		173	4.50				
2.50	356	9.26	70	187	4.86	37			
2.75	388	10.10		198	5.15				
3.00	412	10.70		209	5.43				
3.50	473	12.30		227	5.90				
4.00	511	13.29		248	6.45				
4.50	556	14.46		263	6.84				
5.00	599	15.56	78	278	7.23	36			
5.50	637	16.55		294	7.64				
6.00	672	17.46		310	8.06				
6.50	704	18.30		325	8.45				
7.00	733	19.06		339	8.81				
7.50	761	19.78		355	9.23				
8.00	788	20.50		371	9.65				

SWELL DATA

Date	Time	Gauge(d	Date	Time	Gauge	Date	Time	Gauge(d
					0			
					26			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			0			0
		0			0			0
		0			0			0
		0			26			0

DATE: 10/5/99

SAMPLE DESCRIPTION: **3%BIT**

Proving Ring constant:kN 0.026

Sample K4

Mould No.	A2	N2	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,392	12,326	
Mass of Mould	7,469	7,383	
Mass of wet sample	4,923	4,943	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.318	2.327	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	A35	A23	A12	A18		
Wet sample + container (g)	72.93	77.31	74.24	67.20		
Dry sample + container (g)	69.00	73.04	69.75	63.15		
Mass of container	14.30	15.38	14.25	14.40		
Mass of water	3.93	4.27	4.49	4.05		
Mass of dry sample	54.70	57.66	55.50	48.75		
Water content	7.18	7.41	8.09	8.31		
Average Water content	7.30		8.20			
Dry density	2.16		2.15			
AFTER SOAKING						
Wet sample + Mould (g)			12434			
Mass of wet sample			5044			
Bulk density (g/cc)			2.375			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			A6	A11		
Wet sample + container (g)			78.53	79.29		
Dry sample + container (g)			72.05	72.74		
Mass of container			14.18	15		
Mass of water			6.48	6.55		
Mass of dry sample			57.87	57.75		
Water content			11.20	11.34		
Average Water content			11.27			
Dry density			2.13			

Penetr	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	58	1.51		10	0.26				
0.50	110	2.86		27	0.70				
0.75	161	4.19		42	1.09				
1.00	200	5.20		58	1.51				
1.25	235	6.11		75	1.95				
1.50	264	6.86		89	2.31				
1.75	290	7.54		103	2.68				
2.00	314	8.16		118	3.07				
2.25	336	8.74		132	3.43				
2.50	356	9.26	70	145	3.77	28			
2.75	376	9.78		157	4.08				
3.00	395	10.27		168	4.37				
3.50	432	11.23		188	4.89				
4.00	466	12.12		205	5.33				
4.50	500	13.00		218	5.67				
5.00	531	13.81	69	234	6.08	30			
5.50	558	14.51		245	6.37				
6.00	586	15.24		258	6.71				
6.50	612	15.91		269	6.99				
7.00	640	16.64		281	7.31				
7.50	661	17.19		294	7.64				
8.00	685	17.81		306	7.96				

SWELL DATA

Date	Time	Gauge(d	Date	Time	Gauge	Date	Time	Gauge(d
					0			
					40			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			0			0
		0			0			0
		0			0			0
		0			40			0

KNUST

DATE: 10/5/99

SAMPLE DESCRIPTION: **4%BIT**

Proving Ring constant:kN 0.026

Sample K4

Mould No.	A6	A4	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,388	12,469	
Mass of Mould	7,415	7,479	
Mass of wet sample	4,973	4,990	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.341	2.349	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	A8	A40	A15	K1		
Wet sample + container (g)	78.66	78.10	72.38	76.04		
Dry sample + container (g)	73.51	72.69	67.71	71.58		
Mass of container	14.27	14.78	15.36	16.29		
Mass of water	5.15	5.41	4.67	4.46		
Mass of dry sample	59.24	57.91	52.35	55.29		
Water content	8.69	9.34	8.92	8.07		
Average Water content	9.02		8.49			
Dry density	2.15		2.17			
AFTER SOAKING						
Wet sample + Mould (g)			12528			
Mass of wet sample			5138			
Bulk density (g/cc)			2.419			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			A12	B5		
Wet sample + container (g)			70.36	71.75		
Dry sample + container (g)			64.42	66.05		
Mass of container			14.26	14.2		
Mass of water			5.94	5.70		
Mass of dry sample			50.16	51.81		
Water content			11.84	11.00		
Average Water content			11.42			
Dry density			2.17			

Penetr	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	15	0.40		11	0.29				
0.50	28	0.72		19	0.49				
0.75	42	1.08		28	0.73				
1.00	54	1.42		38	0.99				
1.25	68	1.78		46	1.20				
1.50	79	2.06		55	1.43				
1.75	92	2.39		65	1.69				
2.00	104	2.70		74	1.92				
2.25	116	3.01		82	2.13				
2.50	127	3.29	25	91	2.37	18			
2.75	138	3.58		99	2.57				
3.00	148	3.84		108	2.81				
3.50	165	4.30		123	3.20				
4.00	181	4.71		137	3.56				
4.50	198	5.15		150	3.90				
5.00	213	5.53	28	162	4.21	21			
5.50	227	5.89		171	4.45				
6.00	241	6.25		182	4.73				
6.50	252	6.56		193	5.02				
7.00	264	6.87		205	5.33				
7.50	275	7.16		215	5.59				
8.00	285	7.41		225	5.85				

SWELL DATA

Date	Time	Gauge(d	Date	Time	Gauge	Date	Time	Gauge(d
					0			
					28			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			0			0
		0			0			0
		0			0			0
		0			28			0

DATE: 10/5/99

SAMPLE DESCRIPTION: **6%BIT**

Proving Ring constant:kN 0.026

Sample K4

Mould No.	B2	T	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,400	12,371	
Mass of Mould	7,505	7,438	
Mass of wet sample	4,895	4,933	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.305	2.323	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	A24	A25	E6	A33		
Wet sample + container (g)	69.32	69.21	81.85	84.84		
Dry sample + container (g)	65.09	65.42	76.78	79.15		
Mass of container	14.51	14.25	14.45	14.52		
Mass of water	4.23	3.79	5.07	5.69		
Mass of dry sample	50.58	51.17	62.33	64.63		
Water content	8.36	7.41	8.13	8.80		
Average Water content	7.88		8.47			
Dry density	2.14		2.14			
AFTER SOAKING						
Wet sample + Mould (g)			12421			
Mass of wet sample			5031			
Bulk density (g/cc)			2.369			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			B6	E2		
Wet sample + container (g)			73.61	73.41		
Dry sample + container (g)			67.81	67.76		
Mass of container			14.29	14.8		
Mass of water			5.80	5.65		
Mass of dry sample			53.52	52.99		
Water content			10.84	10.66		
Average Water content			10.75			
Dry density			2.14			

Penetr	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	6.5	0.17		6	0.16				
0.50	10	0.26		8.5	0.22				
0.75	14	0.36		11	0.29				
1.00	18	0.47		13.5	0.35				
1.25	22	0.57		15.5	0.40				
1.50	27	0.70		18.5	0.48				
1.75	31	0.81		21	0.55				
2.00	35.5	0.92		23.5	0.61				
2.25	40	1.04		26	0.68				
2.50	44.5	1.16	9	28.5	0.74	6			
2.75	49	1.27		31	0.81				
3.00	53	1.38		34	0.88				
3.50	62	1.61		39	1.01				
4.00	70	1.82		44	1.14				
4.50	78	2.03		49	1.27				
5.00	86	2.24	11	54	1.40	7			
5.50	93	2.42		59	1.53				
6.00	100	2.60		63	1.64				
6.50	108	2.81		68	1.77				
7.00	116	3.02		73	1.90				
7.50	122	3.17		77	2.00				
8.00	129	3.35		82	2.13				

SWELL DATA

Date	Time	Gauge(d	Date	Time	Gauge	Date	Time	Gauge(d
					0			
					36			

	ΔT	Δh		ΔT			ΔT	Δh
		0			0			0
		0			0			0
		0			0			0
		0			36			0

KNUST

DATE: 10/5/99

SAMPLE DESCRIPTION: **8%BIT**

Proving Ring constant:kN 0.026

Sample K4

Mould No.	N1	6	
No. of blows per layer	55	55	
Wet sample + Mould (g)	12,392	12,459	
Mass of Mould	7,468	7,525	
Mass of wet sample	4,924	4,934	
Volume of mould	2124	2124	
Bulk density (g/cc)	2.318	2.323	

WATER CONTENT OF TRIMMINGS

	TOP	BOT	TOP	BOT		
Container No.	A22	A21	A34	A31		
Wet sample + container (g)	64.41	61.47	67.06	55.23		
Dry sample + container (g)	60.69	58.29	63.72	52.13		
Mass of container	14.74	14.14	14.12	14.36		
Mass of water	3.72	3.18	3.34	3.10		
Mass of dry sample	45.95	44.15	49.60	37.77		
Water content	8.10	7.20	6.73	8.21		
Average Water content	7.65		7.47			
Dry density	2.15		2.16			
AFTER SOAKING						
Wet sample + Mould (g)			12550			
Mass of wet sample			5160			
Bulk density (g/cc)			2.429			

TRIMMINGS AFTER SOAKING

	TOP	BOT	TOP	BOT	TOP	BOT
Container No.			B3	A42		
Wet sample + container (g)			70.79	65.12		
Dry sample + container (g)			66.46	59.46		
Mass of container			15.31	14.7		
Mass of water			4.33	5.66		
Mass of dry sample			51.15	44.78		
Water content			8.47	12.64		
Average Water content			10.55			
Dry density			2.20			

Penetr	Unsoaked			Soaked					
	Load			Load			Load		
(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
0.25	13	0.34		10.5	0.27				
0.50	26	0.68		19	0.49				
0.75	43	1.12		28.5	0.74				
1.00	66	1.72		39	1.01				
1.25	87	2.26		47	1.22				
1.50	107	2.78		56	1.46				
1.75	128	3.33		65	1.69				
2.00	147	3.82		73	1.90				
2.25	162	4.21		80	2.08				
2.50	175	4.55	34	86	2.24	17			
2.75	186	4.84		93	2.42				
3.00	193	5.02		98	2.55				
3.50	203	5.28		108	2.81				
4.00	208	5.41		117	3.04				
4.50	213	5.54		125	3.25				
5.00	215.5	5.60	28	132	3.43	17			
5.50	217	5.64		138	3.59				
6.00	220	5.72		145	3.77				
6.50	222	5.77		151	3.93				
7.00	224.5	5.84		156	4.06				
7.50	226	5.88		161	4.19				
8.00	229	5.95		166	4.32				

SWELL DATA

Date	Time	Gauge(d	Date	Time	Gauge	Date	Time	Gauge(d
					0			
					55			

	ΔT	Δh		ΔT	Δh		ΔT	Δh
		0			0			0
		0			0			0
		0			0			0
		0			55			0

KNUST
NYANSAPƆ WƆ SANE NO BADWENMA

ERODIBILITY RESULTS FOR 0% BITUMEN CONTENT

4 L/min	
Volume of effluent collected	24
Volume of water decanted	22.5
Weight of particles in decanted water	0.17
Weight of settlement	39.97
	43.795

8 L/min	
Volume of effluent collected	49
Volume of water decanted	47
Weight of particles in decanted water	0.24
Weight of settlement	67.96
	79.24

6 L/min	
Volume of effluent collected	39
Volume of water decanted	37.5
Weight of particles in decanted water	0.29
Weight of settlement	37.95
	48.825

9.75 L/min	
Volume of effluent collected	79
Volume of water decanted	76
Weight of particles in decanted water	0.19
Weight of settlement	93.01
	107.45

ERODIBILITY RESULTS FOR 2% BITUMEN CONTENT

4 L/min	
Volume of effluent collected	11.5
Volume of water decanted	12.8
Weight of particles in decanted water	0.23
Weight of settlement	25.52
	28.464

8 L/min	
Volume of effluent collected	11.45
Volume of water decanted	30
Weight of particles in decanted water	0.15
Weight of settlement	11.45
	15.95

6 L/min	
Volume of effluent collected	23
Volume of water decanted	19.8
Weight of particles in decanted water	0.29
Weight of settlement	16.24
	21.982

9.75 L/min	
Volume of effluent collected	53
Volume of water decanted	48
Weight of particles in decanted water	0.16
Weight of settlement	28.6
	36.28

CIVIL ENGINEERING DEPARTMENT

GRADING ANALYSIS

Sample T1-test 1
0 % Bitumen Content Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	13.9	1.4	98.6
⅜ in	9.50	64.5	6.4	92.2
¼	6.70	103.2	10.3	81.8
3/16	4.75	145.3	14.5	67.3
1/8	3.18	96.0	9.6	57.7
No. 7	2.36	94.0	9.4	48.3
No. 14	1.18	61.1	6.1	42.2
No. 25	0.600	81.0	8.1	34.1
No. 36	0.425	38.5	3.9	30.3
No. 52	0.300	17.7	1.8	28.5
NO. 72	0.212	18.7	1.9	26.6
No. 100	0.150	19.2	1.9	24.7
No. 200	0.075	49.72	5.0	19.7
Passing No. 200				
Total		802.7		

Gravel	**52**
Sand	**28**
Silt	**9**
Clay	**11**

Sample T1-test 2
0 % Bitumen Content Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	14.0	1.4	98.6
⅜ in	9.50	81.4	8.1	90.5
¼	6.70	104.9	10.5	80.0
3/16	4.75	124.9	12.5	67.5
1/8	3.18	75.9	7.6	59.9
No. 7	2.36	95.2	9.5	50.4
No. 14	1.18	62.7	6.3	44.1
No. 25	0.600	81.7	8.2	35.9
No. 36	0.425	38.7	3.9	32.1
No. 52	0.300	18.8	1.9	30.2
NO. 72	0.212	20.4	2.0	28.1
No. 100	0.150	20.9	2.1	26.1
No. 200	0.075	47.0	4.7	21.4
Passing No. 200				
Total		786.4		

Gravel	**50**
Sand	**29**
Silt	**9**
Clay	**12**

APPENDIX H1

Sample T1

1 % Bitumen Content Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	99.9	10.0	90.0
⅜ in	9.50	126.0	12.6	77.4
¼	6.70	153.3	15.3	62.1
3/16	4.75	75.5	7.5	54.5
1/8	3.18	81.0	8.1	46.4
No. 7	2.36	51.4	5.1	41.3
No. 14	1.18	68.6	6.9	34.4
No. 25	0.600	35.7	3.6	30.9
No. 36	0.425	17.9	1.8	29.1
No. 52	0.300	19.6	2.0	27.1
NO. 72	0.212	20.9	2.1	25.0
No. 100	0.150	13.6	1.4	23.7
No. 200	0.075	23.5	2.4	21.3
Passing No. 200				
Total		786.7		

Gravel	**59**
Sand	**20**
Silt	**9**
Clay	**12**

Sample T1

2 % Bitumen Content Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.0
½ in	13.20	72.5	7.3	92.8
⅜ in	9.50	114.1	11.4	81.3
¼	6.70	146.1	14.6	66.7
3/16	4.75	86.0	8.6	58.1
1/8	3.18	83.4	8.3	49.8
No. 7	2.36	56.2	5.6	44.2
No. 14	1.18	74.0	7.4	36.8
No. 25	0.600	40.5	4.0	32.7
No. 36	0.425	20.4	2.0	30.7
No. 52	0.300	21.1	2.1	28.6
NO. 72	0.212	22.1	2.2	26.4
No. 100	0.150	18.6	1.9	24.5
No. 200	0.075	31.2	3.1	21.4
Passing No. 200				
Total		786.2		

Gravel	**56**
Sand	**23**
Silt	**9**
Clay	**12**

APPENDIX H2

Sample T1

3 % Bitumen Content Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 1/2 in	63.00			
2 in	53.00			
1 1/2 in	37.10			
1 in	26.50			
3/4 in	19.00			100.0
1/2 in	13.20	80.5	8.0	92.0
3/8 in	9.50	147.4	14.7	77.2
1/4	6.70	162.5	16.2	61.0
3/16	4.75	84.1	8.4	52.6
1/8	3.18	85.8	8.6	44.0
No. 7	2.36	53.1	5.3	38.7
No. 14	1.18	66.4	6.6	32.0
No. 25	0.600	34.7	3.5	28.6
No. 36	0.425	17.7	1.8	26.8
No. 52	0.300	18.5	1.9	24.9
NO. 72	0.212	19.5	1.9	23.0
No. 100	0.150	16.6	1.7	21.3
No. 200	0.075	25.3	2.5	18.8
Passing No. 200				
Total		811.9		

Gravel	**61**
Sand	**20**
Silt	**7**
Clay	**12**

Sample T1

4 % Bitumen Content Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 1/2 in	63.00			
2 in	53.00			
1 1/2 in	37.10			
1 in	26.50			
3/4 in	19.00			100.0
1/2 in	13.20	129.7	13.0	87.0
3/8 in	9.50	144.1	14.4	72.6
1/4	6.70	188.1	18.8	53.8
3/16	4.75	89.3	8.9	44.9
1/8	3.18	91.1	9.1	35.8
No. 7	2.36	52.0	5.2	30.6
No. 14	1.18	60.5	6.1	24.5
No. 25	0.600	30.7	3.1	21.4
No. 36	0.425	14.1	1.4	20.0
No. 52	0.300	14.6	1.5	18.6
NO. 72	0.212	14.4	1.4	17.1
No. 100	0.150	9.3	0.9	16.2
No. 200	0.075	18.9	1.9	14.3
Passing No. 200				
Total		856.8		

Gravel	**69**
Sand	**16**
Silt	**2**
Clay	**12**

Sample T1

6 % Bitumen Content Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 1/2 in	63.00			
2 in	53.00			
1 1/2 in	37.10			
1 in	26.50			
3/4 in	19.00			100.0
1/2 in	13.20	110.2	11.0	89.0
3/8 in	9.50	163.6	16.4	72.6
1/4	6.70	173.1	17.3	55.3
3/16	4.75	87.0	8.7	46.6
1/8	3.18	91.6	9.2	37.4
No. 7	2.36	48.8	4.9	32.6
No. 14	1.18	62.4	6.2	26.3
No. 25	0.600	30.6	3.1	23.3
No. 36	0.425	14.5	1.5	21.8
No. 52	0.300	15.6	1.6	20.3
NO. 72	0.212	15.8	1.6	18.7
No. 100	0.150	11.1	1.1	17.6
No. 200	0.075	20.7	2.1	15.5
Passing No. 200				
Total		845.1		

Gravel	**67**
Sand	**17**
Silt	**3**
Clay	**12**

Sample T1

8 % Bitumen Content Total Dry Weight (g) 1000.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing
BS designation	Metric (mm)			
3 in	75.00			
2 1/2 in	63.00			
2 in	53.00			
1 1/2 in	37.10			
1 in	26.50			
3/4 in	19.00			100.0
1/2 in	13.20	68.7	6.9	93.1
3/8 in	9.50	100.2	10.0	83.1
1/4	6.70	150.0	15.0	68.1
3/16	4.75	83.2	8.3	59.8
1/8	3.18	92.1	9.2	50.6
No. 7	2.36	61.3	6.1	44.4
No. 14	1.18	78.3	7.8	36.6
No. 25	0.600	41.4	4.1	32.5
No. 36	0.425	20.8	2.1	30.4
No. 52	0.300	21.8	2.2	28.2
NO. 72	0.212	22.3	2.2	26.0
No. 100	0.150	18.0	1.8	24.2
No. 200	0.075	30.4	3.0	21.2
Passing No. 200				
Total		788.4		

Gravel	**56**
Sand	**23**
Silt	**9**
Clay	**12**

APPENDIX H4

CIVIL ENGINEERING DEPARTMENT

HYDROMETER ANALYSIS

Total Dry Weight (g) 25.0 **Gs= 2.84**

Sample T1-test 1

Time	Temp, T (oc)	Elapsed time, t (min)	Direct hydrometer reading, RH'	Transformed hydrometer reading, Rh'	Rh=Rh'+Cm	Effective depth, Hr (mm)	Viscosity, η (mPa.s)	D (mm)	M_t	$R_d=R_h'+M_t-R_o'$	K (%)
11:29	27.0	0.5	1.0160	16.0	16.5	135.43	0.847	0.0618	1.5260	13.93	24.50
	27.0	1.0	1.0154	15.4	15.9	137.80	0.847	0.0441	1.5260	13.33	23.45
	27.0	2.0	1.0145	14.5	15.0	141.35	0.847	0.0316	1.5260	12.43	21.86
	27.0	4.0	1.0130	13.0	13.5	147.28	0.85	0.0228	1.5260	10.93	19.22
	26.8	8.0	1.0123	12.3	12.8	150.04	0.85	0.0163	1.4750	10.18	17.90
	26.8	15.0	1.0117	11.7	12.2	152.41	0.85	0.0120	1.4750	9.58	16.85
	26.4	30.0	1.0110	11.0	11.5	155.18	0.86	0.0086	1.3744	8.77	15.44
	26.0	60.0	1.0104	10.4	10.9	157.55	0.87	0.0062	1.2755	8.08	14.21
	25.6	120	1.0100	10.0	10.5	159.13	0.88	0.0044	1.1784	7.58	13.33
	25.0	240	1.0096	9.6	10.1	160.71	0.89	0.0031	1.0358	7.04	12.38
	26.4	1440	1.0084	8.4	8.9	165.45	0.86	0.0013	1.3744	6.17	10.86

KNUST

APPENDIX H5

Sample T1
0 % BIT CONT.

Liquid Limit

CONT. NO	A16	A17	B2	B4	B36
WEIGHT OF CONT.	3.71	3.71	3.74	3.64	3.61
NO. OF BLOWS	45	31	26	16	13
WET+CONT	14.50	17.99	17.47	20.52	25.61
DRY SAMPLE+CONT	11.45	13.87	13.47	15.52	18.91
WEIGHT OF WATER	3.05	4.12	4	5	6.7
WEIGHT OF DRY SAMPLE	7.74	10.16	9.73	11.88	15.3
WATER CONTENT %	39.41	40.55	41.11	42.09	43.79

plastic limit

CONT. NO	C11	C12
WEIGHT OF CONT.	3.61	3.74
WET+CONT	14.14	13.02
DRY SAMPLE+CONT	12.69	11.75
WEIGHT OF WATER	1.45	1.27
WEIGHT OF DRY SAMPLE	9.08	8.01
WATER CONTENT %	15.97	15.86
	15.91	

Sample T1
1 % BIT CONT.

Liquid Limit

CONT. NO	X14	B39	C27	X18	X20
WEIGHT OF CONT.	3.63	3.66	3.76	3.66	3.6
NO. OF BLOWS	41	27	19	15	12
WET SAMPLE+CONT.	17.54	18.88	17.74	18.94	18.27
DRY SAMPLE+CONT.	13.19	13.96	13.17	13.8	13.28
WEIGHT OF WATER	4.35	4.92	4.57	5.14	4.99
WEIGHT OF DRY SAMPLE	9.56	10.3	9.41	10.14	9.68
WATER CONTENT %	45.50	47.77	48.57	50.69	51.55

plastic limit

CONT. NO	A41	B6
WEIGHT OF CONT.	3.7	3.7
WET+CONT	12.03	11.88
DRY SAMPLE+CONT	10.77	10.65
WEIGHT OF WATER	1.26	1.23
WEIGHT OF DRY SAMPLE	7.07	6.95
WATER CONTENT %	17.82	17.70
	18	

Sample T1
2 % BIT CONT.

Liquid Limit

CONT. NO	A21	X16	A1	A5	A24
WEIGHT OF CONT.	3.64	3.64	3.74	3.78	3.70
NO. OF BLOWS	44	29	18	16	10
WET+CONT	15.04	19.19	23.81	20.70	16.14
DRY SAMPLE+CONT	11.69	14.52	17.66	15.34	12.04
WEIGHT OF WATER	3.35	4.67	6.15	5.36	4.1
WEIGHT OF DRY SAMPLE	8.05	10.88	13.92	11.56	8.34
WATER CONTENT %	41.61	42.92	44.18	46.37	49.16

plastic limit

CONT. NO	A39	A32
WEIGHT OF CONT.	3.70	3.66
WET+CONT	10.66	10.00
DRY SAMPLE+CONT	9.66	9.08
WEIGHT OF WATER	1	0.92
WEIGHT OF DRY SAMPLE	5.96	5.42
WATER CONTENT %	16.78	16.97
	17	

Sample T1
3 % BIT CONT.

Liquid Limit

CONT. NO	X12	A13	X29	B10	B23
WEIGHT OF CONT.	3.69	3.78	3.66	3.54	3.71
NO. OF BLOWS	50	34	23	16	12
WET SAMPLE+CONT.	16.89	19.54	23.87	18.18	20.22
DRY SAMPLE+CONT.	12.94	14.67	17.48	13.48	14.8
WEIGHT OF WATER	3.95	4.87	6.39	4.7	5.42
WEIGHT OF DRY SAMPLE	9.25	10.89	13.82	9.94	11.09
WATER CONTENT %	42.70	44.72	46.24	47.28	48.87

plastic limit

CONT. NO	C19	K4
WEIGHT OF CONT.	3.64	3.61
WET+CONT	8.51	8.29
DRY SAMPLE+CONT	7.79	7.61
WEIGHT OF WATER	0.72	0.68
WEIGHT OF DRY SAMPLE	4.15	4
WATER CONTENT %	17.35	17.00
	17	

Sample T1
4 % BIT CONT.

Liquid Limit

CONT. NO	A31	X8	A7	C15	B37
WEIGHT OF CONT.	3.50	3.64	3.74	3.62	3.72
NO. OF BLOWS	43	35	24	18	13
WET+CONT	13.95	16.43	18.76	15.84	20.65
DRY SAMPLE+CONT	10.78	12.51	14.07	11.92	15.11
WEIGHT OF WATER	3.17	3.92	4.69	3.92	5.54
WEIGHT OF DRY SAMPLE	7.28	8.87	10.33	8.3	11.39
WATER CONTENT %	43.54	44.19	45.40	47.23	48.64

plastic limit

CONT. NO	X10	K1
WEIGHT OF CONT.	3.71	3.77
WET+CONT	9.09	9.25
DRY SAMPLE+CONT	8.30	8.44
WEIGHT OF WATER	0.79	0.81
WEIGHT OF DRY SAMPLE	4.59	4.67
WATER CONTENT %	17.21	17.34
	17	

Sample T1
6 % BIT CONT.

Liquid Limit

CONT. NO	C3	K2	X17	B44	X2
WEIGHT OF CONT.	3.69	3.72	3.54	3.68	3.65
NO. OF BLOWS	47	37	26	15	13
WET SAMPLE+CONT.	18.25	15.44	15.25	15.68	20.06
DRY SAMPLE+CONT.	13.69	11.7	11.42	11.65	14.6
WEIGHT OF WATER	4.56	3.74	3.83	4.03	5.46
WEIGHT OF DRY SAMPLE	10	7.98	7.88	7.97	10.95
WATER CONTENT %	45.60	46.87	48.60	50.56	49.86

plastic limit

CONT. NO	B16	C35
WEIGHT OF CONT.	3.65	3.65
WET+CONT	8.86	9.01
DRY SAMPLE+CONT	8.09	8.22
WEIGHT OF WATER	0.77	0.79
WEIGHT OF DRY SAMPLE	4.44	4.57
WATER CONTENT %	17.34	17.29
	17	

Sample T1
8 % BIT CONT.

Liquid Limit

CONT. NO	K7	K5	B29	A4	B43
WEIGHT OF CONT.	3.76	3.65	3.74	3.75	3.73
NO. OF BLOWS	45	29	21	15	12
WET+CONT	22.65	19.24	20.62	19.07	20.71
DRY SAMPLE+CONT	17.02	14.42	15.29	14.11	15.10
WEIGHT OF WATER	5.63	4.82	5.33	4.96	5.61
WEIGHT OF DRY SAMPLE	13.26	10.77	11.55	10.36	11.37
WATER CONTENT %	42.46	44.75	46.15	47.88	49.34

plastic limit

CONT. NO	A22	B30
WEIGHT OF CONT.	3.67	3.67
WET+CONT	9.05	9.36
DRY SAMPLE+CONT	8.23	8.50
WEIGHT OF WATER	0.82	0.86
WEIGHT OF DRY SAMPLE	4.56	4.83
WATER CONTENT %	17.98	17.81
	18	

CIVIL ENGINEERING DEPARTMENT

COMPACTION TEST

Sample T1

0% NOMINAL BITUMEN CONTENT

GRAVEL PIT 1

No of Blows/layer

	1	2	3	4	5			
Sample preparation								
Mass of cylinder + Wet sample (gm)	11970	12531	12540	12301				
Mass of cylinder (gm)	7576	7576	7576	7576				
Mass of wet sample (gm)	4394	4955	4964	4725				
Bulk density (Mg/m^3)	2.07	2.33	2.34	2.22				

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	100	A15	A21	A23	A28	A5	A14	A35				
Mass of container+Wet soil (gm)	85.81	78.12	68.06	72.57	64.52	66.69	105.22	101.46				
Mass of container+Dry soil (gm)	83.78	76.24	64.55	68.44	59.81	62.04	94.15	90.74				
Mass of container (gm)	14.36	15.36	14.12	15.36	14.31	14.20	14.21	14.30				
Mass of water (gm)	2.03	1.88	3.51	4.13	4.71	4.65	11.07	10.72				
Mass of dry soil (gm)	69.42	60.88	50.43	53.08	45.50	47.84	79.94	76.44				
Water content (%)	2.92	3.09	6.96	7.78	10.35	9.72	13.85	14.02				
Average water content	3.01		7.37		10.04		13.94					
Dry density (Mg/m^3)	2.01		2.17		2.12		1.95					

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Sample T1

1% NOMINAL BITUMEN CONTENT

GRAVEL PIT 1

No of Blows/layer

	1	2	3	4	5			
Sample preparation								
Mass of cylinder + Wet sample (gm)	11808	12395	12222	12143				
Mass of cylinder (gm)	7523	7523	7523	7523				
Mass of wet sample (gm)	4285	4872	4699	4620				
Bulk density (Mg/m^3)	2.02	2.29	2.21	2.17				

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	A39	A34	A16	A2	A8	A40	A38	A41				
Mass of container+Wet soil (gm)	77.24	80.63	68.63	65.75	67.93	77.33	89.28	89.87				
Mass of container+Dry soil (gm)	74.84	78.14	64.71	61.99	63.02	71.22	82.05	81.92				
Mass of container (gm)	14.28	14.11	14.22	14.38	14.26	14.35	14.27	14.24				
Mass of water (gm)	2.40	2.49	3.92	3.76	4.91	6.11	7.23	7.95				
Mass of dry soil (gm)	60.56	64.03	50.49	47.61	48.76	56.87	67.78	67.68				
Water content (%)	3.96	3.89	7.76	7.90	10.07	10.74	10.67	11.75				
Average water content	3.93		7.83		10.41		11.21					
Dry density (Mg/m^3)	1.94		2.13		2.00		1.96					

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

APPENDIX H8

Sample T1
2% NOMINAL BITUMEN CONTENT GRAVEL PIT 1 No of Blows/layer

Sample preparation	1	2	3	4	5			
Mass of cylinder + Wet sample (gm)	11653	12406	12268	12167				
Mass of cylinder (gm)	7522	7522	7522	7522				
Mass of wet sample (gm)	4131	4884	4746	4645				
Bulk density (Mg/m^3)	1.94	2.30	2.23	2.19				

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	A37	A27	A5	B1	E2	A31	A32	A3				
Mass of container+Wet soil (gm)	82.18	75.50	61.58	61.96	59.79	61.32	87.70	79.19				
Mass of container+Dry soil (gm)	79.42	73.01	58.13	58.70	56.51	57.77	80.12	72.79				
Mass of container (gm)	15.68	12.91	14.21	14.59	14.77	14.35	14.77	15.47				
Mass of water (gm)	2.76	2.49	3.45	3.26	3.28	3.55	7.58	6.40				
Mass of dry soil (gm)	63.74	60.10	43.92	44.11	41.74	43.42	65.35	57.32				
Water content (%)	4.33	4.14	7.86	7.39	7.86	8.18	11.60	11.17				
Average water content	4.24		7.62		8.02		11.38					
Dry density (Mg/m^3)	1.87		2.14		2.07		1.96					

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Sample T1
3% NOMINAL BITUMEN CONTENT GRAVEL PIT 1 No of Blows/layer

Sample preparation	1	2	3	4	5			
Mass of cylinder + Wet sample (gm)	11760	12249	11983	11529				
Mass of cylinder (gm)	7476	7476	7476	7476				
Mass of wet sample (gm)	4284	4773	4507	4053				
Bulk density (Mg/m^3)	2.02	2.25	2.12	1.91				

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	K3	A22	A21	A35	100	A28	B5	A10				
Mass of container+Wet soil (gm)	60.56	65.54	61.81	58.57	67.29	71.61	81.93	84.10				
Mass of container+Dry soil (gm)	57.71	62.84	59.08	55.59	62.40	67.09	74.75	76.53				
Mass of container (gm)	14.86	14.74	14.17	14.33	14.39	14.26	14.22	14.42				
Mass of water (gm)	2.85	2.70	2.73	2.98	4.89	4.52	7.18	7.57				
Mass of dry soil (gm)	42.85	48.10	44.91	41.26	48.01	52.83	60.53	62.11				
Water content (%)	6.65	5.61	6.08	7.22	10.19	8.56	11.86	12.19				
Average water content	6.13		6.65		9.37		12.02					
Dry density (Mg/m^3)	1.90		2.11		1.94		1.70					

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

APPENDIX H9

4% NOMINAL BITUMEN CONTENT

GRAVEL PIT 1

No of Blows/layer

Sample preparation	1	2	3	4	5			
Mass of cylinder + Wet sample (gm)	11822	12098	12260	12154				
Mass of cylinder (gm)	7493	7493	7493	7493				
Mass of wet sample (gm)	4329	4605	4767	4661				
Bulk density (Mg/m^3)	2.04	2.17	2.24	2.19				

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	A5	A27	A40	A38	B1	A23	A18	A11				
Mass of container+Wet soil (gm)	86.11	86.25	87.75	85.51	82.37	85.81	92.52	88.32				
Mass of container+Dry soil (gm)	83.04	82.91	83.84	81.56	77.68	81.05	86.19	82.97				
Mass of container (gm)	14.82	12.91	14.72	14.29	14.59	15.36	14.39	14.99				
Mass of water (gm)	3.07	3.34	3.91	3.95	4.69	4.76	6.33	5.35				
Mass of dry soil (gm)	68.22	70.00	69.12	67.27	63.09	65.69	71.80	67.98				
Water content (%)	4.50	4.77	5.66	5.87	7.43	7.25	8.82	7.87				
Average water content	4.64		5.76		7.34		8.34					
Dry density (Mg/m^3)	1.95		2.05		2.09		2.03					

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Sample T1

6% NOMINAL BITUMEN CONTENT

GRAVEL PIT 1

No of Blows/layer

Sample preparation	1	2	3	4	5			
Mass of cylinder + Wet sample (gm)	11617	11893	12076	11897				
Mass of cylinder (gm)	7423	7423	7423	7423				
Mass of wet sample (gm)	4194	4470	4653	4474				
Bulk density (Mg/m^3)	1.97	2.10	2.19	2.11				

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	B5	A10	A22	A41	A34	K3	A39	A28				
Mass of container+Wet soil (gm)	81.33	80.92	76.95	83.27	81.51	73.72	84.18	83.46				
Mass of container+Dry soil (gm)	79.03	78.72	73.49	78.90	75.55	69.03	76.90	77.10				
Mass of container (gm)	14.24	14.44	14.74	14.24	14.09	14.86	14.29	14.26				
Mass of water (gm)	2.30	2.20	3.46	4.37	5.96	4.69	7.28	6.36				
Mass of dry soil (gm)	64.79	64.28	58.75	64.66	61.46	54.17	62.61	62.84				
Water content (%)	3.55	3.42	5.89	6.76	9.70	8.66	11.63	10.12				
Average water content	3.49		6.32		9.18		10.87					
Dry density (Mg/m^3)	1.91		1.98		2.01		1.90					

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

Sample T1

8% NOMINAL BITUMEN CONTENT GRAVEL PIT 1 No of Blows/layer

Sample preparation	1	2	3	4	5			
Mass of cylinder + Wet sample (gm)	11641	11908	12010	11904				
Mass of cylinder (gm)	7423	7423	7423	7423				
Mass of wet sample (gm)	4218	4485	4587	4481				
Bulk density (Mg/m^3)	1.99	2.11	2.16	2.11				

Water Content Determination

Test No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B		
Container No.	A34	A35	K3	A28	A22	A39	B5	A41				
Mass of container+Wet soil (gm)	75.00	86.23	81.7	78.18	75.02	69.08	88.91	79.1				
Mass of container+Dry soil (gm)	72.55	83.47	77.85	74.15	70.57	64.61	82.64	73.55				
Mass of container (gm)	14.09	14.32	14.87	14.25	14.74	14.74	14.26	14.23				
Mass of water (gm)	2.45	2.76	3.85	4.03	4.45	4.47	6.27	5.55				
Mass of dry soil (gm)	58.46	69.15	62.98	59.90	55.83	49.87	68.38	59.32				
Water content (%)	4.19	3.99	6.11	6.73	7.97	8.96	9.17	9.36				
Average water content	4.09		6.42		8.47		9.26					
Dry density (Mg/m^3)	1.91		1.98		1.99		1.93					

Mould characteristics

Height of Mould (cm)	11.6
Diameter of mould (cm)	15.27
Volume of Mould (cc)	2124

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CIVIL ENGINEERING DEPARTMENT
CBR TEST RECORDING SHEET

Sample T1

Description: 0% Bitumen Emulsion

								Penetratio n	Unsoaked			Proving Ring constant:k	Soaked			0.026		
Mould No.	N1		6						Load			Load			Load		
No. of blows per layer	55		55		10			(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
Wet sample + Mould (g)	12,321		12,416					0.25	20	0.5		29	0.8				
Mass of Mould	7,422		7,568					0.50	67	1.7		55	1.4				
Mass of wet sample	4,899		4,848		0			0.75	102	2.7		82	2.1				
Volume of mould	2088		2088					1.00	138	3.6		107	2.8				
Bulk density (g/cc)	2.347		2.322					1.25	175	4.6		130	3.4				
WATER CONTENT OF TRIMMINGS								1.50	211	5.5		152	4.0				
	1	2	1	2	1	2		1.75	246	6.4		173	4.5				
Container No.	A34	A35	A10	A40				2.00	281	7.3	**64**	192	5.0	**43**			
Wet sample + container (g)	66.17	67.40	80.08	72.46				2.25	315	8.2		212	5.5				
Dry sample + container (g)	62.82	63.62	76.07	68.17				2.50	347	9.0	**68**	231	6.0	**45**			
Mass of container	14.10	14.31	14.43	14.35				2.75	378	9.8		250	6.5				
Mass of water	3.35	3.78	4.01	4.29				3.00	406	10.6		269	7.0				
Mass of dry sample	48.72	49.31	61.64	53.82				3.50	457	11.9		300	7.8				
Water content	6.88	7.67	6.51	7.97				4.00	505	13.1		330	8.6				
Average Water content	7.27		7.24					4.50	546	14.2		356	9.3				
Dry density	2.19		2.17					5.00	590	15.3	**77**	381	9.9	**50**			
AFTER SOAKING								5.50	633	16.5		405	10.5				
Wet sample + Mould (g)			12454					6.00	670	17.4		429	11.2				
Mass of mould			7568					6.50	701	18.2		452	11.8				
Mass of wet sample	0		4886					7.00	732	19.0		472	12.3				
Bulk density (g/cc)	0.00		2.34					7.50	760	19.8		493	12.8				
TRIMMINGS AFTER SOAKING								8.00	785	20.4		510	13.3				
	1	2	1	2	1	2		**SWELL DATA**									
Container No.			X11	XX3					Date	Time	Gaug	Date	Time	Gaug	Date	Time	Gaug
Wet sample + container (g)			100.1	80.27							0						
Dry sample + container (g)			93.97	75.33							13						
Mass of container			17.82	17.77							13						
Mass of water			6.09	4.94							13						
Mass of dry sample			76.15	57.56							12						
Water content			8.00	8.58						ΔT	Δh		ΔT	Δh		ΔT	Δh
Average Water content			8.29								13			0			0
Dry density			2.16								0			0			0
											0			0			0
											0			0			0
											-1			0			0

Sample T1

Description: 1% Bitumen Emulsion

								Penetratio	Unsoaked			Proving Ring constant:k	Soaked			0.026		
Mould No.	A4		A8						Load			Load			Load		
No. of blows per layer	55		55		10			(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
Wet sample + Mould (g)	12,283		12,200					0.25	42	1.1		33	0.9				
Mass of Mould	7,435		7,352					0.50	87	2.3		60	1.6				
Mass of wet sample	4,848		4,848		0			0.75	136	3.5		91	2.4				
Volume of mould	2088		2088					1.00	177	4.6		123	3.2				
Bulk density (g/cc)	2.322		2.322					1.25	217	5.6		150	3.9				
WATER CONTENT OF TRIMMINGS								1.50	256	6.7		174	4.5				
	1	2	1	2	1	2		1.75	295	7.7		196	5.1				
Container No.	B5	A28	A39	A41				2.00	330	8.6	**75**	216	5.6	**49**			
Wet sample + container (g)	89.10	97.01	84.41	91.23				2.25	358	9.3		237	6.2				
Dry sample + container (g)	84.50	91.70	79.89	86.64				2.50	385	10.0	**76**	255	6.6	**50**			
Mass of container	14.24	14.25	14.29	14.23				2.75	413	10.7		274	7.1				
Mass of water	4.60	5.31	4.52	4.59				3.00	439	11.4		290	7.5				
Mass of dry sample	70.26	77.45	65.60	72.41				3.50	486	12.6		322	8.4				
Water content	6.55	6.86	6.89	6.34				4.00	528	13.7		345	9.0				
Average Water content	6.70		6.61					4.50	566	14.7		371	9.6				
Dry density	2.18		2.18					5.00	602	15.7	**78**	391	10.2	**51**			
AFTER SOAKING								5.50	632	16.4		411	10.7				
Wet sample + Mould (g)			12243					6.00	659	17.1		428	11.1				
Mass of mould			7352					6.50	684	17.8		442	11.5				
Mass of wet sample	0		4891					7.00	710	18.5		459	11.9				
Bulk density (g/cc)	0.00		2.34					7.50	735	19.1		477	12.4				
TRIMMINGS AFTER SOAKING								8.00	755	19.6		495	12.9				
	1	2	1	2	1	2		**SWELL DATA**									
Container No.			X2	C67					Date	Time	Gaug	Date	Time	Gaug	Date	Time	Gaug
Wet sample + container (g)			90.46	92.24							0						
Dry sample + container (g)			85.47	86.92							5						
Mass of container			18.04	18.13							11						
Mass of water			4.99	5.32							11.5						
Mass of dry sample			67.43	68.79							12						
Water content			7.40	7.73						ΔT	Δh		ΔT	Δh		ΔT	Δh
Average Water content			7.57								5			0			0
Dry density			2.18								6			0			0
											0			0			0
											0.5			0			0
											0.5			0			0

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Sample T1

Description: 2% Bitumen Emulsion

SAMPLE PREPARATION:SERIES A SAMPLE2								Penetration	Unsoaked			Proving Ring constant:k	Soaked		0.026		
Mould No.	6		A8						Load			Load			Load		
No. of blows per layer	55		55		10			(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
Wet sample + Mould (g)	12,345		12,227					0.25	18	0.5		16	0.42				
Mass of Mould	7,531		7,386					0.50	35	0.9		33	0.9				
Mass of wet sample	4,814		4,841		0			0.75	55	1.4		56	1.5				
Volume of mould	2088		2088					1.00	78	2.0		83	2.2				
	2.306		2.319					1.25	102	2.6		111	2.9				
WATER CONTENT OF TRIMMINGS								1.50	130	3.4		141	3.7				
	1	2	1	2	1	2		1.75	158	4.1		173	4.5				
Container No.	A10	A35	A40	A41				2.00	186	4.8	**42**	204	5.3	**46**			
Wet sample + container (g)	87.51	82.66	97.09	98.82				2.25	215	5.6		236	6.1				
Dry sample + container (g)	82.68	77.57	91.76	94.27				2.50	244	6.3	**48**	261	6.8	**51**			
Mass of container	14.44	14.30	14.35	14.23				2.75	276	7.2		286	7.4				
Mass of water	4.83	5.09	5.33	4.55				3.00	305	7.9		312	8.1				
Mass of dry sample	68.24	63.27	77.41	80.04				3.50	360	9.3		357	9.3				
Water content	7.08	8.04	6.89	5.68				4.00	411	10.7		399	10.4				
Average Water content	7.56		6.29					4.50	455	11.8		439	11.4				
Dry density	2.14		2.18					5.00	500	13.0	**65**	478	12.4	**62**			
AFTER SOAKING								5.50	540	14.0		507	13.2				
Wet sample + Mould (g)			12265					6.00	577	15.0		540	14.0				
Mass of mould			7386					6.50	609	15.8		563	14.6				
Mass of wet sample	0		4879					7.00	647	16.8		599	15.6				
Bulk density (g/cc)	0.00		2.34					7.50	681	17.7		632	16.4				
TRIMMINGS AFTER SOAKING								8.00	718	18.7		651	16.9				
	1	2	1	2	1	2		SWELL DATA									
Container No.			B5	A31					Date	Time	Gaug	Date	Time	Gaug	Date	Time	Gaug
Wet sample + container (g)			88.00	75.10							0						
Dry sample + container (g)			81.69	70.35							2.5						
Mass of container			14.23	14.35							2.5						
Mass of water			6.31	4.75							2.5						
Mass of dry sample			67.46	56.00							2.5						
Water content			9.35	8.48					ΔT	Δh		ΔT	Δh		ΔT		Δh
Average Water content			8.92							0			2.5				0
Dry density			2.15							0			0				0
										0			0				0
										0			0				0

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Sample T1

Description: 3% Bitumen Emulsion

SAMPLE PREPARATION:SERIES A SAMPLE2								Penetration	Unsoaked			Proving Ring constant:k	Soaked		0.026		
Mould No.	B2		A2						Load			Load			Load		
No. of blows per layer	55		25		10			(mm)	(div)	(kN)	CBR	div	kN	CBR	div	kN	CBR
Wet sample + Mould (g)	12,281		12,157					0.25	20	0.5		35	0.9				
Mass of Mould	7,496		7,351					0.50	38	1.0		47	1.2				
Mass of wet sample	4,785		4,806		0			0.75	57	1.5		60	1.6				
Volume of mould	2088		2088					1.00	75	2.0		72	1.9				
Bulk density (g/cc)	2.292		2.302					1.25	94	2.4		82	2.1				
WATER CONTENT OF TRIMMINGS								1.50	114	3.0		91	2.4				
	1	2	1	2	1	2		1.75	134	3.5		100	2.6				
Container No.	A	B6	A24	A15				2.00	152	4.0	**34**	116	3.0	**26**			
Wet sample + container (g)	84.87	80.31	77.28	77.64				2.25	169	4.4		128	3.3				
Dry sample + container (g)	79.24	75.50	73.29	73.67				2.50	188	4.9	**37**	138	3.6	**27**			
Mass of container	14.75	14.29	14.51	15.35				2.75	205	5.3		149	3.9				
Mass of water	5.63	4.81	3.99	3.97				3.00	224	5.8		160	4.2				
Mass of dry sample	64.49	61.21	58.78	58.32				3.50	260	6.8		179	4.7				
Water content	8.73	7.86	6.79	6.81				4.00	291	7.6		198	5.1				
Average Water content	8.29		6.80					4.50	321	8.3		217	5.6				
Dry density	2.12		2.16					5.00	350	9.1	**46**	235	6.1	**31**			
AFTER SOAKING								5.50	376	9.8		253	6.6				
Wet sample + Mould (g)			12193					6.00	398	10.3		269	7.0				
Mass of mould			7351					6.50	422	11.0		287	7.5				
Mass of wet sample	0		4842					7.00	443	11.5		304	7.9				
Bulk density (g/cc)	0.00		2.32					7.50	464	12.1		320	8.3				
TRIMMINGS AFTER SOAKING								8.00	482	12.5		336	8.7				
	1	2	1	2	1	2		SWELL DATA									
Container No.			A9	B3					Date	Time	Gaug	Date	Time	Gaug	Date	Time	Gaug
Wet sample + container (g)			84.15	86.10							0						
Dry sample + container (g)			77.28	80.43							3						
Mass of container			14.29	15.28							5						
Mass of water			6.87	5.67							5						
Mass of dry sample			62.99	65.15							5						
Water content			10.91	8.70					ΔT	Δh		ΔT	Δh		ΔT		Δh
Average Water content			9.80							3			3				0
Dry density			2.11							2			2				0
										0			0				0
										0			0				0

Sample T1

Description: 4% Bitumen Emulsion

SAMPLE PREPARATION:SERIES A SAMPLE2								Penetration	Unsoaked			Proving Ring constant:k	Soaked			0.026		
Mould No.	A6		A7						Load			Load				Load		
No. of blows per layer	55		55		10			(mm)	(div)	(kN)	CBR	div	kN	CBR		div	kN	CBR
Wet sample + Mould (g)	12,118		12,094					0.25	36	0.9		22	0.6					
Mass of Mould	7,425		7,402					0.50	63	1.6		44	1.1					
Mass of wet sample	4,693		4,692					0.75	88	2.3		66	1.7					
Volume of mould	2088		2088					1.00	110	2.9		86	2.2					
Bulk density (g/cc)	2.248		2.248					1.25	131	3.4		106	2.8					
WATER CONTENT OF TRIMMINGS								1.50	150	3.9		124	3.2					
	1	2	1	2	1	2		1.75	167	4.3		139	3.6					
Container No.	B3	A15	A50	100				2.00	185	4.8	**42**	152	4.0	**34**				
Wet sample + container (g)	77.91	84.90	78.68	76.87				2.25	198	5.1		163	4.2					
Dry sample + container (g)	74.06	80.37	74.94	72.26				2.50	212	5.5	**42**	173	4.5	**34**				
Mass of container	15.28	15.35	14.32	14.37				2.75	226	5.9		184	4.8					
Mass of water	3.85	4.53	3.74	4.61				3.00	239	6.2		192	5.0					
Mass of dry sample	58.78	65.02	60.62	57.89				3.50	265	6.9		209	5.4					
Water content	6.55	6.97	6.17	7.96				4.00	290	7.5		223	5.8					
Average Water content	6.76		7.07					4.50	315	8.2		236	6.1					
Dry density	2.11		2.10					5.00	338	8.8	**44**	250	6.5	**33**				
AFTER SOAKING								5.50	362	9.4		263	6.8					
Wet sample + Mould (g)			12150					6.00	382	9.9		272	7.1					
Mass of mould			7402					6.50	401	10.4		283	7.4					
Mass of wet sample	0		4748					7.00	421	10.9		291	7.6					
Bulk density (g/cc)	0.00		2.27					7.50	441	11.5		302	7.9					
TRIMMINGS AFTER SOAKING								8.00	460	12.0		309	8.0					
	1	2	1	2	1	2		SWELL DATA										
Container No.			B6	A38					Date	Time	Gaug	Date	Time	Gaug		Date	Time	Gaug
Wet sample + container (g)			73.89	77.89										0				
Dry sample + container (g)			68.63	71.46										14				
Mass of container			14.29	14.30										18				
Mass of water			5.26	6.43										20				
Mass of dry sample			54.34	57.16										23				
Water content			9.68	11.25						ΔT	Δh		ΔT	Δh			ΔT	Δh
Average Water content			10.46								0			14				0
Dry density			2.06								0			4				0
											0			2				0
											0			3				0

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Sample T1

Description: 6% Bitumen Emulsion

SAMPLE PREPARATION:SERIES A SAMPLE2								Penetration	Unsoaked			Proving Ring constant:k	Soaked			0.026		
Mould No.	N1		6						Load			Load				Load		
No. of blows per layer	55		55		10			(mm)	(div)	(kN)	CBR	div	kN	CBR		div	kN	CBR
Wet sample + Mould (g)	12,045		12,187					0.25	33	0.8		14	0.4					
Mass of Mould	7,414		7,532					0.50	59	1.5		23	0.6					
Mass of wet sample	4,631		4,655		0			0.75	82	2.1		34	0.9					
Volume of mould	2088		2088					1.00	103	2.7		44	1.1					
Bulk density (g/cc)	2.218		2.230					1.25	123	3.2		55	1.4					
WATER CONTENT OF TRIMMINGS								1.50	141	3.7		65	1.7					
	1	2	1	2	1	2		1.75	158	4.1		74	1.9					
Container No.	A8	A9	A22	A24				2.00	173	4.5	**39**	83	2.2	**19**				
Wet sample + container (g)	71.74	74.56	80.85	73.46				2.25	190	4.9		91	2.4					
Dry sample + container (g)	67.54	70.63	75.71	69.12				2.50	204	5.3	**40**	98	2.5	**19**				
Mass of container	14.26	14.30	14.74	14.50				2.75	218	5.7		105	2.7					
Mass of water	4.20	3.93	5.14	4.34				3.00	231	6.0		112	2.9					
Mass of dry sample	53.28	56.33	60.97	54.62				3.50	255	6.6		124	3.2					
Water content	7.88	6.98	8.43	7.95				4.00	278	7.2		135	3.5					
Average Water content	7.43		8.19					4.50	297	7.7		144	3.7					
Dry density	2.06		2.06					5.00	319	8.3	**41**	153	4.0	**20**				
AFTER SOAKING								5.50	337	8.8		162	4.2					
Wet sample + Mould (g)			12231					6.00	356	9.3		170	4.4					
Mass of mould			7,532					6.50	375	9.7		177	4.6					
Mass of wet sample	0		4699					7.00	392	10.2		184	4.8					
Bulk density (g/cc)	0.00		2.25					7.50	409	10.6		191	5.0					
TRIMMINGS AFTER SOAKING								8.00	424	11.0		197	5.1					
	1	2	1	2	1	2		SWELL DATA										
Container No.			A3	A21					Date	Time	Gaug	Date	Time	Gaug		Date	Time	Gaug
Wet sample + container (g)			90.92	75.73										0				
Dry sample + container (g)			84.01	69.63										8				
Mass of container			15.49	14.15										11.5				
Mass of water			6.91	6.10										15				
Mass of dry sample			68.52	55.48										18.5				
Water content			10.08	10.99						ΔT	Δh		ΔT	Δh			ΔT	Δh
Average Water content			10.54								0			8				0
Dry density			2.04								0			3.5				0
											0			3.5				0
											0			3.5				0

Sample T1

Description: 8% Bitumen Emulsion

SAMPLE PREPARATION:SERIES A SAMPLE2																				
Mould No.	N1		A2																	
No. of blows per layer	55		55		10															
Wet sample + Mould (g)	12,068		11,976																	
Mass of Mould	7,422		7,347																	
Mass of wet sample	4,646		4,629																	
Volume of mould	2088		2088																	
Bulk density (g/cc)	2.226		2.217																	
WATER CONTENT OF TRIMMINGS																				
	1	2	1	2	1	2														
Container No.	A5	E6	A42	A12																
Wet sample + container (g)	76.75	74.90	90.84	87.62																
Dry sample + container (g)	70.91	71.20	85.55	83.20																
Mass of container	14.20	14.44	14.68	14.24																
Mass of water	5.84	3.70	5.29	4.42																
Mass of dry sample	56.7	56.8	70.9	68.96																
Water content	10.30	6.52	7.46	6.41																
Average Water content	8.41		6.94																	
Dry density	2.05		2.07																	
AFTER SOAKING																				
Wet sample + Mould (g)			12005																	
Mass of mould			7,347																	
Mass of wet sample	0		4658																	
Bulk density (g/cc)	0.00		2.23																	
TRIMMINGS AFTER SOAKING																				
	1	2	1	2	1	2														
Container No.			A2	A23																
Wet sample + container (g)			83.25	84.29																
Dry sample + container (g)			78.22	78.24																
Mass of container			14.38	15.36																
Mass of water																				
Mass of dry sample																				
Water content																				
Average Water content																				
Dry density																				

Penetration	Unsoaked			Soaked			
	Load			Load			
(mm)	(div)	(kN)	CBR	div	kN	CBR	
0.25	21	0.5		10	0.3		
0.50	36	0.9		18	0.5		
0.75	50	1.3		26	0.7		
1.00	63	1.6		34	0.9		
1.25	76	2.0		42	1.1		
1.50	89	2.3		50	1.3		
1.75	101	2.6		58	1.5		
2.00	114	3.0	**26**	65	1.7	**15**	
2.25	126	3.3		73	1.9		
2.50	137	3.6	**27**	80	2.1	**16**	
2.75	149	3.9		86	2.2		
3.00	160	4.2		92	2.4		
3.50	180	4.7		105	2.7		
4.00	200	5.2		118	3.1		
4.50	216	5.6		127	3.3		
5.00	235	6.1	**31**	136	3.5	**18**	
5.50	251	6.5		144	3.7		
6.00	266	6.9		153	4.0		
6.50	280	7.3		159	4.1		
7.00	294	7.6		164	4.3		
7.50	305	7.9		170	4.4		
8.00	315	8.2		176	4.6		

Proving Ring constant:k 0.026

SWELL DATA

	Date	Time	Gaug	Date	Time	Gaug	Date	Time	Gaug
						0			
						2			
						4.5			
						11			
						17			
		ΔT	Δh		ΔT	Δh		ΔT	Δh
			0			2			0
			0			2.5			0
			0			6.5			0
			0			6			0

KNUST

FALLING HEAD PERMEABILITY TEST

Sample T1

PROJECT : 0% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c_0 (cm)	adjusted initial water level in standpipe, $h_0=b+c_0$ (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c_1 (cm)	adjusted final water level in standpipe, $h_1=b+c_1$ (cm)	h_0/h_1	2.3 *log(h_0/h_1)	K
1	11.67	109.5	78	187.5	84.73	65	174.5	1.0745	0.0718	8.999E-05
2	11.67	109.5	88	197.5	100.06	73	182.5	1.0822	0.0789	8.377E-05
3	11.67	109.5	69	178.5	113.3	55	164.5	1.0851	0.0816	7.650E-05
4	11.67	109.5	52	161.5	105.24	41	150.5	1.0731	0.0705	7.113E-05
										8.035E-05

Diameter of sample	10.481
Diameter of pipe	1
Cross sectional area of sample	86.288
Cross sectional area of pipe	0.786

Sample T1

PROJECT : 1% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c_0 (cm)	adjusted initial water level in standpipe, $h_0=b+c_0$ (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c_1 (cm)	adjusted final water level in standpipe, $h_1=b+c_1$ (cm)	h_0/h_1	2.3 *log(h0/h1)	K
1	11.67	109.5	85	194.5	72.15	62	171.5	1.1341	0.1257	1.96E-04
2	11.67	109.5	76	185.5	70.7	56	165.5	1.1208	0.1140	1.82E-04
3	11.67	109.5	85	194.5	76.98	62	171.5	1.1341	0.1257	1.84E-04
4	11.67	109.5	75	184.5	77.08	55	164.5	1.1216	0.1146	1.67E-04
5	11.67	109.5	85	194.5	76.59	62	171.5	1.1341	0.1257	1.85E-04
6	11.67	109.5	75	184.5	72.48	55	164.5	1.1216	0.1146	1.78E-04
										1.87E-04

Diameter of sample	10.18
Diameter of pipe	1
Cross sectional area of sample	81.403
Cross sectional area of pipe	0.786

PROJECT : 2% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c_0 (cm)	adjusted initial water level in standpipe, $h_0=b+c_0$ (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c_1 (cm)	adjusted final water level in standpipe, $h_1=b+c_1$ (cm)	h_0/h_1	2.3 *log(h_0/h_1)	K
1	11.67	109.5	85	194.5	124.51	60	169.5	1.1475	0.1374	1.24E-04
2	11.67	109.5	85	194.5	137.17	60	169.5	1.1475	0.1374	1.13E-04
3	11.67	109.5	85	194.5	147.79	60	169.5	1.1475	0.1374	1.05E-04
4	11.67	109.5	85	194.5	261.4	65	174.5	1.1146	0.1084	4.67E-05
5	11.67	109.5	85	194.5	259.06	65	174.5	1.1146	0.1084	4.71E-05
6	11.67	109.5	85	194.5	273.31	65	174.5	1.1146	0.1084	4.47E-05
										8.00E-05

Diameter of sample	10.18
Diameter of pipe	1
Cross sectional area of sample	81.403
Cross sectional area of pipe	0.786

PROJECT : 3% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c_0 (cm)	adjusted initial water level in standpipe, $h_0=b+c_0$ (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c_1 (cm)	adjusted final water level in standpipe, $h_1=b+c_1$ (cm)	h_0/h_1	2.3 *log(h_0/h_1)	K
1	11.67	109.5	85	194.5	208.86	60	169.5	1.1475	0.1374	7.50E-05
2	11.67	109.5	85	194.5	196.18	60	169.5	1.1475	0.1374	7.98E-05
3	11.67	109.5	85	194.5	226.04	60	169.5	1.1475	0.1374	6.93E-05
4	11.67	109.5	85	194.5	239.6	60	169.5	1.1475	0.1374	6.54E-05
5	11.67	109.5	85	194.5	338.4	60	169.5	1.1475	0.1374	4.63E-05
6	11.67	109.5	85	194.5	324.13	60	169.5	1.1475	0.1374	4.83E-05
										6.40E-05

Diameter of sample	10.12
Diameter of pipe	1
Cross sectional area of sample	80.447
Cross sectional area of pipe	0.786

PROJECT : 4% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c_0 (cm)	adjusted initial water level in standpipe, $h_0=b+c_0$ (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c_1 (cm)	adjusted final water level in standpipe, $h_1=b+c_1$ (cm)	h_0/h_1	2.3 *log(h_0/h_1)	K
1	11.67	109.5	85	194.5	39	60	169.5	1.1475	0.1374	4.02E-04
2	11.67	109.5	85	194.5	38.57	60	169.5	1.1475	0.1374	4.06E-04
3	11.67	109.5	85	194.5	38.5	60	169.5	1.1475	0.1374	4.07E-04
4	11.67	109.5	86	195.5	38.7	60	169.5	1.1534	0.1425	4.20E-04
5	11.67	109.5	85	194.5	44.45	60	169.5	1.1475	0.1374	3.52E-04
										3.97E-04

Diameter of sample	10.18
Diameter of pipe	1
Cross sectional area of sample	81.403
Cross sectional area of pipe	0.786

PROJECT : 6% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c_0 (cm)	adjusted initial water level in standpipe, $h_0=b+c_0$ (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c_1 (cm)	adjusted final water level in standpipe, $h_1=b+c_1$ (cm)	h_0/h_1	2.3 *log(h_0/h_1)	K
1	11.67	109.5	85	194.5	82.03	60	169.5	1.1475	0.1374	1.91E-04
2	11.67	109.5	85	194.5	83.87	60	169.5	1.1475	0.1374	1.87E-04
3	11.67	109.5	85	194.5	85.64	60	169.5	1.1475	0.1374	1.83E-04
4	11.67	109.5	85	194.5	86.78	60	169.5	1.1475	0.1374	1.80E-04
5	11.67	109.5	86	195.5	82.07	60	169.5	1.1534	0.1425	1.98E-04
6	11.67	109.5	85	194.5	81.5	60	169.5	1.1475	0.1374	1.92E-04
										1.88E-04

Diameter of sample	10.18
Diameter of pipe	1
Cross sectional area of sample	81.403
Cross sectional area of pipe	0.786

PROJECT : 8% BITUMEN CONTENT

Trial No.	length of soil sample, l (cm)	adjustment height, b (cm)	Initial reading of water level in stand pipe, c_0 (cm)	adjusted initial water level in standpipe, $h_0=b+c_0$ (cm)	Elapsed time, t (sec)	Final water level reading in standpipe, c_1 (cm)	adjusted final water level in standpipe, $h_1=b+c_1$ (cm)	h_0/h_1	2.3 *log(h_0/h_1)	K
1	11.67	109.5	85	194.5	71.37	60	169.5	1.1475	0.1374	2.19E-04
2	11.67	109.5	85	194.5	69.33	60	169.5	1.1475	0.1374	2.26E-04
3	11.67	109.5	85	194.5	70.11	60	169.5	1.1475	0.1374	2.23E-04
4	11.67	109.5	85	194.5	68.68	60	169.5	1.1475	0.1374	2.28E-04
										2.26E-04

Diameter of sample	10.18
Diameter of pipe	1
Cross sectional area of sample	81.403
Cross sectional area of pipe	0.786

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