# UNIVERSITY OF NAIROBI

## IMPROVEMENT OF SUBGRADE LAYERS USING RECLAIMED ASPHALT PAVEMENT (RAP)

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A PROJECT SUBMITTED AS A PARTIAL FULFILLMENT

FOR THE REQUIREMENT FOR THE AWARD OF DEGREE

OF

**BACHELOR OF SCIENCE IN CIVIL ENGINEERING**

**2014**

## Abstract

Soil stabilization is a process of treating a soil in such a manner as to maintain or improve the performance of the soil as a construction material.The changes in the soil properties are brought about either by incorporation of additives or by mechanical blending of soil types.

Milled reclaimed asphalt pavement (RAP) has been used in bituminous recycling.RAP is mixed with fresh bitumen, rejuvenators and new aggragates in suitable proportions.Addition of RAP to soil indicated a shift of the grain size distribution curve and acted as a mechanical stabilizer.

There has been the need for the construction industry to embrace sustainable construction.The use of RAP for improvement of soil is a step in that direction as it will reduce the cost of construction,make use of locally available material and preserve the environment.

Laboratory tests such as CBR,Atterberg Limits, Proctor compaction test and grading analysis were carried out on RAP and gravel mixture to give an assessment of its performance.It was determined that with an increase in RAP there was a significant increase in the soil bearing capacity.The 50% RAP and 50% gravel ensured a better performance and was more realistic.

## Dedication

This project is dedicated to my family members,my mum,brother and uncle Odindo who have sacrificed so much to ensure that I have reached this far,may the almighty God bless and reward them abundantly.

## Acknowledgements

I would like to acknowledge my supervisor Dr. Simpson Osano,for ensuring that I was on the right track and for enlightening me on various  issues with regard to the project.

I would also like to acknowledge the help of laboratory technicians Mathew and Martin for their support.I want to thank the entire civil engineering fraternity as well.

To God  be the glory.

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## Glossary of Acronyms

AASHTO: American Association of State Highway and Transportation Officials

RAP: Reclaimed Asphalt Pavement

FDR: Full Depth Reclamation

HMA: Hot mix asphalt

OMC: Optimum moisture content

MDD: Maximum dry density

ASTM: American Standard and Testing of Materials

GCT: Gyratory compaction test

PCT: Proctor compaction test

MWD: Maximum wet density

# CHAPTER ONE

# 1. INTRODUCTION

## 1.1 BACKGROUND OF THE STUDY

Soil stabilization refers to the process of changing soil properties to improve strength and durability. There are many techniques for soil stabilization, including compaction, dewatering and by adding material to the soil. Mechanical stabilization improves soil properties by mixing other soil materials with the target soil to change the gradation and therefore change the engineering properties. Chemical stabilization used the addition of cementitious or pozzolanic materials to improve the soil properties. Chemical stabilization has traditionally relied on Portland cement and lime for chemical stabilization. Whereas most construction materials are specified and manufactured to a given purpose, soils are simply there,to be either used or avoided depending on the good or bad qualities they may possess. It is this qualities that a geotechnical engineer having a sufficient understanding of geology and soil science should reliably identify,test and evaluate the relevant soil properties and property variations at a site.It then becomes commonplace where the soil characteristics are manipulated depending on the design that one is working on to eventually meet their specifications.

There have been a number of materials that have been used to stabilize soil for various soil constructions such as earth embankments,levees,earth dams and subgrades for foundations or pavements.The bituminous pavement rehabilitation alternatives are mainly overlying,recycling and reconstruction.In recycling process the material from deteriorated pavement,known as reclaimed asphalt pavement(RAP),is partially or fully reused in fresh construction.In advanced countries bituminous material is the most recycled material in the construction industry.RAP is a deteriorated bituminous mix that contains aged bitumen and aggregates.Hence its performance is poorer when compared to fresh mix.The purpose of bituminous recycling is to regain the property of the RAP,such that it tends to perform as good as the fresh mix.Thus, the process of bituminous recycling involves mixing of the RAP,fresh bitumen,rejuvenators and new aggregates in suitable proportions.(Aravind K. and Animesh Das,Department of civil engineering IIT Kanpur)

A case study on fly ash a chemical stabilizer and an existing pavement was milled and mixed into the subgrade to increase the aggregate content of the soil.The conclusions of the study as a result of comprehensive testing was that;

- Addition of fly ash to soil RAP mixtures shows stiffness gain in terms of DCP(dynamic cone penetrometer) penetration resistance of about minus 30mm/blow.DCP is highly correlated to the California Bearing Ratio.
- Addition of RAP to soil shifts the grain size distribution curve and acts as a mechanical stabilizer
- The process of recycling existing asphalt into subgrade soils and stabilizing the mixture with fly ash was effective at that site.(Tyson.D Rupnow,IOWA STATE UNIVERSITY)

## 1.2 PROBLEM STATEMENT

Stability of soils overtime has experienced a changing phase as more materials are used to establish to what degree it can be manipulated so as to determine the required strength design.Therefore with research being undertaken on materials for use as stabilizers it is important to note that other factors such as the efficieny,cost etc. ought to be considered for use of that material as compared to those that have been used before.In cases of road rehabilitation,during excavations rather than disposing off of the asphalt pavement layer as waste material it would be more economical to use it as a soil stabilizer as it:

- Conserves energy-
- Preserves the environment-There is no disposal as the waste is recycled.
- Reduces cost of construction-When compared to other treatment alternatives that have to be acquired at a cost,it is cheaper as it is available at no cost.
- It preserves existing pavement geometrics-After excavation the original alignment is maintained and is often used for the new road.

## 1.3 OBJECTIVE OF THE STUDY

**Main objectives**

To establish that reclaimed asphalt pavement can be used to improve a subgrade layer.

**Specific objectives**

- To determine the proportions of RAP required to increase the bearing capacity of subgrade material.
- To determine its economic viability ie whether its cost effective as compared to other treatment methods.
- To determine the CBR value,OMC and MDD values,Plasticity Index,shrinkage limit and to establish how addition of RAP affects these parameters.
- To determine whether its use has any impact on the environment.
- RAP has predominantly been re-used in hot mix asphalt,however it can also be used in subgrade for improvement.

## 1.4 RESEARCH HYPOTHESIS

- There is a positive relationship between the use of RAP as a recycled material and the effects on cost of construction.
- There is a positive relationship between the use of RAP as a recycled material and its preservation of the environment.

## 1.5 SCOPE AND LIMITATIONS OF THE STUDY

This study will be confined to the test for bearing capacity,plasticity index,shrinkage limit,particle size distribution, and the environmental conservation.

The limited time frame of the research would not allow for assessment of the durability of the roads and comprehensive cost analysis.This was because it would take a long time to come up with conclusive reports on performance and the expected life of the resulting road pavement. The benefit cost analysis could not be undertaken as comparison with other alternatives would need longer period for evaluation.

# CHAPTER TWO

## 2. LITERATURE REVIEW

Soil stabilization is the permanent physical and chemical alteration of soils to enhance their physical properties.This is usually done to improve strength and durability or to prevent erosion and dust generation.It increases the shear strength of soil and/or control the shrink-swell properties of a soil, thus improving the load bearing capacity of a sub-grade to support pavements and foundations.Regardless of the purpose for stabilization,the desired result is the creation of a soil material or soil system that will remain in place under the design use conditions for the design life of a project.Stabilization can be used to treat a wide range of sub-grade materials from expansive clays to granular materials.Benefits of the stabilization process can include:

- Higher resistance (R) values
- Reduction in plasticity
- Lower permeability
- Reduction of pavement thickness
- Elimination of excavation, material hauling and handling, and base importation
- Aids compaction
- Provides the “all-weather” access onto and within project sites.

### 2.1 Stabilization Methods

There are many techniques for soil stabilization,including compaction,dewatering and by adding material to the soil.The most widely used techniques/procedures are mechanical and chemical stabilization methods.

#### 2.1.1 Chemical Stabilization

Stabilization can be achieved with a variety of chemical additives such as lime,fly-ash,by-products such as lime-kiln dust(LKD) and cement kiln dust(CKD),addition of cementitious or pozzolanic materials to improve the soil properties.Chemical stabilization has traditionally relied on Portland cement and lime for chemical stabilization.Proper design and testing is an important component of any stabilization project.This allows for the establishment of design criteria as well as the determination of the proper chemical additive and admixture rate to be used to achieve the desired engineering properties. Chemical admixtures are often used to stabilize soils when mechanical methods of stabilization are inadequate and replacing an undesirable soil with a desirable is not possible or is too costly. When selecting a stabilizer additive, the factors that must be considered are the;

- Type of soil to be stabilized
- Purpose for which the stabilized layer will be used.
- Type of soil quality improvement desired
- Required strength and durability of the stabilized layer
- Cost and environmental conditions

**CEMENT**

Cement can be used as an effective for a wide range of materials.In general however the soil should have a PI less than 30.Portland cement can be used either to modify and improve the quality of the soil or to transform the soil into a cemented mass,which significantly increases its strength and durability.The amount of cement additive depends on whether the soil is to be modified or stabilized.The only limitation to the amount of cement to be used to stabilize or modify a soil pertains to the treatment of the base courses to b used in flexible pavement systems. If the objective of modification is to improve the gradation of granular soil through the addition of fines, the analysis should be conducted on samples at various treatment levels to determine the minimum acceptable cement content. To determine the cement content to reduce the swell potential of fine grained plastics soils, mold several samples at various cement contents and soak the specimen along with untreated specimens for four days. The lowest cement content that eliminates the swell characterized to the minimum becomes the design cement content. The cement content determined to accomplish soil modification should be checked to see if it provides an unconfined compressive strength great enough to qualify for a reduced thickness design according to criteria established for soil stabilization.(Soil stabilization for roads and airfields, FM 5-410)

**LIME**

Experience has shown that lime reacts with medium-moderately fine ,and fine-grained soils to produce decreased plasticity, increased workability and strength and reduced swell. Lime gains strength slowly and requires about 14 days in hot weather and 28 days in cool weather to gain significant strength. Unsurfaced lime-stabilized soils abrade rapidly under traffic,so bituminous surface treatment is recommended to prevent surface deterioration.

Lime can be used either to modify some of the physical properties and thereby improve the quality of a soil or to transform the soil into a stabilized mass,which increases its strength and durability.The amount of lime additive depends on whether the soil is to be remodified or stabilized.The lime to be used maybe either hydrated or or quicklime, although most stabilization is done using hydrated lime.The reason is that quicklime is highly caustic and dangerous to use.The reaction that takes place when lime is introduced to a soil generally causes a significant change in the plasticity of the soil,so the changes in the PL and the LL also become indicators of the desired lime content.(soil stabilization for roads and airfields, FM 5-410)

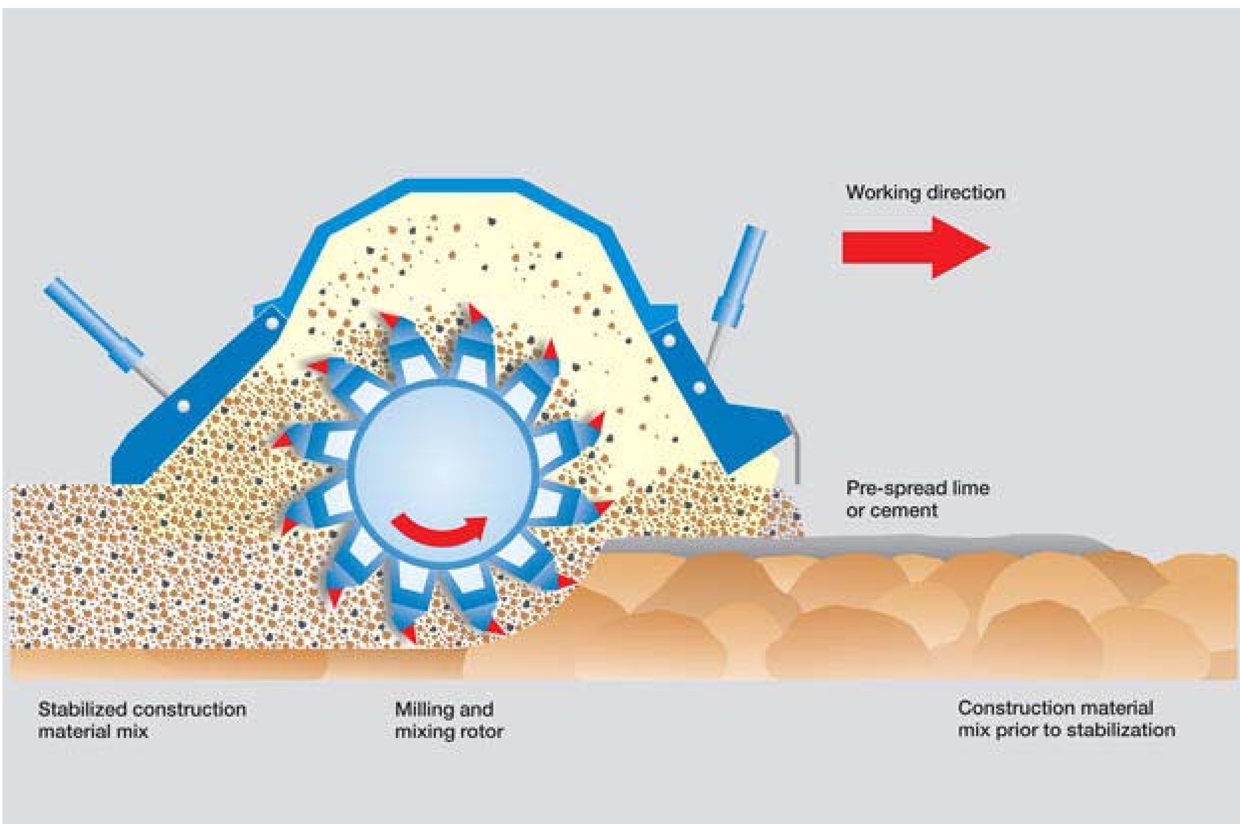



**Figure 1:stabilized construction material mix(www.bodenstab.com)**

**FLY ASH**

Fly ash is a pozzolanic material that consists mainly of silicon and aluminium compounds that when mixed with lime and water, forms a hardened cementitious mass capable of obtaining high compression strengths.Fly ash is a by-product of coal fired electric power generation facilities.The liming quality of fly ash is highly dependent on the type of coal used in power generation.

**BITUMINOUS MATERIALS**

Types of bituminous-stabilized soils are **Soil bitumen**:A cohesive soil system made water-resistant by admixture.

**Sand bitumen**: a system in which sand is cemented together by bituminous material.

**Oiled earth**: An earth road system made resistant to water absorption and abrasion by means of a sprayed application of slow-or medium-curing liquid asphalt. (soil stabilization of roads and airfields, FM 5-410 Chapter 9)

**Bitumen-water proofed**: mechanically stabilized soil.A system in which two or more soil materials are blended to produce a good gradation of particles from coarse to fine. Comparatively small amounts of bitumen are needed, and the soil is compacted.

**Bitumen-lime blend.** A system in which small percentages of lime are blended with fine-grained soils to facilitate the penetration and mixing of bitumens into the soil.

### 2.1.2 Mechanical stabilization

Mechanical stabilization is brought about by compaction and interlocking of soil-aggregate particles.The grading of the soil-aggregate mixture must be such that a dense mass is produced when it is compacted.Mechanical stabilization can be accomplished by uniformly mixing the material and then compacting the mixture.As an alternative,additional fines or aggregates maybe blended before compaction to form a uniform,well graded,dense soil-aggregate mixture after compaction.The choice of methods should be based on the gradation of the material.(Soil stabilization for roads and airfields, FM 5-410 chapter 9)

The three essentials for obtaining a properly stabilized soil mixture are-:

I. Proper gradation
II. A satisfactory binder soil
III. Proper control of the mixture content

To obtain uniform bearing capacity,uniform mixture and blending of all materials is essential.The mixture will normally be compacted at or near OMC to obtain satisfactory densities.Practically all materials of a granular nature that do not soften when wet or pulverize under traffic can be used; however the best aggregates are those that are made of hard, durable, angular particles.The gradation of this portion of the mixture is important, as the most suitable aggregates generally are well-graded from coarse to fine.

Well-graded mixtures are preferred because of their greater stability when compacted more easily.They also have greater increases in stability with corresponding increases in density.

Satisfactory materials for this use include-

I. Crushed stone
II. Crushed and uncrushed gravel
III. Sand
IV. Crushed slag
V. e.t.c

Many other locally available materials have been successfully used. When local materials are used, proper gradation requirements cannot always be met.

Note that if conditions are encountered in which the gradation obtained by blending local materials is either finer or coarser than the specified gradation, the size requirements of the finer fractions should be satisfied and the gradation of the coarser sizes should be neglected.(Soil stabilization of roads and airfields, FM 5-410 chapter 9)

Mechanical soil stabilization maybe used in preparing soils to function as-

a) Subgrades
b) Bases
c) Surfaces

Several commonly encountered situations maybe visualized to indicate the usefulness of this method.One of these situations occurs when the surface soil is a loose sand that is incapable of providing support for wheeled vehicles, particularly in dry weather. If suitable binder soil is available in the area, it maybe brought in and mixed in the proper proportions with the existing sand to provide an expedient all- weather surface for light traffic. A common method of mechanically stabilizing an existing clay soil is to add gravel, sand or other granular materials.

The objectives here are to-

i. Increase the drainability of the soil
ii. Increase stability
iii. Reduce volume changes
iv. Control the undesirable effects associated with clays

The objective of mechanical stabilization is to blend available soils so that, when properly compacted, they give the desired stability. (Soil stabilization of roads and airfields, FM 5-410 chapter 9)

## 2.2 Reclaimed asphalt pavement (RAP) stabilization

RAP refers to the removal and reuse of hot mix asphalt (HMA) layer of an existing roadway; full depth reclamation (FDR) refers to the removal and reuse of HMA and the entire base course layer and part of the underlying subgrade implying a mixture of pavement layer materials. Unless specified these three distinct recycled asphalt materials will be collectively referred to as RAP.

RAP is typically produced through milling operations which involves the grinding and collection of existing HMA,FDR and RPM are typically excavated using full-size reclaimers or portable asphalt recycling machines.RAP can be stockpiled, but is most frequently reused immediately after processing at the site.Typical aggregate gradations of RAP are achieved through pulverization of the material, which is typically performed with a rubber tired grinder.


**Figure 2:A milling machine grinding and collecting the milled RAP at Kericho-Nyamasaria road (SBI)**

## 2.3 Design Considerations

### 2.3.1 Material properties

The gradation of RAP can be compared to that of a crushed natural aggregate, although with a higher content of fines.The high fine content is the result of degradation of the material during milling and crushing operations.In RPm the inclusion of subgrade materials in the recycled material also contributes to higher instance of fines.Finer gradation of RAP are produced through milling operations compared to crushing operations.The table below provides a breakdown of typical physical and mechanical properties of RAP.

Table 1: Typical Physical Properties of RAP [7]

| Physical Properties | |
|---|---|
| Unit Weight | 1940 - 2300 kg/m$^3$ (120 - 140 pcf) |
| Moisture Content | Normal: Up to 5%<br>Maximum: 7 - 8% |
| Asphalt Content | Normal: 4.5 – 6% |
| Asphalt Penetration | Normal: 10 – 80% at 25°C (77°F) |
| Absolute Viscosity or Recovered Asphalt Cement | Normal: 4000 – 25000 poises at 60°C (140°F) |
| Mechanical Properties | |
| Compacted Unit Weight | 1600 – 2000 kg/m$^3$ (100 – 125 pcf) |
| California Bearing Ratio (CBR) | 100% RAP: 20 – 25%<br>40% RAP and 60% Natural Aggregate: 150% or Higher |

**Figure 3:Physical properties of RAP (Literature search and report on RAP and RCA)**

### 2.3.2 Method for Specification

The two most commonly used specifications when considering a recycled material for use as an unbound base course are the gradation and the moisture-density relationship of the material.The gradation of a material can provide an indication of what permeability,frost susceptibility and shear strength of the material might be and is determined through the use of material screening tests.Screening tests are typically conducted through sieve analysis according to ASTM standards C117 and C136 and AASHTO standards T-27 and T-11.

Classification of soils is performed using the Unified soil and AASHTO methods according to ASTM D2487 and AASHTO M 145,respectively.

The determination of moisture-density relationships can help define the ideal density conditions that a material can achieve through compaction.Moisture-density relationships are established through compaction tests conducted according to the following standards:AASHTO T99 method C,AASHTO T-180 or ASTM D 1557.

Depending on the compaction effort to be used in the field,compaction tests can be performed in standard or modified variations.The information is used to determine the optimum moisture content (OMC) and the maximum dry density (MDD) of a material.Through testing of specimens prepared based on this data, material properties such as strength, stiffness and moisture susceptibility can be determined.Other aggregate classification methods involve the determination of the specific gravity, absorption and Atterberg limits of the soils.

The specific gravity and absorption characteristics of a given recycled aggregate are determined using ASTM D854, and Atterberg limits of recycled aggregates using ASTM D4318,AASHTO T89 and T90.(Gregory *et al*,2009)

### 2.3.4 Moisture-Density characteristics

For various blends of RAP with pure aggregate,some trends were noted regarding the effect of RAP content on MDD and OMC of a material.

An increase in RAP content led to a decrease in MDD and OMC values.The aggregates particles in the RAP were partially encased in asphalt, which decreased the specific gravity.It was further assumed that the partial asphalt coating reduced the aggregate water absorption potential and inter-particle frictions leading to a reduction in the required water to achieve MDD.(Guthrie *et al* 2007)

Table 6: Maximum Dry Density and Optimum Moisture Content of RAP and RPM

| Material | Proctor Effort | Maximum Dry Density, kg/m3 | Optimum Moisture Content, % |
|---|---|---|---|
| Bejarano: Pulverized [8] | Caltrans CTM 216 | 2332 | 5.5 |
| Bennert RAP[3] | Standard | 1872 | 5 |
| Guthrie R1[6] | Modified | 2083 | 5.6 |
| Guthrie R2[6] | Modified | 1842 | 5.8 |
| Saeed RAP-LS-MS[9] | Standard | 1988 | 6.3 |
| Saeed RAP-GR-CO[9] | Standard | 2015 | 10.3 |
| Saeed RAP-GV-LA[9] | Standard | 1978 | 5.4 |
| Carmargo RPM[11] | Standard | 2161 | 7.5 |
| Wen et al[13] | Modified | 2162 | 6.5 |

**Figure 4:Maximum dry densities and optimum moisture content of RAP and RPM(Literature search and report on RAP and RCA)**

For various blends of RAP with pure aggregate, some trends were noted regarding the effect of RAP content on MDD and OMC of a material. An increase in RAP content led to a decrease in MDD and OMC values.The aggregates particles in the RAP were partially encased in asphalt, which decreased the specific gravity.It was further assumed that the partial asphalt coating reduced the aggregate water absorption potential and inter-particle friction,leading to a reduction in the require water to achieve MDD.(Guthrie *et al***,** 2007)

With the use of a gyratory compaction test (GCT) instead of a proctor compaction test (PCT) to prepare RAP specimens.Comparisons with field density measurements indicated that MDD and OMC calculations determined from GCT methods were a better correlation than those by PCT testing.When compared to PCT results, GCT results showed a large change in MDD values and a small change in OMC values.Kim noted the effect of RAP content on the MDD and OMC of aggregates/RAP blends.As the RAP content of the material increased, the OMC of the material decreased for both the GCT and PCT prepared specimens.As with the study by Guthrie, the increase in asphalt content most likely reduced the absorption of the material, leading to the decrease in OMC.As the RAP content of the material increased, the MDD decreased for the PCT-prepared specimens and remained the same for GCT-prepared specimens.(Kim *et al*, 2007)

Investigations on two RPM at the University of Wisconsin-Madison indicated an OMC of 6.5 to 7.5% and a MDD of 2162 kg/m$^3$

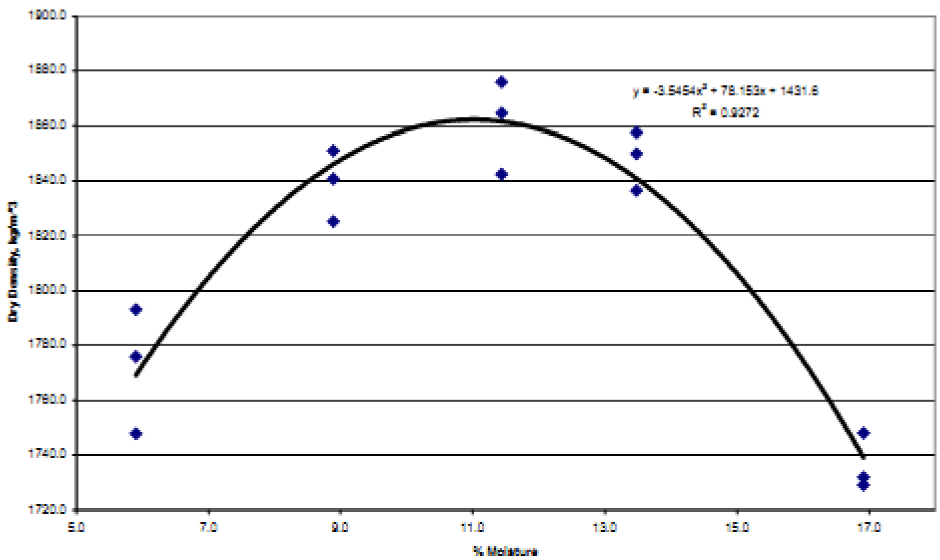



**Figure 5: Proctor curve for 50% RAP, 50% subgrade soil and 10% Ames municipal Fly ash mixture by Dry weight(www.rupnow.com)**

### 2.3.5 Strength and Stiffness characteristics

The two most common tests used to determine strength parameters for unbound recycled materials are the static triaxial test and the California Bearing Ratio test.The static triaxial test is typically performed in accordance with ASTM D2850 and AASHTO T 296.The California bearing ratio test is typically performed in accordance with ASTM D1883 or AASHTO T 193.

A static triaxial test was conducted on RAP and two different aggregate materials.Individual RAP and aggregate specimens were compacted at OMC and 95% and 100% of maximum wet density (MWD) according calTRANS specifications CTM 216. Static triaxial tests were conducted at confining pressures of 0,35,70 and 105 kPa.After comparing the shear strengths of the RAP and aggregate it was determined that the shear strength calculated for the RAP was comparable in magnitude to shear strengths calculated for the representative aggregate materials.This shear strength correlation was valid at both 95% and 100% MWD and each of the confining pressures.Bejarano also conducted stiffness tests for the three material according to SHRP test protocol P-46.Of the three tested materials the RAP had a higher resilient modulus than the two aggregate materials tested at 95% and 100% MWD.When the compaction level was increased from 95% to 100%  the resilient modulus of the RAP and one of the aggregate materials increased.This change in compaction level had no effect on the resilient modulus of the second aggregate material (Bejarano *et al*, 2003).

A study was made on the effect of RAP content on the resilient modulus of blended aggregate base course.An in-situ blend of FDR was taken during the reconstruction of an existing road along with pure samples of RAP and aggregate materials.The FDR and several blends of the pure RAP and aggregate base material were tested for material stiffness using the resilient modulus test in accordance with NCHRP 1-28A protocol.Blended mixtures of the pure materials were prepared at RAP to aggregate ratios (%/%) of 0/100, 25/75,50/50 and 75/25. The study found that for an increase in RAP content, the resilient modulus of the blended materials increased. The effects of  increased RAP content were more defined when blends were exposed to higher confining pressures, however specimens also experienced higher permanent deformation at higher confining pressures.Specimens tested at 65% optimum moisture content had higher resilient modulus values when compared to specimens prepared at 100% OMC.This trend was consistent for all confining pressures.At low confining pressures (20 kPa), specimens  RAP to aggregate ratios of 50% to 50% and specimens consisting of 100% aggregate had resilient modulus values that were approximately equivalent.As the confining pressures increased, the 50/50, 100% RAP and in-situ material tested at the corresponding site had similar resilient modulus values.**(**Kim *et al*, 2007)

A field site was constructed using RAP and limerock control section.It included surface water and leachate water collection systems in both the RAP and Limerock.The initial strength gains were evaluated over an 8-week period and the environmental performance was analyzed over 12 months.Construction with RAP was equivalent to or better than construction with Limerock.RAP’s strength-deformation behavior increased throughout the 8-week study period based on field califonia bearing ratio(CBR) data converted to Limerock Bearing Ratio(LBR),initial Stiffness Modulus(ISM) values from the Falling Weight Deflectometer(FWD),and stiffness values from both the Clogg Impact Hammer and the soil stiffness Gage (SSG).LBR,Clegg and  ISM data indicated that RAP experienced a 50% strength gain over 8 weeks while SSG results indicated that the strength gain was 15%.The Clegg,FWD and SSG testing also indicated that RAP stiffness was similar to Limerock.RAP-Soil mixes were evaluated by adding varying percentages of a poorly graded sand with clay,an A-2-6(SM-SP) soil dredged from the turkey creek area in palm Bay,Florida.The 80% RAP-20% soil mix produced the most desirable engineering behavior.(Winter,2006)

### 2.3.6 Moisture susceptibility characteristics

In the tube suction test, a specimen is oven dried for 72 hours before being allowed to soak in shallow water bath for 10 days.Over the course of the soaking period, unbound water within the material rises through the aggregate matrix and collects at the surface.The dielectric value at the surface of the material increases with an increase in the amount of unbound water permeating the specimen, and thereby provides an estimate of the materials susceptibility to moisture permeation.

Guthrie *et al* (2007) used the tube suction test to determine the effect of RAP content on the moisture susceptibility of RAP/aggregate blends.It was found that the moisture susceptibility of the material increased as RAP was added to the mixture.However, tests were only conducted with the addition of 25% and 50% RAP.Materials with RAP contents above 75% were classified as non-moisture-susceptible and were not tested.Overall, the dry density of the blended material decreased as RAP content increased.

## CHAPTER THREE

# 3. METHODOLOGY

## 3.1 Introduction

The undertaking of this project was to determine the practicability of using RAP as an improvement for a subgrade layer.The tests taken were sequential and follows the procedures of BS and AASHTO. The sample source for the RAP was from the ongoing rehabilitation of Kericho-Nyamasaria road,the lateritic gravel was sourced from Ruiru. The samples were collected and laboratory tests conducted on varying proportions/percentages of RAP only and a blend of RAP and gravel in varying percentages. The following laboratory tests were carried out.

## 3.2 Proctor compaction test (PCT)

Compaction test or moisture-density relationship.The test is carried out to determine the mass of the material that can be compacted in a unit volume.

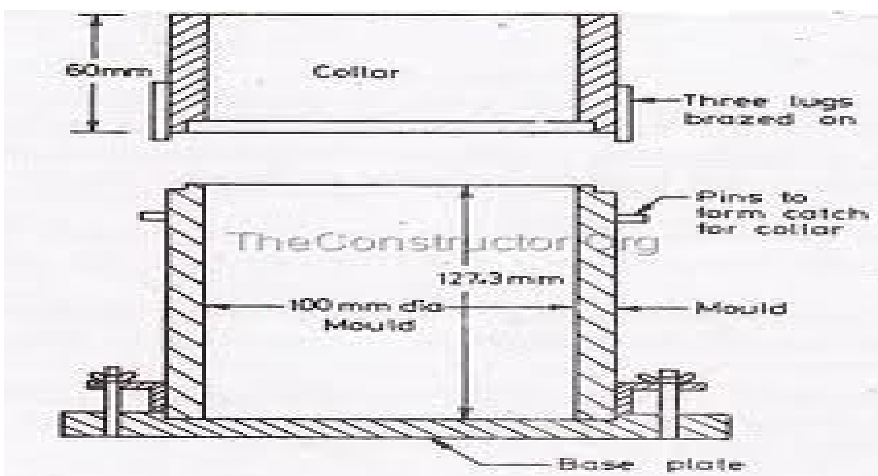



**Figure 6:Proctor Mould(www.construction.org)**

## 3.3 Grading/Particle size Distribution (PSD)

Also known as particle size analysis.The test is carried out to determine the proportion of the different size of particle present in the materials (e.g soil,aggregates e.t.c)

## 3.4 CBR

The abbreviations shorten the name **California Bearing Ratio.**This is the basic test used to measure the strength(bearing capacity of soil for pavement construction).It involves penetration of a moulded soil sample with a cylindrical plunger at a constant rate 1mm/min. The force corresponding to penetration of 2.5mm and 5.0mm are computed and then are compared to the standard force attained by the California materials(Reported as percentage).

**Figure 7:A CBR setup (www.mandava.ac.in)**

### 3.4.1 Types of CBR

#### *3.4.1.1 Static Compaction*

This compaction done using a jerk for formation materials to achieve optimum compaction (100%MDD)

#### *3.4.1.2 Dynamic compaction*

## 3.5 Atterberg Limits

The objective of the atterberg limits test is to obtain basic index information about the soil used to estimate strength and settlement characteristics.It is the primary form of classification for cohesive soils.Fine grained soil is tested to determine the liquid and plastic limits, which are moisture contents that define boundaries between material consistency states.These standardized tests produce comparable numbers used for soil identification,classification and correlations to strength.The liquid (LL) and plastic (PL) limits define the water content boundaries between non-plastic, plastic and viscous fluid states.The plasticity index (PI) defines the complete range of plastic state.

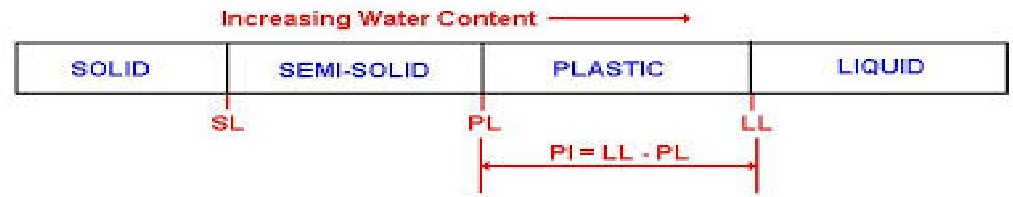



**Figure 8:Atterberg limits chart(www.uwplatt.edu)**

### Liquid Limit (LL)

The liquid limit defines the boundary between plastic and viscous fluid states.It is determined using a standard “liquid limit Device” which drops a shallow cupful of soil 1cm consistently.When a groove cut through the sample closes ½”,the number of drops is recorded and a moisture content sample processed.Repeating the procedure for a total of four drop-count ranges provides enough data to plot on a semi-log scale.From the plot, the moisture content at 25 drops defines the Liquid Limit.

**Figure 9:A cone penetrometer(www.marcofavaretti.net)**

## Plastic Limit (PL)

The plastic limit defines the boundary between non-plastic and plastic states.It is determined simply by rolling a thread of soil and adjusting the moisture content until it breaks at 1/8 inch diameter or 3mm.

**Figure 10: Plastic limit determination(www.denichsoiltest.com)**

## Linear shrinkage

This refers to the change in linear dimensions that has occurred in test specimens after they have been subjected to soaking heat for a period 24h and then cooled to room temperature.

**Figure 11:linear shrinkage mould (www.utest.com)**

## Plastic Index

This is the difference in moisture content of soils between the liquid and plastic limits expressed in percentage.

# CHAPTER FOUR

## 4. ANALYSIS AND DISCUSSION OF RESULTS

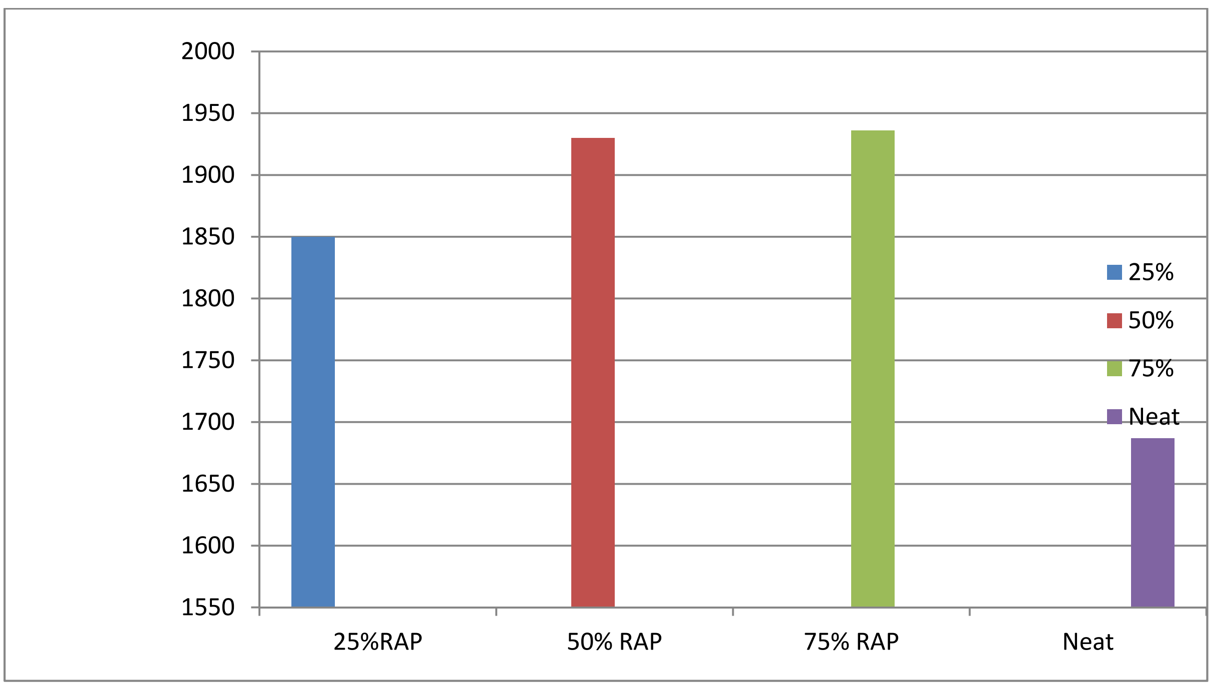
Tests were conducted using gravel as a neat sample then with different proportions of RAP, this was to establish the various geotechnical properties such as the

- Moisture and density characteristics
- Particle size distribution
- Plasticity index
- California bearing ratio
- Linear shrinkage

## 4.1 Moisture and density characteristics

This was established from the proctor compaction test.The neat sample produced an MDD of 1687kg/$m^3$ and an OMC of 16.69%.The proportions of 25% RAP gave an MDD of 1850kg/$m^3$ and an OMC of 15.5%, while that of 50% RAP gave an MDD of 1930kg/$m^3$ and an OMC of 10.4% and that of 75% RAP had an MDD of 1936kg/$m^3$ and 8.7% OMC.The values obtained for the MDD concur with those of studies that had been conducted earlier giving the range of MDD as between 1600-2000kg/$m^3$.

It can thus be deduced that with increase in RAP content there was an increase in maximum dry density and a decrease in optimum moisture content.A chart showing in summary these characteristics is given below.



## 4.2 Particle size distribution

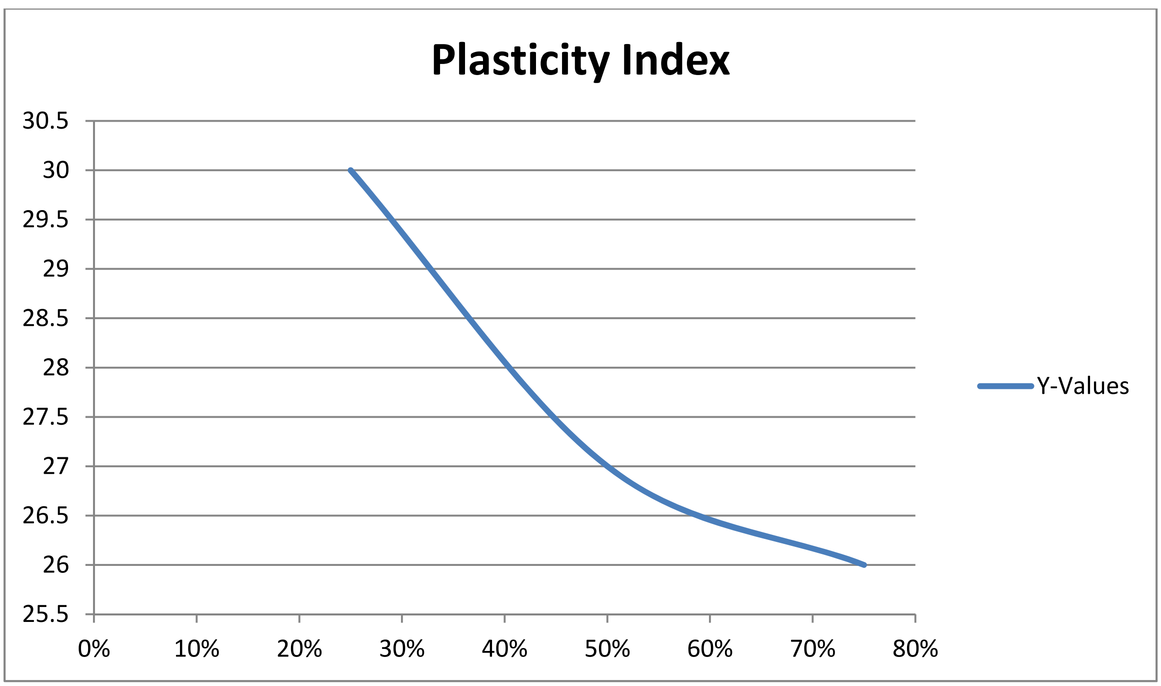
This was determined  by grading the samples using neat and the varying proportions of RAP.There was a considerable shift in the particle size from less fines to more coarse.When the different proportions of  RAP was added the more coarse the blend became.This was evident as it was noted that there was more fines and with the introduction of 25%RAP there was a notable decrease and this was the trend with an increase in RAP content in the blend.This supported the idea that mechanical stabilization increases the grading of the sample.

### 4.3 Plasticity index (PI)

In the determination of the plasticity index, a cone penetrometer was used to first determine the liquid limit and later on the plastic limit was also established.The difference between the plastic and liquid limit gives the plasticity index.

The plasticity index of the neat sample was ,that of the 25%,50%,75% was 30,27 and 26 respectively.It can be deduced that with the increase of RAP there was a decrease in plasticity index.

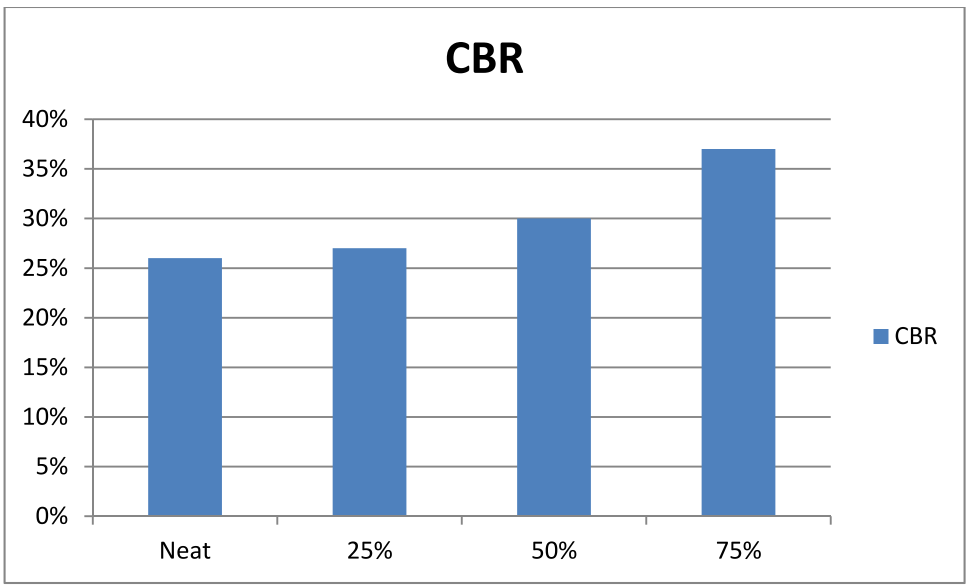
This indicates that when RAP was added there was an introduction of coarse size particles in the blend,hence the decrease in PI.A diagrammatic representation of the variation in PI is given below.



## 4.6 California Bearing Ratio

Analysis of CBR  showed that there was an increase in the bearing capacity with the blending of RAP with the gravel.This indicates that there's a closer packing of the particles when RAP is added to the gravel.

The CBR for neat was 26%,and that for RAP/Gravel for 25/75 was 27%, 50/50 was 30%, 75/25 was 37%.A chart on the variation of CBR is given below.



## 4.7 Environmental impact analysis

The extent to which the use of RAP does interfere with the environment is difficult to quantify,however research and studies have been undertaken to establish its environmental friendliness.

Reclaimed Asphalt pavement (RAP) does not leach toxic materials into the ground and can be used as a construction fill,according to a study conducted by University of Florida researchers.The study helps refute theories that RAP piles at asphalt plants pollutes groundwater and gives contractors more options for using the material.

An environmental evaluation was conducted and it indicated that RAP poses no environmental concern when used as a highway material.The concentrations of heavy metals were well below the EPA standards.Samples were taken over a 12-month period and subjected to four different environmental testing procedures.All four yielded the same conclusions,indicating that the testing program was valid.

It was determined that RAP posed no environmental threats and was reccomendable for use as a highway material.

# CHAPTER FIVE

# 5. CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

The main idea of this project was to establish the use of RAP for improvement of subgrade materials.In particular certain characteristics were determined through various tests conducted and the results obtained with respect to its moisture and density characteristics were that with an increase in RAP in the blend there was an increase in MDD with the subsequent decrease in OMC.

An increase in RAP in the blend led to the increase in CBR value,this was fundamental as the main aim was to determine if indeed RAP could be used for improvement,since  improvement is usually conducted to increase the bearing capacity of a soil.

There was a significant reduction in the plasticity index(PI), this was a good indication as a lower PI is more preferable.

The particle size distribution indicated that with an increase in RAP there was increase in coarse size of particles and this resulted in a better grading and increased strength and a reduced plasticity.

## 5.2 Recommendations

1. Owing to time constraint this project only used lateritic gravel for improvement, however other different types of soil would also be recommendable for improvement so as to know their behavior when improved with RAP.
2. Though there's little research or studies that has been done before on RAP,a lot more ought to go into studying its environmental impact to further solidify its use as a highway material.
3. The use of reclaimed asphalt pavement in road construction is a form of sustainable construction and it is more advisable to recycle it than disposing it for developing countries such as Kenya as this goes far to tell the scope of research that has been undertaken as well as the awareness of the construction community in sustainable construction.
4. The proportion of 50% RAP and 50% gravel would be more appropriate as it gave an acceptable performance in all the tests.

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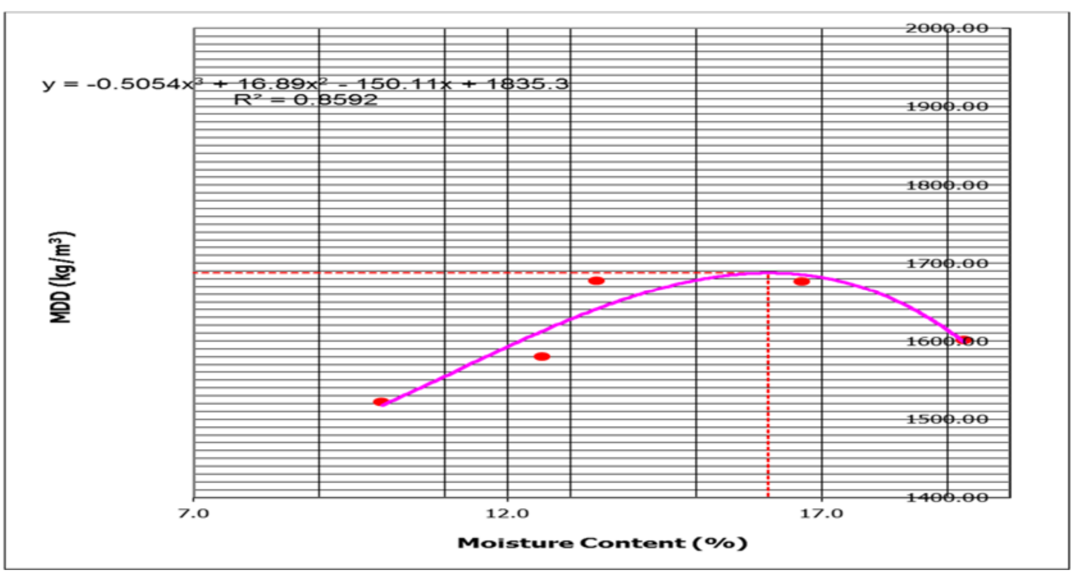
# APPENDICES

## APPENDIX A:PROCTOR COMPACTION TEST

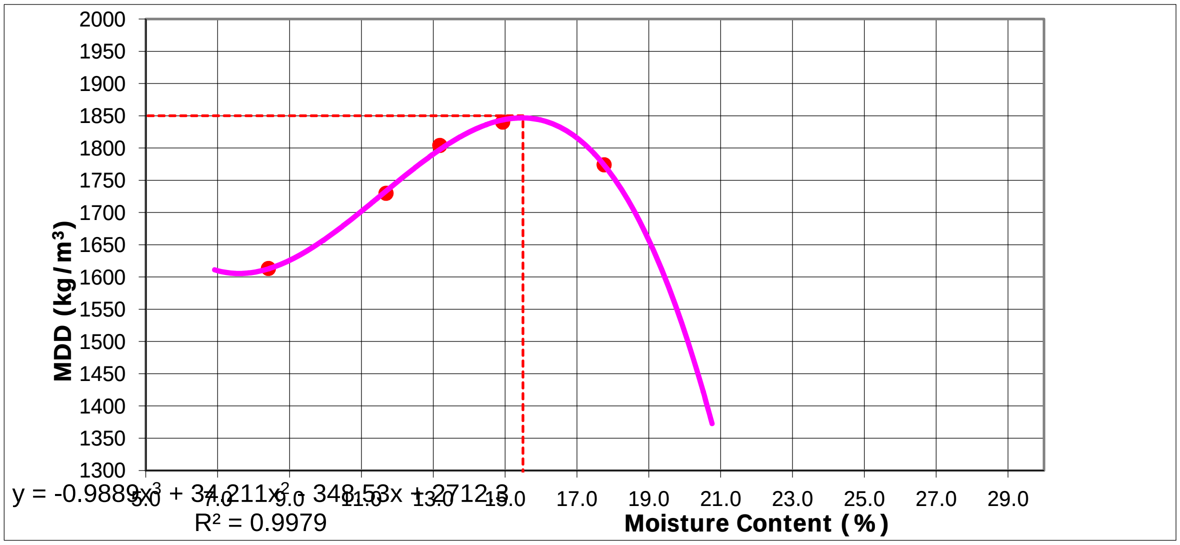
proctor compaction test - neat gravel

| | | | | | |
|---|---|---|---|---|---|
| Water added (ML) | 100 | 200 | 300 | 400 | 500 |
| Mass of mould + base | 4135 | 4135 | 4135 | 4135 | 4135 |
| Mass of mould + base+soil | 5735 | 5835 | 5954 | 6005 | 5960 |
| Mass of compacted soil (g) | 1600 | 1700 | 1819 | 1870 | 1825 |
| Volume of mould($m^3$) | 0.956 | 0.956 | 0.956 | 0.956 | 0.956 |
| Bulk density(kg/$m^3$) | 1673.64 | 1778.24 | 1902.72 | 1956.07 | 1908.99 |
| Moisture content (%) | 10.00 | 12.56 | 13.43 | 16.69 | 19.26 |
| Dry density( kg/$m^3$) | 1521.49 | 1579.79 | 1677.46 | 1680.32 | 1600.65 |



## Proctor compaction Test-25%RAP & 75% Gravel

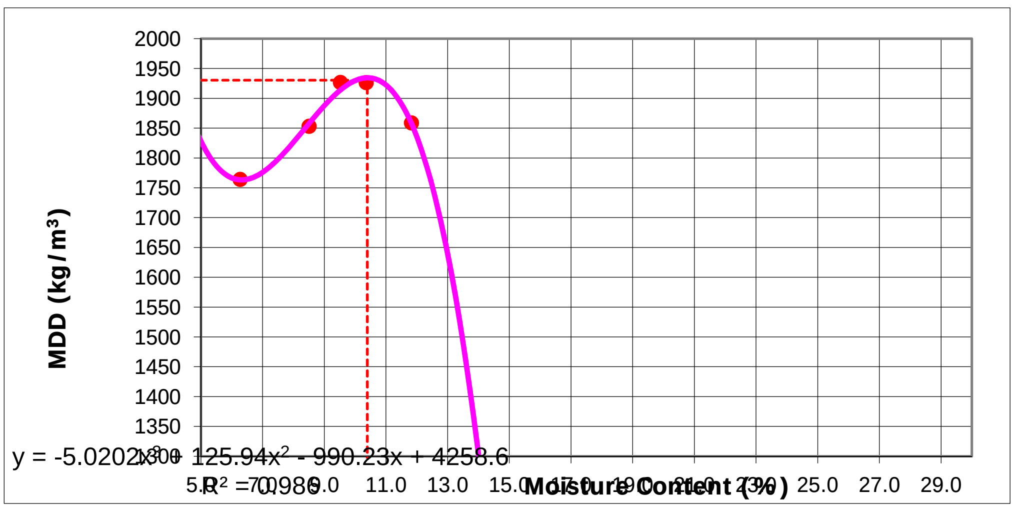
| **Wt of Mould (g)** | **4128** | | **Volume of Mould (l)** | **0.956** | | | |
|---|---|---|---|---|---|---|---|
| **Test No** | NMC | 1 | 2 | 3 | 4 | 5 | |
| **Wt of mould + wet material (g)** | | 5800 | 5975 | 6080 | 6150 | 6125 | |
| **Wt wet material (g)** | | 1672 | 1847 | 1952 | 2022 | 1997 | |
| **Wet density (kg/m$^3$)** | | 1749 | 1932 | 2042 | 2115 | 2089 | |
| **Moisture content** | | | | | | | |
| **Container No** | 62A | 13A | 68A | 92A | 62A | 108A | |
| **Wt of container + wet material (g)** | 140.00 | 198.80 | 144.75 | 175.09 | 174.46 | 219.90 | |
| **Wt of container (g)** | 14.80 | 26.20 | 15.30 | 18.10 | 14.70 | 15.70 | |
| **Wt of container + dry material (g)** | 134.40 | 185.40 | 131.20 | 156.80 | 153.70 | 189.10 | |
| **Wt dry material (g)** | 119.60 | 159.20 | 115.90 | 138.70 | 139.00 | 173.40 | |
| **Wt of moisture (g)** | 5.60 | 13.40 | 13.55 | 18.29 | 20.76 | 30.80 | |
| **Moisture content (%)** | 4.68 | 8.42 | 11.69 | 13.19 | 14.94 | 17.76 | |
| **Dry density (kg/m$^3$)** | | 1613 | 1730 | 1804 | 1840 | 1774 | |




| | |
|---|---|
| **Optimum Moisture Content (%)** | **15.5** |
| **Maximum Dry Density (kg/m$^3$)** | **1850** |

## Proctor compaction Test-50%RAP&50% Gravel

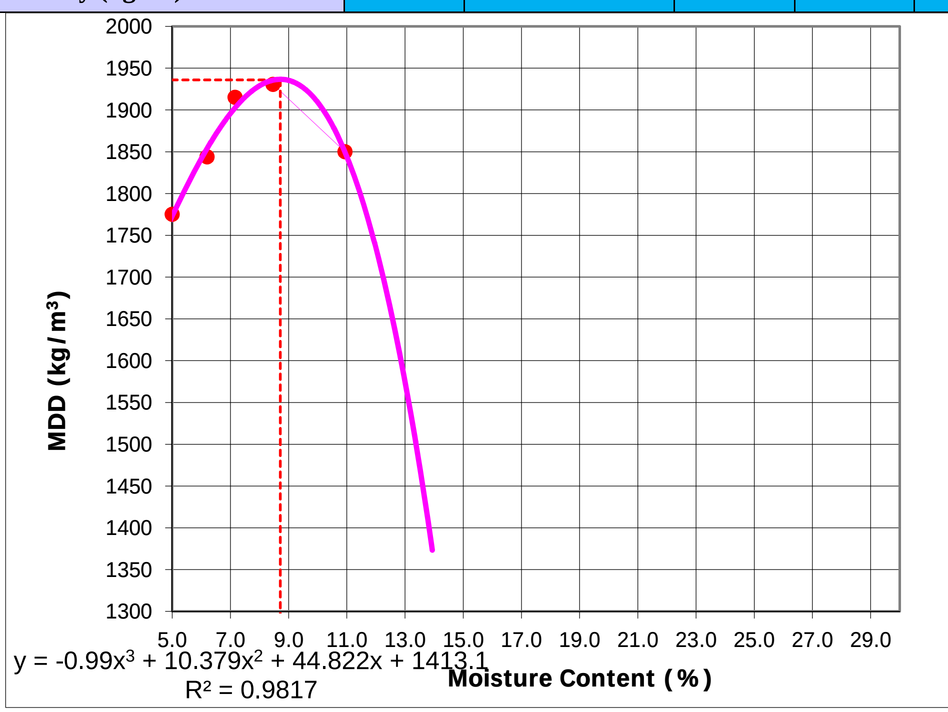
| **Wt of Mould (g)** | **4128** | | **Volume of Mould (l)** | **0.956** | | |
|---|---|---|---|---|---|---|
| **Test No** | NMC | 1 | 2 | 3 | 4 | 5 |
| **Wt of mould + wet material (g)** | | 5920 | 6050 | 6145 | 6160 | 6115 |
| **Wt wet material (g)** | | 1792 | 1922 | 2017 | 2032 | 1987 |
| **Wet density (kg/m³)** | | 1874 | 2010 | 2110 | 2126 | 2078 |
| **Moisture content** | | | | | | |
| **Container No** | 17A | 63A | 80A | 108A | 92A | 68A |
| **Wt of container + wet material (g)** | 210.20 | 123.20 | 126.90 | 145.60 | 134.30 | 157.20 |
| **Wt of container (g)** | 44.90 | 16.50 | 16.00 | 15.70 | 18.20 | 15.40 |
| **Wt of container + dry material (g)** | 204.10 | 116.90 | 118.20 | 134.30 | 123.40 | 142.20 |
| **Wt dry material (g)** | 159.20 | 100.40 | 102.20 | 118.60 | 105.20 | 126.80 |
| **Wt of moisture (g)** | 6.10 | 6.30 | 8.70 | 11.30 | 10.90 | 15.00 |
| **Moisture content (%)** | 3.83 | 6.27 | 8.51 | 9.53 | 10.36 | 11.83 |
| **Dry density (kg/m³)** | | 1764 | 1853 | 1926 | 1926 | 1859 |




| | |
|---|---|
| **Optimum Moisture Content (%)** | **10.4** |
| **Maximum Dry Density (kg/m³)** | **1930** |

## Proctor compaction Test-75% RAP & 25% Gravel

| | | | | | | |
|---|---|---|---|---|---|---|
| **Wt of Mould (g)** | **4128** | | **Volume of Mould (l)** | **0.956** | | |
| **Test No** | NMC | 1 | 2 | 3 | 4 | 5 |
| **Wt of mould + wet material (g)** | | 5910 | 6000 | 6090 | 6130 | 6090 |
| **Wt wet material (g)** | | 1782 | 1872 | 1962 | 2002 | 1962 |
| **Wet density (kg/m³)** | | 1864 | 1958 | 2052 | 2094 | 2052 |
| **Moisture content** | | | | | | |
| **Container No** | 17A | 121A | 85A | 13A | 65A | 99A |
| **Wt of container + wet material (g)** | 210.20 | 157.80 | 137.10 | 175.70 | 133.90 | 168.60 |
| **Wt of container (g)** | 44.90 | 15.00 | 17.20 | 26.10 | 17.30 | 18.50 |
| **Wt of container + dry material (g)** | 204.10 | 151.00 | 130.10 | 165.70 | 124.80 | 153.80 |
| **Wt dry material (g)** | 159.20 | 136.00 | 112.90 | 139.60 | 107.50 | 135.30 |
| **Wt of moisture (g)** | 6.10 | 6.80 | 7.00 | 10.00 | 9.10 | 14.80 |
| **Moisture content (%)** | 3.83 | 5.00 | 6.20 | 7.16 | 8.47 | 10.94 |
| **Dry density (kg/m³)** | | 1775 | 1844 | 1915 | 1931 | 1850 |



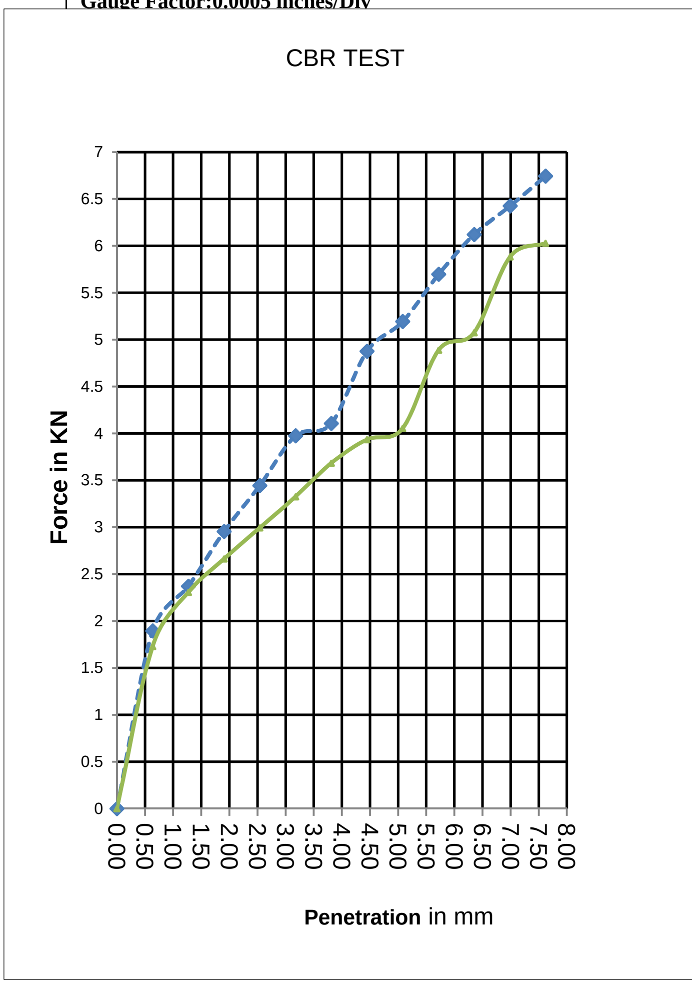

| | |
|---|---|
| **Optimum Moisture Content (%)** | **8.7** |
| **Maximum Dry Density (kg/m³)** | **1936** |

# APPENDIX B: CBR

## CBR for Neat sample

| SWELL DATA | |
|---|---|
| **Initial gauge Reading (div)** | 100 |
| **Final gauge Reading (div)** | 115 |
| **Difference (div)** | 15 |
| **Ring Factor** | 0.01 |
| **Gauge Factor:0.0005 inches/Div** | |

| SAMPLE DETAILS | | | |
|---|---|---|---|
| **Type** | **~~Stabilized~~/unstabilized** | **MDD** | 1684 |
| **Stabilizer** | **Nil** | **OMC** | 16.7 |
| | | **NMC** | 13.6 |
| **%** | | | |
| **Swell %** | 0.15 | | |




| **Penetration of the plunger (mm)** | **Bot (KN)** | **Top (KN)** | **Standard Load(KN)** | **CBR%** | |
|---|---|---|---|---|---|
| | | | | **Bott.** | **Top** |
| **0.00** | **0** | **0** | | | |
| **0.64** | **1.8948** | **1.73** | | | |
| **1.27** | **2.3718** | **2.306** | | | |
| **1.91** | **2.9548** | **2.663** | | | |
| **2.54** | **3.4451** | **2.995** | **13.2** | **26.1** | **22.69** |
| **3.18** | **3.9751** | **3.326** | | | |
| **3.81** | **4.1076** | **3.684** | | | |
| **4.45** | **4.8761** | **3.935** | | | |
| **5.08** | **5.1941** | **4.055** | **20.0** | **26** | **20.27** |
| **5.72** | **5.6976** | **4.889** | | | |
| **6.99** | **6.4263** | **5.883** | | | |
| **7.62** | **6.7444** | **6.029** | | | |
| **6.35** | **6.1216** | **5.075** | | | |

| **Moulding Data** | | |
|---|---|---|
| **Wt.of Mould + Wet soil** | **g** | |
| **Wt. of Mould** | **g** | |
| **Moisture Content** | **%** | |
| **Wet Density** | **Kg/m$^3$** | |
| **Dry Density** | **Kg/m$^3$** | |
| | **% MDD** | |

| **MOULDING MOISTURE CONTENT** | |
|---|---|
| **Tin No.** | 80A |
| **Tin +Wet soil** | 149.7 |
| **Tin + Dry soil** | 120.6 |
| **Wt of Tin** | 16 |
| **Wt of Moisture** | 29.1 |
| **Wt. of dry soil** | 133.7 |
| **Moisture content** | 21.77 |

| **RESULTS** | | | | |
|---|---|---|---|---|
| **Penetration(mm)** | **Standard Force(KN)** | **Specification** | **CBR%(top)** | **CBR%(bott.)** |
| **2.5** | **13.2** | | **23** | **26** |
| **5** | **20** | | **20** | **26** |
| | | **CBR = 26%** | **Checked:** | |

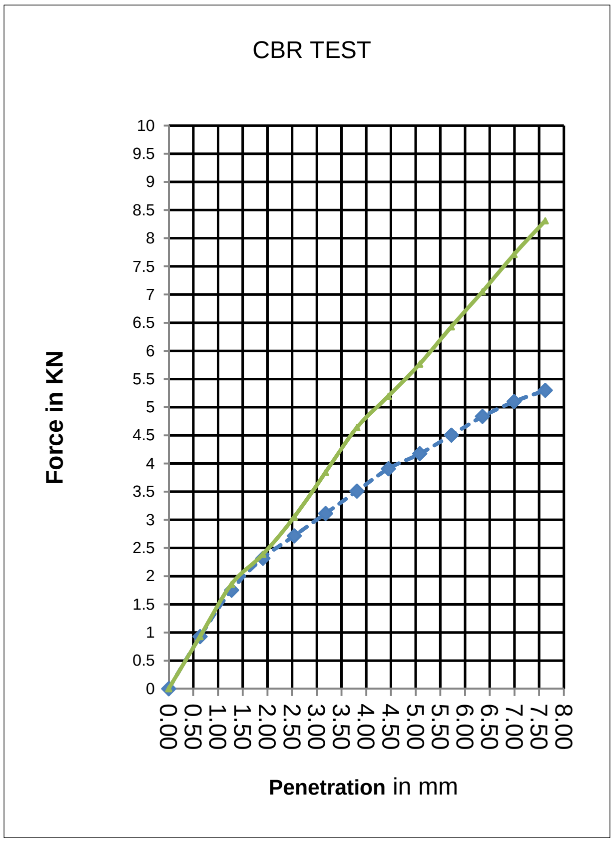
# CBR for 50%RAP & 50% Gravel

| SWELL DATA | | | |
|---|---|---|---|
| Initial gauge Reading(div) | | | 0 |
| Final gauge Reading (div) | | | 72 |
| Difference (div) | | | 72 |
| Ring Factor | | | 0.01 |
| Gauge Factor:0.0005 inches/Div | | | |

| SAMPLE DETAILS | | | |
|---|---|---|---|
| Type | ~~Stabilized~~ | OMC | 15.5 |
| Stabilizer | | NMC | 4.68 |
| % | 50 | | |
| Swell % | 0.72 | | |

MDD 1850

| Penetration of the plunger (mm) | Bot (KN) | Top (KN) | Standard Load(KN) | CBR% Bott. | CBR% Top |
|---|---|---|---|---|---|
| 0.00 | 0 | 0 | | | |
| 0.64 | 0.9275 | 0.928 | | | |
| 1.27 | 1.749 | 1.855 | | | |
| 1.91 | 2.3188 | 2.385 | | | |
| 2.54 | 2.7163 | 3.048 | 13.2 | 20.6 | 23.09 |
| 3.18 | 3.1138 | 3.843 | | | |
| 3.81 | 3.5113 | 4.638 | | | |
| 4.45 | 3.9088 | 5.194 | | | |
| 5.08 | 4.1738 | 5.764 | 20.0 | 20.9 | 28.82 |
| 5.72 | 4.5051 | 6.426 | | | |
| 6.35 | 4.8363 | 7.049 | | | |
| 6.99 | 5.1013 | 7.712 | | | |
| 7.62 | 5.3001 | 8.308 | | | |




| Moulding Data | |
|---|---|
| Wt.of Mould + Wet soil | g |
| Wt. of Mould | g |
| Moisture Content | % |
| Wet Density | Kg/m³ |
| Dry Density | Kg/m³ |
| % MDD | |

| MOULDING MOISTURE CONTENT | |
|---|---|
| Tin No. | 17A |
| Tin +Wet soil | 233.3 |
| Tin + Dry soil | 211 |
| Wt of Tin | 45.1 |
| Wt of Moisture | 22.3 |
| Wt. of dry soil | 188.2 |
| Moisture content | 11.85 |

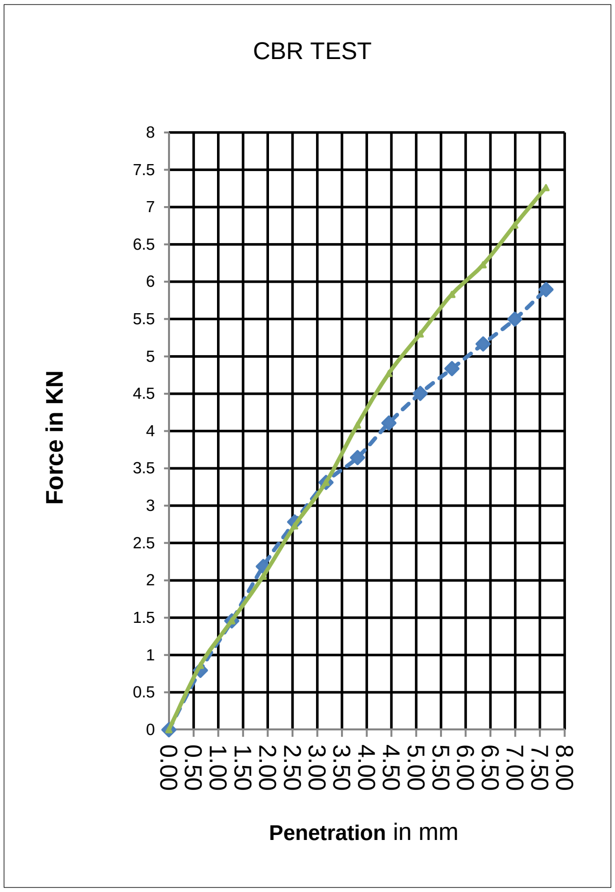
**RESULTS**

| Penetration(mm) | Standard Force(KN) | Specification | CBR%(top) | CBR%(bott.) |
|---|---|---|---|---|
| 2.5 | 13.2 | | 23.09 | 20.6 |
| 5 | 20 | | 28.82 | 20.9 |
| | | CBR= 29% | Checked: | |

# CBR for 25% RAP & 75% Gravel

| SWELL DATA | | | |
|---|---|---|---|
| Initial gauge Reading (div) | | | 0 |
| Final gauge Reading (div) | | | 72 |
| Difference (div) | | | 72 |
| Ring Factor | | | 0.01 |
| Gauge Factor:0.0005 inches/Div | | | |

| SAMPLE DETAILS | | | |
|---|---|---|---|
| Type | ~~Stabilized/~~ | MDD | 1955 |
| | | OMC | 9.9 |
| Stabilizer | | NMC | 3.83 |
| % | 25 | | |
| Swell % | 0.72 | | |




| Penetration of the plunger (mm) | Bot (KN) | Top (KN) | Standard Load(KN) | CBR% Bott. | CBR% Top |
|---|---|---|---|---|---|
| 0.00 | 0 | 0 | | | |
| 0.64 | 0.795 | 0.861 | | | |
| 1.27 | 1.4575 | 1.458 | | | |
| 1.91 | 2.1863 | 2.054 | | | |
| 2.54 | 2.7825 | 2.73 | 13.2 | 21.1 | 20.68 |
| 3.18 | 3.3126 | 3.313 | | | |
| 3.81 | 3.6438 | 4.081 | | | |
| 4.45 | 4.1076 | 4.77 | | | |
| 5.08 | 4.5051 | 5.3 | 20.0 | 22.5 | 26.5 |
| 5.72 | 4.8363 | 5.83 | | | |
| 6.35 | 5.1676 | 6.228 | | | |
| 6.99 | 5.4988 | 6.758 | | | |
| 7.62 | 5.8963 | 7.261 | | | |

| Moulding Data | | |
|---|---|---|
| Wt.of Mould + Wet soil | g | |
| Wt. of Mould | g | |
| Moisture Content | % | |
| Wet Density | $Kg/m^3$ | |
| Dry Density | $Kg/m^3$ | |
| | % MDD | |

| MOULDING MOISTURE CONTENT | |
|---|---|
| Tin No. | 17A |
| Tin +Wet soil | 233.3 |
| Tin + Dry soil | 211 |
| Wt of Tin | 45.1 |
| Wt of Moisture | 22.3 |
| Wt. of dry soil | 188.2 |
| Moisture content | 11.85 |

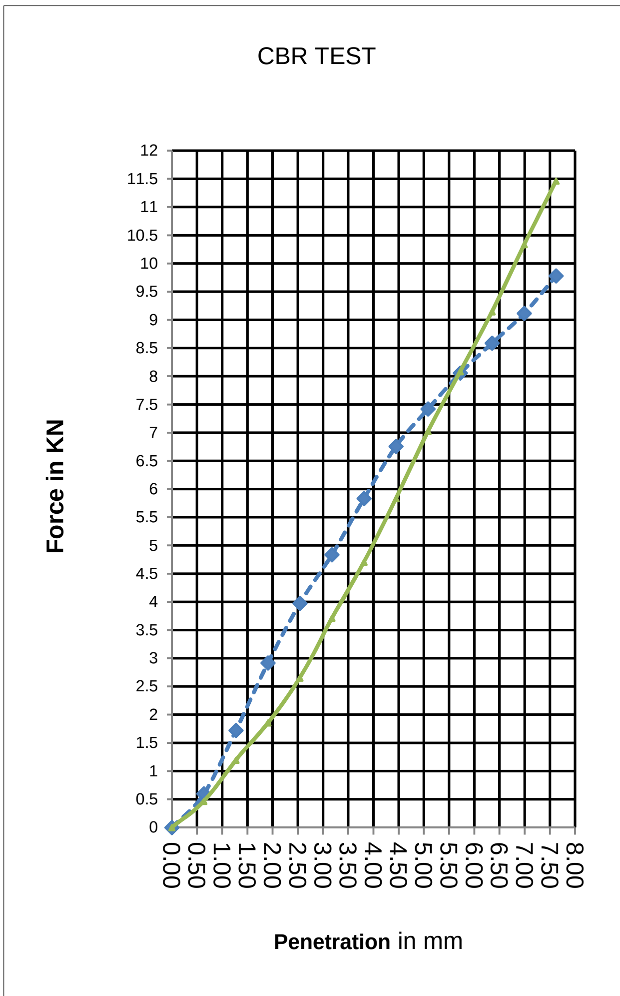
**RESULTS**

| Penetration(mm) | Standard Force(KN) | Specification | | CBR%(top) | CBR%(bott.) |
|---|---|---|---|---|---|
| 2.5 | 13.2 | | | 20.68 | 21.1 |
| 5 | 20 | | | 26.5 | 22.5 |
| | | CBR= | 27% | Checked: | |

# CBR for 75% RAP & 25% Gravel

| SWELL DATA | | | |
|---|---|---|---|
| **Initial gauge Reading(div)** | | | 0 |
| **Final gauge Reading (div)** | | | 72 |
| **Difference(div)** | | | 72 |
| **Ring Factor** | | | 0.01 |
| Gauge Factor:0.0005 inches/Div | | | |

| SAMPLE DETAILS | | | |
|---|---|---|---|
| Type | ~~Stabilized~~/ | MDD | 1936 |
| | | OMC | 8.7 |
| Stabilizer | | NMC | 3.83 |
| % | 75 | | |
| Swell % | 0.72 | | |




| Penetration of the plunger (mm) | Bot (KN) | Top (KN) | Standard Load(KN) | CBR% Bott. | CBR% Top |
|---|---|---|---|---|---|
| 0.00 | 0 | 0 | | | |
| 0.64 | 0.5963 | 0.464 | | | |
| 1.27 | 1.7225 | 1.193 | | | |
| 1.91 | 2.915 | 1.855 | | | |
| 2.54 | 3.9751 | 2.65 | 13.2 | 30.1 | 20.08 |
| 3.18 | 4.8363 | 3.71 | | | |
| 3.81 | 5.8301 | 4.704 | | | |
| 4.45 | 6.7576 | 5.83 | | | |
| 5.08 | 7.4201 | 7.023 | 20.0 | 37.1 | 35.11 |
| 5.72 | 8.0561 | 8.083 | | | |
| 6.35 | 8.5861 | 9.143 | | | |
| 6.99 | 9.1161 | 10.34 | | | |
| 7.62 | 9.7786 | 11.46 | | | |

| Moulding Data | |
|---|---|
| Wt.of Mould + Wet soil g | |
| Wt. of Mould g | |
| Moisture Content % | |
| Wet Density Kg/m³ | |
| Dry Density Kg/m³ | |
| % MDD | |

| MOULDING MOISTURE CONTENT | |
|---|---|
| Tin No. | 17A |
| Tin +Wet soil | 233.3 |
| Tin + Dry soil | 211 |
| Wt of Tin | 45.1 |
| Wt of Moisture | 22.3 |
| Wt. of dry soil | 188.2 |
| Moisture content | 11.85 |

**RESULTS**

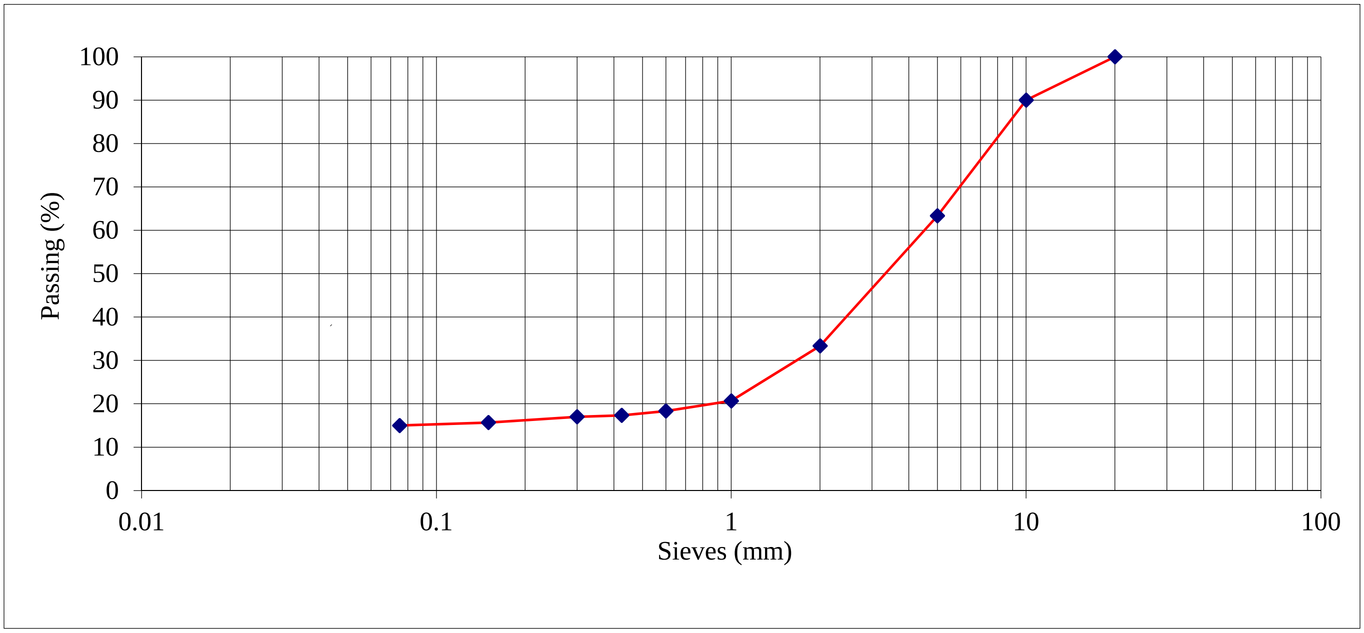
| ) | Force(KN) | Specification | CBR%(top) | CBR%(bott.) |
|---|---|---|---|---|
| 2.5 | 13.2 | | 20.08 | 30.1 |
| 5 | 20 | | 35.11 | 37.1 |
| | | CBR= 37% | Checked: | |

## APPENDIX C :GRADING ANALYSIS

## Grading Analysis for Neat

| | | | | |
|---|---|---|---|---|
| Pan mass | (gm.) | 100 | | |
| Initial dry sample mass + pan | (gm.) | 400 | | |
| Initial dry sample mass | (gm.) | 300 | Fine mass | (gm.) |
| Washed dry sample mass + pan | (gm.) | 355 | Fine percept | (%) |
| Washed dry sample mass | (gm.) | 255 | Acceptance Criteria | (%) |

| Sieve size (mm) | Retained mass (gm.) | % Retained (%) | Cumulative passed percentage (%) | Acceptance Criteria | |
|---|---|---|---|---|---|
| | | | | Min (%) | Max (%) |
| **20** | 0 | **0.0** | **100.0** | **100** | **100** |
| **10** | 30 | **10.0** | **90.0** | **90** | **100** |
| **5** | 80 | **26.7** | **63.3** | **42** | **85** |
| **2** | 90 | **30.0** | **33.3** | **30** | **68** |
| **1** | 38 | **12.7** | **20.7** | **25** | **64** |
| **0.6** | 7 | **2.3** | **18.3** | **17** | **47** |
| **0.425** | 3 | **1.0** | **17.3** | **12** | **30** |
| **0.3** | 1 | **0.3** | **17.0** | **10** | **26** |
| **0.15** | 4 | **1.3** | **15.7** | **8** | **24** |
| **0.075** | 2 | **0.7** | **15.0** | **0** | **12** |
| | 255 | | | | |

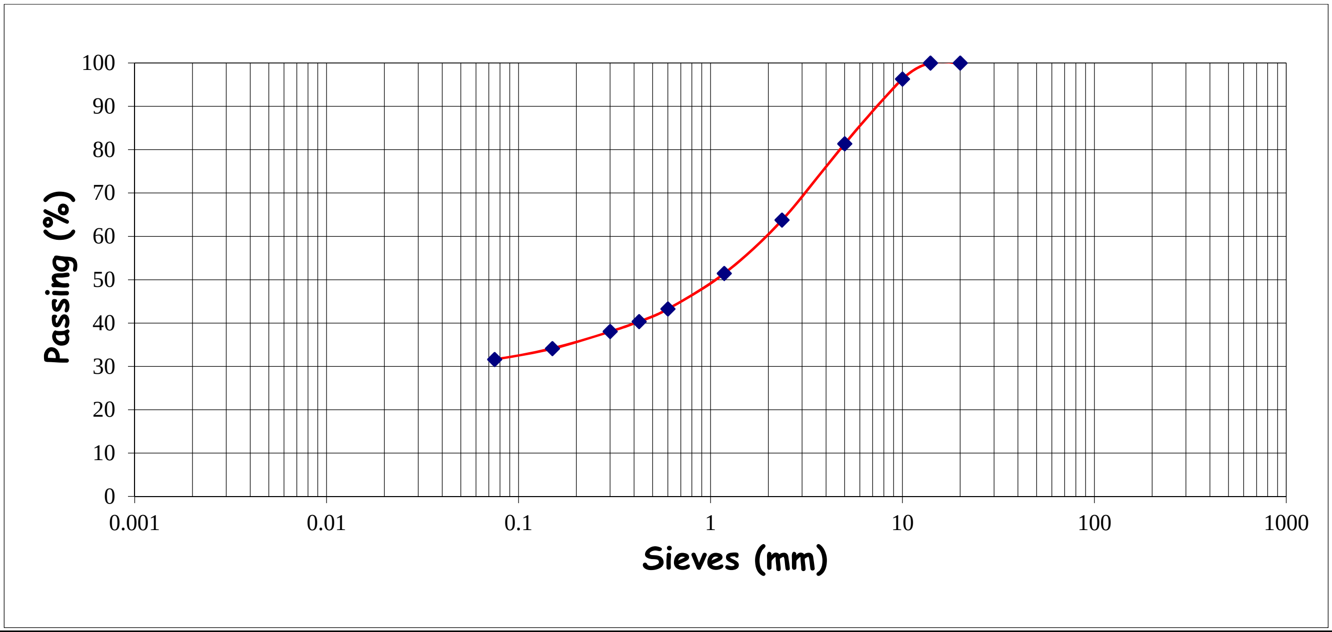



| CLAY | Fine | Medium | Coarse | Fine | Medium | Coarse | Fine | Medium | Coarse | Cobbles |
|---|---|---|---|---|---|---|---|---|---|---|
| | SILT | | | SAND | | | GRAVEL | | | |

## Sieve analysis for 25% RAP and 75% Gravel

| | | | | |
|---|---|---|---|---|
| Pan mass | (gm) | 0 | | |
| Initial dry sample mass + pan | (gm) | | | |
| Initial dry sample mass | (gm) | 200 | Fine mass | 63.2 |
| Washed dry sample mass + pan | (gm) | | Fine percent | 31.6 |
| Washed dry sample mass | (gm) | 136.8 | Acceptance Criteria | |

| Sieve size (mm) | Retained mass (gm) | % Retained (%) | Cumulative passed percentage (%) | Acceptance Criteria | |
|---|---|---|---|---|---|
| | | | | Min(%) | Max (%) |
| **20** | 0 | **0.0** | **100.0** | | |
| **14** | 0 | **0.0** | **100.0** | | |
| **10** | 7.4 | **3.7** | **96.3** | | |
| **5** | 29.9 | **15.0** | **81.4** | | |
| **2.36** | 35.2 | **17.6** | **63.8** | | |
| **1.18** | 24.6 | **12.3** | **51.5** | | |
| **0.6** | 16.4 | **8.2** | **43.3** | | |
| **0.425** | 5.8 | **2.9** | **40.4** | | |
| **0.3** | 4.6 | **2.3** | **38.1** | | |
| **0.15** | 7.9 | **4.0** | **34.1** | | |
| **0.075** | 5 | **2.5** | **31.6** | | |
| | 63.2 | **31.6** | | | |
| TOTAL | 200 | | | | |

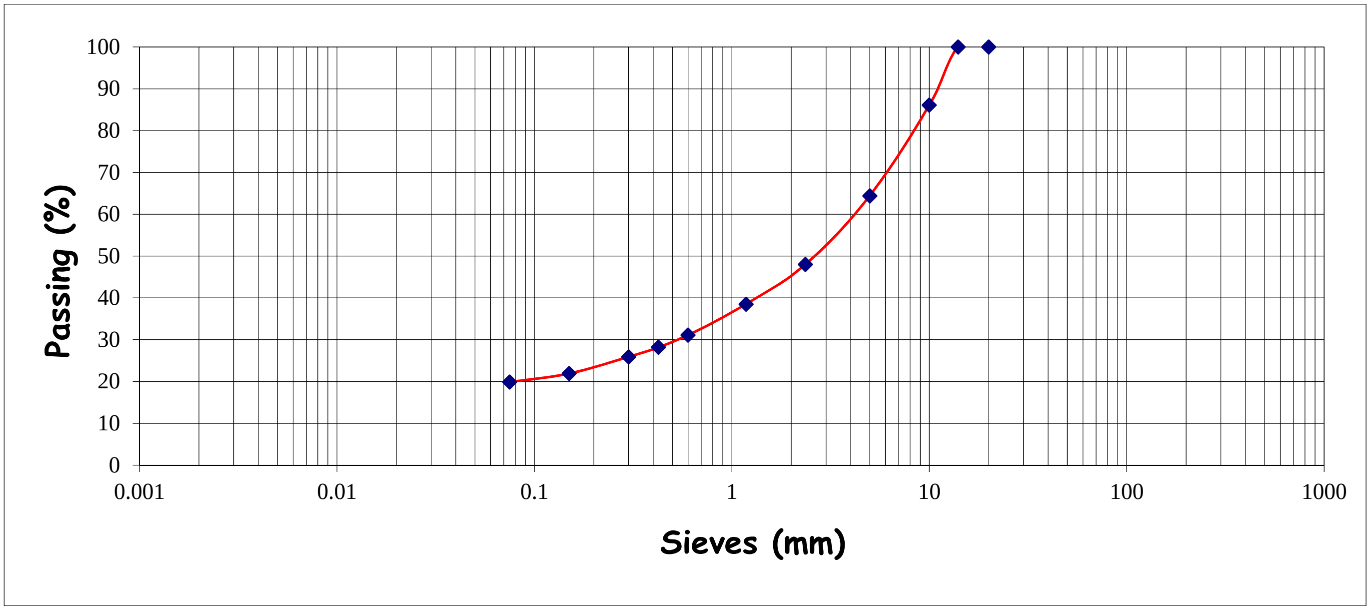



| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CLAY | Fine | Medium | Coarse | Fine | Medium | Coarse | Fine | Medium | Coarse | **Cobbles** |
| | SILT | | | SAND | | | GRAVEL | | | |

## Grading analysis for 50% RAP & 50% Gravel

| | | | | |
|---|---|---|---|---|
| Pan mass | (gm) | 0 | | |
| Initial dry sample mass + pan | (gm) | | | |
| Initial dry sample mass | (gm) | 200 | Fine mass | 40.6 |
| Washed dry sample mass + pan | (gm) | | Fine percent | 20.3 |
| Washed dry sample mass | (gm) | 159.4 | Acceptance Criteria | |

| Sieve size (mm) | Retained mass (gm) | % Retained (%) | Cumulative passed percentage (%) | Acceptance Criteria | |
|---|---|---|---|---|---|
| | | | | Min(%) | Max (%) |
| **20** | 0 | **0.0** | **100.0** | | |
| **14** | 0 | **0.0** | **100.0** | | |
| **10** | 27.8 | **13.9** | **86.1** | | |
| **5** | 43.4 | **21.7** | **64.4** | | |
| **2.36** | 32.8 | **16.4** | **48.0** | | |
| **1.18** | 19 | **9.5** | **38.5** | | |
| **0.6** | 14.8 | **7.4** | **31.1** | | |
| **0.425** | 5.8 | **2.9** | **28.2** | | |
| **0.3** | 4.6 | **2.3** | **25.9** | | |
| **0.15** | 8 | **4.0** | **21.9** | | |
| **0.075** | 4 | **2.0** | **19.9** | | |
| | 40.6 | **20.3** | | | |
| TOTAL | 200.8 | | | | |

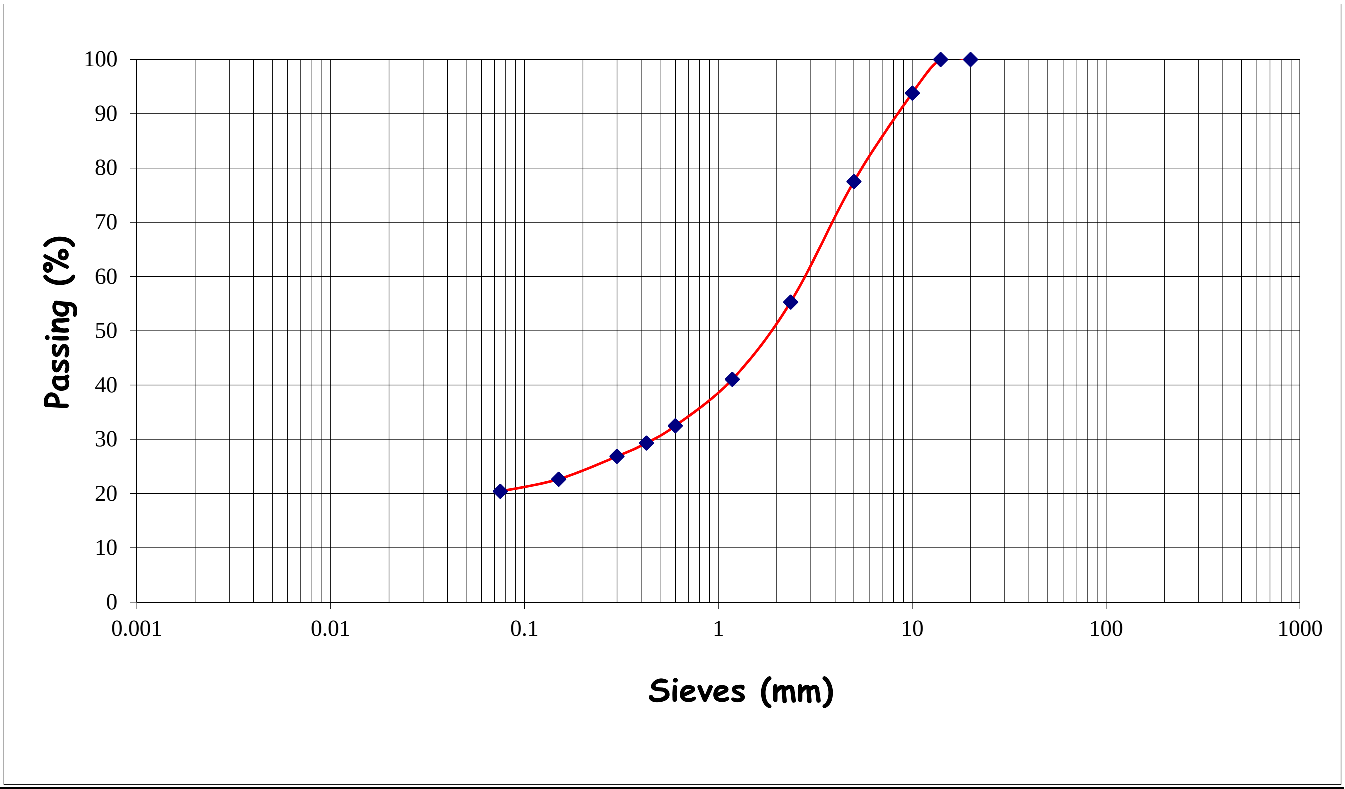



| CLAY | Fine | Medium | Coarse | Fine | Medium | Coarse | Fine | Medium | Coarse | Cobbles |
|---|---|---|---|---|---|---|---|---|---|---|
| | SILT | | | SAND | | | GRAVEL | | | |

## Grading analysis for 75% RAP & 25% Gravel

| | | | | | |
|---|---|---|---|---|---|
| Pan mass | (gm) | 0 | | | |
| Initial dry sample mass + pan | (gm) | | | | |
| Initial dry sample mass | (gm) | 200 | Fine mass | | 39.9 |
| Washed dry sample mass + pan | (gm) | | Fine percent | | 20.0 |
| Washed dry sample mass | (gm) | 160.1 | Acceptance Criteria | | |

| Sieve size (mm) | Retained mass (gm) | % Retained (%) | Cumulative passed percentage (%) | Acceptance Criteria | |
|---|---|---|---|---|---|
| | | | | Min(%) | Max (%) |
| **20** | 0 | **0.0** | **100.0** | | |
| **14** | 0 | **0.0** | **100.0** | | |
| **10** | 12.4 | **6.2** | **93.8** | | |
| **5** | 32.6 | **16.3** | **77.5** | | |
| **2.36** | 44.4 | **22.2** | **55.3** | | |
| **1.18** | 28.5 | **14.3** | **41.1** | | |
| **0.6** | 17.1 | **8.6** | **32.5** | | |
| **0.425** | 6.4 | **3.2** | **29.3** | | |
| **0.3** | 4.9 | **2.5** | **26.9** | | |
| **0.15** | 8.4 | **4.2** | **22.7** | | |
| **0.075** | 4.5 | **2.3** | **20.4** | | |
| | 40.8 | **20.4** | | | |
| TOTAL | 200 | | | | |



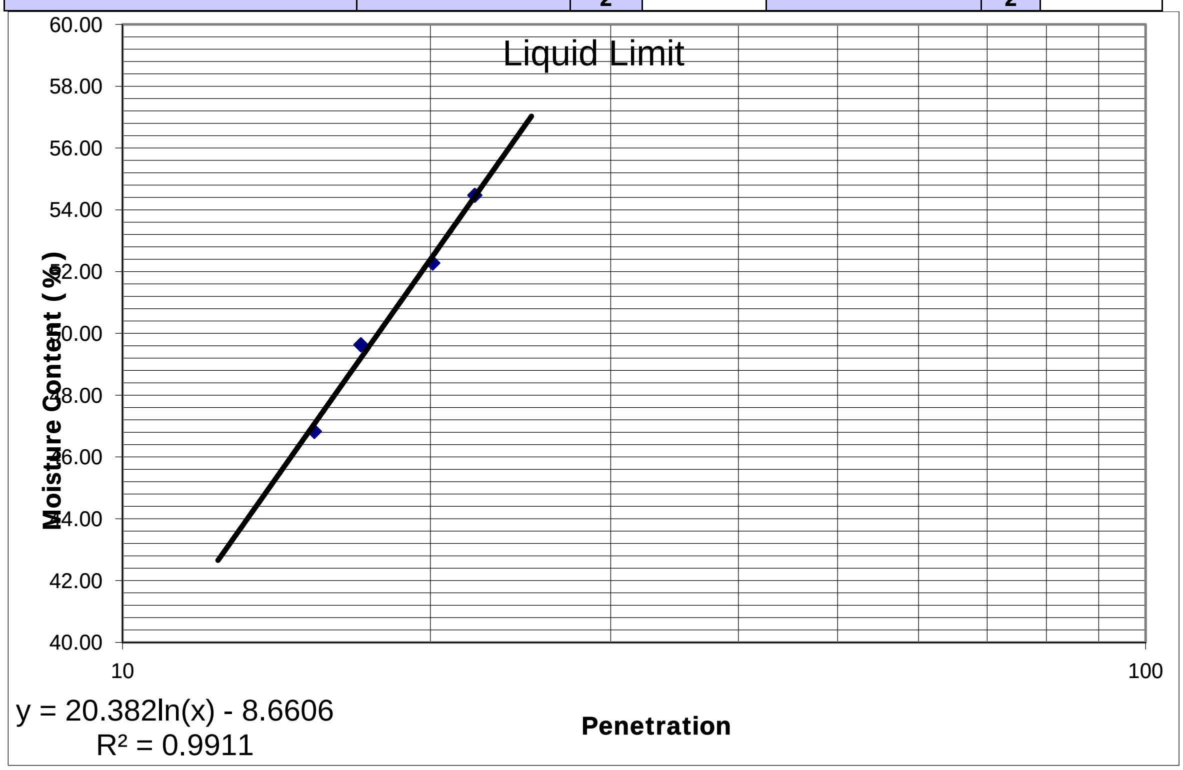

| | Fine | Medium | Coarse | Fine | Medium | Coarse | Fine | Medium | Coarse | |
|---|---|---|---|---|---|---|---|---|---|---|
| **CLAY** | **SILT** | | | **SAND** | | | **GRAVEL** | | | **Cobbles** |

# APPENDIX D: ATTERBERG LIMITS

Atterberg Limits for Neat Sample

| | | Liquid Limit | | | | Plastic Limit | |
|---|---|---|---|---|---|---|---|
| **Container No** | | 27 | 34 | 13 | 2 | 4R | N |
| **Penetration (mm)** | | 15.4 | 17.1 | 20.1 | 22.1 | | |
| **Wt of Container + Wet Soil (g)** | | 64.9 | 70.2 | 79.7 | 85.8 | 10.57 | 11.22 |
| **Wt of Container + Dry Soil (g)** | | 53.1 | 56.7 | 62.5 | 65.7 | 9.7 | 10.23 |
| **Wt of Container (g)** | | 27.9 | 29.5 | 29.6 | 28.8 | 5.52 | 5.62 |
| **Wt of Moisture (g)** | | 11.8 | 13.5 | 17.2 | 20.1 | 0.87 | 0.99 |
| **Wt of Dry Soil (g)** | | 25.2 | 27.2 | 32.9 | 36.9 | 4.18 | 4.61 |
| **Moisture Content (%)** | | 46.83 | 49.63 | 52.28 | 54.47 | 20.81 | 21.48 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Linear Shrinkage** | **Initial Length (mm)** | **No1** | 140 | **Final Length (mm)** | **No 1** | 126 |
| | | **No 2** | 140 | | **No 2** | 126 |

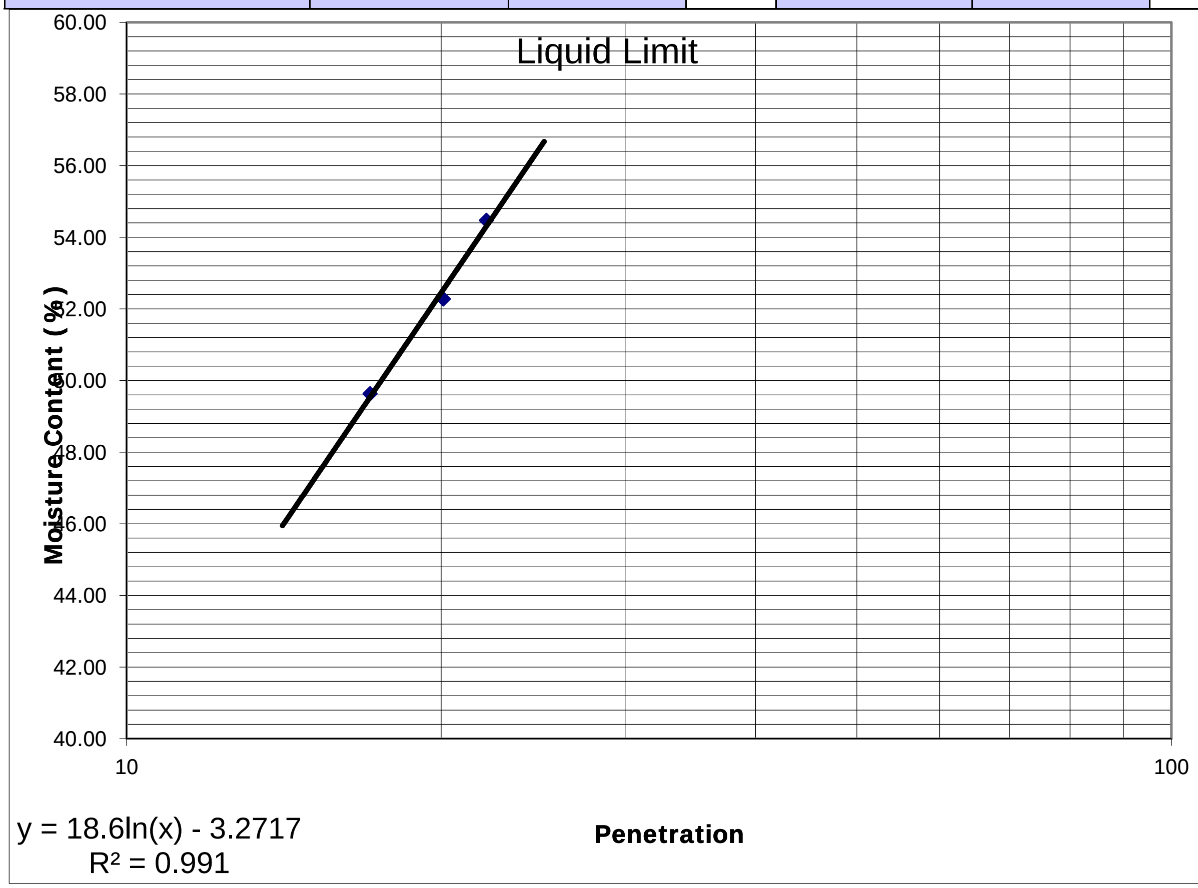



| | |
|---|---|
| **Liquid Limit** | 53 |
| **Plastic Limit** | 21 |
| **Plasticity Index** | 32 |
| **Linear Shrinkage** | 10 |

## Atterberg Limits for 25% RAP & 75% Gravel

| | Liquid Limit | | | | | Plastic Limit | |
|---|---|---|---|---|---|---|---|
| **Container No** | | 27 | 34 | 13 | 2 | K | Q |
| **Penetration (mm)** | | 15.4 | 17.1 | 20.1 | 22.1 | | |
| **Wt of Container + Wet Soil (g)** | | 64.9 | 70.2 | 79.7 | 85.8 | 13.5 | 13.7 |
| **Wt of Container + Dry Soil (g)** | | 53.1 | 56.7 | 62.5 | 65.7 | 12.7 | 12.8 |
| **Wt of Container (g)** | | 27.9 | 29.5 | 29.6 | 28.8 | 9 | 8.9 |
| **Wt of Moisture (g)** | | 11.8 | 13.5 | 17.2 | 20.1 | 0.8 | 0.9 |
| **Wt of Dry Soil (g)** | | 25.2 | 27.2 | 32.9 | 36.9 | 3.7 | 3.9 |
| **Moisture Content (%)** | | 46.83 | 49.63 | 52.28 | 54.47 | 21.62 | 23.08 |

| Linear Shrinkage | Initial Length (mm) | No1 | 140 | Final Length (mm) | No 1 | 126 |
|---|---|---|---|---|---|---|
| | | No 2 | 140 | | No 2 | 126 |

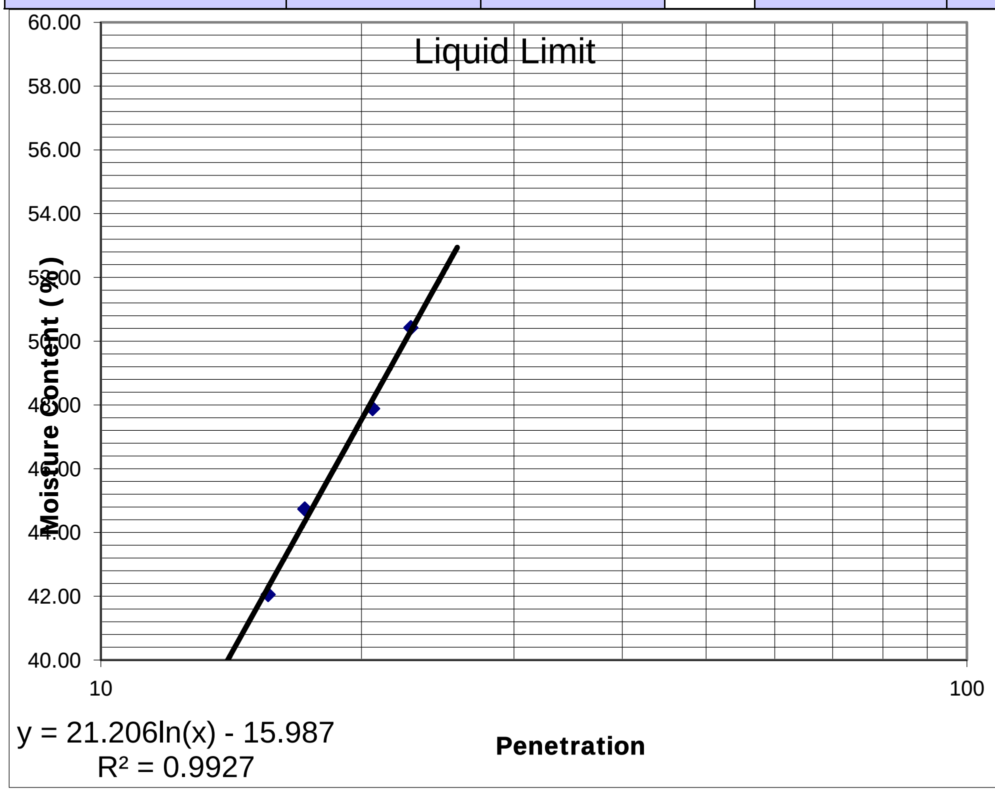



| | |
|---|---|
| **Liquid Limit** | 52 |
| **Plastic Limit** | 22 |
| **Plasticity Index** | 30 |
| **Linear Shrinkage (%)** | 10 |

# Atterberg Limits for 50% RAP & 50% Gravel

| | Liquid Limit | | | | | Plastic Limit | |
|---|---|---|---|---|---|---|---|
| Container No | | 15 | 26 | 4 | 17 | ZB | DD |
| Penetration (mm) | | 15.6 | 17.2 | 20.6 | 22.8 | | |
| Wt of Container + Wet Soil (g) | | 74.5 | 84.7 | 90.8 | 98.9 | 15.2 | 15.1 |
| Wt of Container + Dry Soil (g) | | 61 | 67.7 | 70.4 | 75.2 | 14.2 | 14.1 |
| Wt of Container (g) | | 28.9 | 29.7 | 27.8 | 28.2 | 9.1 | 9.2 |
| Wt of Moisture (g) | | 13.5 | 17 | 20.4 | 23.7 | 1 | 1 |
| Wt of Dry Soil (g) | | 32.1 | 38 | 42.6 | 47 | 5.1 | 4.9 |
| Moisture Content (%) | | 42.06 | 44.74 | 47.89 | 50.43 | 19.61 | 20.41 |

| Linear Shrinkage | Initial Length (mm) | No1 | 140 | Final Length (mm) | No 1 | 121 |
|---|---|---|---|---|---|---|
| | | No 2 | 140 | | No 2 | 120 |

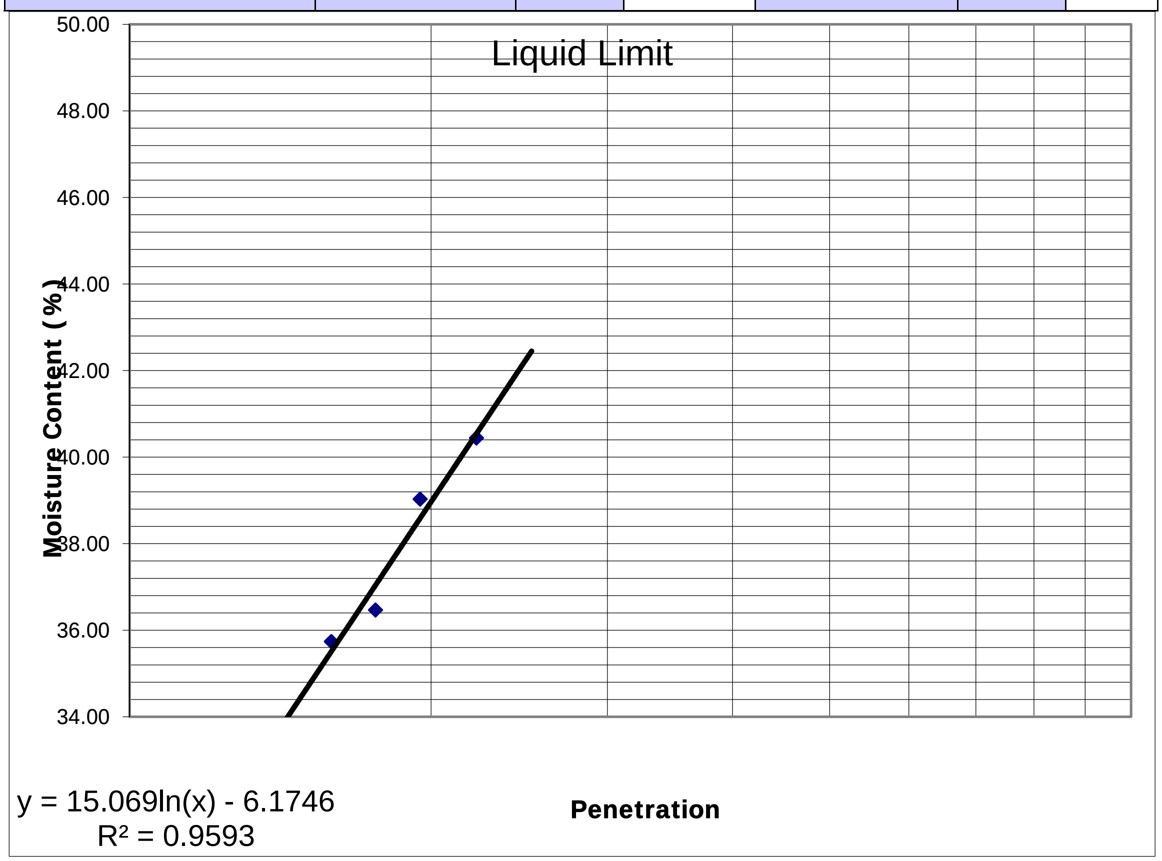



| | |
|---|---|
| Liquid Limit | 47 |
| Plastic Limit | 20 |
| Plasticity Index | 27 |
| Linear Shrinkage (%) | 14 |

## Atterberg Limits for 75% RAP & 25% Gravel

| | | Liquid Limit | | | | Plastic Limit | |
|---|---|---|---|---|---|---|---|
| Container No | | 11 | 12 | 3 | 38 | BC | 1R |
| Penetration (mm) | | 15.9 | 17.6 | 19.5 | 22.2 | | |
| Wt of Container + Wet Soil (g) | | 68.4 | 76.4 | 78.7 | 91.4 | 14.6 | 14.6 |
| Wt of Container + Dry Soil (g) | | 58 | 63.6 | 65 | 73.2 | 14 | 13.9 |
| Wt of Container (g) | | 28.9 | 28.5 | 29.9 | 28.2 | 9 | 8.8 |
| Wt of Moisture (g) | | 10.4 | 12.8 | 13.7 | 18.2 | 0.6 | 0.7 |
| Wt of Dry Soil (g) | | 29.1 | 35.1 | 35.1 | 45 | 5 | 5.1 |
| Moisture Content (%) | | 35.74 | 36.47 | 39.03 | 40.44 | 12.00 | 13.73 |

| Linear Shrinkage | Initial Length (mm) | No1 | 140 | Final Length (mm) | No 1 | 122 |
|---|---|---|---|---|---|---|
| | | No 2 | 140 | | No 2 | 123 |




| | |
|---|---|
| Liquid Limit | 39 |
| Plastic Limit | 13 |
| Plasticity Index | 26 |
| Linear Shrinkage (%) | 13 |