Jimma University

School Of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Highway Engineering Stream

# Evaluation of the Combined Effects of Hallow Concrete Block Waste and Recycled Asphalt Pavement for Using in Road Pavement Sub- base Course.

A thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway engineering stream

By:

Aster Bekele

March 2020

Jimma, Ethiopia

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Co –Advisor: Engr. Yibas Mamuye (Msc)

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## DECLARATION

I hereby declare that this thesis entitled "Evaluation on the Combined Effects of Hallow Concrete Block Waste and Recycled Asphalt Pavement for Using in Road Pavement Sub -base Course**"** The work contained herein is my own original work except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification.

Candidate

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As master research advisor, we hereby certify that we have read and evaluated this MSC research prepared under our guidance, miss. Aster Bekele entitled: "Evaluation on the Combined Effects of Hallow Concrete Block Waste and Recycled Asphalt Pavement for Used in Road Pavement Sub-base Course"

Prof. Emer T. Quezon, P.Eng ____________________ 12/12/2019
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Co- Advisor Signature Date

# ACKNOWLEDGEMENT

First I would like to gratefully acknowledge the almighty God to get the chance of this program. My deepest gratitude goes to my advisor Prof. Emer T. Quezon and my co-advisor, Engr. Yibas Mamuye (Msc) for all their limitless efforts in guiding me through my work and for providing me useful reference materials.

Secondly, my deepest appreciation goes to Jimma University, School of Graduate Studies, Jimma Institute of Technology, Civil Engineering Department, and Highway Engineering Stream.

Lastly, but not least all my good friends and relatives are acknowledged for direct and indirect support in my study and research work

## ABSTRACT

*Road network is the prime mover for the development of every country. In Ethiopia, the capital investment for the network development is increasing to meet its medium and long term development plan. To expand the road network, the construction materials are the perennial main issues because of the availability of virgin materials which is very limited, and their costs are becoming high. To lessen such impact of the problem, used of recycled materials with low cost and environmentally friendly could be the alternative approach. Unfortunately, using Reclaimed asphalt pavement (RAP) and waste HCB had not been fully recognized in Ethiopia despite the current ambitions of road-building programs in the country. However, RAP and waste HCB materials may not be conventional road-making materials as compared with the other materials, of which requires further study. This study focused to evaluate the Combined Effects of Waste Hollow Concrete Block (HCB) and Recycled Asphalt Pavement for used in Road Pavement Sub-base Course. The Reclaimed Asphalt Pavement (RAP) was taken from road from Hana Mariam to garment, while the waste HCB was taken from Legehare which shipping and logistic building was demolished. In this study, the waste HCB and RAP were blended in their natural state in the laboratory and determined the mechanical and physical properties, and compared with the Standard Specifications. The proportions considered waste HCB and RAP with 100/0, 80/20, 70/30, 60/40, 50/50, 0/100 by total weights in percent. Laboratory test results indicated, the ACV, AIV, LAA, SG, Water absorption , CBR and FI 0f 5.63 to 20, 5.9 to 24.2,8.5.%to30.35% ,1.88 to 2.6, and 0.371to13.9% 22.5 to 78.3%, 14.16 to 16.4 respectively. Further laboratory tests conducted by blending of 30% RAP and 70% waste HCB showed a test results of 16.87% ACV, 17.1 AIV, 29% LAA, SG of 2.6, 0.85% water absorption, and a CBR value of 40%.Hence, these results indicated that meet with the ERA,BS,AASHTO, Standard Specifications. 30% RAP and 70% waste HCB could be used for sub-base course in road pavement construction recommended.*


***Keywords: Mechanical Properties, Physical Properties, Recycled Asphalt Pavement, Sub-base and Waste Hollow Concrete block***

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# ACRONYMS

| | |
|---|---|
| AASHTO | American Association State Highway and Transportation Officials |
| ACV | Aggregate crushed value |
| AIV | Aggregate impact value |
| ERA | Ethiopian road authority |
| ASTM | American standard test for material |
| BS | Britain standard |
| CDW | Construction and demolition wastes |
| CBR | California bearing ratio |
| EW | Excavation wastes |
| GS | Granular sub base |
| FI | Flakiness index |
| HCB | Hallow concrete block |
| $Kg / mm^3$ | kilogram per millimeter cube |
| L.A A | Los angles abrasion |
| MDD | Maximum dry density |
| $MM^3$ | Mile meter cube |
| PL | Plastic limit |
| NP | Non plastic |
| OMC | optimum moisture content |
| RAP | Recycled Asphalt pavement |
| RCA | Recycled concrete aggregate |
| SW | solid wastes |
| TPFV | Ten percent fine value |

# CHAPTER ONE

# INTRODUCTION

## 1.1. Background

Humanity has traveled the face of the earth throughout untold millenniums and used the natural earth surface for transportation. After the time the road surface was widened and covered with rock and gravel and thus made suitable to tackle and better increasing number of traffic and challenges from environmental condition has led to establishing pavement design guidelines involving two major pavement types which are based on the assumption that aggregate is essential ingredients of the pavement structure [1].

As the world population is increasing rapidly, more goods will be produced to satisfy their consumption as the result more waste also generated [2]. Environmental Protection Agency in 1993 estimated that over 73million tons of asphalt material is recycled each year which is about 80%of total asphalt pavement removed each year [3].

In 2014, more than 70 million tons of RAPS material was used in new pavements making RAP one of, if not the largest, recycled materials in the US [4]. The primary the total quantum of waste from the construction industry is estimated to be between 12 million to 14.7 million tons per annum, out of which seven to eight million tones are concrete and brick waste [5].Recycled materials from construction and demolition operations were once disposed of in landfill sites. Construction and demolition wastes will contain concrete, stone, bricks, ceramics, tiles, steel, wood and soils [6].

Recycled materials used in asphalt pavements and base/sub-base applications mainly come from construction and demolition wastes (CDW), solid wastes (SW) and by-products from industrial processes [7].The tends of societies/countries to replace the old building with new modern ones, caused in creating of millions of tones from the waste construction materials like concrete and asphalt .

Several waste materials have been used for highway construction [8]. Currently, in Ethiopia the old houses and roads are under demolishing [9].The demolished materials have the tendency of being used as a raw material for the production of waste HCB and RAP. Studies have revealed that performance of pavement by using up to 30% RAP material is similar to that of pavement constructed with natural aggregates without RAP materials. Increase demand of aggregates and binder supply can be meeting out up to certain extent by using Reclaimed. It was observed that the RAP materials can be successfully used in granular sub base layer of flexible pavements after blending to match the required grading as per MORTH specifications for sub base material [10].

Physical and mechanical tests were conducted on a variety of sample combinations to determine their suitability according to Qatar's Construction Specifications (QCS) 2010. In current pavement engineering practice, the shortage of natural aggregate supplies along with the increase in processing cost has encouraged the use of various reclaimed materials from old structures as a source of construction material. This technology reduces both the cost of highway construction and protects the environment by reducing construction waste. Reclaimed Asphalt Concrete Pavement (RAP) had been used as aggregate for pavement construction for some time [11].

Ethiopia is one of the newly industrialized countries and this can be witnessed by observable enhancement of construction activities in the country and demolitions for the replacement of old buildings, rehabilitation of land uses and rehabilitation of urban streets. Even though Utilizing construction and demolition wastes as road building materials is customary to developed countries there is no trials to use in Ethiopia except including the specification to use recycled asphalt pavement (RAP) in the national road authority manual[6].

Reuse of these materials after proper recycling can be the right solution for the same. There will be a reduction in cost about 25 to 30% by reusing the recycled road aggregate generated at same site [10].

In Addis Ababa large amount of recycled material is produced during demolishing of building and flexible pavement for reconstruction and maintenance, but the use of these recycled materials are not known. The use of the waste materials has important for

Development of the country by saving the cost expensed to virgin materials for road construction. The purpose of the study was evaluation of combination of recycled asphalt pavement and hollow concrete block for sub base layer prepared the tests have been conducted.

### 1.2. Problem statement

Globally, more recycled and waste materials are making environmental pollution. Those waste materials are like recycled asphalt pavements and hollow concrete block. In Ethiopia the old houses and roads are under demolishing. A lot of old buildings in Egypt are collapsed .As a result, the demolition and structure processes naturally introduce the problem of recycling materials where Many waste materials are also produced as by-products from various industries and construction sites, the disposal of which cause a major problem. Thus it becomes necessary to find an alternate source of raw material for infrastructure development and a proper method of utilization of waste materials from industries and demolished buildings [11].

The disposal of waste hollow block concrete and recycled asphalt pavements is difficult to municipalities for expenditure their budget to waste management, Furthermore, there is growing public awareness given to use the combination of waste hollow block concrete and recycled asphalt pavement for road construction material, which need special and organized consideration to overcome the problem that result. Even though Utilizing construction and demolition wastes as road building materials is customary to developed countries there is no trials to use in Ethiopia except including the specification to use recycled asphalt pavement (RAP) in the national road authority manual [6].

Therefore, this research focus on the combination of waste hollow concrete block and recycled asphalt pavement used for road sub-base material to conduct and recommend a permanent solution.

Through basic experimental research was analyzed in the possibilities of combination of waste hollow concrete block and recycled asphalt pavement used for sub-base material. Diverting waste from our disposal facilities involves finding ways to reduce, reuse and recycle. The major problem is environmental pollution by the rising generation of waste material. Disposal of wastes has become a significant problem in our country; In Addis Ababa, the recycling material has not been used for road construction for eliminating and disposes of as wastage material.

The use of cheaper construction materials without loss of performance is crucial for developing country like Ethiopia. Since pavements (sub base course layer) would need material meet standard specification AASHTO, ERA and ASTM for construction of asphalt pavement, the locally available material at road project may not provide the projected quality and may not be accessible. To overcome such problems, appropriate modification and utilization of available waste materials is the best alternative. All of this has attracted the attention of researcher to modify and utilize the available marginal material that is less expensive and environmentally friendly.

## 1.3. Research questions

The primary research questions are:

1) What are the physical and mechanical properties of the selected materials prior for blending in the laboratory?

2) What are the various parameters from blending which most influence the strength of the sub base layer?

3) What are the combined effects of the HCB wastage and Recycled asphalt pavement considering varying proportions when compared with the Standard Specifications?

## 1.4 Objectives

### 1.4.1 General objective

The general objective of the study is to evaluate the combined effects both Hollow concrete block waste and Recycled asphalt pavement use for road sub-base course materials.

### 1.4.2 Specific objectives

- To determine the physical, mechanical properties of the selected materials prior for blending in the laboratory.
- To evaluate various parameters of HCB wastage and Recycled asphalt pavement blending which influence the strength of the sub base layer.
- To determine the optimum percentage of reclaimed Asphalt Pavement and wastage HCB meet standard specification.

## 1.5. Significance of the Research

This research enlighten as how the blending of waste HCB and RAP could be utilized for road construction. The recycling waste HCB and RAP give as additional source of aggregate for road construction Therefore additional information has been provided for further investigation and formulation of policies on recycling of waste HCB and RAP to include in the specifications for the next amendment by the concerning road authorities and other stakeholders using this research as a mound.

### 1.6. Scope of the research

This study reported here in confined to the laboratory test to investigated the use of Reclaimed asphalt pavement collected from Addis Ababa Hana Mariam to Garment road was deteriorated and waste HCB collected from legehare Addis Ababa both sample can be packed to transport to Jimma institute of technology laboratory test carried out at different mix proportion of RAP and waste HCB. The relevant laboratory tests that had conducted were Gradation test, ACV, AIV, LAA test, Compaction test, CBR test, Water absorption , SG and Atterberg`s (liquid limit, plastic limit and plastic index ) tests. To achieve the objective of this study, suitability only for sub base course construction based on ERA, AASHTO and ASTM specification was checked. This thesis explores the literatures about blended of waste HCB and RAP used as sub base course material and conduct tests in laboratory that evaluate the physical and mechanical properties waste HCB,RAP, blending of waste HCB and RAP. Then finally after the laboratory test of each test for which the specific objective to investigated and determined the study result has been compared with AASHTO, ERA, BS and ASTM specification.

# CHAPTER TWO

# REVIEW OF THE RELATED LITERATURE

## 2.1. Introduction

The tends of societies/countries to replace the old building with new modern ones, caused in creating of millions of tones from the waste construction materials like concrete and asphalt mixes[8]. In Australia, approximately 8.7 million tons of demolition concrete, 1.3 million tons of demolition brick, 3.3 million tons of waste excavation rock, 1.0 million tons of waste glass and1.2 million tons of reclaimed asphalt pavements is stockpiled annually and these stockpiles are growing [12].

Demolished Buildings for expansion of city: The old houses and roads constructed are demolished in all parts of Addis Ababa especially in central of the city for reconstruction according the revised master plan. The amount of demolish in four sub city of Addis Ababa starting from 2009 are shown in table 3.3 below;[9].Crushed concrete and reclaimed asphalt pavement (RAP) or combinations of both are often used for sub grade replacement and construction of granular sub base layers over soft, unstable**.** Reclaimed asphalt pavement (RAP) with current construction specifications is becoming imperative [13].

Many scientific kinds of research and works of literature show that recycled concrete is crushed and the entire aggregate product can be used as a sub-base material. The quality of sub-base material is important to the pavement service life as it provides a foundation for the overlying pavement layers. The materials may be either unbound granular or bound, depending on the requirements for the layer [5].

In current pavement engineering practice, the shortage of natural aggregate supplies along with the increase in processing cost has encouraged the use of various reclaimed materials from old structures as a source of construction material. This technology reduces both the cost of highway construction and protects the environment by reducing construction waste. Reclaimed Asphalt Pavement (RAP) had been used as aggregate for pavement construction for some time [11]. It has been shown that the presence of recycled fine aggregate has a negative impact on the physical-mechanical properties of concrete, therefore, even through a careful mix design and application of appropriate production technology these effects can be reduced to an acceptable level [14].

### 2.2. Theoretical review

As most of African cities, Addis Ababa also has the world's largest proportion of urban residents living in slums. About 80% of Addis Ababa housing units and neighborhoods in the city are considered to be slums[15].The use of recycled or secondary material in pavement construction is gaining popularity owing to added the advantage over conventional material, which includes the conservation of the natural resource, conservation of energy, preservation of the environment and reduction in life-cycle costs [16].

The principal factor behind recycling effort includes reduction of construction waste preservation of non-renewable natural resource and lower energy costs. Typically, economic saving and environmental benefits of using recycled material are balanced by the performance requirement of pavement design. It commonly acknowledges that the use of recycled construction material to the maximum extent possible should be carried out in overall [17].Recycled materials used in asphalt pavements and base/sub-base applications mainly come from construction and demolition wastes (CDW), solid wastes (SW) and by-products from industrial processes [7]. Out of the total construction demolition waste, 40% is of concrete, 30% ceramics, 5% plastics, 10% wood, 5%metal, & 10% other mixtures [18].

In the last11 years led to generate huge quantities of construction and demolition waste materials. In Addis Ababa, this C and D started after the frailer of the dreg regime 1991 which led the acceleration in the construction industry; and rapidly increasing after the beginning of the five years transformation plan of 2005. The main transformation plan in the construction sector includes rehabilitation of the existing infrastructures and construction of new civil engineering works, real estate ,highways, bridges, railway tracks, airports, power plants and water works, The disposal of construction and demolition wastes in Addis Ababa is one of the challenging problems; due to the scarcity of open lands and the limited size of municipal dumping sites to accommodate large quantities of debris and unprocessed construction wastes. The random and uncontrolled disposal of construction and demolition wastes creates several open dump sites. Waste arising from construction and demolition of construction materials which are obtained from demolished building and civil engineering infrastructures constitutes one of the largest waste streams in many developed countries. Of this a large proportion of potentially useful material disposed of as landfill [11].

Recyclable concrete often become available from demolition works and other construction (figure2.1) has been produced (currently up to 2 million tons annually and supplied to wide range of road application including the stabilized sub base of various section of the western ring road, where past practice would have been to use traditional quarried rock products. Crushed concrete by definition is composed of rock fragments coated with cement, with or without brick, sands and/or filler, produced to comply with tolerances for grading and minimum foreign material content, and supplied at lower density than that for crushed igneous rock (VicRoads (2006d-Standard Specifications for Road works and Bridge works, Section820 Recycled crushed concrete for pavement sub base and light duty base, July) .The crushed concrete aggregate was collected from Addis Ababa University institute of technology compound in which one of the buildings was demolished. The reason for demolishing of the entire building was not investigated in this research but simply sample was collected. The sample collected was the one broken down in small size to pick easily by hand [6].

Figure2.1: crushed concrete waste [19].

The sub-base is an important load spreading layer in the completed pavement. It enables traffic stresses to be reduced to acceptable levels in the sub grade, it acts as a working platform for the construction of the upper pavement layers and it acts as a separation layer between sub grade and base course. Under special circumstances, it may also act as a filter or as a drainage layer. In wet climatic conditions, the most stringent requirements are dictated by the need to support construction traffic and paving equipment.

In these circumstances, the sub-base material needs to be more tightly specified [20].Limit material passing the No. 200 (75µm) sieve to 15% maximum for all Grading (A – F) for un stabilized (granular) sub base. The complete sub-base shall contain no material having a maximum dimension exceeding two-thirds of the compacted layer thickness [21].

Table2.1: Quality requirements of sub base course materials [21].

| QUALITY REQUIREMENTS | |
|---|---|
| Sand Equivalent | 25 min. |
| Plasticity Index | 6 max. |
| Abrasion Loss | 50 max. |
| California Bearing Ratio (CBR) | 50 min. |

Recycled concrete could be used as a sub base material for highways. However, further tests may be needed to show the effect of having different proportions from mixing the recycled concrete and ordinary sub base [8].

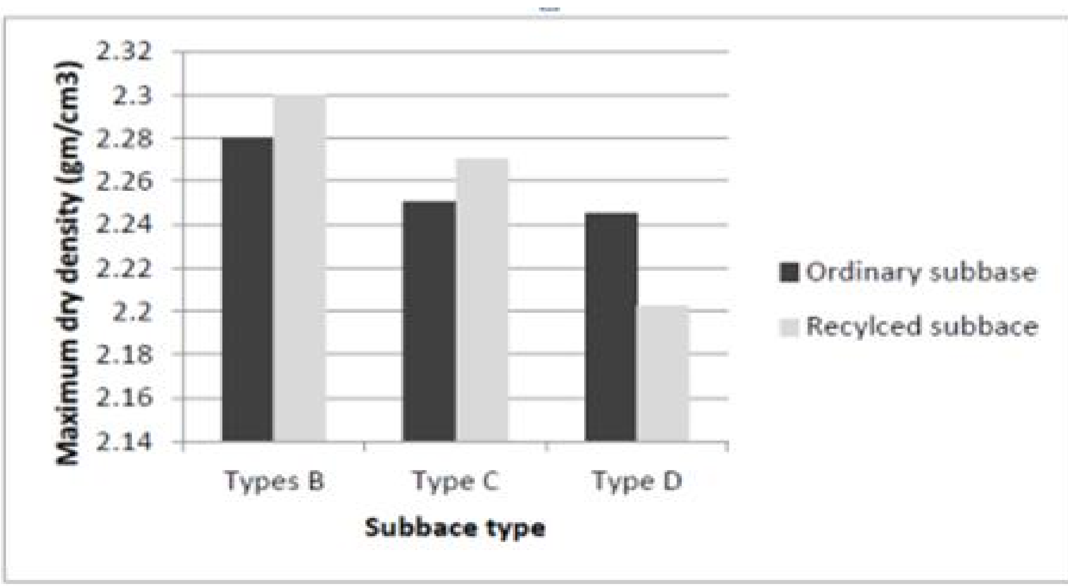


Figure 2.2: Maximum dry density results [8].

Hollow concrete blocks are one of the most extensively used wall construction material in major cities of our country, Ethiopia. Aggregates, cement, and water are the main materials required for the production of this building material [23].HCB masonry is believed to be cost and time efficient and economical solution in construction [23].The hollow block has a standard size of 390 x 190 x 190 mm; with a 25% to 50% of this size is a void. In the manufacturing process, a typical hollow block is estimated to consume 2.0 kg of cement, 9.0 kg of sand, 11.0 kg of aggregate, and 0.80 kg of water [24].

Figure 2.3: Recycled hollow concrete block [24].

## 2.3. Waste of hollow concrete block

The three main causes of block waste were: Manufacturing defects, such as deviations in the dimension of block and cracks. Lack of halves and quarter of blocks was the second source of waste for blocks. The third source of waste was cutting blocks due to the lack of modular coordination in design [25].Recycling of building wastes, usage of materials with a long period of durability and limitation of usage of building materials which pollute the environment are the basic recommendations of the strategy of the sustainable building trade and an element in the sustainable development.

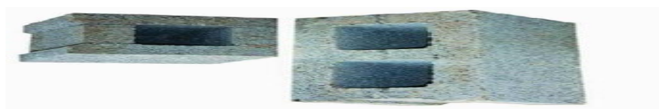

Figure2.4: Recycled hollow block 390x190x190 [25].

We have also observed in the site visit that material handling contribution to the Generation of waste in the construct site is significant. The figure 2.6 is portraying the negligence in material handling as an example. The picture taken one of the project in Addis Ababa how they store hollow concrete blocks [26]. This picture has been taken from Addis Ababa and illustrate the extent of wastage in hollow concrete block partly. Portrait the extent of material waste in building construction in those selected sample projects and believed that can show the case of Addis Ababa.

Figure2.5: Poor material handling [26].

Figure 2.6: Tile and HCB recycling in small scale around goffa comp [26].

Figure2.7: Showing the process of breaking the demolished concrete [26].

## 2.4 Recycled Asphalt Pavement (RAP)

The most used recycled materials are reclaimed asphalt pavement (RAP) materials and recycled concrete aggregate. The generation of RAP and RCA result in an aggregate of high quality and grading. Due to coating of asphalt on the aggregate of RAP it reduces the water absorption in aggregates [11].Production of reclaimed asphalt pavement (RAP) materials**:** Removal and reuse of asphalt layer of existing pavement is termed as RAP) The use of reclaimed asphalt pavement (RAP) in roadway construction fits with the global objective of sustainable development by the prudent use of natural resources [27].

More than 90% of U.S. roads are constructed with hot-mix asphalt and as the pavement infrastructure ages, there is a growing need to maintain and rehabilitate these roads. In principle, the same materials used to build the original highway system can be re-used to repair, reconstruct, and maintain it RAP, being produced from asphalt concrete, is mostly aggregate material and is itself granular and can be used in a variety of applications for which freshly produced natural Aggregates have traditionally been used With regard [25].

RAP intended for use as granular material in base and sub base applications, key factors for good performance are grading, particle toughness as measured by the plasticity of fines [29].

Reclaimed Asphalt Pavement (RAP) is used as an alternative of fresh or virgin aggregates word-wide. UK, USA, Japan, Canada and other developed countries have well established procedure, guidelines and standards to classify and to reuse recycled asphalt materials.

In India and other developing countries sufficient standards and guidelines as well efficient procedures are not available to characterize the reclaimed asphalt materials. Large quantities of Reclaimed asphalt pavement (RAP) materials are produced during highway maintenance and construction. A part of this can be used in new hot mix asphalt concrete and rest is available for other uses. If these materials could be re-used in base and sub-base of the roads, resulting in minimization of environmental impact, reduce the waste stream and also transportation costs connected with road maintenance and construction activities [10].

Reclaimed Asphalt Pavement (RAP) is another waste material generated when asphalt pavements are removed for reconstruction and resurfacing [30].

Figure2.8: Recycled asphalt pavement [30].

Figure2.9: Various Stockpiles of smaller size RAP materials [30].

## 2.5 Physical and mechanical properties

The physical and mechanical characteristics of the aggregate are one of the significant factor in determine the strength of the asphalt-aggregate bond. This also helps to determine where and how these aggregates can be used most effectively in roads.

Physical Properties and mechanical properties test

- Aggregate Impact test
- Crushing Test
- Abrasion Test
- Specific Gravity
- Flakiness Index
- Elongation Index
- Compacted Unit Weight 1600 - 2000 kg/m3 (100-125 lb/ft3)
- California Bearing Ratio (CBR)

Mechanical properties of aggregates are important, especially when the aggregate is to be used in road construction where it is subjected to high wear. It is generally under stood that the compressive strength of pavement layer cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. The required information about the aggregate particles has to be obtained from indirect tests, such as crushing strength of prepared rock samples, crushing value of bulk aggregate, and performance of aggregate in road pavement layer. The aggregate crushing value (ACV) test is prescribed by different standards, and is a useful guide when dea1ing with aggregates of unknown performance [31].

## 2.6 Laboratory test result

Laboratory tests were subsequently undertaken on these recycled Construction and Demolish aggregates. The laboratory investigation included basic characterization tests such as particle size distribution, particle density (coarse and fine fraction) and water absorption (coarse and fine fraction), flakiness index, Los Angeles abrasion(LAA) modified Proctor compaction and CBR test modified Proctor compaction effort, at optimum moisture content (OMC) to reach at least 98% of maximum dry density (MDD). The particle size distributions of the five recycled materials as-received to the laboratory (before compaction) and after modified compaction. For reference purposes, the grading ranges (i.e., the upper and lower limits) of the standard specifications for type 1gradation C material recommended in ASTM specification for materials for soil-aggregate sub base, base, and surface courses (ASTM 2007b) are also shown in table 2.2 [12]

Table 2.2: Tests for Aggregates with IS codes [11].

| Property of aggregate | Type of test | Test method |
|---|---|---|
| Crushing strength | Crushing test | Is:2386(part4) |
| Hardness | Loss angles abrasion test | Is:2386(part5) |
| Toughness | Aggregate impact test | Is:2386(part4) |
| Shape factors | Shape test | IS:2386(part1) |
| Specific gravity and porosity | Specific gravity and water absorption | Is:2386(part3) |

The LA abrasion test indicates that RCA, waste rock and Fine Recycled Glass are more durable in abrasion than Crushed Brick and RAP. RCA, crushed brick and waste rock meet the CBR requirements for usage as a sub base material while RAP would need to be blended with other higher quality aggregates to improve their CBR performances for usage as a sub base material RAP and Fine Recycled Glass on the other hand were unable to meet the CBR requirement. The properties of CB, RAP and Fine Recycled Glass however may be enhanced with additives or mixed in blends with high quality aggregates to enable their usage in pavement sub bases [12].

Table2.3: Result on Sample of Different Compositions of RAP and Natural Aggregates Combinations [11].

| Sample compostion | Aggregate Crushing value | Aggregate impact value | Flakiness &Elongation index ( combined) | Loss Angeles abrasion test value | Specific gravity | Water abrasion value | Soundness test |
|---|---|---|---|---|---|---|---|
| RAP10%+90% natural aggregate | 22.8 | 21.7 | 20.8 | 21.1 | 2.65 | 1.32 | 7.2 |
| RAP20%+80% natural aggregate | 22.7 | 20.9 | 20.5 | 20.1 | 2.66 | 1.0 | 7.1 |
| RAP30%+70% natural aggregate | 20.3 | 19.4 | 20.4 | 19.8 | 2.73 | 0.98 | 6.5 |
| RAP40%+60% natural aggregate | 20.2 | 19.6 | 20.3 | 19.8 | 2.74 | 1.12 | 6.2 |

### 2.6.1. Atter berg limit tests

The fine fractions used for Atter berg limit tests (i.e. particles smaller than 0.425 mm) are low and are mainly sand or silt by nature, so the plastic limit and liquid limit could not be obtained for any of C&D material studied in this research As the clay content is low some difficulties may occur with the workability of the recycled materials as cohesion of particles and a tight prepared surface is usually a sought after characteristic. The blending of these recycled materials with other aggregates or addition of small quantities of clayey sand or crushed fines may overcome this potential issue[12].For ordinary sub base materials, the results may vary depend on the amount of clay particles. The results obtained from the recycles concrete suggested no values for both plastic and liquid limits which mean zero plasticity index (PI-0). This is because the fine materials within the recycled concrete non-clay materials (i.e. sand particles) which prevent forming a sample tests according the Atterberg limits test's procedure. This is satisfying the Iraqi specifications requirements [8].

Similar to RG/CR blends, the fine contents in the RG/RCC blends were also non-plastic made out of silt size particles. Therefore, the plastic limit and liquid limit could not be obtained. The primary reason for this is the fact that the Atter berg limit is directly related to the clay mineralogy and as such, very low fines content with silt materials results in immeasurable plasticity. The results may vary depend on the amount of clay particles. The results obtained from the recycles concrete suggested no values for both plastic and liquid limits which mean zero plasticity index (PI-0). This is because the fine materials within the recycled concrete non-clay materials (i.e. sand particles) which prevent forming a sample tests according the Atterberg limits test's procedure [7].

### 2.6.2. Particle size distribution tests

The particle size distribution tests are also referred to as particle size analysis, sizing tests or mechanical analysis tests. Sieving is used for gravel and sand size (coarse) particles, which can be separated into different size ranges with a series of sieves of standard aperture openings [32].

Table2.4: Details of composite GSB with use of RAP [11].

| Sieve size(mm) | | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 63.0 | 100 | - | | - |
| 50.0 | 90-100 | 100 | 100 | - |
| 37.5 | | | 80-100 | |
| 25 | 51-80 | 55-85 | | 100 |
| 20 | | | 60-100 | |
| 9.5 | - | 40-70 | | 51-85 |
| 5 | | | 30-100 | |

| | | | | |
|---|---|---|---|---|
| 4.75 | 35-70 | 30-60 | | 35-65 |
| 2.0 | - | 20-51 | | 25-51 |
| 1.18 | | | 17-75 | |
| 0.425 | | 10-30 | | 15-30 |
| 0.3 | | | 9-50 | |
| 0.075 | 5-15 | 5-15 | 5-25 | 5-15 |

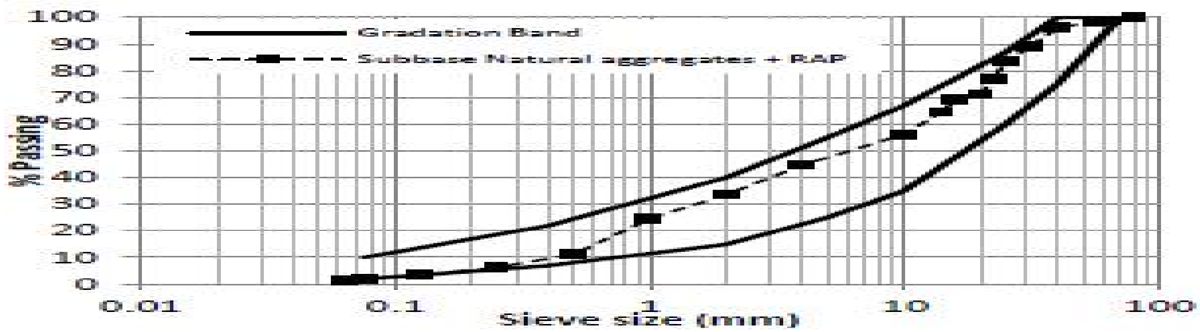


Figure2.10: Grading curve of sub base with only natural aggregates and blended with 50% RAP [33].

### 2.6. 3. Water Absorption test

The increase in the mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass [34]. Water absorption Values of different compositions of RAP & Natural Aggregates. The water absorption value for 30% RAP along with 70% Natural Aggregates combination was found to be 0.98% and 6.56% respectively [10].

According to all available research in this area, it has been shown that recycled concrete aggregate has significantly higher absorption level compared to natural aggregates. The reason for that is that the original cement mortar, which is an integral part of the recycled aggregate, has a significantly more porous structure in comparison to natural aggregate, whereby its porosity primarily depends on the water Cement ratio of the original (old) concrete [14].

The generation of RAP and RCA result in an aggregate of high quality and grading. Due to coating of asphalt on the aggregate of RAP it reduces the water absorption in aggregates [10].The bulk density of the recycled aggregate, due to a higher porosity of mortar layer, has a lower value than the bulk density of natural aggregates and their mutual difference decreases if recycling is conducted by an advanced technology, which can remove a significant portion of the old cement mortar .Also, the smaller the fraction, the greater the amount of cement mortar in the total mass of aggregates, so the bulk density is accordingly lower[14].

Aggregates with high water absorption usually indicate low durability and can also cause Problems during hot-mix asphalt design [30]. The natural aggregates have the highest density value, while crushed concrete has the highest water absorption value. Indeed, the high amount of adhered mortar attached to RCA particle leads to a decrease in particle density and an increase in the water absorption [35].

Specific gravity is the ratio of the density of the substance to the density of water. Density is the weight per unit of volume of a substance [31]. The specific gravity of RCA was in the order of 2.19–2.48 which is lower as compared to NCA (2.58) since the RCA from demolished concrete consists of crushed stone aggregate with old mortar adhering to it .When using recycled concrete aggregate as a base or sub base course, it is necessary to focus on its gradation, angularity, soundness, and solubility [35].RAP specific gravity of 2.45 was obtained. The sample passing the sieve was used as the replacement for the fine aggregate [36].

### 2.6.4. Flakiness index and elongation index

The particle shape of aggregates is determined by the percentages of flaky and elongated particles contained in it [37].Flakiness index is a measure of the thin and flat particles in the sample. This influences the material strength in two ways. Firstly, reduced strength is yielded when load is applied to the flat side or across shortest dimension of the aggregate. Secondly, flaky materials are prone to segregation and breakdown during compaction which is an important consideration while using for road pavement Flakiness index values for the recycled materials varied from 11 to 23 [12].

Flaky or elongated materials, when used in the construction of a pavement, may cause the pavement to fail due to the preferred orientation that the aggregates take under repeated loading and vibration. It is important that the flakiness and elongation of the aggregate are contained to within permissible levels. An aggregate is classified as being flaky if it has a thickness (smallest dimension) of less than 0.6 of its mean sieve size. The flakiness index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test is not applicable to materials passing the 6.30 mm test sieve or retained on the 63.00 mm test sieve [34].

An aggregate is classified as being elongated if it has a length (greatest dimension) of more than 1.8 of its mean sieve size. The elongation index of an aggregate sample is found by separating the elongated particles index pressing their mass as a percentage of the mass of the sample tested. The test is not applicable to materials passing the 6.30 mm test sieve or retained on the 50.00 mm test sieve [34].

### 2.6.5 California Bearing Ratio (CBR) Test

The minimum soaked Californian Bearing Ratio (CBR) shall be 30% when determined in accordance with the requirements of AASHTO T-193. The Californian Bearing Ratio (CBR) shall be determined at a density of 98% of the maximum dry density when determined in accordance with the requirements of AASHTO D-180 [21].

#### 2.6.5.1 Optimum Moisture Content

No swelling was observed in the soaked samples. The data indicates that none of the samples satisfied the minimum CBR requirement of 80% specified in QCS 2010 for base/sub-base materials. However, there was an increase in CBR with an increase in RAP content in the mixes [7].

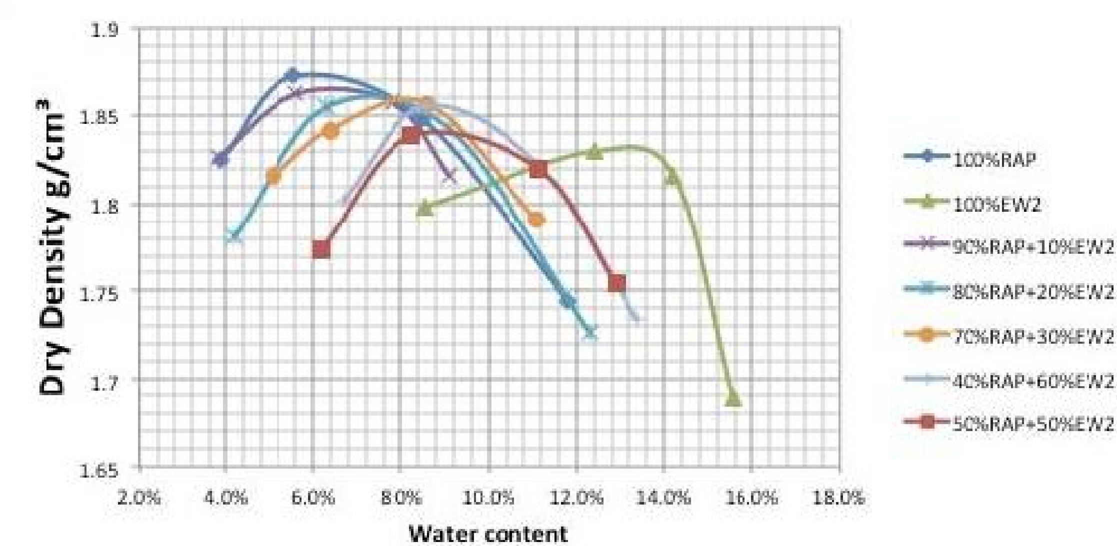


Figure2.11: Plots of dry density versus water content for sample mixes [7].

Figure 2.11 shows the results obtained from the CBR test for both ordinary and waste materials. The results suggest that the CBR values obtained from the recycled concrete give significantly higher CBR values when compared with those values obtained from the ordinary sub base. This could be related with the amounts of dust materials which are usually higher in the ordinary sub base. The whole materials quality may be another reason since the concrete material should have more resistance for the applied load compared with the ordinary sub base materials[8].The CBR test's results suggests that the CBR values obtained from recycled concrete are significantly higher than those CBR values obtained from the ordinary sub base [8].

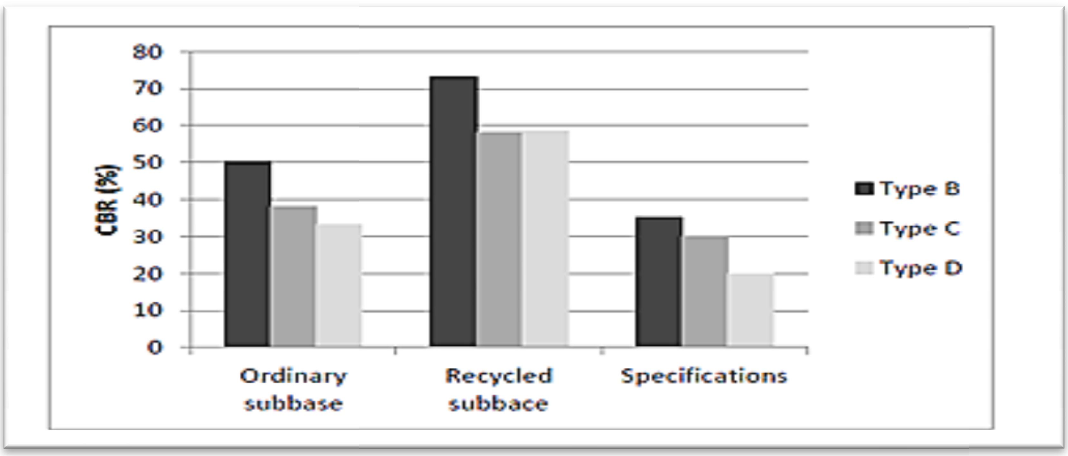


Figure2.12: California bearing ratio (CBR) results [8].

Recycled construction and demolition materials in pavement sub base results of their study suggested that a 4-day soaked period has a negligible effect on the CBR value of the recycled material while they exhibit a negligible swell percentage after the soaking period [12].

### 2.6.6 Aggregate Crushing Value

Crushing values test uses the ability of the aggregates used in road construction to with stand .The stresses induced by moving vehicles in the form of crushing and also provide sufficient resistance to crushing under the roller during construction [2].Aggregate crushing value of the discarded aggregate is (28.91%) while the natural aggregate is (23.63%)[38].

### 2.6.7 Aggregate Impact Value

The aggregate impact value indicates a relative measure of the resistance of aggregate to a sudden shock or an impact, which in some aggregates differs from its resistance to a slow compressive load. The method of test covers the procedure for determining the aggregate impact value of aggregates. The result of impact test on fresh aggregates is shown in Table1.13.The result shows that impact value for the fresh aggregate is 14.81% [37].

Table 2.5: Result of aggregate impact value of fresh aggregate

| |
|---|
| Weight of collar 1259.5 |
| Weight of material 1328gm |
| Weight of material passing 48.60g |
| Through the is 2.36mm sieve |
| Impact value 14.81% |

Table2.6: Result of aggregate impact value of recycled aggregate

| |
|---|
| Weight of collar 1259.5 |
| Weight of material 1345gm |
| Weight of material passing 42.30g |
| Through the is 2.36mm sieve |
| Impact value 12.26% |

The result shows that impact value for the fresh aggregate is higher than the recycled aggregate value, but still the impact value of recycled aggregates are fairly good to use in GSB construction [37].The aggregate impact value for discarded or used aggregate (24.17%) is higher than that of the natural aggregate (20.73%) which implies that the discarded aggregate is lower in strength than the natural aggregate. Construction Standard (CSC, 2013) recommended that aggregate impact value of coarse natural aggregate when determined in accordance with section 15 of the standard shall not exceed 30%. The results of both coarse aggregates satisfy the recommendation [38].

### 2.6.8. Loss Angeles Abrasion Test

Los Angeles (LA) abrasion tests were conducted in accordance with the ASTM C131

Standard specification to determine resistance to abrasion [13].

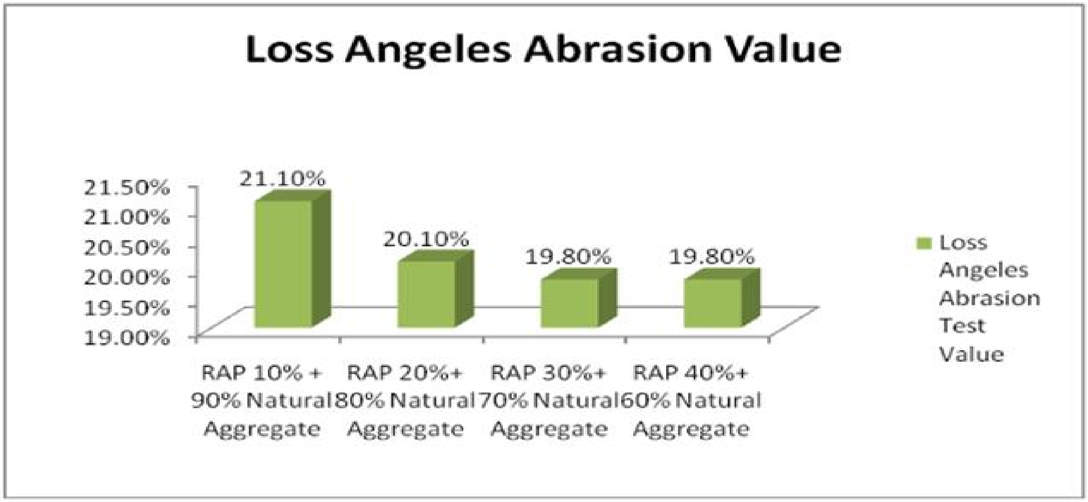


Figure2.13: Variation of Loss Angeles Abrasion value for different Sample.

### 2.6.9. Compaction

Compaction requirements

The minimum dry density to which the material shall be compacted shall be 95% unless specified otherwise, shown on the drawings or ordered by the Engineer, of the maximum dry density as determined by AASHTO T 180. Field dry densities shall be determined by the sand replacement method as specified in AASHTO T 191 or nuclear method as specified in AASHTO T 238 [21].The maximum dry density and a small difference in the OMC. As the RAP content of the blend increased, the OMC decreased [27].

The maximum densities obtained from the ordinary sub base are 2.280, 2.250, 2.245 gm/cm3 for types B, C and D respectively. While the corresponding densities for the recycled samples were 2.23, 2.27 and 2.202 gm/cm3.

Generally, the results more or less are identical and that suggest that the sub base material obtained from the recycled concrete can be compacted to reach reasonable density. When aggregate is used as road sub base material or fill, one of the most important influences on its behavior is density. Since best compaction can be achieved at the optimum moisture content (OMC) its determination will help to carry out compaction in the field by adding that much amount of water to the soil during compaction. Moreover, the compaction effort will continue in the field till maximum dry density is obtained in the compacted soil. Hence, the laboratory determination of OMC and maximum dry density [39].

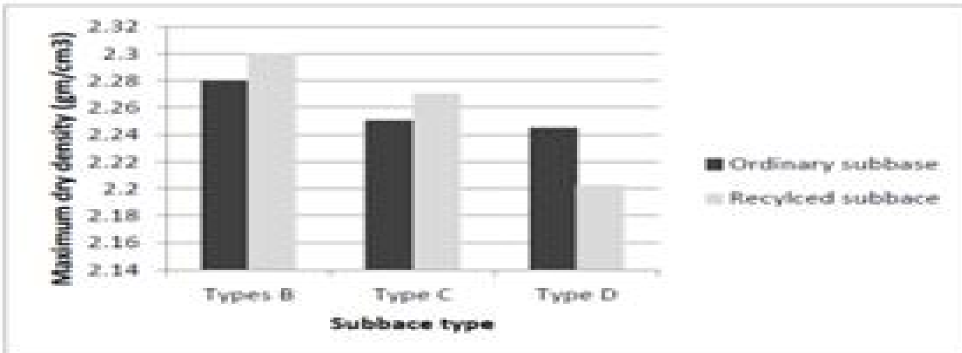


Figure2.14 Maximum dry density results [8].

#### 2.6.9.1Bulk density

An increase in a share of recycled aggregate in total mass of the component aggregate reduces the bulk density of fresh concrete, where it was shown that the bulk density of The recycled aggregate concrete was 5% to 10% lower than in the comparable natural aggregate concrete, while concretes made with the recycled coarse aggregate and natural fine aggregates had densities of 1% up to 5% lower than in the comparable natural aggregate concrete [40].

# CHAPTER THREE

# MATERIAL AND RESEARCH METHODOLOGY

## 3.1 Study Area

The RAP samples used for this research were obtained from Addis Ababa, road from Hana Mariam to Garment. The geographical location of Hana Mariam is located at 8 º 56' 9.56" latitude and 38 º44' 39.2" longitudes. The waste HCB samples used for this research were obtained from Addis Ababa, around legehare. The geographical location of legehare located at 9 º 0' 41.19" latitude 38 º45' 9.37 " longitudes.


Figure3.1: Geographic Location of the study Area. [Google earth]

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### 3.2. Study Design

A study design is a process that guides researchers on how to collected samples; the test was conducted and analysis the result. Study design of this research was presented in the flowing flow chart.

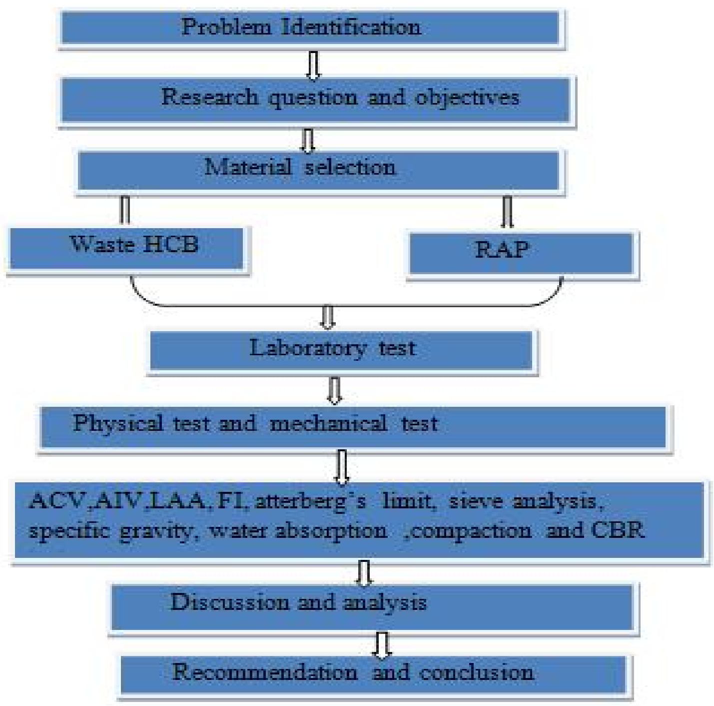


Figure3.2: Study design

### 3.3. Study population

The population for this research were the material to be used such as recycled asphalt pavement and waste of hollow concrete block used us sub base material based on standard specification of ERA, BS, AASHTO and ASTM.

### 3.4. Material Collection & preparation

The waste HCB was collected from on the Capital city of the country, Addis Ababa legehare in which logistic and shipping building was demolished. The reason for demolishing of the entire building was not investigated in this research but simply sample was collected. The RAP was collected from on the Capital city of the country; Addis Ababa Hana Mariam to Garment road was deteriorated.

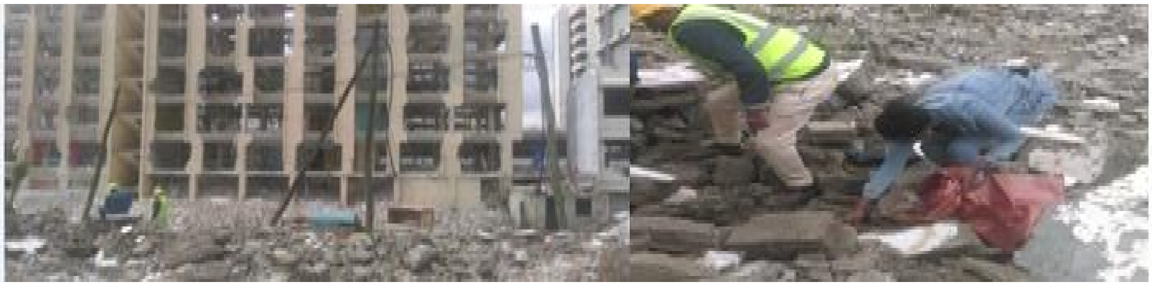

Figure3.3: Waste HCB site on lagehare [Tasfaye 2, 3:45]

Figure3.4: RAP site on Hana Mariam to Garment [Diriba 2, 7:30]

### 3.5. Sample preparation method

Include the first activity was carried out on representative sample before laboratory tests begun by air dried under the sun to allow moisture to evaporate till just below value. Extracted RAP then broken down in small size to pick easily by using hammer. This obtained material was hand crushed using hammers to obtain a representative sample containing wastes HCB and RAP of size ranging from 0.075mm – 37.5mm. After air-drying.

sieving and the mechanical splitter was used to obtained uniform and representative sample for all test and was used before sample of waste HCB and RAP starting with the testing sub sampling (quartering) Accordingly, as per AASHTO T248-96 the waste HCB sample and RAP sample was quartered and prepared for intended tests Riffle box is available for quartering the sample and done with this apparatus. All the tests conducted as per ERA, BS, AASHTO and ASTM specification.

The first procedure was to prepare the sample by quartering to get equitable sample.

The test specimens were prepared using a different amount of RAP and waste HCB based on the rate of replacement Proportion by weight in the blending. After taking a representative sample by Mechanical splitting, 6 blends sample was prepared with waste HCB to RAP of 0/100%, 20/80%, 30/70%, 40 /60 %, 50/50%, and 100/0%.

Figure3.5: Photo show preparation of specimen for laboratory test [Lami 6, 4:30]

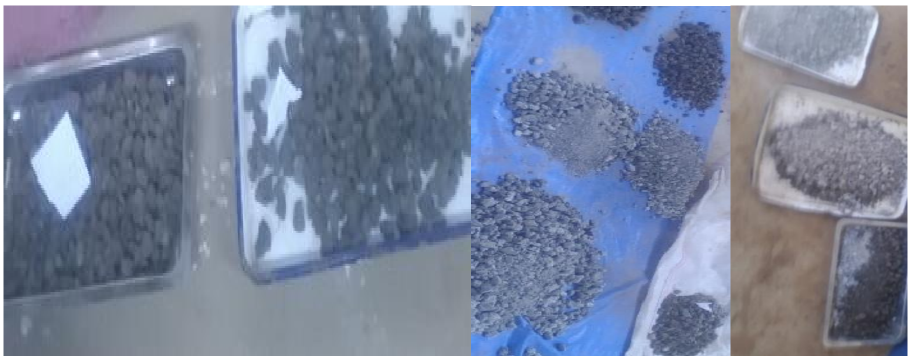

Figure 3.6: Sample preparation for RAP and waste HCB [Merid7, 3:20]

Table 3.1: Blending Ratios Waste HCB and RAP

| No | % RAP | % HCB |
|---|---|---|
| 1 | 100% RAP | 0% HCB |
| 2 | 20% RAP | 80% HCB |
| 3 | 30% RAP | 70% HCB |
| 4 | 40% RAP | 60% HCB |
| 5 | 50% RAP | 50% HCB |
| 6 | 0%RAP | 100%HCB |

### 3.6. Laboratory test

The laboratory test was conducted to evaluate the physical and mechanical properties of blending of waste HCB and RAP. The laboratory test was under taken to evaluate the physical and mechanical properties of RAP and waste HCB in detail procedure .the blending was designed for granular sub base course.

To ensure the accuracy of laboratory result, a careful following of proper test procedure as described by AASHTO, BS and ASTM standard specification were carefully under taken. Laboratory tests were conducted on the samples of waste HCB and RAP materials. The gathered representative samples for laboratory test were performed in the laboratory of JIT. This study had to meet objective of the research.

- To determine the physical, mechanical properties of the selected materials prior for blending in the laboratory.
- To evaluate various parameters of HCB wastage and Recycled asphalt pavement blending which influence the strength of the sub base layer.
- To determine the combined effects of the HCB wastage and Recycled asphalt pavement considering varying proportions and to compare with the Standard Specification.

The following tests were carried out in the first phase includes: Sieve analysis, Atterberg's limits, compaction and CBR tests, ACV, AIV, LAA, SG and Water absorption had been conducted on waste HCB and RAP samples collected from two different locations (legehare- and Hana Mariam roads). The composed waste HCB and RAP determine the physical and mechanical properties of material was conform quality and strength requirements of standard specification of AASHTO, ERA, BS.

Table 3.2: Summary of test carried out and their uses

| Parameters | Standard | purpose of test |
|---|---|---|
| Sieve analysis | AASHTO T27 | to know quantitatively the mass of particles in each range |
| Atterberg limit test | AASHTOT89 andAASHTOT90 | To evaluate plastic limit ,liquid limit and plastic index |
| ACV | BS 812, Part 110 | Used to evaluate the crushing resistance of aggregate under gradually applied load. |
| AIV | BS 812, Part 112 | To evaluate the toughness of coarse aggregate under sudden shock or impact. |

| | | |
|---|---|---|
| LAA | ASTM C131 and ASTM C535-89 | Used to evaluate how the aggregate is sufficiently hard to resist the abrasion effect. Or resistance to wearing action |
| CBR test | AASHTO T193 | Used to, evaluating the strength of cohesive materials having maximum particle sizes less than 19 mm (3/4 in.). |
| Compaction test | ASTM C 566-84 | Used to determine the dry density and moisture contents of aggregate |
| Specific gravity absorption test | AASHTO T 85 | Used for analysis, aggregate density with relative to water |
| Flakiness index | BS 812, Part 105 | Used to test course aggregate shape and classify aggregates and stones. |

### 3.6.1. Sieve analysis

Soils consist of particles with various shapes and sizes. Particle Size Distribution test is used to separate particles into size ranges and to know quantitatively the mass of particles in each range [42].

Grading of material used was determined by this method. In this test, representative samples of approximately 3 kg were used for the test. The sample was washed and oven dried before sieving. The sieving was carried out using an automatic shaker with a set of sieves stacked in order of decreasing sieve sizes. From the weights retained on each of the sieves, the percentage passing was obtained which was then plotted on semi log graph to give the particle distribution curve.

The material was not suitable for sub-base since it did not meet the graduation requirements. Particle sizes of 2.00, 0.425 and 0.075 mm were out of the grading percentage limits. However, blending it with 30% waste aggregates improved the particle size distribution within the percentage limits [43].

Since waste HCB and Recycled Asphalt pavement were often have made up of a grain of many different sizes, the size used in a sub base course layer should be processed to coarse and fine RAP waste HCB size. Grain-size analysis of aggregate containing relatively large particles is accomplished using sieves. It is an apparatus having openings of equal size and shape through which grains smaller than the size of the opening will pass, while larger grains are retained. Sieve analysis involves a nested column of sieves with punch plate, woven wire mesh and or cloth screens nested in decreasing order and the sample is shaken through the sieve until no more will pass and the retained portion on each sieve is weighed and recorded .All states set gradation limits for material that are to be used as sub base course material .the gradation of a material is an indicator of other properties such as atterberg limit, AIV,ACV,LAA,SG, Absorption, FI,CBR and compaction test.

This parameter consists of shaking sample of known mass through a sieve size. For each size was conducted as per AASHTO T 27-99 manual. Blending of waste HCB and RAP was done by the particle size distributions of the blending of waste HCB and RAP OF 100% RAP, 80% HCB&20% RAP waste 70% HCB and 30 RAP &60% waste HCB, 40% RAP& 50% waste HCB 50%waste HCB, 100 % waste HCB Blending of these material was done to get the desired specification limit grading as per AASHTO T 27 and ERA flexible pavement design manual for sub base course requirements. For reference purposes, the Grading ranges (i.e., the upper and lower limits) of the standard specifications for type 1Gradation C material recommended in ASTM specification for materials for soil-aggregate sub base, (ASTM 2007b) are also shown in table 3.3

Table 3.3: Typical Particle Size Distribution for Sub-bases (GS)

| test sieve seize (mm) | Percentage by mass of total aggregate passing test sieve (%) |
|---|---|
| 50 | 100 |
| 37.5 | 80-100 |
| 20 | 60-100 |
| 5 | 30-100 |
| 1<br>.18 | 17-75 |
| 0.3 | 9-50 |
| 0.075 | 5-25 |

Figure 3.7: Sieve Analysis [Adamu 5, 4:30]

### 3.6.2. Atterberg's limit

The plasticity of the minus No. 40 (0.425mm) sieve size material was evaluated using Atterberg Limits. Plastic limits are used to identify the moisture content at which a material begins to exhibit plastic behavior. The liquid limit is used to define when the material behaves as a viscous liquid. The numerical difference between the two limits is called the Plasticity Index (PI) which indicates the magnitude of the range of moisture contents a material will remain in a plastic state.

Obtain the water content corresponding to the intersection of the line with 25 drops on the abscissa as the liquid limit, LL, of soil. Compute the average of the water contents obtained from the two plastic limit tests. The plastic limit, PL, is the average of the two water contents. If either the liquid limit or plastic limit cannot be determined, the plasticity index cannot be computed and should be reported as "NP" (indicating sample is non plastic). The plasticity index should also be reported as "NP" if the plastic limit turns out to be greater than or equal to the liquid limit [44]. RCA, CB, WR, and RAP of fine fractions used for Atterberg limit tests (i.e. particles smaller than 0.425 mm) are low and are mainly sand or silt by nature, so the plastic limit and liquid limit could not be obtained for any of C&D material studied in this research [45].

Figure 3.8: Atterberg limit test [ Dabela 9, 3:20]

### 3.6.3. Specific Gravity and Absorption

The specific gravity of blending waste HCB and RAP is done as per AASHTO T 84 & AASHTO T 85 for fine and course aggregates respectively. In this definition fine aggregates are the aggregate size less than 4.75mm sieve size and coarse aggregates are greater than 4.75mm. This test was conducted for bulk specific gravity (dry and saturated surface dry) and apparent specific gravity.

Usual procedures were followed to conduct the test for RAP and waste HCB. The reduction in water absorption of concrete containing RAP is due to the air voids created in the matrix preventing water getting access. More so, the replacement of fine aggregates RAP which may fill up voids within the specimen with bituminous tiny particles could also contribute to the water resistance of the specimens [29].

The bulk specific gravity test which is used in the phase relationship of air, water and solids in a given volume of the material was carried out in accordance with ASTM Standard Test Method D854:2006: Standard Test Methods for Specific Gravity of Soil Solids by water Pycnometer. The discarded coarse aggregate is specific gravity is (2.54) while the natural coarse aggregate is (2.78). The specific gravity of the natural coarse aggregate satisfies the BS 882 (1992) requirements of greater than 2.6 while the discarded coarse aggregate failed to meet the requirement of greater than 2.6 [38].

Usual procedures were followed to conduct the test for both waste HCB and RAP.

- The representative sample of 2kg passing 19mm IS sieve

- Two trial specimen taken and filled in wire basket and then basket which filled with sample kept in water which filled in side of cylinder
- The representative specimen measured inside the water filled inside the cylinder after 24 hours
- Measurement was taken which submerged in water
- The weight of wire basket in water was taken
- Cotton cloth to make them surface dry and saturated surface of representative sample calculated
- The sample was kept in oven dry for 4 hours
- Then water absorption and specific gravity sample was calculated.

A=Mass of oven dry sample in air

B= Mass of sample in air Saturated, Surface Dry (SSD) the condition in which the aggregate has been soaked in water and has absorbed water into its pore spaces. The excess, free surface moisture has been removed so that the particles are still saturated, but the surface of the particle is essentially dry.

C= Mass of saturated sample in water

Specific gravity = A/ (A-C)

Water absorption = (B-A)*100/A

Figure 3.9: water absorption test for waste HCB and RAP [Tesfaye 21, 9:45]

### 3.6.4. Los Angeles Abrasion (LAA) Test

ERA pavement design manual rates materials for use as a sub base course material in road by the Los Angeles abrasion value shall not exceed 45% when determined in accordance with the requirements of AASHTO T-96.Los Angeles Abrasion is a measure of wearing/degradation capacity of the aggregate by revolving the aggregate in rounded steel container and impacted by steel balls. This test was conducted as per AASHTO T 96/ ASTM C131 test procedures. Since the nominal sample size was 10-6.3 and 6.3-4.75 mm, grading c was chosen for testing LAA.

Usual procedures were followed to conduct the test for both waste HCB and RAP. The test sample and the abrasive charge was place in the Los Angles abrasion. The loss in weight of granular material shall not exceed 45% after 500 revolutions, when tested in accordance with AASHTO T 96 (Los Angeles Abrasion Test).At the completion of the test, the material was discharge and Sieved through 1.70mm IS Sieve. The material that was coarser than 1.7 mm size had been washed and dried in an oven and weighed. The difference between the original and final weights of the sample was expressed as a percentage of the total weight of the sample and recorded as the percentage wear. The RCA had aconsistent results for Los Angeles Abrasion value which is 20% -25% greater than that for the NA which is only 11% [31].

LAA calculation formula

Mass (g) A=sample pass 10- retained 6.3 and pass 6.3- retained 4.75 total weigh was 5000 gram Mass of sample retained on 1.70 mm sieve after washing and oven dried (B)

Loss through 1.70 mm sieve= A-B=C

LAA=C/A*100

Figure 3.10: Los Angeles abrasion Test and apparatus [ Lami 29, 4:50]

### 3.6.5. Aggregate Crushing Value (ACV) Test

The toughness and strength of coarse aggregates can be measured by ACV test which was a relative measure of the resistance of an aggregate to crushing under gradually applied load.ACV is determined by measuring the material passing a 2.36 mm.

Aggregate crushing value was conducted as per ERA specification sample was prepared that passes 12.5 mm sieve size and retain 10mm.

About 4600gm sample was prepared each blending and divided into two test specimens. Under a load of 400 kn applied to test specimens. The strength and toughness of material can be measured by ACV test which is a relative measure of the resistance of an aggregate to crushing under gradually applied load.ACV was determined by measuring the material passing a 2.36 mm BS. Testing machine after 4 hours of drying in an oven and letting them cool. Two trials for each material were conducted and the Average value taken as an ACV for the material. Detailed test procedures can be referred in BS 812: part 110 of ACV and BS 812:

$$ACV = \frac{W2}{W1}$$

Where**:** WI= Total weight of dry sample taken (in gm).

W2= weight of the portion of crushed material passing 2.36mm IS sieve (in gm).

(In British standard pavement design manual there are specific requirements of ACV should be fulfilled by materials to approve their use of a flexible pavement sub base course The maximum value set under this manual for ACV is less than 25.

Both waste HCB and RAP was suitable the laboratory result of ACV were less than 30 in such case ten percent fine value described in BS812-111 is not applicable.


Figure 3.11: Crushing Value Test and apparatus to crush aggregate [Terefe 27, 3:45]

### 3.6.6. Aggregate impact value test

Aggregate impact value test was carried out to determine the resistance to impact of aggregates and the resistance of aggregates subjected to a sudden loading. Size of aggregates that passing 12.5 mm sieve and retained on 10 mm sieve are to be used. Then the waste HCB and RAP filled in a cylindrical steel cup with the diameter size of 10.2 mm and depth of 50 mm where it is attached to a base made up from metal of the impact testing machine.

Compact the material by giving 25 gentle blows with the rounded end of the tamping rod. Add two more layers in similar manner, so that cylinder is full. Strike off the surplus aggregates. The waste HCB and RAP filled in 3 layers where each layer is hammered for 15 numbers of blows. Metal hammer with the weight of 13.5 to 14 Kg was drop with a free fall of 38.0 cm high. The crushed aggregate that pass through 2.36 mm IS sieve was weight as an impact value. And the impact value was measured as percentage of aggregates passing sieve to the total weight of the sample

Total weight of dry sample (W1 gm)

Weight of portion passing 2.36 mm sieve (W2 gm)

Aggregate Impact Value (percent) = W2 / W1 X 100

Table 3.4: Classification of aggregates using Aggregates Impact Value is as given below [31].

| Aggregate impact value | classification |
|---|---|
| <20 | Exceptionally Strong |
| 10-20 | Strong |
| 20-30 | Satisfactory for road surfacing |
| >35 | Weak for road surfacing |

Figure 3.12: Aggregate impact value test and apparatus used [Tigist25, 4:08]

### 3.6.7. Compaction test

Compaction test was carried out to determine the dry density of material based on different moisture contents. The outputs were plotted as a compaction test which specified maximum dry unit weight and corresponding water content for effective compaction of recycled concrete aggregate [42].

Soil compaction is the process in which a stress applied to a soil causes densification as air is displaced from the pores between the soil grains causes densification as air is displaced from the pores between the soil grains. This laboratory test is performed to determine the relationship between the moisture content and the dry density of soil in a specified compaction effort. The compact effort is the amount of Mechanical energy that is applied to the soil mass. Optimum water content is the water content that results in the greatest density in a specified compaction level [2].

Moisture density relationship or proctor test was conducted as per AASHTO T 180-97 for waste HCB and RAP. This test has two versions. For this study modified proctor test was conducted with 4.5 kg rammer and 457mm dropping height. Method C was followed by taking the material passing 19.0mm sieve and mould diameter 101.6mm. The optimum moisture determined here was also used for CBR testing. The modified Proctor compaction test was performed on each material in accordance with ASTM D 1557, and the optimum moisture content (OMC) and maximum dry unit weight (MDU) were determined. Before running the compaction test, the samples were screened through a 19.5 mm sieve.

Figure 3.13: Compaction test and apparatus used [Lami 24, 3:35]

### 3.6.8 California bearing ratio (CBR) test

The CBR test's results suggest that the CBR values obtained from recycled concrete is significantly higher than those CBR values obtained from the ordinary sub base. The results obtained from maximum dry density test suggested that the waste materials could be compacted to reach reasonable density [8].

The minimum soaked Californian Bearing Ratio (CBR) shall be 30% when determined in accordance with the requirements of AASHTO T-193.According to AASHTO Designation: T 193-99 (2003) this test method covers the determination of the California Bearing Ratio (CBR) of pavement sub grade, sub base, and base/course materials from laboratory compacted specimens. The test method is primarily intended for but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than 19 mm (3/4 in.).

The method uses material passing19 mm size and provides the CBR value of material at optimum water content. The specimen shall be soaked before penetration. A surcharge placed on the surface to represent the mass of pavement material above sub base course. The sample is soaked to simulate its weakest condition in the field. The material strength has been used for design purpose by interpolating the CBR values at different compaction levels, with 10, 30 and 65 blows and compacted in 5 layers by heavy compaction. This procedure was necessary to obtain 98% of maximum dry density as determined by laboratory compaction test. Water to be added was calculated from compaction test results.

The CBR value at 2.50mm penetration will be greater than that at 5.00mm penetration and in such case take the value at 2.50mm as the CBR value. If the CBR value corresponding to a penetration of 5.00 mm exceeds that of 2.50mm.Samples were compacted at the OMC in accordance with ASTM D 698 (standard proctor compaction test). Then, compacted samples were soaked in water for 96 hours prior to conducting the California Bearing Ratio (CBR) test (ASTM D 1883). No swelling was observed in the soaked samples [7].

Figure 3.14: CBR test and apparatus used [Tesfaye 2, 3:5]

### 3.6.9. Flakiness index Test

The flakiness index of a waste HCB and RAP sample were found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test was not applicable to materials passing 6.3mm, BS test sieve or retained on a

63.0mm BS test sieve. The test performed a measure gauge that has standard sized slots through which the sample pieces are either passed through or retained. The result was based on a combined Calculation of that which passes through the slots divided by those retained on the gauge. The test conducted by trying to pass materials prepared by sieving through Standard gauges for each fraction of aggregates (50.0mm, 37.5 mm, 28.0 mm, 20.0 mm, 14.0mm, 10.0 mm, and 6.3 mm) and recording the weights of particles passing and retained. Sieve the aggregates first in IS sieve 63 mm and collect the aggregates Passing through this sieve and retained on Is sieve 50 mm. Collect the aggregates which are passing in the gauge in a separate tray. Repeat the same procedure for the remaining sample of aggregate. Weigh the aggregate passing through the various slots of the thick Repeat the same procedure for the remaining sample of aggregate.

The Value of the flakiness index is calculated from the expression blow. This test was conducted on waste HCB and RAP samples.

Flakiness Index in %, $FI = \frac{M3}{M2} * 100$

Where: M2=total weight of the sample taken,

M3= combine and weight all the particle Passing each of the gauges.

Figure 3.15: flakkines index test and apparatus used [Diriba 8.3:45]

### 3.7. Study variables

There are two types of variables that were taken into consideration

#### 3.7.1 Independent variable

Recycled asphalt pavement

Waste of hollow block concrete

Sieve analysis,

LAA

CBR

AIV

ACV

Flakiness index

Water absorption

Specific gravity

#### 3.7.2. Dependent variable

Effect of combined waste hallow block concrete and recycled asphalt pavements for sub base course.

### 3.8. Source of Data

#### 3.8.1. Primary data

The primary data was collected materials & experimental out put

#### 3.8.2. Secondary Data

Journals, book, website and manuals.

### 3.9. Sampling Techniques

The sampling technique used for this research was a purposive sampling which is non – probability method. Because the experimental investigation of the study was executed.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1. Physical Properties and mechanical properties

The physical properties and mechanical properties of waste HCB collected from of legehare demolished building and the RAP which was collected from Hana Mariam. Was tested in laboratory of jimma institute of technology are discussed here:

### 4.1.1. Atterberg limits

The plastic limit turned greater than the liquid limit Result in immeasurable plasticity

The fine contents in the waste HCB /RAP blends were also non-plastic made out of silt size particles. Therefore, the plastic limit and liquid limit could not be obtained. The primary reason for this is the fact that the Atterberg limit is directly related to the clay mineralogy and as such, very low fines content with silty materials. This aspect suggest that some difficulties may be experienced with the workability of the blends as HCB /RAP cohesion of particles and a "tight" prepared surface are usually sought after characteristics.

The Atterberg limit is directly related to clay mineralogy and as such, higher clay contents result in higher plasticity. However, waste HCB and RAP is made of aggregate, cement and sand, hence the clay contents in materials are very low. Therefore, the plastic limit and liquid limit of the waste HCB the fines were non-plastic with silt size materials and RAP samples could not be obtained. Hence it can be taken as non-plastic. The waste HCB and RAP were non-plastic with silt size materials.

Table 4.1: determination of plastic index for blended material

| percentage of different proportion | material description | plastic index |
|---|---|---|
| 0% RAP+100% waste HCB | Waste HCB | NP |
| 20% RAP+80% Waste HCB | RAP-WASTE HCB | NP |
| 30% RAP+ 70%Waste HCB | RAP-WASTE HCB | NP |
| 40%RAP+60%Waste HCB | RAP-WASTE HCB | NP |
| 50%RAP+50 %waste HCB | RAP-WASTE HCB | NP |

### 4.1.2. Particle size distribution

The mechanical analysis to determine the proportion of course material distribution by use of sieve analysis were undertaken on RAP sample collected from Hana Mariam sites and waste HCB sampled from lagehare site, and all blended proportional in percent by weight were conducted for gradation tests.

The result was expressed by a plot of percent finer (% passing) by weight against the size of soil particles in millimeters on a log scale. Samples of different compositions were prepared by adding different percentage of RAP materials (0% RAP, 20%RAP, 30%RAP, 40%RAP, 50RAP and 100% RAP).

The result indicated 30% RAP and 70% HCB were satisfying upper and lower specification ERA but the blending of both RAP and waste HCB materials failed to fit within the gradation limit of the ERA manual specification for granular sub base course of 0% RAP, 20%RAP, 40%RAP, 50RAP and 100% RAP. The grain size analysis results are plotted below and the data is given in AppendixA-1

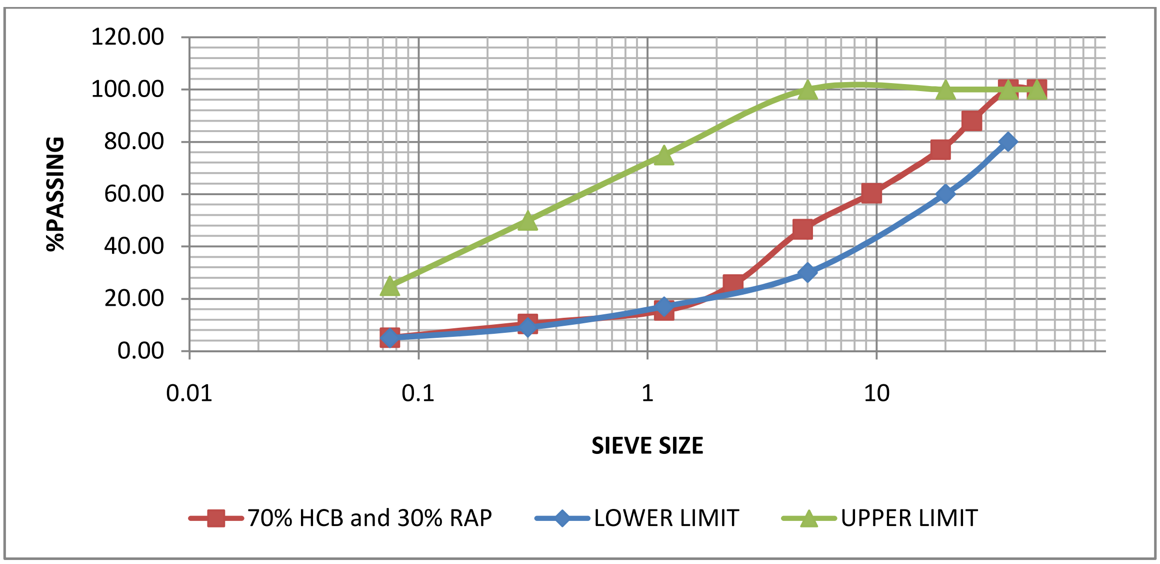


Figure 4.1: particle size distribution curve for blended 70% waste HCB and30% RAP

### 4.1.3. Specific Gravity and Absorption

The water absorption shall not exceed 2% when determined in accordance with the requirements of AASHTO T-85.Waste HCB and RAP, blended waste HCB and RAP was fractioned above or below specification RAP-100, RAP-20, RAP-50, RAP- 40and HCB-100 not fit with ERA specification for sub base course, Through trial and error, 30% RAP blended with 70% waste HCB were fully fitted with specification for sub base course**.** The specific gravity blended waste HCB and recycled Asphalt pavement was found from 2.017 to 2.6 as it can be observed from the results the absorption of waste Hallow concrete block waste was greater than recycled asphalt pavement.

This indicates that more mortar is found in the waste Hallow concrete block portion.

Due to the porosity of the mortar attached coarse waste HCB .The results of the specific gravities and absorption for blended waste hallow concrete block waste and recycled asphalt pavements.

Waste HCB having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable based on strength, impact. This test helps to determine .The result indicated 30% RAP and 70% HCB greater than 2.4.waste HCB consist of crushed HCB with old mortar adhering to it, the water absorption 13% which is relatively higher than that of the RAP.

RAP water absorption results satisfactory. RAP sample had a specific gravity 2.06 which indicate the lightweight nature of RAP and also implies that lower density of RAP gives lower specific gravity. This is due to minimal fine material in RAP particles.

For RAP mix with waste HCB by percent in weight based Water absorption range from 1.08% to 13.5%. As a percent of RAP blending were increased the water absorption values are decreased. For the absorption the absorption capacity of each waste HCB samples was higher than RAP sample.

This is indicated that the waste HCB has a lower density than the RAP and also has the higher porosity of the waste HCB particles. The water absorption of coarse blended waste HCB and RAP passing 19 mm and retained on 4.75mm sieve varies from 0.371 % to 13.9% in Figure 4.3. Laboratory test results revealed that the absorption & specific gravity of the blended waste HCB and RAP that pass sieve 4.75 mm are12.4 % and 2.3 respectively as indicated in Appendix A-2. Therefore, the blended waste HCB and RAP has high water absorption capacity because of its high porosity.

Water absorption gives an idea about the strength of waste HCB and RAP .Waste HCB having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable based on strength, impact test.

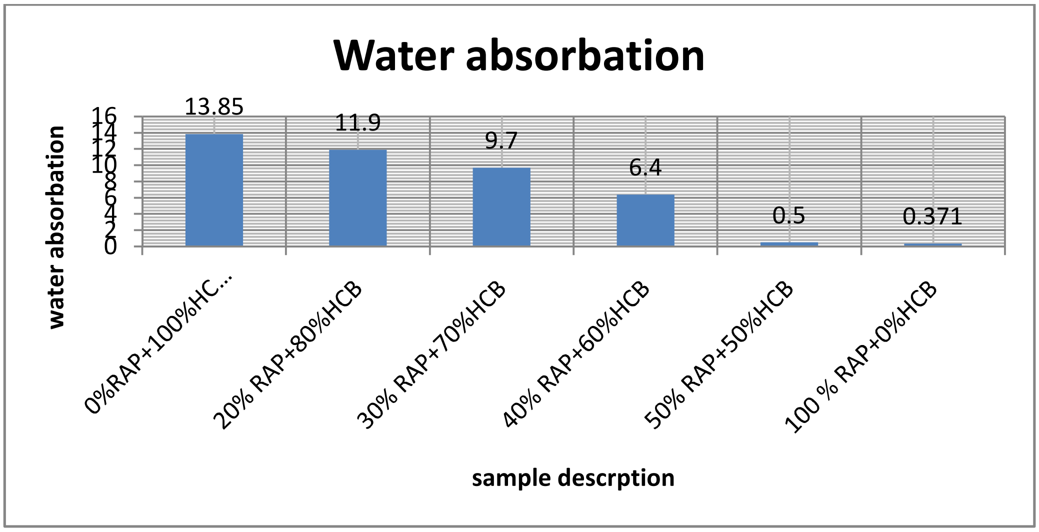


Figure 4.2: water absorption of waste HCB, RAP

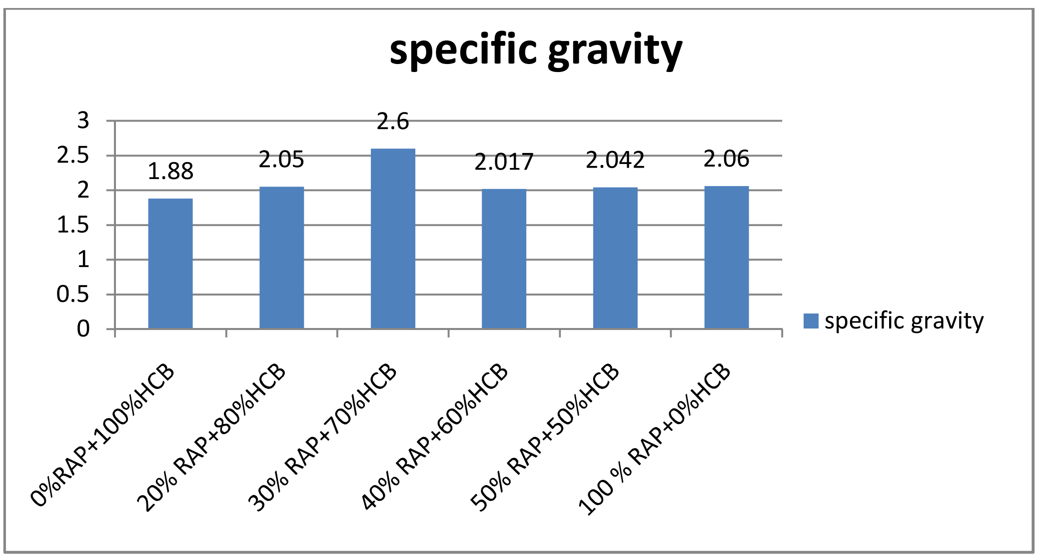


Figure 4.3: Specific gravity for waste HCB, RAP

### 4.1.4. Los Angeles Abrasion (LAA) Test

RAP samples, HCB and samples prepared by blending of RAP with HCB in Different proportion by their weight were tested for LAA to evaluate the Mechanical strength of the material and judge their suitability according to ERA specification for sub base course material .The Los Angeles abrasion value shall not exceed 45% when determined in accordance with The requirements of AASHTO T-96 for sub base course material. Blended RAP with waste HCB all samples of RAP were within the allowable ERA specification requirement. This implies that RAP material is so hardest material to resist wearing load happen on it, and it was covered by asphalt that would resist as it was not crushed under any load. Hence the material has higher resistance to abrasion than the tested waste HCB. had wear values of 8.5%.The waste HCB /RAP blends had wear values in the range of to 8.50% to 30.35% as shown in Figure 4.4 .

The Los Angeles abrasion test (LA) is commonly used in highway and materials engineering to assess the abrasion resistance of blended waste HCB and RAP specify the maximum limit of LA as 45% when determined in accordance with the requirements of AASHTO T-96 for sub base course material. Therefore, the Los Angeles abrasion values of RAP, HCB and RAP/HCB blends are well within this typical range. Los Angeles abrasion represented in the summary of test result for RAP-waste HCB blends, RAP waste HCB shown appendix B-1

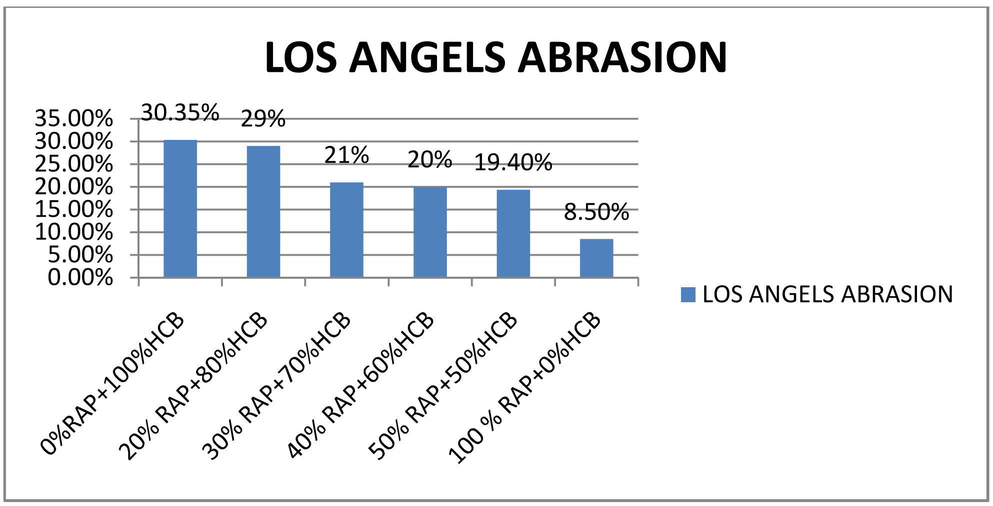


Figure 4.4: The result of Los Angeles Abrasion for waste HCB, RAP

### 4.1.5. Aggregate Crushing Value (ACV) Test

The table is shown in Table 4.1 the result of ACV of RAP from Hana Mariam sites 5.63%and waste HCB 20% before blended to each other. The average ACV of RAP samples were smaller than that of waste HCB .RAP samples were more durable to resist crushing than waste HCB. Blended waste HCB-RAP range from 16.36% to 17% were satisfying British Standard 812, Part (110). The RAP material more hard material to stand under crushing force than the waste HCB material. The summary of test result for RAP-waste HCB blends, RAP waste HCB shown appendix B-2

Table 4.2: Result of aggregate crushing value (ACV)

| Sample | ACV% | British Standard 812, Part (110) may be used | Remark |
|---|---|---|---|
| RAP | 5.63% | be less than 25 | satisfied |
| Waste HCB | 20% | be less than 25 | satisfied |
| 20% RAP | 17% | be less than 25 | satisfied |
| 30% RAP | 16.87% | be less than 25 | satisfied |
| 40% RAP | 16.48% | be less than 25 | satisfied |
| 50% RAP | 16.36% | be less than 25 | satisfied |

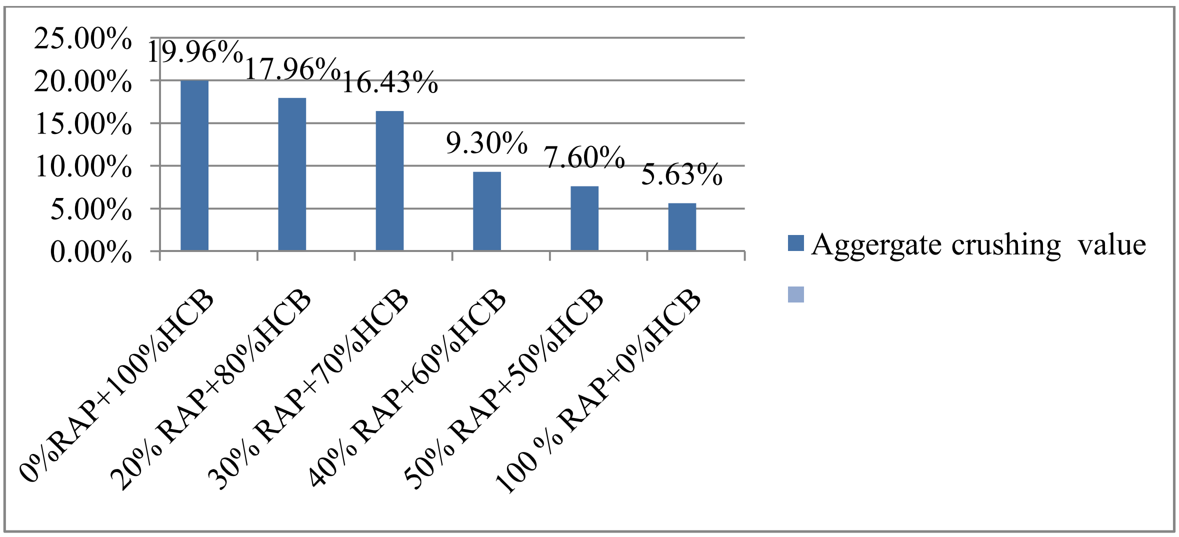


Figure 4.5: The result of ACV

### 4.1.6. Aggregate impact value (AIV)

Toughness is the property of material to most comfortable impact due to moving loads, there is a possibility of breaking into smaller pieces. Therefore, a test designed to evaluate the toughness of the aggregate Impact value indicates a relative measure of the resistance of the waste HCB, RAP and blending of waste HCB and RAP to a sudden shock or an Impact, result showed that waste HCB attained higher value than RAP contents. This laboratory result shows at state RAP was good resistance to sudden shock or impact occurred due to vehicles than that of waste HCB tested here. This could be occurred because the aggregate used in RAP during construction has good resistance to impact and the RAP was covered by asphalt content that would resist to crush under sudden force. The summary of test result for RAP-waste HCB blends, RAP waste HCB shown appendix C-1

Table 4.3: Results of AIV test for RAP waste HCB and blended RAP-waste HCB

| Samples | AIV | Specification | |
|---|---|---|---|
| 100% RAP | 5.9% | <20 | Exceptionally Strong<br>Strong |
| 20% RAP | 19.9% | 10-20 | Satisfactory for road surfacing |
| 30% RAP | 17.1% | 20-30 | Weak for road surfacing |
| 40% RAP | 15.7% | >35 | Weak for road surfacing |
| 50% RAP | 14.9% | | |
| 100 HCB | 24.2 | | |

Toughness is the property of material to most comfortable impact. The resistance of the waste HCB to aggregates [39].

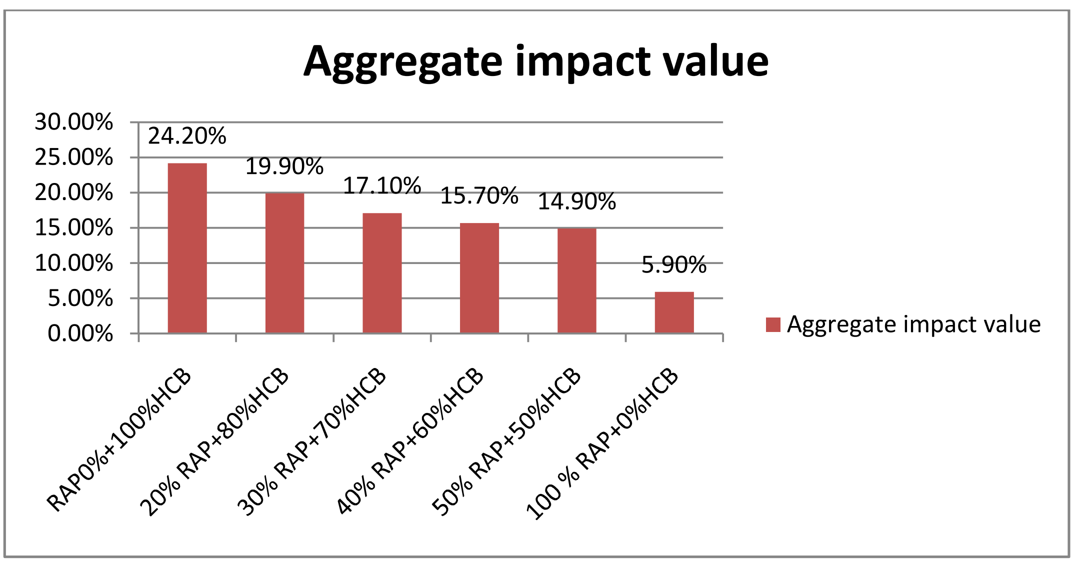


Figure 4.6: Result for Aggregate impact value test

### 4.1. 7.Compaction

Compaction was a process by which the blended waste HCB and RAP particles were artificially rearranged and packed together into a closer state of contact by mechanical means in order to decrease the porosity (or void ratio) of the blended waste HCB and RAP thus increase its dry density. Standard Procter compaction test is used to determine the optimum moisture content and maximum dry density as per for different materials as shown in Fig 4.7 In case of RAP the MDD was 1.47 and OMC was 1 and in case of waste HCB MDD 2.07 and OMC 18.70 . While, waste HCB had higher MDD and OMC when related to RAP since the presence of coated asphalt reduces the amount of water needed to achieve the required compaction level of the RAP mixture.

It was found that waste HCB had a higher MDD than pure RAP (100% RAP) materials. It was further assumed that the partial coating reduces the RAPs water absorption, which leading from tests it is very clear that the maximum dry density and optimum moisture continent of blended waste HCB and RAP were varied.

When comparing with ERA specification important properties that need to be determined are OMC and MDD of the waste HCB and RAP and blended proportional. The summary of the test results was shown in the tables 4.3, and individual results of all samples were included in appendix D-1 of this paper. From the result, we observe that the increase in RAP content of the blend leads to a decrease in maximum dry density and OMC values this is due to the coat on asphalt concrete prevent compaction by consolidation and minimizing the number of fines in RAPs particles. Hence, as the RAP contents in waste HCB-RAP blends.

Table 4.4: MDD and OMC of waste HCB, RAP and blended waste HCB –RAP

| Sample size | 100%HCB | 100%RAP | 20%RAP | 30%RAP | 40%RAP | 50%RAP |
|---|---|---|---|---|---|---|
| OMC | 18.7 | 1 | 14.5 | 8.24 | 2.65 | 2.45 |
| MDD | 2.07 | 2.3 | 1.47 | 1.36 | 1.15 | 1.1 |

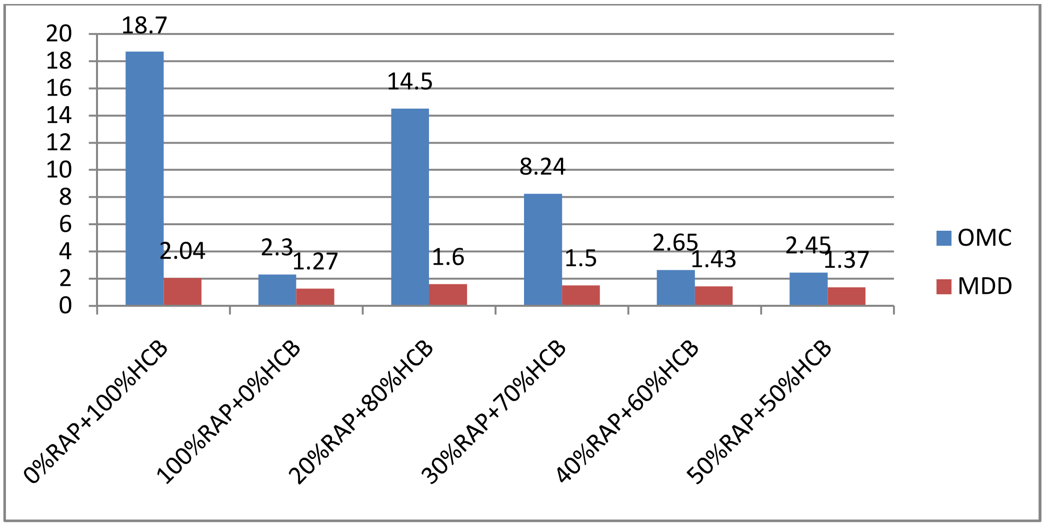


Figure 4.7: Relationship of MDD and OMC of different sample contents

### 4.1.7.1 Maximum dry density

A minimum CBR of 30 per cent is required at the highest anticipated moisture content When compacted to the specified field density. Figure 4.8 shows the relationship between the optimum moisture content and the maximum dry density. The figure shows the maximum densities obtained from the blended waste HCB and RAP Respectively. Thus satisfying the fundamental requirement of using the RAP and waste HCB in GSB mixes.

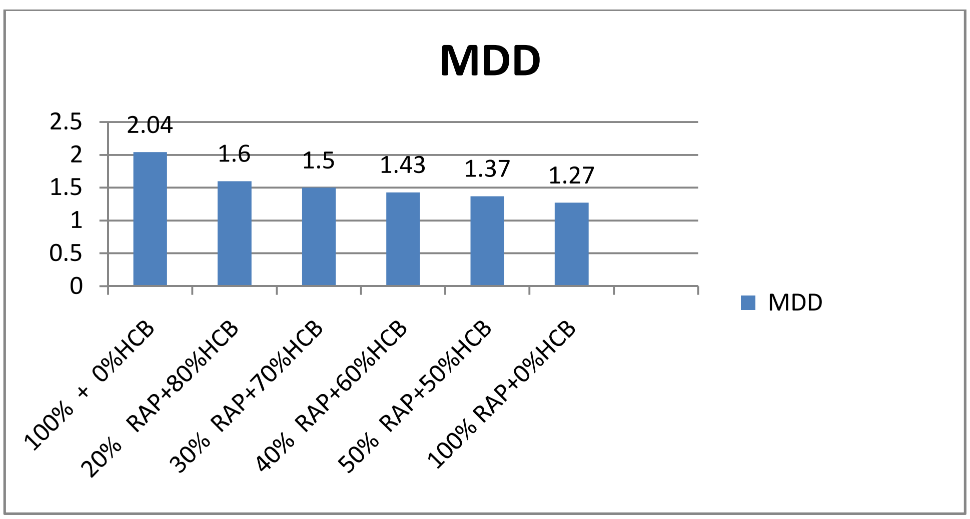


Figure 4.8: Result of Maximum dry density

### 4.1.8. California bearing result

Mixing of RAP-waste HCB materials are experimental tested for CBR at a different rate. CBR was conducted on RAP and waste HCB was conducted on mixes of RAP-waste HCB in weight basis. . Hence to investigate the possibility use of RAP and waste HCB for sub base course material CBR. The CBR results obtained from each sample of RAP, waste HCB and blends of them were under on specific. The laboratory test results for each blended and unblended were listed in appendix C-2.

The result show that CBR values of blended RAP waste HCB were ranging from 12.74% to about 78.3%.The results suggest that the CBR values obtained from the waste HCB give significantly higher CBR values when compared with those values obtained from the RAP.

This may be due to the reduction in the angle of internal friction of the mixture due to the bitumen –coated particles of RAP. To check for potential swelling to determine the strength and swelling potential of the samples, a test has been carried out by 4-days soaking-3-point CBR and no Swelled waste HCB and RAP had a negligible effect on the CBR value of the waste HCB and RAP material while they exhibit a negligible swell percentage after the soaking period The reason between higher differences can be the compaction test of density attained during a compaction test.

From compaction laboratory test result, it can observe that there is a big difference between waste HCB, RAP material and blended waste HCB-RAP at the same compaction effort. RAP have an average of with that of waste HCB were 2.04 when comparing with ERA specification.RAP, waste HCB and the mixing of RAP-waste HCB materials are experimental tested for CBR at a different rate.

CBR was conducted on RAP and waste HCB test was conducted on mixes of RAP-waste HCB in weight basis. The strength of material layers are evaluated by CBR parameters. Hence to investigate the possibility use of RAP, waste HCB and blending waste HCB-RAP for sub base course material as a CBR test is performed on RAP-waste HCB materials in proportion of 20%, 30%, 40% and 50% of RAP and waste HCB. The laboratory test results for each blended and unblended were listed appendix E-2

Table 4.5: Laboratory result for different compaction of RAP with waste HCB sample OMC, MDD and 95% MDD from modified proctor test.

| Sample size | OMC | MDD | 95% OF MDD(g/cc) |
|---|---|---|---|
| 100%HCB | 18.7 | 2.07 | 1.96 |
| 20%RAP | 14.5 | 1.47 | 1.39 |
| 30%RAP | 8.24 | 1.36 | 1.29 |
| 40%RAP | 2.65 | 1.15 | 1.09 |
| 50%RAP | 2.45 | 1.1 | 1.05 |
| 100%RAP | 2.3 | 1 | 0.95 |

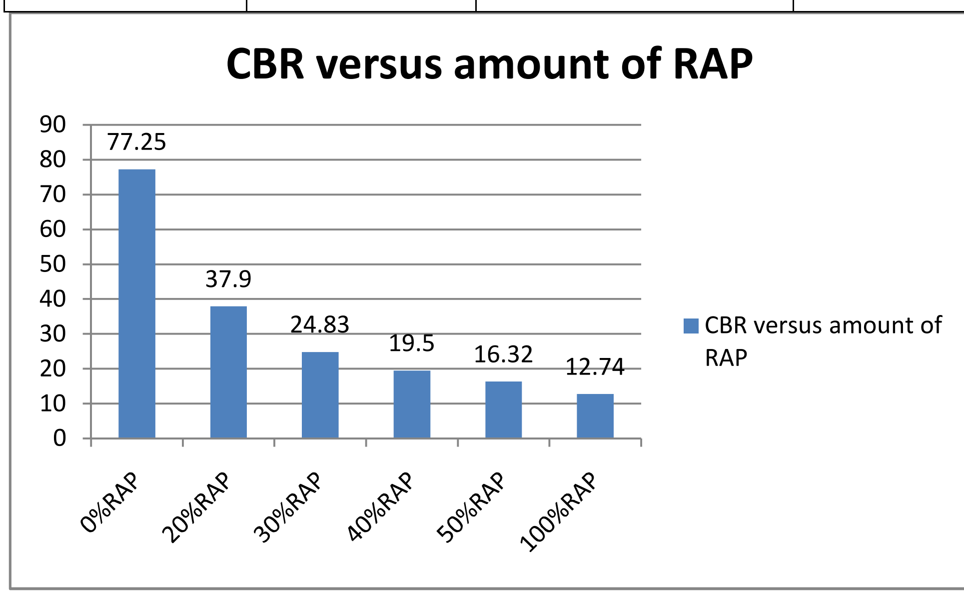


Figure 4.9: Result of CBR versus amount of RAP

### 4.1.9. Flakiness index

The flakiness index values for the RAP materials 16.4% and waste HBC 21%. This was however still within the requirements of typical state road authorities for usage as a sub base course material, which specifies a maximum value of 35.

This is however still within the requirements of typical state road authorities for usage as a sub base material, which specifies ERA pavement design manual rates materials for use as a sub base course material inroad by using their flakiness index as determined by tests conducted based on BS The summary of the test results was shown in the tables below, and individual results of all samples were included in appendix E-1 of this paper 812: Section 105.1: 1989 BS812, Part 105 or ASTM D 3398 shall not exceed 35.

# CHAPTER FIVE

# CONCLUSIONS & RECOM MENDATIONS

This section presents the conclusions and recommendations drawn from analysis of the previous chapters.

## 5.1. Conclusion

This study was essential to deal with the use of waste HCB, RAPs material, the wasted and environmentally friendly construction materials, specifically sub-base course material. Several experimental findings were evaluated on the mechanical and physical properties of sub base material (waste HCB, RAPs, and various RAP-waste HCB blends) under different laboratory tests. Based on those laboratory results, the following conclusions were drawn.

Results show that RAP material excellent resistance to crushing under the roller during road construction and when it was opened to traffic with ACV in the range of 5.63% and 20%, RAP was good resistance to sudden shock or impact occurred due to vehicles than that of waste HCB tested here. This could be occurred because the aggregate used in RAP during construction has good resistance to impact and the RAP was covered by asphalt content that would resist crushing under sudden force. AIV 5.9% and 24.2%, LAA of 8.5% and 30.35% minimum to maximum values respectively. The CBR value of RAP was far below that of waste HCB. With a value of 12.74%.

The Los Angeles abrasion value of waste HCB was slightly higher than the RAP but satisfied AASHTO T-96 specifications. It was covered by bitumen that would resist as it was not crushed under any load. The material has higher resistance to abrasion than the tested waste HCB.

Plastic limit and liquid limit of the waste HCB the fines were non-plastic with silt size materials and RAP samples could not be obtained. Hence it can be taken as non-plastic.

The specific gravity of testing was ranging 1.8 to about 2.6, and water absorption was very low due to covered by asphalt contents of RAP. 30% RAP and 70% HCB were satisfying upper and lower specification ERA For the rest sample ratio the blending of both RAP and waste HCB materials failed to fit within the gradation limit of the ERA manual specification for granular sub base course.

## 5.2. Recommendations

- Since the natural resources for aggregate production are becoming depleted, it is recommended that Ethiopia especially Addis Ababa uses waste materials obtained from demolished building and a recycled Asphalt pavements.
- Ethiopia should learn from the experience of other countries and start using recycled asphalt pavement and waste HCB to preserve its natural resources and to eliminate quantities of demolished materials before they become unmanageable.
- In Addis Ababa the concept of recycled Asphalt pavements and waste HCB is not well known, therefore arranging and giving trainings to the different construction parties and other concerned bodies is vital.
- Further tests and studies on the recycled asphalt pavements and waste HCB are highly recommended to indicate the different characteristics of recycled asphalt pavements and waste HCB used as road construction material
- It required the research of new technology of recycling waste and managing mechanism for applying to construction companies in Ethiopia, especially in Addis Ababa

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# Appendix

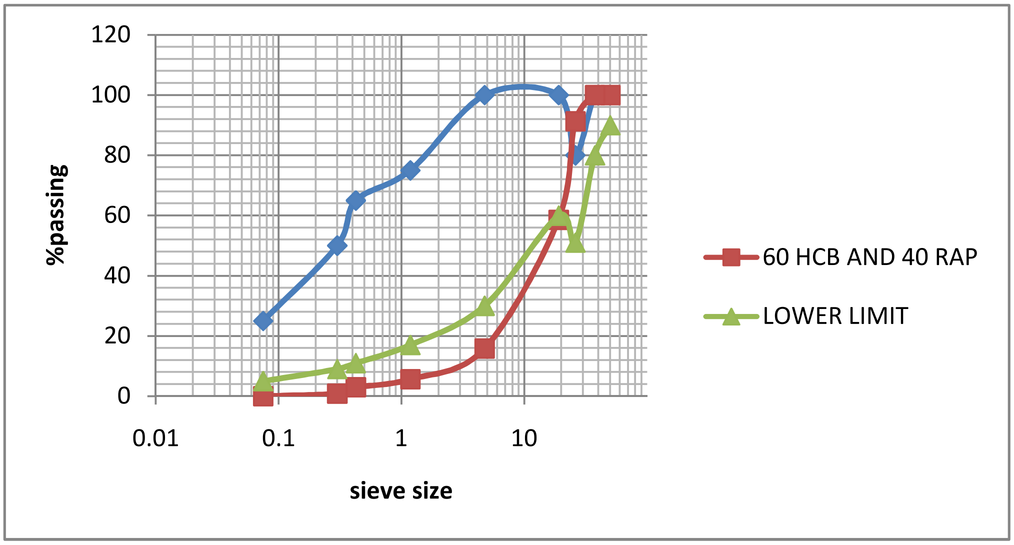
## A-1 Gradation result of blending 30%RAP and 70%

| Sieve size (mm) | mass of retain on each sieve (g) | Percentage of retained | cumulative % of retained | percentage of passing particle |
|---|---|---|---|---|
| 50 | 0 | 0 | 0 | 100 |
| 37.5 | 0 | 0 | 0 | 100 |
| 26 | 1101.44 | 11.97 | 11.97 | 88.03 |
| 19 | 1017.5 | 11.06 | 23.03 | 76.97 |
| 9.5 | 1528.4 | 16.61 | 39.64 | 60.36 |
| 4.75 | 1268.2 | 13.78 | 53.43 | 46.57 |
| 2.36 | 1941.9 | 21.11 | 74.54 | 25.46 |
| 1.18 | 917.45 | 9.97 | 84.51 | 15.49 |
| 0.3 | 466.68 | 5.07 | 89.58 | 10.42 |
| 0.075 | 485.27 | 5.27 | 94.86 | 5.14 |
| PAN | 473.2 | | | |
| | 9200 | | | |

### A-1.1.Gradation result of blending 40%RAP and 60%waste HCB

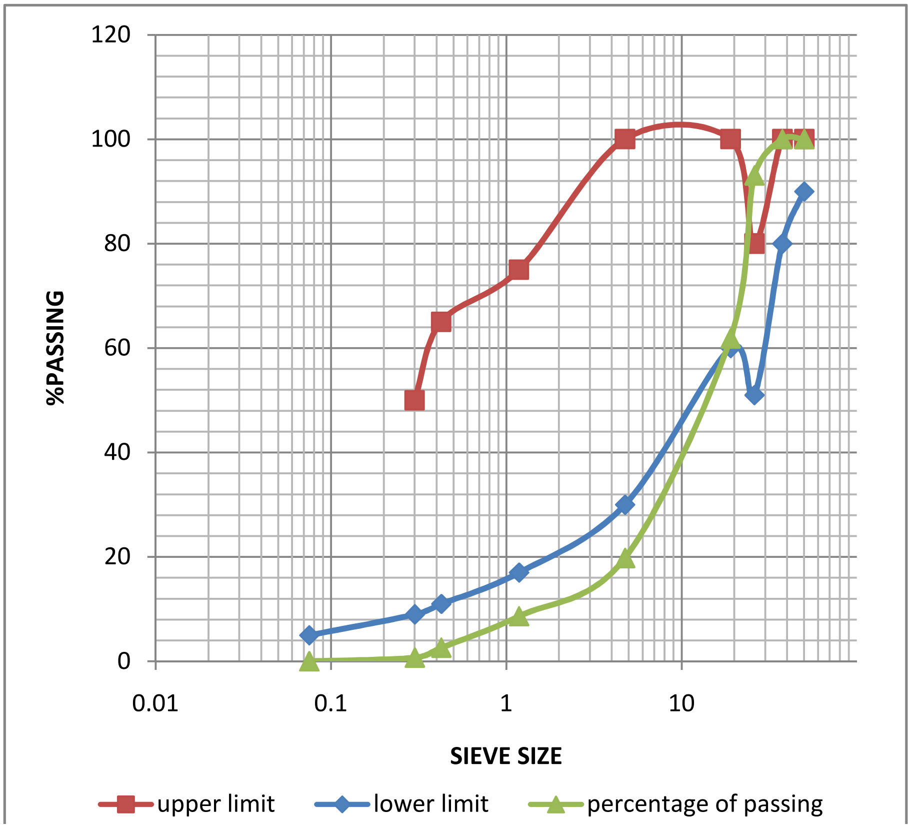
| Sieve size (mm) | mass of retain on each sieve (g) | Percentage of retained | cumulative % of retain | Percentage ofpassing particle |
|---|---|---|---|---|
| 50 | 0 | 0.00 | 0.00 | 100.00 |
| 37.5 | 0 | 0.00 | 0.00 | 100.00 |
| 26 | 869.12 | 8.69 | 8.69 | 91.31 |
| 19 | 3271.9 | 32.72 | 41.41 | 58.59 |
| 4.75 | 4277.08 | 42.77 | 84.19 | 15.81 |
| 1.18 | 1018.4 | 10.18 | 94.37 | 5.63 |
| 0.425 | 270.05 | 2.70 | 97.07 | 2.93 |
| 0.3 | 205.7 | 2.06 | 99.13 | 0.87 |
| 0.075 | 87.04 | 0.87 | 100.00 | 0.00 |

| | |
|---|---|
| sum | 9999.3 |



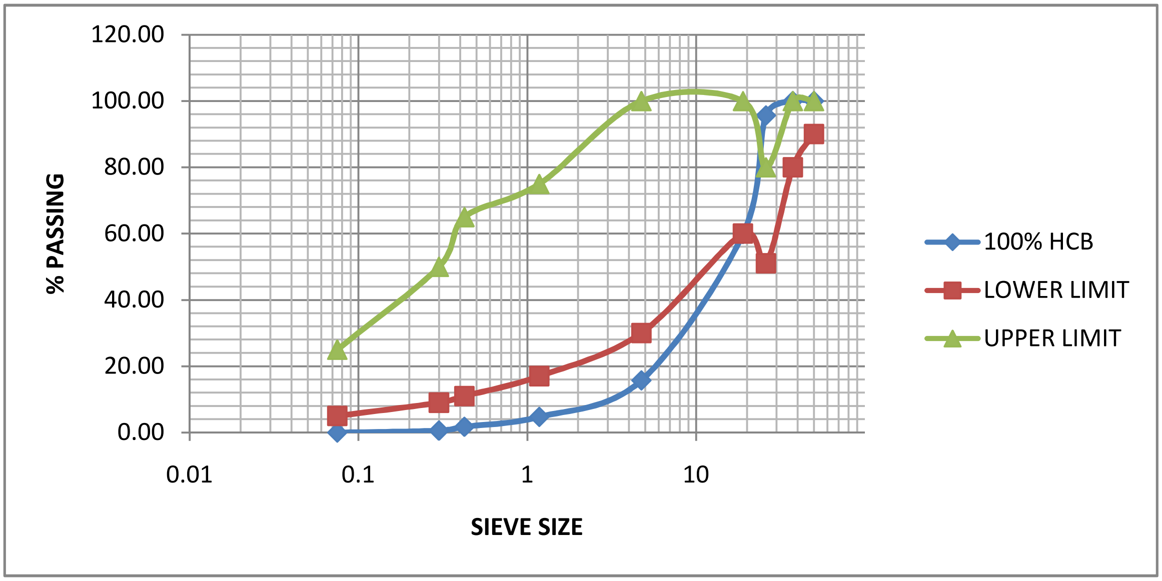

## A-1.2.Gradation result of blending 50%RAP and 50% waste HCB

| Sieve size (mm) | mass of retain on each sieve(g) | Percentage of retained | cumulative % of retain | percentage of passing particle | Lower limit | Upper limit |
|---|---|---|---|---|---|---|
| 50 | 0 | 0.00 | 0.00 | 100.00 | 90 | 100 |
| 37.5 | 0 | 0.00 | 0.00 | 100.00 | 80 | 100 |
| 26 | 695.75 | 6.96 | 6.96 | 93.04 | 51 | 80 |
| 19 | 3120.9 | 31.21 | 38.17 | 61.83 | 60 | 100 |
| 4.75 | 4205.6 | 42.06 | 80.22 | 19.78 | 30 | 100 |
| 1.18 | 1114.65 | 11.15 | 91.37 | 8.63 | 17 | 75 |
| 0.425 | 602.7 | 6.03 | 97.40 | 2.60 | 11 | 65 |
| 0.3 | 190.6 | 1.91 | 99.30 | 0.70 | 9 | 50 |
| 0.075 | 69.6 | 0.70 | 100.00 | 0.00 | 5 | 25 |
| | 9999.8 | | | | | |



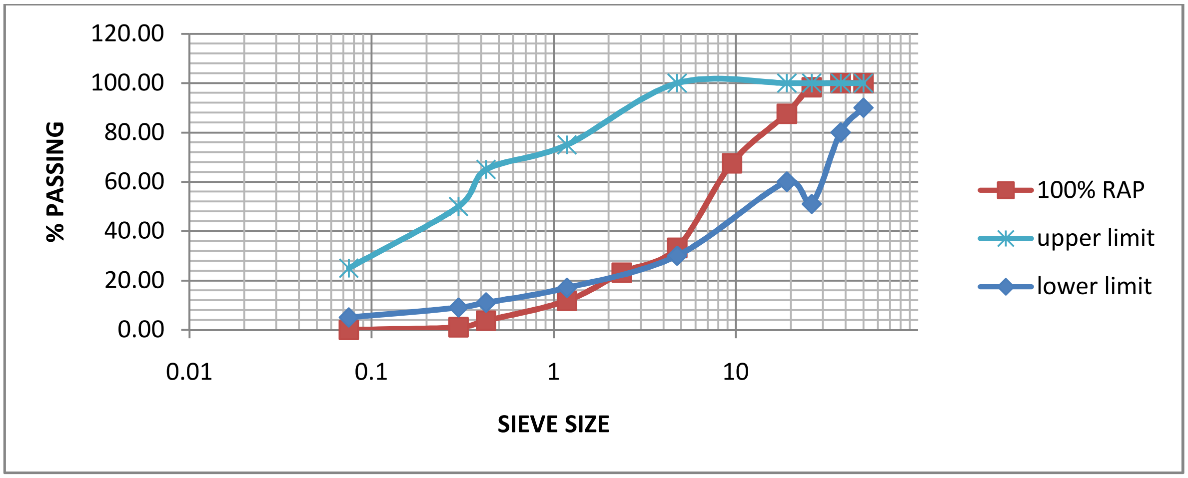

### A-1.3.Gradation result of blending 100% waste HCB

| Sieve size (mm) | mass of retain on each sieve(g) | Percentage of retained | cumulative % of retain | percentage of passing particle |
|---|---|---|---|---|
| 50 | 0 | 0.00 | 0.00 | 100.00 |
| 37.5 | 0 | 0.00 | 0.00 | 100.00 |
| 26 | 428.9 | 4.29 | 4.29 | 95.71 |
| 19 | 3565.9 | 35.66 | 39.95 | 60.05 |
| 4.75 | 4388.2 | 43.88 | 83.83 | 16.17 |
| 1.18 | 1095.9 | 10.96 | 94.79 | 5.21 |
| 0.425 | 296.3 | 2.96 | 97.75 | 2.25 |
| 0.3 | 115.4 | 1.15 | 98.91 | 1.09 |
| 0.075 | 58 | 0.58 | 99.49 | 0.51 |
| pan | 51.4 | | | |
| | 10000.0 | | | |



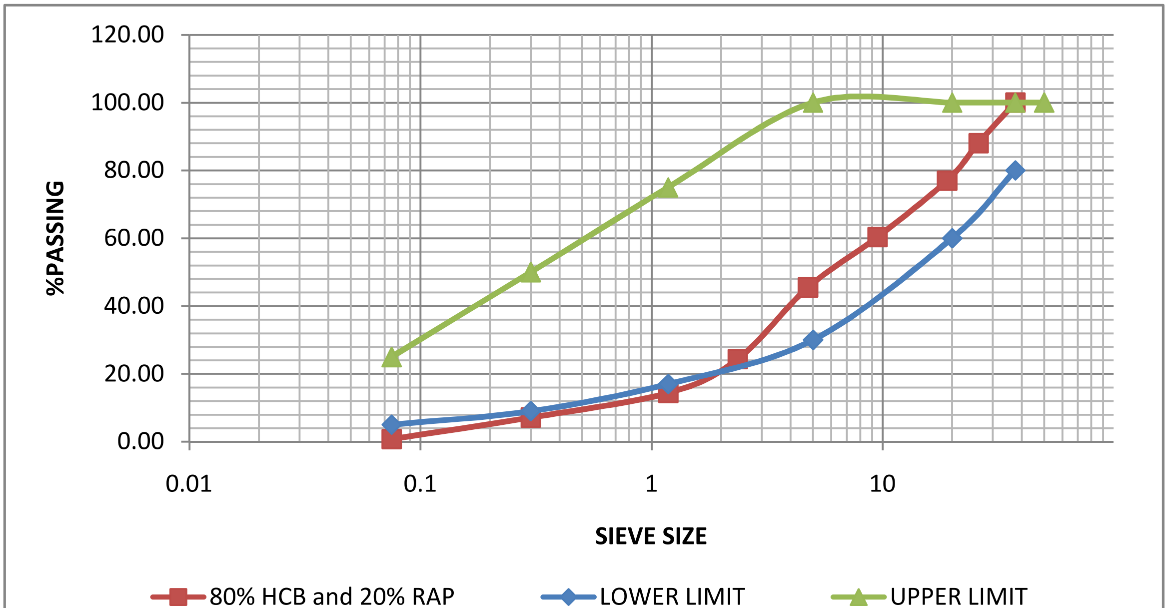

### A-1.4.Gradation result of blending 100% RAP

| Sieve size (mm) | mass of retain on each seive(g) | Persentage of retained | cumulative % of retain | Percentage of passing particle |
|---|---|---|---|---|
| 50 | 0 | 0.00 | 0.00 | 100.00 |
| 37.5 | 0 | 0.00 | 0.00 | 100.00 |
| 26 | 162.6 | 1.63 | 1.63 | 98.37 |
| 19 | 1075.9 | 10.80 | 12.43 | 87.57 |
| 9.5 | 2000 | 20.08 | 32.51 | 67.49 |
| 4.75 | 3413 | 34.26 | 66.78 | 33.22 |
| 2.36 | 1000 | 10.04 | 76.82 | 23.18 |
| 1.18 | 1133.4 | 11.38 | 88.19 | 11.81 |
| 0.425 | 803.5 | 8.07 | 96.26 | 3.74 |
| 0.3 | 266 | 2.67 | 98.93 | 1.07 |
| 0.075 | 106.4 | 1.07 | 100.00 | 0.00 |
|  | 9960.8 |  |  |  |




## A-1.5.Gradation result of blending 20% RAP and 80% waste HCB

| mass of retain on each sieve(g) | Percentage of retained | cumulative % of retain | percentage of passing particle |
|---|---|---|---|
| 0 | 0.00 | 0.00 | 100.00 |
| 0 | 0.00 | 0.00 | 100.00 |
| 1101.44 | 11.97 | 11.97 | 88.03 |
| 1017.5 | 11.06 | 23.03 | 76.97 |
| 1528.4 | 16.61 | 39.64 | 60.36 |
| 1368.2 | 14.87 | 54.52 | 45.48 |
| 1941.9 | 21.11 | 75.62 | 24.38 |
| 917.45 | 9.97 | 85.60 | 14.40 |
| 666.68 | 7.25 | 92.84 | 7.16 |
| 585.27 | 6.36 | 99.20 | 0.80 |
| 73.2 | | | |
| 9200.0 | | | |




### A-2. Specific gravity and water absorption for waste HCB, RAP, blended waste HCB and RAP.

| | | |
|---|---|---|
| For HCB | Trial | |
| | B. Mass of SSD sample in air | 2166.01 |
| | C. Mass of saturated sample in water | 871.3 |
| | A. Mass of oven dry sample in air | 1862.9 |
| | Bulk sp. gravity (oven dry) Sd = A/(B-C) | 1.44 |
| | Bulk sp. gravity (SSD) Ss = B/(B-C) | 1.67 |
| | Apparent specific gravity Sr = A/(A-C) | 1.88 |
| | Water absorption Aw = (B-A)*100/A | 13.9 |
| FOR RAP | C. Mass of saturated sample in water | 1030.7 |
| | A. Mass of oven dry sample in air | 2003.43 |
| | Bulk sp. gravity (oven dry) Sd = A/(B-C) | 2.04 |
| | Bulk sp. gravity (SSD) Ss = B/(B-C) | 2.05 |
| | Apparent specific gravity Sr = A/(A-C) | 2.06 |
| | Water absorption Aw = (B-A)*100/A | 0.371 |
| 20%RAP | B. Mass of SSD sample in air | 2160.2 |

| | | |
|---|---|---|
| | C. Mass of saturated sample in water | 990.5 |
| | A. Mass of oven dry sample in air | 1930 |
| | Bulk sp. gravity (oven dry) Sd = A/(B-C) | 1.65 |
| | Apparent specific gravity Sr = A/(A-C) | 2.05 |
| | Water absorption Aw = (B-A)*100/A | 11.9 |
| 50%RAP | B. Mass of SSD sample in air | 2140 |
| | C. Mass of saturated sample in water | 995.6 |
| | A. Mass of oven dry sample in air | 1950.9 |
| | Bulk sp. gravity (oven dry) Sd = A/(B-C) | 1.7 |
| | Bulk sp. gravity (SSD) Ss = B/(B-C) | 1.87 |
| | Apparent specific gravity Sr = A/(A-C) | 2.042 |
| | Water absorption Aw = (B-A)*100/A | 9.7 |
| 40% RAP | B. Mass of SSD sample in air | 2108 |
| | C. Mass of saturated sample in water | 998.7 |
| | A. Mass of oven dry sample in air | 1980.3 |
| | Bulk sp. gravity (oven dry) Sd = A/(B-C) | 1.8 |
| | Bulk sp. gravity (SSD) Ss = B/(B-C) | 1.9 |
| | Apparent specific gravity Sr = A/(A-C) | 2.017 |
| | Water absorption Aw = (B-A)*100/A | 6.4 |
| 30% RAP | B. Mass of SSD sample in air | 2017 |
| | C. Mass of saturated sample in water | 1234 |
| | A. Mass of oven dry sample in air | 1999.9 |
| | Bulk sp. gravity (oven dry) Sd = A/(B-C) | 2.54 |
| | Bulk sp. gravity (SSD) Ss = B/(B-C) | 2.57 |
| | Apparent specific gravity Sr = A/(A-C) | 2.6 |
| | Water absorption Aw = (B-A)*100/A | 0.85 |

## B- 1. LAA (For 100 % RAP, HCB and blended waste HCB and RAP)

| Grading of test sample | Fraction and Mass | | No of spheres | Mass of sample retained on 1.70 mm sieve after washing and oven dried (B) | Loss through 1.70 mm sieve | |
|---|---|---|---|---|---|---|
| 20% RAP | 9.5-6.3 | 2500 | 8 | | | LAA=991.1/5000*100 |
| | 6.3-4.75 | 2500 | | 4008.9 | 5000-4008.9=991.1 | 20% |
| 30% RAP | 9.5-6.3 | 2500 | 8 | | | LAA=1497.9/5000*100 |
| | 6.3-4.75 | 2500 | | 3502.1 | 5000-3502.1=1497.9 | 29% |
| 40% RAP | 9.5-6.3 | 2500 | 8 | | | LAA=991.1/5000*100 |
| | 6.3-4.75 | 2500 | | 4008.9 | 5000-4008.9= | 20% |
| 50% RAP | 9.5-6.3 | 2500 | 8 | 3943.2 | 5000-3943.2=1056.8 | LAA=1056.8/5000*100 |
| | 6.3-4.75 | 2500 | | | | 21% |
| 100%RAP | 9.5-6.3 | 2500 | 8 | 4575.6 | | LAA=424/5000*100= |
| | 6.3-4.75 | 2500 | | | 5000-4575.6=424.4 | 8.50% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 100% HCB | 9.5-6.3 | 2500 | 8 | 3482.1 | 5000-3482.1=1517.9 | LAA=570/500 0*100=30.35% |

### B- 2. ACV (For 100 % RAP, HCB and blended waste HCB and RAP)

| Test No | Mass of Sample (A) gm | Mass of proportion passing B.S 2.36 mm sieve (B) after crushing | Aggregate crushing Value (A.C.V %) |
|---|---|---|---|
| | | | Individual (B/A*100) |
| 20% RAP | 593.08 | 349.08 | 17% |
| 30% | 2053.42 | 347.24 | 16.87% |
| 40% | 2090.94 | 344.66 | 16.48% |
| 50% | 2093.5 | 342.94 | 16.36% |
| 100% RAP | 2149.8 | 121 | 5.63% |
| 100% HCB | 2037.6 | 405.9 | 20% |

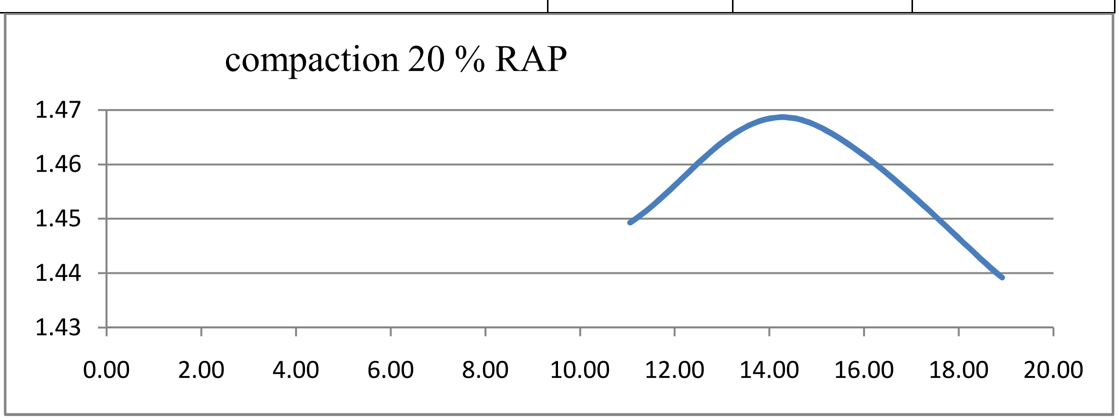
### C- 1. Aggregate impact value (A.I.V %) (For HCB, RAP ,blending HCB and RAP)

| Sample description | Total Weight of aggregate sample filling the cylindrical measure (W1) | Weight of aggregate passing 2.36 mm sieve after the test (W2) W2=W1-W3 | Weight of aggregate retained on 2.36 mm sieve after the test (W3) | AIV = w2/w1*100 |
|---|---|---|---|---|
| 20% RAP | 400.5 | 79.6 | 320.9 | 19.9% |
| 30% RAP | 412.6 | 70.4 | 342.2 | 17.1% |
| 40% RAP | 420.3 | 65.8 | 354.5 | 15.7% |
| 50% RAP | 424.7 | 63.2 | 361.7 | 14.9% |

| | | | | |
|---|---|---|---|---|
| 100 RAP | 576.9 | 34.6 | 542.3 | 5.9% |
| 100 HCB | 392.4 | 94.9 | 297.5 | 24.2% |

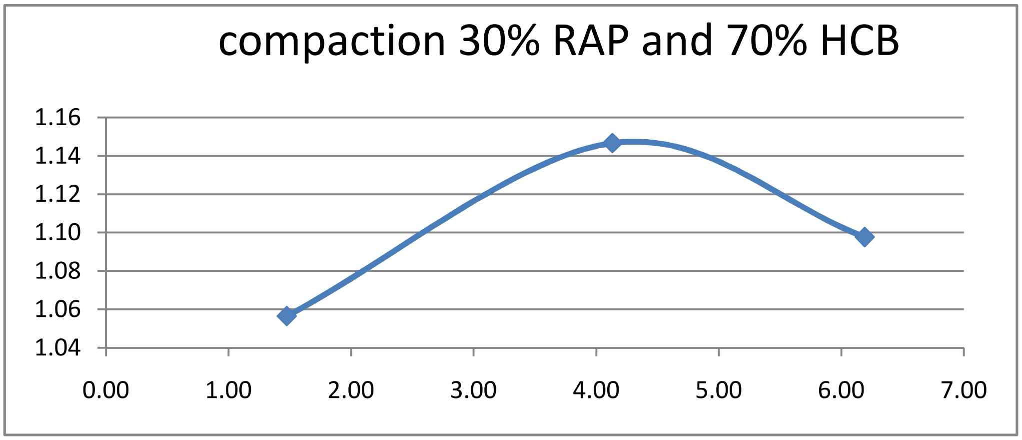
## D- 1. Compaction Test Result and Analysis 20% RAP

| Test No. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of sample (gm) | 4200 | 4200 | 4200 |
| Water Added(cc) | 300 | 426 | 594 |
| Mass of Mold+Wet soil(gm)(A) | 6138.8 | 6294.5 | 6354.7 |
| Mass of Mold(gm)(B) | 2719.9 | 2723.1 | 2719.4 |
| Mass of Wet Soil(gm)A-B=C | 3418.9 | 3571.4 | 3635.3 |
| Volume of Mold $cm^3$(D) | 2124 | 2124 | 2124 |
| Bulk Density $gm/cm^3$ C/D=(E) | 1.61 | 1.68 | 1.71 |
| Container Code . | G3T3 | T2 | P66 |
| Mass of Wet soil+Container(gm)(F) | 93.8 | 219.8 | 132.1 |
| Mass of dry soil+container(gm)(G) | 86.2 | 196.7 | 117 |
| Mass of container(gm)(H) | 17.5 | 37.3 | 37.2 |
| Mass of moisture(gm)F-G=(I) | 7.6 | 23.1 | 15.1 |
| Mass of Dry soil(gm)G-H=(J) | 68.7 | 159.4 | 79.8 |
| Moisture content % (I/J)*100=K | 11.06 | 14.50 | 18.92 |
| Dry Density $gm/cm^3$ E/(100+K)*100 | 1.45 | 1.47 | 1.44 |



## D- 2. Compaction Test Result and Analysis 30% RAP

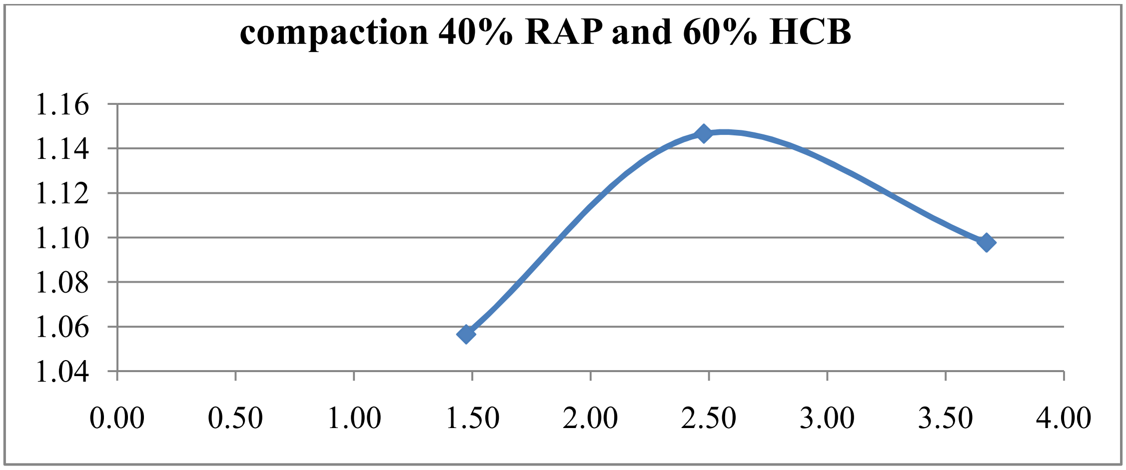
| Test No. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of sample (gm) | 4200 | 4200 | 4200 |
| Water Added(cc) | 318 | 402 | |
| Mass of Mold+Wet soil(gm)(A) | 5709.9 | 5928 | 5860 |
| Mass of Mold(gm)(B) | 2723.8 | 2724.2 | 2722.9 |
| Mass of Wet Soil(gm)A-B=C | 2986.1 | 3203.8 | 3137.1 |
| Volume of Mold $cm^3$(D) | 2124 | 2124 | 2124 |
| Bulk Density $gm/cm^3$ C/D=(E) | 1.41 | 1.51 | 1.48 |
| Container Code . | T2 | D4 | K3 |
| Mass of Wet soil+Container(gm)(F) | 124.2 | 100.1 | 176.53 |
| Mass of dry soil+container(gm)(G) | 118.7 | 96.6 | 165.7 |
| Mass of container(gm)(H) | 17 | 35.1 | 34.21 |
| Mass of moisture(gm)F-G=(I) | 5.5 | 3.5 | 10.83 |
| Mass of Dry soil(gm)G-H=(J) | 101.7 | 61.5 | 131.49 |
| Moisture content % (I/J)*100=K | 5.41 | 5.69 | 8.24 |
| Dry Density $gm/cm^3$ E/(100+K)*100 | 1.33 | 1.43 | 1.36 |


compaction 30% RAP and 70% HCB
1.16
1.14
1.12
1.10
1.08
1.06
1.04
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00

## D- 3. Compaction Test Result and Analysis 40% RAP

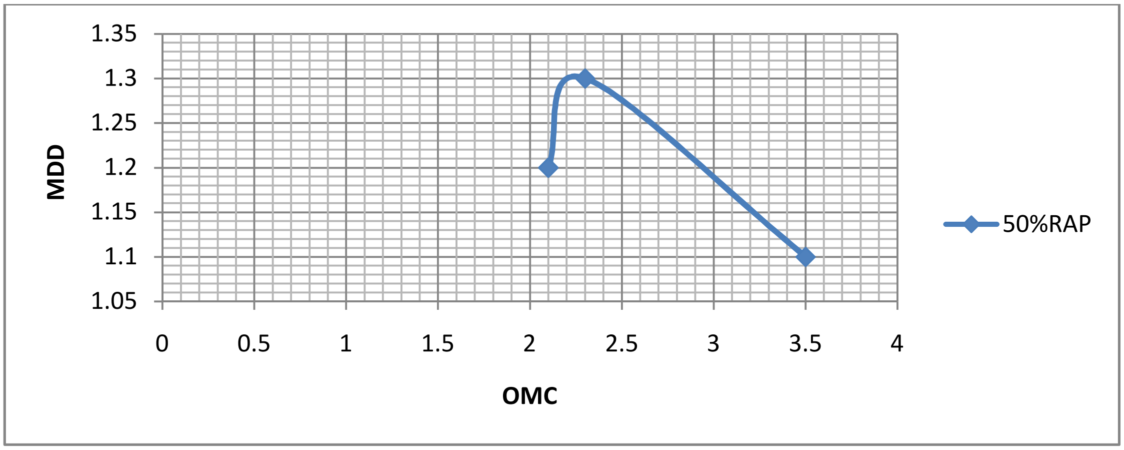
| Test No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Mass of sample (gm) | 4200 | 4200 | 4200 | 4200 |
| Water Added(cc) | 300 | 426 | 594 | 762 |
| Mass of Mold+Wet soil(gm)(A) | 6159.8 | 6315.5 | 6375.7 | 6668.2 |
| Mass of Mold(gm)(B) | 2719.9 | 2723.1 | 2719.4 | 2723.2 |
| Mass of Wet Soil(gm)A-B=C | 3439.9 | 3592.4 | 3656.3 | 3924 |
| Volume of Mold $cm^3$(D) | 2124 | 2124 | 2124 | 2124 |
| Bulk Density $gm/cm^3$ C/D=(E) | 1.62 | 1.69 | 1.72 | 1.85 |
| Container Code. | T3L | P4 | D46 | K2 |
| Mass of Wet soil+Container(gm)(F) | 109.8 | 226.8 | 139.3 | 152.8 |
| Mass of dry soil+container(gm)(G) | 95.7 | 200.4 | 120.1 | 131.2 |
| Mass of container(gm)(H) | 18.5 | 39.3 | 38.2 | 35.3 |
| Mass of moisture(gm)F-G=(I) | 14.1 | 26.4 | 19.2 | 21.6 |
| Mass of Dry soil(gm)G-H=(J) | 77.2 | 161.1 | 81.9 | 95.9 |
| Moisture content % (I/J)*100=K | 18.26 | 14.50 | 15.50 | 23.44 |
| Dry Density $gm/cm^3$ E/(100+K)*100 | 1.37 | 1.48 | 1.60 | 1.39 |

| | | | |
|---|---|---|---|
| Mass of sample (gm) | 4200 | 4200 | 4200 |
| Water Added(cc) | 318 | 402 | |
| Mass of Mold+Wet soil(gm)(A) | 5000.9 | 5220 | 5140 |
| Mass of Mold(gm)(B) | 2723.8 | 2724.2 | 2722.9 |
| Mass of Wet Soil(gm)A-B=C | 2277.1 | 2495.8 | 2417.1 |
| Volume of Mold $cm^3$(D) | 2124 | 2124 | 2124 |
| Bulk Density $gm/cm^3$ C/D=(E) | 1.07 | 1.18 | 1.14 |
| Container Code . | T2 | D4 | K3 |
| Mass of Wet soil+Container(gm)(F) | 120.2 | 97.1 | 170.53 |
| Mass of dry soil+container(gm)(G) | 118.7 | 95.6 | 165.7 |
| Mass of container(gm)(H) | 17 | 35.1 | 34.21 |
| Mass of moisture(gm)F-G=(I) | 1.5 | 1.5 | 4.83 |
| Mass of Dry soil(gm)G-H=(J) | 101.7 | 60.5 | 131.49 |
| Moisture content % (I/J)*100=K | 1.47 | 2.48 | 3.67 |
| Dry Density $gm/cm^3$ E/(100+K)*100 | 1.06 | 1.15 | 1.10 |




### D- 4. Compaction Test Result and Analysis 50% RAP

| Test No. | 1 | 2 | 3 |
|---|---|---|---|
| Mass of sample (gm) | 4200 | 4200 | 4200 |
| Water Added(cc) | 200 | 326 | 662 |
| Mass of Mold+Wet soil(gm)(A) | 6424.8 | 6640.6 | 6744.4 |
| Mass of Mold(gm)(B) | 2722.4 | 2719.2 | 2719.6 |
| Mass of Wet Soil(gm)A-B=C | 3702.4 | 3921.4 | 4024.8 |
| Volume of Mold $cm^3$(D) | 2124 | 2124 | 2124 |
| Bulk Density gm/$cm^3$ C/D=(E) | 1.74 | 1.85 | 1.89 |
| | | | |
| Container Code . | G19 | P67 | 30B |
| Mass of Wet soil+Container(gm)(F) | 148.6 | 128.6 | 185.9 |
| Mass of dry soil+container(gm)(G) | 131.4 | 119 | 157.6 |
| Mass of container(gm)(H) | 17.4 | 17.1 | 35.3 |
| Mass of moisture(gm)F-G=(I) | 17.2 | 9.6 | 28.3 |
| Mass of Dry soil(gm)G-H=(J) | 114 | 101.9 | 122.3 |
| Moisture content % (I/J)*100=K | 2.1 | 2.3 | 3.5 |
| Dry Density gm/$cm^3$ E/(100+K)*100 | 1.2 | 1.3 | 1.1 |

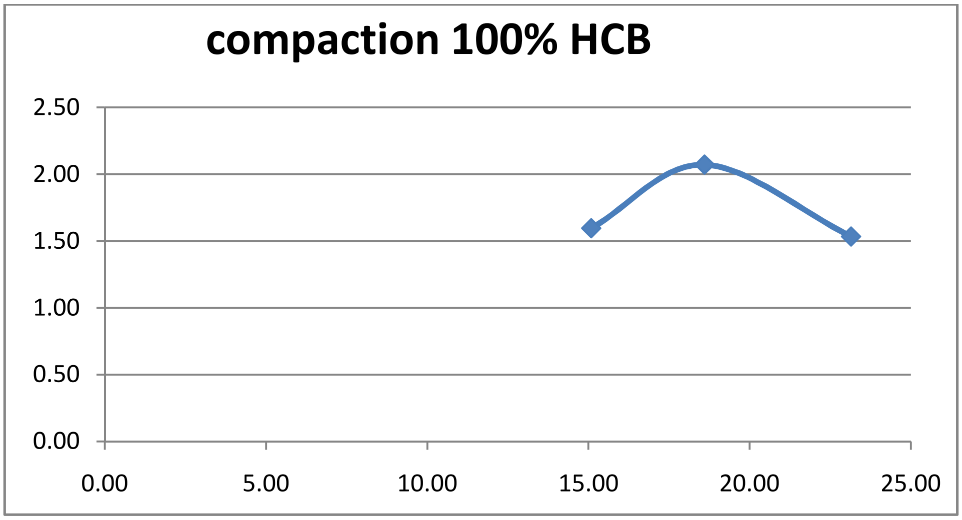



| | | | |
|---|---|---|---|
| Mass of sample (gm) | 4200 | 4200 | 4200 |
| Water Added(cc) | 318 | 402 | |
| Mass of Mold+Wet soil(gm)(A) | 5009.9 | 5228 | 5160 |
| Mass of Mold(gm)(B) | 2723.8 | 2724.2 | 2722.9 |
| Mass of Wet Soil(gm)A-B=C | 2286.1 | 2503.8 | 2437.1 |
| Volume of Mold $cm^3$(D) | 2124 | 2124 | 2124 |
| Bulk Density $gm/cm^3$ C/D=(E) | 1.08 | 1.18 | 1.15 |
| Container Code . | T2 | D4 | K3 |
| Mass of Wet soil+ Container(gm)(F) | 120.2 | 98.1 | 170.53 |
| Mass of dry soil+ container(gm)(G) | 118.7 | 96.6 | 165.7 |
| Mass of container(gm)(H) | 17 | 35.1 | 34.21 |
| Mass of moisture(gm) F-G=(I) | 1.5 | 1.5 | 4.83 |
| Mass of Dry soil(gm)G-H=(J) | 101.7 | 61.5 | 131.49 |

| | | | |
|---|---|---|---|
| Moisture content % (I/J)*100=K | 1.47 | 2.44 | 3.67 |
| Dry Density gm/cm$^3$ E/(100+K)*100 | 1.06 | 1.15 | 1.11 |

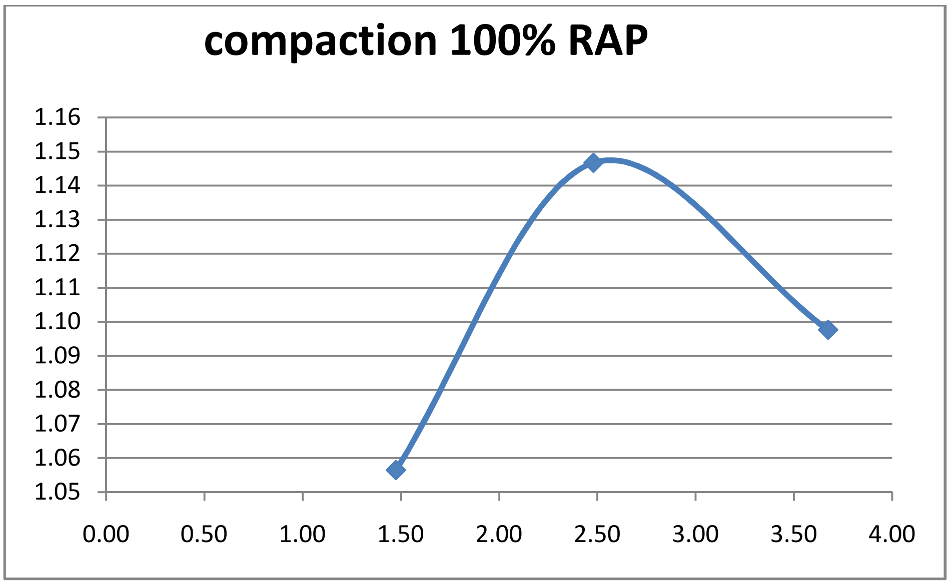
### D- 5. Compaction Test Result and Analysis100% waste HCB

| | | | |
|---|---|---|---|
| Mass of sample (gm) | 4200 | 4200 | 4200 |
| Water Added(cc) | 200 | 326 | 662 |
| Mass of Mold+Wet soil(gm)(A) | 6624.8 | 7940.6 | 6744.4 |
| Mass of Mold(gm)(B) | 2722.4 | 2719.2 | 2719.6 |
| Mass of Wet Soil(gm)A-B=C | 3902.4 | 5221.4 | 4024.8 |
| Volume of Mold cm$^3$(D) | 2124 | 2124 | 2124 |
| Bulk Density gm/cm$^3$ C/D=(E) | 1.84 | 2.46 | 1.89 |
| | | | |
| Container Code . | G19 | P67 | 30B |
| Mass of Wet soil+Container(gm)(F) | 148.6 | 150.6 | 185.9 |
| Mass of dry soil+container(gm)(G) | 131.4 | 134.9 | 157.6 |
| Mass of container(gm)(H) | 17.4 | 27.1 | 35.3 |
| Mass of moisture(gm)F-G=(I) | 17.2 | 15.7 | 28.3 |
| Mass of Dry soil(gm)G-H=(J) | 114 | 107.8 | 122.3 |
| Moisture content % (I/J)*100=K | 15.09 | 18.60 | 23.14 |
| Dry Density gm/cm$^3$ E/(100+K)*100 | 1.60 | 2.07 | 1.53 |




| | | | |
|---|---|---|---|
| Mass of sample (gm) | 4200 | 4200 | 4200 |
| Water Added(cc) | 318 | 402 | |
| Mass of Mold+Wet soil(gm)(A) | 4900.9 | 5120 | 5040 |
| Mass of Mold(gm)(B) | 2723.8 | 2724.2 | 2722.9 |
| Mass of Wet Soil(gm)A-B=C | 2177.1 | 2395.8 | 2317.1 |
| Volume of Mold $cm^3$(D) | 2124 | 2124 | 2124 |
| Bulk Density $gm/cm^3$ C/D=(E) | 1.03 | 1.13 | 1.09 |
| Container Code . | KD | B44 | LM |
| Mass of Wet soil+Container(gm)(F) | 122.2 | 93.1 | 118.53 |
| Mass of dry soil+container(gm)(G) | 120.7 | 91.6 | 115.7 |
| Mass of container(gm)(H) | 17 | 35.1 | 34.21 |

| | | | |
|---|---|---|---|
| Mass of moisture(gm)F-G=(I) | 1.5 | 1.5 | 2.83 |
| Mass of Dry soil(gm)G-H=(J) | 103.7 | 56.5 | 81.49 |
| Moisture content % (I/J)*100=K | 1.45 | 2.3 | 3.47 |
| Dry Density gm/cm$^3$ E/(100+K)*100 | 1.01 | 1.10 | 1.05 |




### E-1. Flakiness Index

| Sieve size | Wt. Retained W1 | Gauge Range | Wt. of sample passing the gauge (W2)g | BS 812: Section 105.1: 1989 BS812, Part 105 or ASTM D 3398 shall not exceed |
|---|---|---|---|---|
| 63-50 | - | 63-50 | - | |
| 50-37.50 | - | 50-37.50 | - | |
| 37.50-28 | 1004.5 | 37.50-28 | 243.5 | |
| 28-20 | 100.5 | 28-20 | 91.5 | |
| 20-14 | 998.5 | 20-14 | 215.8 | |

| | | | | |
|---|---|---|---|---|
| 14-10 | 815.8 | 14-10 | 82.5 | 35 |
| 10-6.3 | 328.6 | 10-6.3 | 50.4 | |
| | 4167.9 | | 683.7 | |

Flakiness index in %, FI=M3 *100 /M2 = 683.7*100/4167.9 =16.4%

| Sieve analysis | | Gauging | | Remarks |
|---|---|---|---|---|
| Sieve size | Wt. Retained W1 | Gauge Range | Wt. of sample passing the gauge (w2) g | BS 812: Section 105.1: 1989 BS812, Part 105 or ASTM D 3398 shall not exceed 35 |
| 63-50 | - | 63-50 | - | |
| 50-37.50 | - | 50-37.50 | - | |
| 37.50-28 | 1018.5 | 37.50-28 | 243.5 | |
| 28-20 | 1003.5 | 28-20 | 91.5 | |
| 20-14 | 1001.5 | 20-14 | 215.8 | |
| 14-10 | 815.8 | 14-10 | 82.5 | |
| 10-6.3 | 328.6 | 10-6.3 | 50.4 | |
| | 4167.9 | | 683.7 | |

Flakiness index in %, FI=M3 *100/M2 = 683.7*100/4167.9 = 16.4%

| Sieve size | Wt. Retained W1 | Gauge Range | Wt. of sample passing the gauge (w2) g | |
|---|---|---|---|---|
| 63-50 | - | 63-50 | - | BS 812: Section 105.1: 1989 BS812, Part 105 or ASTM D 3398 shall not exceed 35 |
| 50-37.50 | - | 50-37.50 | - | |
| 37.50-28 | 1002.5 | 37.50-28 | 235.5 | |
| 28-20 | 999.9 | 28-20 | 87.5 | |
| 20-14 | 996.5 | 20-14 | 204.8 | |
| 14-10 | 830.8 | 14-10 | 76.5 | |
| 10-6.3 | 320.6 | 10-6.3 | 65.4 | |

| | | | | |
|---|---|---|---|---|
| | 4150.3 | | 669.7 | |

Flakiness index in %, FI=M3*100/M2 = 669.7*100/4150.3 = 16.14%

| Sieve size | Wt. Retained W1 | Gauge Range | Wt. of sample passing the (w2) g | |
|---|---|---|---|---|
| 63-50 | - | 63-50 | - | BS 812: Section 105.1: 1989 BS812, Part 105 or ASTM D 3398 shall not exceed 35 |
| 50-37.50 | - | 50-37.50 | - | |
| 37.50-28 | 998.7 | 37.50-28 | 230.6 | |
| 28-20 | 995.3 | 28-20 | 83.4 | |
| 20-14 | 992.5 | 20-14 | 202.6 | |
| 14-10 | 825.8 | 14-10 | 73.4 | |
| 10-6.3 | 315.4 | 10-6.3 | 63.2 | |
| | 4127.7 | | 653.2 | |

Flakiness index in %, FI=M3 *100/M2 =653.2 *100/4127.7 =15.85 %

| Sieve size | Wt. Retained W1 | Gauge Range | Wt. of sample Passing the gauge (w2) g | |
|---|---|---|---|---|
| 63-50 | - | 63-50 | - | 35BS 812: Section 105.1: 1989 BS812, Part 105 or ASTM D 3398 shall not exceed |
| 50-37.50 | - | 50-37.50 | - | |
| 37.50-28 | 984.3 | 37.50-28 | 220.6 | |
| 28-20 | 961.5 | 28-20 | 70.4 | |
| 20-14 | 950.2 | 20-14 | 150.6 | |
| 14-10 | 817.6 | 14-10 | 68.9 | |
| 10-6.3 | 299.5 | 10-6.3 | 57.2 | |
| | 4013.1 | | 567.7 | |

Flakiness index in %, FI=M3 *100 /M2 =567.7*100/4013.1 = 14.16%

| Sieve size | Wt. Retained W1 | Gauge Range | Wt. of sample passing the gauge (w2) g | |
|---|---|---|---|---|
| 63-50 | - | 63-50 | - | BS 812: Section 105.1: 1989 BS812, Part 105 or ASTM D 3398 shall not exceed 35 |
| 50-37.50 | - | 50-37.50 | - | |
| 37.50-28 | 978.3 | 37.50-28 | 210.6 | |
| 28-20 | 956.4 | 28-20 | 60.4 | |
| 20-14 | 930.2 | 20-14 | 130.6 | |
| 14-10 | 812.6 | 14-10 | 60.9 | |
| 10-6.3 | 290.5 | 10-6.3 | 53.2 | |
| | 3968 | | 515.7 | |

Flakiness index in %, FI=M3 *100/M2 =515.7*100/3968 = 14.16%

### E-2 CBR Result waste HCB

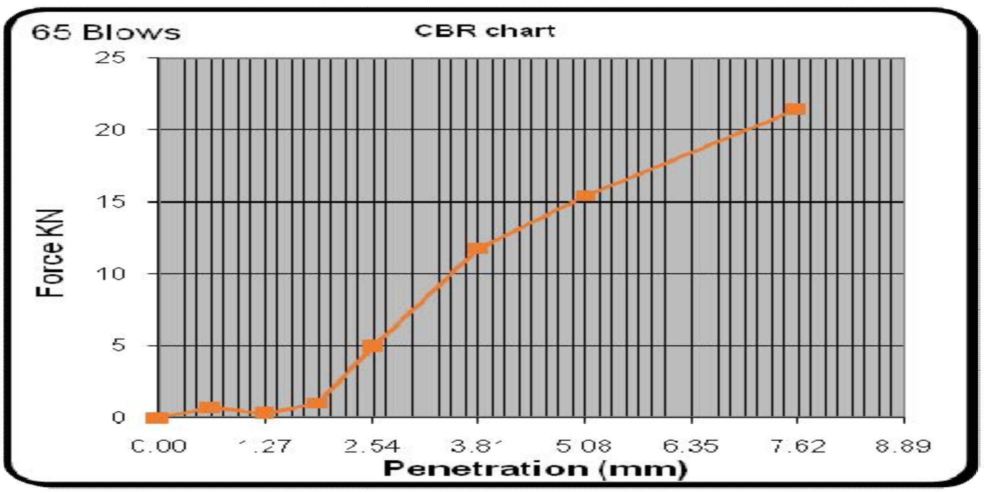
| Compaction Determination | | | | |
|---|---|---|---|---|
| COMPACTION DATA | units | 65 blows | 30 blows | 10 blows |
| | | before soak | before soak | before soak |
| Mould No. | No. | N7 | N6 | N15 |
| Mass of soil + Mould | g | 7860.6 | 7639.6 | 7433.2 |
| Mass Mould | g | 4150.8 | 4215.8 | 4152.8 |
| Mass of Soil | g | 3709.8 | 3423.8 | 3280.4 |
| Volume of Mould | g | 2124 | 2124 | 2124 |
| Wet density of soil | g/cc | 1.747 | 1.612 | 1.544 |
| Dry density of soil | g/cc | 1.747 | 1.612 | 1.544 |

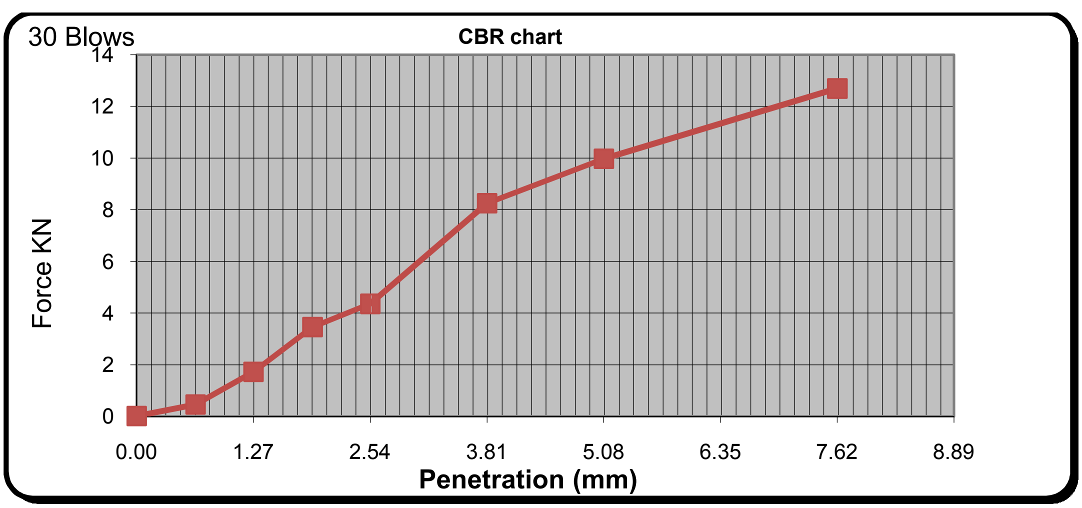
| Moisture Determination | | | |
|---|---|---|---|
| MOISTURE CONTENT DATA | 65 Blows | 30 Blows | 10 Blows |
| | Before soak | Before soak | Before soak |

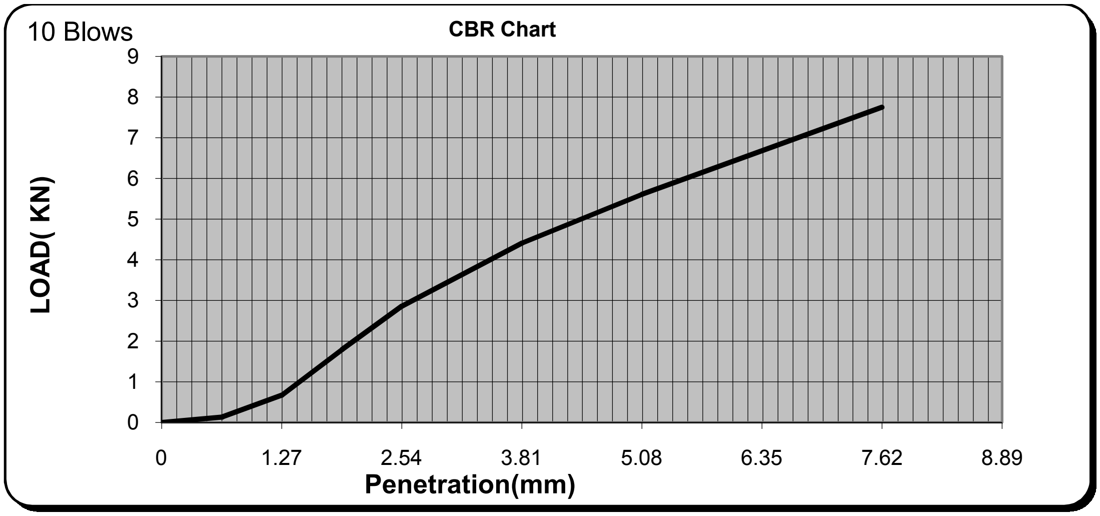
| Container no.<br>Mass of wet soil + Container | g | E<br>159.8 | A16<br>171.1 | G19<br>159.2 |
|---|---|---|---|---|
| Mass of dry soil + Container | g | 146.2 | 152.8 | 143.9 |
| Mass of container | g | 37.9 | 25.1 | 35.8 |
| Mass of water | g | 13.6 | 18.3 | 15.3 |
| Mass of drysoil | g | 108.3 | 127.7 | 108.1 |
| Moisture content | % | 12.5 | 14.3 | 14.2 |

| CBR Penetration Determination | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Penetration after 96 hrs Soaking Period | | | Surcharge Weight:-4.55 KG | | | | | |
| 65 Blows | | | 30 Blows | | | 10 Blows | | |
| Pen.mm | Load, KN | CBR % | Pen.mm | Load ,KN | CBR % | Pen.mm | Load, KN | CBR % |
| 0.00 | 0.000 | | 0.00 | 0.002 | | 0.00 | 0 | |
| 0.64 | 0.067 | | 0.64 | 0.466 | | 0.64 | 0.13 | |
| 1.27 | 0.235 | | 1.27 | 1.724 | | 1.27 | 0.668 | |
| 1.91 | 0.997 | | 1.91 | 3.461 | | 1.91 | 1.794 | |
| 2.54 | 4.897 | 36.71 | 2.54 | 4.363 | 32.71 | 2.54 | 2.853 | 21.39 |
| 3.81 | 11.730 | | 3.81 | 8.257 | | 3.81 | 4.41 | |
| 5.08 | 15.450 | 77.25 | 5.08 | 9.986 | 49.93 | 5.08 | 5.602 | 28.01 |
| 7.62 | 21.450 | | 7.62 | 12.659 | | 7.62 | 7.744 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Modified Max.Dry Density g/cc | | 1.540 | | OMC % | 26.5 | |
| Gauge Rdg | 65 Blows | | 30 Blows | | 10 Blows | |
| | Gauge rdg | Swell in % | Gauge rdg | Swell in % | Gauge rdg | Swell in % |
| | mm | | mm | | mm | |
| Initial | 9.50 | 0.00 | 7.5 | 0.00 | 6.80 | 0.00 |
| Final | 9.50 | | 7.50 | | 6.80 | |



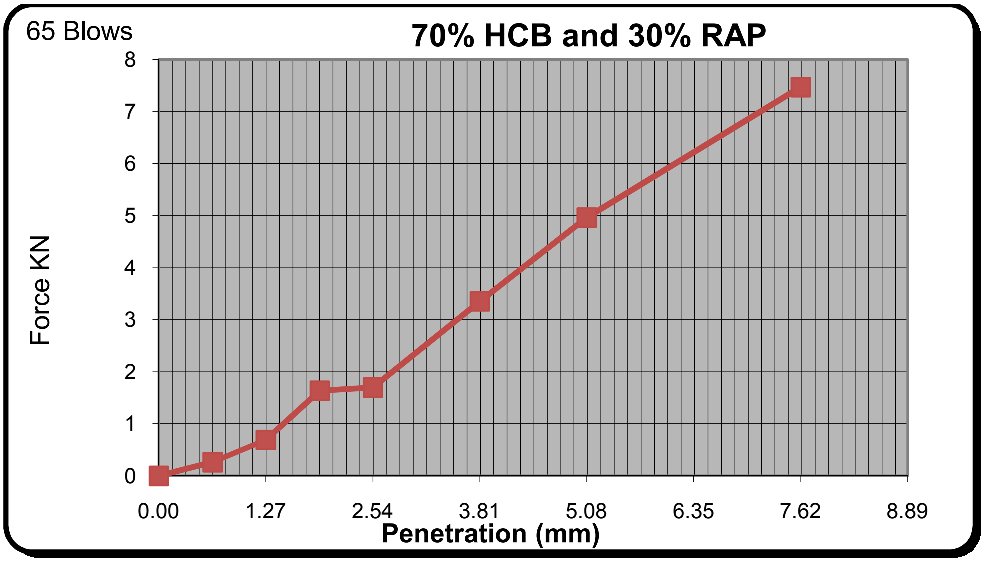


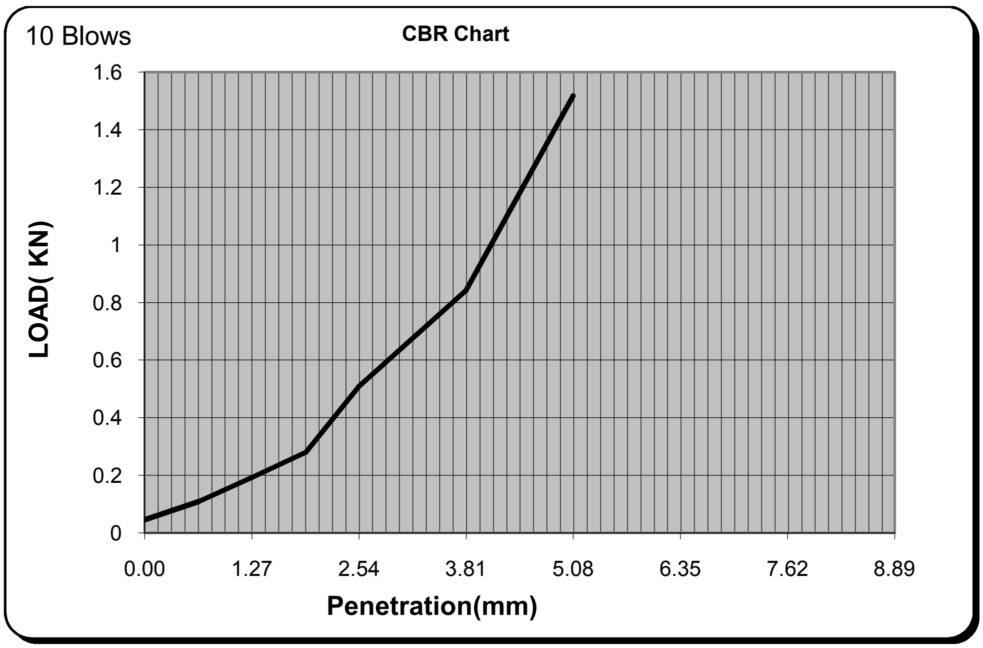

## E- 2. CBR Result for blended 70% waste HCB and 30%RAP

| | | | | |
|---|---|---|---|---|
| Compaction Determination | | | | |
| COMPACTION DATA | | 65 Blows<br>Before soak | 30 Blows<br>Before soak | 10 Blows<br>Before soak |
| Mould No. | | N7 | N6 | N15 |
| Mass of soil + Mould | g | 7904.6 | 7853.6 | 7218.7 |
| Mass Mould | g | 4150.5 | 4153.5 | 4148.3 |
| Mass of Soil | g | 3754.1 | 3700.1 | 3070.4 |
| Volume of Mould | g | 2124 | 2124 | 2124 |
| Wet density of soil | g/cc | 1.767 | 1.742 | 1.446 |
| Dry density of soil | g/cc | 1.628 | 1.601 | 1.300 |
| moisture content determination | | | | |
| MOISTURE CONTENT DATA | | 65 Blows<br>Before soak | 30 Blows<br>Before soak | 10 Blows<br>Before soak |
| Container no. | | E | A16 | G19 |
| Mass of wet soil + Container | g | 174.1 | 168.6 | 106.7 |

| | | | | |
|---|---|---|---|---|
| Mass of dry soil + Container | g | 162.5 | 157.8 | 97.8 |
| Mass of container | g | 26.7 | 34.6 | 17.9 |
| Mass of water | g | 11.6 | 10.8 | 8.9 |
| Mass of dry soil | g | 135.8 | 123.2 | 79.9 |
| Moisture content | % | 8.6 | 8.8 | 11.2 |
| CBR Penetration Determination | | | | |

| Penetration after 96 hrs Soaking Period | | | Surcharge Weight:-4.55 KG | | | | | |
|---|---|---|---|---|---|---|---|---|
| 65 Blows | | | 30 Blows | | | 10 Blows | | |
| Pen.mm | Load, KN | CBR % | Pen.mm | Load ,KN | CBR % | Pen.mm | Load ,KN | CBR % |
| 0.00 | 0 | | 0.00 | 0.001 | | 0.00 | 0 | |
| 0.64 | 0.265 | | 0.64 | 0.158 | | 0.64 | 0.046 | |
| 1.27 | 0.692 | | 1.27 | 0.313 | | 1.27 | 0.109 | |
| 1.91 | 0.638 | | 1.91 | 0.297 | | 1.91 | 0.193 | |
| 2.54 | 1.697 | 12.72 | 2.54 | 0.533 | 4.00 | 2.54 | 0.28 | 2.10 |
| 3.81 | 3.355 | | 3.81 | 1.253 | | 3.81 | 0.509 | |
| 5.08 | 4.965 | 24.83 | 5.08 | 2.418 | 12.09 | 5.08 | 0.842 | 4.21 |
| 7.62 | 7.471 | | 7.62 | 4.912 | | 7.62 | 1.518 | |


65 Blows
70% HCB and 30% RAP
8
7
6
5
4
3
2
1
0
Force KN
0.00
1.27
2.54
3.81
5.08
6.35
7.62
8.89
Penetration (mm)

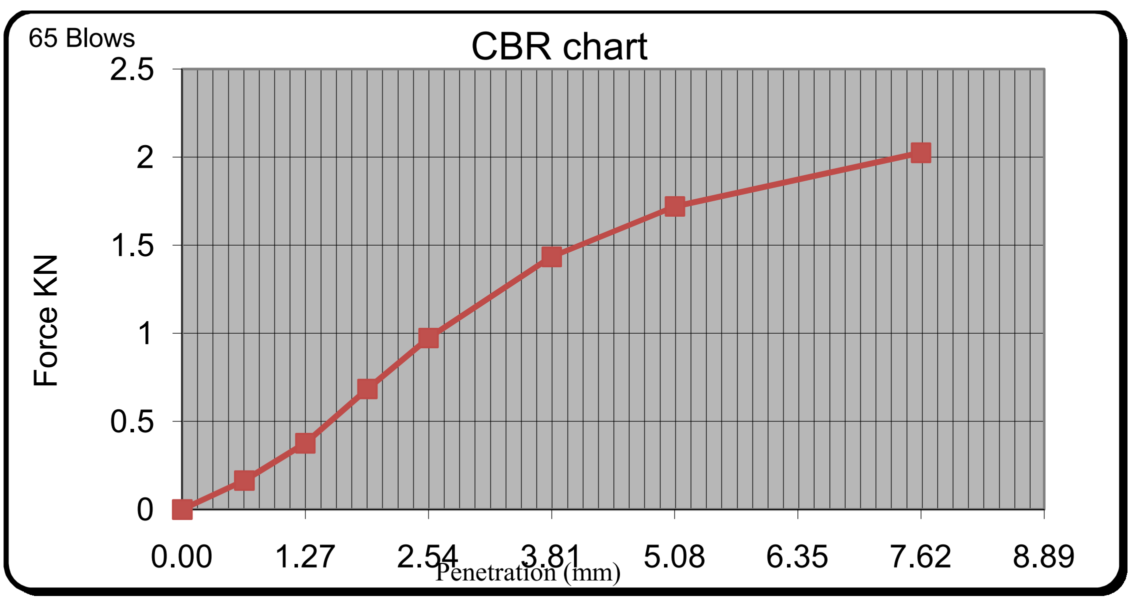

10 Blows
CBR Chart
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
LOAD( KN)
0.00
1.27
2.54
3.81
5.08
6.35
7.62
8.89
Penetration(mm)

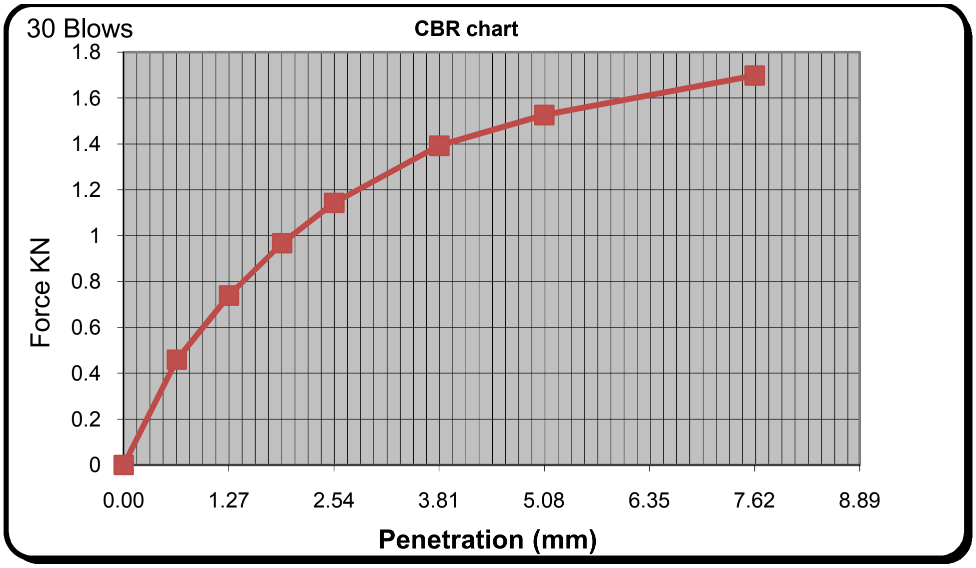
### E-3.100% RAP

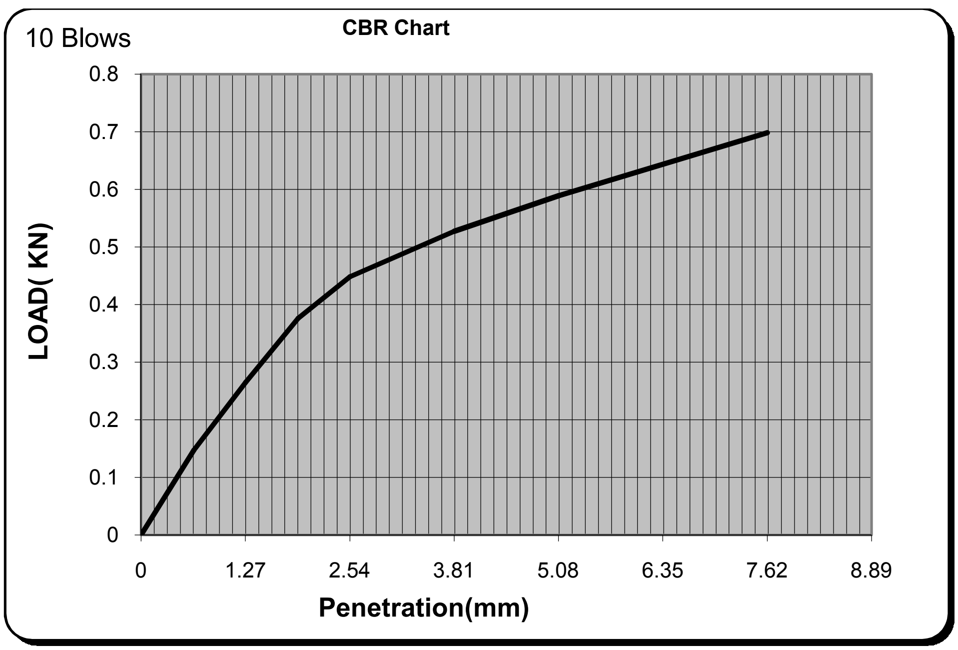
| COMPACTION DETERMINATION | | | | |
|---|---|---|---|---|
| COMPACTION DATA | | 65 Blows | 30 Blows | 10 Blows |
| | | Before soak | Before soak | Before soak |
| Mould No. | | TN | N6 | N22 |
| Mass of soil + Mould | g | 8430 | 8170.4 | 8029 |
| Mass Mould | g | 4151.8 | 4214.4 | 4152.4 |
| Mass of Soil | g | 4278.2 | 3956 | 3876.6 |
| Volume of Mould | g | 2124 | 2124 | 2124 |
| Wet density of soil | g/cc | 2.014 | 1.863 | 1.825 |
| Dry density of soil | g/cc | 1.881 | 1.765 | 1.729 |

| Moisture Determination | | | | |
|---|---|---|---|---|
| MOISTURE CONTENT DATA | | 65 Blows | 30 Blows | 10 Blows |
| | | Before soak | Before soak | Before soak |
| Container no. | | T3P6 | NB | P3SB26 |
| Mass of wet soil + Container | g | 218.5 | 120.2 | 128.5 |
| Mass of dry soil + Container | g | 206.5 | 114.8 | 122.7 |
| Mass of container | g | 37.6 | 17.4 | 18.3 |
| Mass of water | g | 12.0 | 5.4 | 5.8 |
| Mass of drysoil | g | 168.9 | 97.4 | 104.4 |
| Moisture content | % | 7.1 | 5.5 | 5.5 |

| 65 Blows | | | 30 Blows | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pen.mm | Load, KN | CBR % | Pen.mm | Load, KN | CBR % | Pen.mm | Load , KN | CBR % |
| 0.00 | 0.005 | | 0.00 | 0 | | 0.00 | 0 | |
| 0.64 | 0.29 | | 0.64 | 0.049 | | 0.64 | 0.04 | |
| 1.27 | 0.555 | | 1.27 | 0.094 | | 1.27 | 0.09 | |
| 1.91 | 0.803 | | 1.91 | 0.155 | | 1.91 | 0.15 | |
| 2.54 | 1.082 | 8.11 | 2.54 | 0.207 | 1.55 | 2.54 | 0.23 | 1.75 |
| 3.81 | 1.771 | | 3.81 | 0.404 | | 3.81 | 0.46 | |
| 5.08 | 2.547 | 12.74 | 5.08 | 0.657 | 3.29 | 5.08 | 0.71 | 3.55 |
| 7.62 | 4.133 | | 7.62 | 1.411 | | 7.62 | 1.51 | |
| Modified Max.Dry Density g/cc | | | | | OMC % | | | |




30 Blows
CBR chart
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Force KN
0.00
1.27
2.54
3.81
5.08
6.35
7.62
8.89
Penetration (mm)


10 Blows
CBR Chart
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
LOAD( KN)
0
1.27
2.54
3.81
5.08
6.35
7.62
8.89
Penetration(mm)