Investigation on Characterization and Partial Replacement of Recycled Asphalt Pavement with Virgin Crushed Aggregate and Volcanic Ash Filler as Un Bound Base Course Material

(Case of Addis – Adama Express Way)

By: Girma Demeke

A Thesis Submitted to

Civil Engineering Program

School of Civil Engineering and Architecture Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Civil Engineering (Geotechnical Engineering)

Office of Graduate Studies

Adama Science and Technology University

March, 2021

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APPROVAL PAGE

We, the undersigned, members of the Board of Examiners of the final open defense by Girma Demeke have read and evaluated his thesis entitled "Partial replacement of Crushed standard aggregate with recycled asphalt pavement as un bound base course material (case of Addis – Adama Express way)" and examined the candidate. This is, therefore, to certify that the thesis accepted in partial fulfillment of the requirement of the Degree of Master's.

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Chairperson Signature Date

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Internal Examiner Signature Date

______________________________ ______________________ ____________________

External Examiner Signature Date

DECLARATION

I hereby declare that this MSc Thesis entitled **“**Partial replacement of Crushed standard aggregate with recycled asphalt pavement as un bound base course material (case of Addis – Adama Express way)“ is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: Girma Demeke

Signature: ____________

This MSc Thesis submitted for examination with my approval as thesis advisor Supervisor.

Main advisor : Siraj Mulugeta (Phd) Signature: ____________ Date ____________

Date of submission:………..

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ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Course
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BS	British Standard
ERA	Ethiopian Road Authority
CBR	Californian Bearing Ratio
CSA	Crushed Standard aggregate
GB	Granular Base
HMA	Hot Mix Asphalt
LAA	Loss Angeles Abrasion Resistance
LEED	Leadership in Energy and Environmental Design
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plastic Index
RAP	Recycled Asphalt Pavement
TFV	Ten Percent Fines Value

ABSTRUCT

Recycling asphalt pavement has become a common practice in road construction due to environmental benefit such as preservation of natural material, reduction of carbon emission and energy saving in the processing and haulage of Crushed standard aggregate(CSA), reduction of disposal of recycled asphalt pavement (RAP) and landfill. In addition, use of RAP has economic benefit due to reduction of material cost and haulage and time saving. Furthermore, its use fits with global objective of sustainable development. Nevertheless, their use in Ethiopia for road construction is unfamiliar and waste at fill area or disposes on the shoulder creating disposal and environmental problem. This research aims to partially replace Crushed standard aggregate with recycled asphalt pavement as un bound base course material for heavily trafficked road. The first phase of this study consists of conducting laboratory tests on RAP and CSA collected from Addis-Adama expressway at south Bishoftu entrance and ICT Park stoke pile respectively. Whereas, the second phase comprises of testing CSA- RAP blend at replacement percentage of 20, 30 and 40 RAP by total mass aggregate and addition of 4% volcanic ash filler. The laboratory test performed were gradation, California Bearing Ratio (C.B.R), Modified Procter, Aggregate Impact value, Aggregate Crushing value, Ten Percent Fines value, Flakiness Index, Loss Angles Abrasion value, Specific gravity and Water absorption tests. The test results of RAP aggregate shows value of LAA 27%, AIV 17%, ACV 16%, TFV 227KN, flakiness index 29% and non-plastic which satisfies ERA specification for GB1. However, RAP having particle size distribution of gap grade, lower maximum dry density of 1.918g /cc and lower CBR value of 14%, RAP does not qualify criteria of GB1. Except CBR test at 40% RAP content, all laboratory test Results conducted on all CSA-RAP blend samples satisfy the requirement of ERA of GB1 material. Therefore, for the studied CSA and RAP material, replacing CSA with RAP up to 30% by total mass of aggregate and 4% volcanic ash filler satisfy bearing capacity specification measured by CBR test having CBR value of 100%. Finally, the researcher concludes that it is possible to Replace CSA with RAP up to 30% by total mass of aggregate for un bound base course material for heavily trafficked road and recommends the variability of RAP material, performance of CSA and volcanic ash filler amount should be determined before use as GB1 material.

Keywords: CBR, Crushed Standard Aggregate, Ethiopian Road Authority, Granular unbound Base material 1, Recycled Asphalt Pavement, Volcanic ash.

CHAPTER 1:

1. INTRODUCTION

1.1 Back Ground and Justification

Currently, sustainable construction and infrastructure has great emphasis. Recycled materials have seen increasingly more use in the past 20 years. One way to construct environmentally sound roads is using recycled materials such as Recycled asphalt pavement (RAP). RAP materials produced by milling old or failed asphalt pavement surfaces to a specific depth (depending on the asphalt course thickness) and processing the milled material (McGarrah 2007).

Use of RAP for base layer construction is an encouraging approach as RAP bases can perform equally as base layers constructed with Crushed standard aggregate (CSA) and has positive environmental consequences by reducing consumption of natural sources, improving waste utilization, and decreasing greenhouse gas emissions and energy consumption (Lee et al. 2010). In addition, using RAP materials can provide overall project savings by minimizing transportation costs for CSA and decreasing disposal costs when RAP are generated and used in place (Gonzalez and Moo-Young 2004), e.g., up to 30% of cost saving could be achieved by the in-place recycling (Edil 2011). Therefore, recycling of RAP has become a common practice in the transportation industry.

The Washington State Department of Transportation (WSDOT) currently allows use of RAP into new HMA up to 20%. Therefore, a large portion of the milled asphalt ends up at contractors' pits or landfills. Due to the possible reduction in product and construction cost by using RAP as base course, WSDOT is investigating the possibility of blending RAP with virgin material for use as a base course material (McGarrah 2007).

The use of RAP in road base and subbase materials is viable and a number of transportation agencies have implemented it. There seemed to be no major environmental concerns associated with using unbound RAP without chemical stabilization agents. There is a potential for significant economic benefits in using RAP in base and subbase applications. Using between 20%- 50% RAP can result in a cost savings of between 14%- 34% per tonnage (TFHRC. 2010). Approximately 30% in material cost savings could be realized with a 50/50 blend of RAP and Crushed standard aggregate (Edward J. Hoppe 2015).

RAP alone is a poor material and could not use for base course due to gap graded, lower compaction characteristics of significantly lower maximum dry density and CBR value than CSA. RAP can be blended with CSA or stabilized by cement and fly ash to increase its strength and to reduce its creep and permanent deformations (J. a. Thakur 2015). Researchers found that Modifying RAP through blending with Crushed standard aggregate improves its property (Mokwa 2005). In addition adding filler material passing 0.425mm sieve increases particle interlock, CBR value, dry density and easy of compaction. However, excessive fines can result in long-term total and differential settlement, leading to collapse (Rathje 2001). Moreover stabilizing RAP with a high carbon/high calcium fly ash significantly increases the CBR and the MR and lowers the plastic strain of this material (nearly five folds) (Felipe F. Camargo 2012).

The percent by total weight allowed for RAP blended with CSA for base course should be limited to 50%. At percentages greater than 50%, permeability and CBR greatly reduce;

despite occasional increases in resilient modulus and accumulated permanent deformation (Bennett 2005).Permanent deformation increases with increasing RAP contents. In addition, the asphalt binder content of total blend should not exceed 1.5% by weight (P. K. Cosentino 2012).

Multilayer elastic analysis of typical pavement sections with the base layer constructed of CSA and RAP blends showed good performance (Mousa 2007). However, more studies require to better pinpointing a maximum percentage range of RAP.

1.2 Statement of the problem

In some locations of our country, sources that give standard quality materials may not be available near by the project area and transporting and processing materials from large distances mostly beyond 10 Km is not economical (Ethiopian Roads Authority. 2013). Following these there will be scarcity of natural sources of materials, which used directly without modification especially for heavily trafficked highways that require high quality materials (GB1). This leads to the requirement of recycling waste materials, which could have marginal properties. RAP is one material that has been extensively recycled.

In Ethiopia due to lack of regular over load control mechanism and increasing of vehicle number, many roads fail before the end of design period, requiring frequent maintenance and rehabilitation. As a result, a large amount of Recycled asphalt pavement (RAP) produced and wasted along the roadside or damped in the filled without any use. This creates environmental problem and landfill problem. Reusing non-renewable resources and decreasing the size of the land fill of RAP can both be accomplished by using RAP as base course and are both beneficial to sustainable construction.

Even though the use of RAP has economic and environmental benefits, such as reductions in virgin material cost, carbon emissions, no durability concerns and use of nonrenewable natural resources. Because quality of RAP aggregates usually exceeds the requirements for granular aggregates. However, the thin film of asphalt on the aggregates has some effect on the performance of RAP, as aggregate in unbound pavement layers (Yuan 2010). As a result, RAP alone is not applicable in base course construction. Therefore, Blended with CSA or stabilized with cement or fly ash. As most milling machines do not produce consistent size pieces of RAP and varying bitumen content so, the engineering properties of the RAP-CSA blends vary depending on the type of CSA used and RAP material. Even though the properties of RAP as base course material not completely known and conflicting reports exist, RAP is being in use extensively in many countries like USA, Canada, European countries etc. (McGarrah 2007).Yet the use of RAP for road construction in Ethiopia is limited due to lack of sufficient research and field performance.

Therefore, conclusion shall be drawn out as whether RAP could be used as base course material and the optimum content of RAP to be blended that satisfies the requirement of un bound base course material for highly trafficked road as per ERA based on laboratory test result and literature review.

1.3 Objectives

General objective: is partial replacement of Crushed standard aggregate with recycled asphalt pavement as unbound road base materials for road construction (case of Addis- Adama).

1.3.1 Specific objectives:

The specific objectives of this research include:

To evaluate Characteristics of recycled asphalt pavement (RAP) and Crushed standard aggregate (CSA) based on laboratory test results.

To examine the properties of CSA- RAP blends with volcanic ash filler at different RAP content.

To find out the optimum percent of recycled asphalt pavement (RAP) to be blend with crushed aggregate standard (CSA)and volcanic ash filler to be used as base course material for road construction.

CHAPTER 2:

2. LITERATURE REVIEW

2.1 Introduction

"Base course is the main structural layer of a flexible pavement whose function is to support the applied wheel stress and strains incident on it which is coming from traffic and distribute the same in such a manner that the materials beneath it will not become overloaded" (Martin.R 2003).

Materials used for base course shall consist of hard, durable, tough and strong particles or fragments of stone, which must be resistant to carry load imposed on them during construction and design life. They must have mechanical interlocking stability, must be resistance to mineralogical change and physical break down due to any cyclic environmental change (Ethiopian Roads Authority. 2013).

In Ethiopia, materials acquiring such kind of characteristics labeled by ERA as standard materials namely GB1, GB2, GB3 and GB2A with certain specification of grading, shape and minimum strength. A wide range of materials is included in this categories and the selection among them depend up on traffic level and local climate. Dense graded un weathered crushed stone with non – plastic parent fines are referred as GB1 materials whereas GB2 and GB3 category covers natural gravels and weathered rocks with fines having slight plasticity including lateritic, calcareous and quartzite gravels, river gravels, boulders and other transported gravels. Materials consisting of nominal single-sized crushed stone and non-plastic fine aggregate (passing the 5.0 mm sieve) classified under GB2A, which is suitable when there is cheap layer and scarcity of water. The fine material should preferably be well graded and consist of crushed rock fines or natural, angular pit sand (Ethiopian Roads Authority. 2013).

Table 2-1: properties of road making materials to be investigated **(Martin.R 2003)**

Key engineering factor	Material requirements
Strength	Aggregate particles need to be load resistant to any loads imposed during construction and the design life of the pavement.
Mechanical stability	Aggregate as a placed layer must have a mass mechanical interlocking stability sufficient to resist loads imposed during construction and design life of the pavement.
Durability	Aggregate particles need to be resistant to mineralogical change and to physical breakdown due to any wetting and drying cycles imposed during construction or pavement design life.
Haul distance	Reserves must be within physically and economically feasible haulage distance.
Utilization	Material must be capable of being placed and compacted by the available plant.
Environmental impact	Material reserves must be capable of being won and hauled with in any governing environmental impact regulations.

Table 2-2: properties of un bound materials **(Ethiopian Roads Authority. 2013)**

Code	Description	Summary of Specification
GB1	Fresh, crushed rock	Dense graded, unweathered crushed stone, non-plastic parent fines

GB2	crushed weathered rock, gravel or boulders	Dense grading, PI<6, soil or parent fines; PP<60
GB2A	Dry-bound and water-bound macadam	Dense grading, PI<6, soil or parent fines; PP<60
GB3	Natural coarsely graded granular material, including processed and modified gravels.	Dense grading, PI<6, CBR after soaking > 80%
GS	Natural gravel	CBR after soaking > 30%
GC	Gravel or gravel-soil	Dense graded, CBR after soaking > 15%

Note: PP= plasticity product= PI x(percent passing sieve size 0.075mm)

GB = Granular base, GS= Granular Subbase, GC= granular Capping layer.

In some locations of our country, sources that give standard quality materials may not be available near by the project area and transporting and processing materials from large distances is not economical. Following these there will be scarcity of natural sources of materials, which used directly without modification especially for heavily trafficked highways that require high quality materials (GB1). This leads to the requirement of recycling waste materials, which could have marginal properties. Recycled asphalt pavement (RAP) is one material that has been extensively recycled.

2.2 Milling process

Milling is the process of extracting Recycled asphalt pavement by milling machine from old pavement surface in the time of maintenance or removal of pavement. RAP created when existing asphalt concrete surfacing milled or completely removed. Milling the existing roadway surface and replacing it with a new Hot Mix Asphalt (HMA) is a rehabilitation method utilized in most countries.

RAP derived from different sources can have significantly different gradation, oil content and density. This can be due to the milling process, rock source, type of oil, etc. RAP combined from several sources may change the quality of the product throughout the construction project because of this variation. (McGarrah 2007). As a result, the various pavements within the RAP have different types of aggregate and asphalt that could affect the quality of the base course when blended with Virgin crushed aggregate. Determining the type of RAP and its gradation prior to approving its use as a base course material would ensure more consistent test results. (McGarrah 2007)

2.3 Storage temperature

RAP is a mixture of aggregate and bitumen. As the bitumen is a viscoelastic material, RAP should be stored at desired temperature. The laboratory tests revealed that increasing the storage temperature from 75(23.8^{o}c) to 100°F (37.7^{o}c) increased the maximum principal stress at failure, stiffness and cohesion. Increasing the temperature to 125°F (51.6^{o}c) did not cause the properties to change. (P. J. Cosentino 2001)Study did not cover the RAP base course with an AC surface course. Moreover, Consentino found that below 18-inches (457.2mm), air temperature variations caused little effect on the RAP temperature. Thus, temperature may not have a great effect on the performance of the base course material once a surface course placed over top.

Stiffness (Cooley 2005) also noted variations to properties due to temperature. When the stiffness was tested at optimum moisture content, the values decreased as the RAP percentage increased from 0 to 25%. As more RAP was blended into the material, from 25 to 100%, the stiffness values increased. On the other hand, when the RAP dried for 72 hours at 140°F (60 ^{o}c), then soaked and tested, the trend reversed. Stiffness values increased as the RAP percentage was increased from 0 to 25% and then decreased when the RAP percentage was increased from25-100%. Cooley stated that the heat from the drying oven softened the asphalt in the RAP samples and, after a cooling period, the asphalt hardened and enhanced the bonding between the aggregates.

2.4 Compaction characteristics

Compaction characteristics evaluated by the maximum dry unit weight (density). Higher dry unit weight indicates better compressibility (Rathje 2001). The maximum dry unit weight of compacted RAP is 19.4 kN/m^3 (Soleimanbeigi 2014). Dry unit weight of RAP is not sensitive to moisture, since bitumen coating of RAP forms a large impermeable volume of solids ((Rathje 2001), (Soleimanbeigi 2014).

Though the compaction effort has a great influence on the maximum dry unit weight, the addition of fine aggregates (i.e. passing the #40 sieve size), rather than double compaction effort, contributes more to high lime rock bearing ratio. However, excessive fines can result in long-term total and differential settlement, leading to collapse (Rathje 2001). Static compaction rather than the dynamic, vibratory or Proctor compaction is favorable to gain higher lime rock bearing ratio (P. J. Cosentino 2003).

The maximum dry density (MDD) tends to decrease as the level of RAP replacement in the blend increases however, the optimum moisture content (OMC) in general found to decrease with increase in the RAP percentage. This attributed to the very low moisture holding capability of RAP due to the asphalt coated aggregate in the RAP. Thus, the addition of Crushed standard aggregate would make it much easier to compact RAP as a base material ((Taha 1999), (Guthrie 2007) and (Ganne 2009)).

A binding and/or agglomeration effect where residual asphalt binder within RAP causes finer particles to adhere to each other as well as larger particles, reducing the amount of water needed to achieve the required compaction level of the RAP blends. This factor considered when the suitable moisture content of compaction is determined (A.Gunes 2018).

The typical OMC and MDD of a compacted RAP blended material reported to be lower than that for crushed standard aggregate (Peebles 2008). However, the OMC and MDD reported to be higher for RAP blends treated with cement, due to higher fine content and the absorptive capacity of these fines. As the cement added to the RAP material, the MDD and OMC values are increased (M. Alireza 2014). Increasing RAP contents decreases the maximum dry density (MDD) for cement treated mixes/RAP-base blends, because of reduced specific gravity caused by asphalt coating on RAP aggregates (Ganne 2009), (Guthrie 2007).

Optimum moisture content (OMC) varies between 5.3% and 7.1% for RAP-base blends, comparable to that of conventional granular aggregate base ranging from 5% and 8% (Ganne 2009). Optimum moisture content (OMC) varies between 5.3%- 7.1% for cement or fly ash-treated RAP-base blends (Ganne 2009). Increasing RAP content decreases OMC for cement or fly ash-treated RAP blends, due to reduced water absorption because of asphalt coating of RAP aggregates ((Ganne 2009), (Guthrie 2007)).

2.5 Modulus of resilient (MR)

For unbound materials, the resilient modulus tests simulate the field traffic conditions involving smaller strains and are more representative than the large-strain conditions of the CBR test. Therefore, resilient modulus is more appropriate to characterize the materials for pavement design (Felipe F. Camargo 2012). Resilient modulus (MR) ranges between 100 ksi and 800 ksi. (The range reflects a variety of aggregates, binders, mixing and curing conditions, and compaction).

Un stabilized RAP exhibited a higher modulus in the order of about 17% than the conventional natural base course material (i.e., crushed aggregate); however, RAP showed a higher plastic strain, indicating a higher potential for rutting by un stabilized RAP (Felipe F. Camargo 2012).

Cement addition increased MR and dependency on bulk stress (Jenkins 2007). Temperature sensitive; there was a 30%- 44% stiffness reduction as testing temperature increased from 50ºF to 104ºF (Nataatmadja 2002).

Influential factors to MR are the following:

- More by loading rate and less by stress (P. J. Fu 2009).
- Higher influence by confining pressure than deviatoric stresses (P. a. Fu 2007).
- Higher influence by loading rate and temperature than deviatoric stresses and confining pressure (Khosravifar 2012).

Cement appears to be an effective stabilizer for RAP in achieving high strength and stiffness. MR increases with an increasing percent of cement (Potturi 2006).

MR increases with increasing fly ash content and curing period (Wen 2010).MR of chemically stabilized RAP also increases with higher stabilizing agent content (J. a. Thakur 2015).Higher compaction effort (i.e., compact to 95% of maximum dry density) improves MR (Bennett 2005).

MR decreases with increasing moisture content. RAP percentage has little effect on sensitivity of MR to moisture content (M. Wu 2011). MR decreases with increase of temperature due to reduction of asphalt stiffness. Mixtures with higher RAP content are more sensitive to temperature changes. MR increases with an increase of confining pressure. There is a higher MR for mixtures containing a higher RAP content, which may be associated with lower air void (M. Wu 2011). Geogrid and geocell improve MR of RAP layers by providing lateral confinement whereas geotextile provides a tensioned membrane effect (J. Thakur 2011).

According study made by (Mousa 2007) in Egypt, resilient modulus for different RAP blends satisfy South Australian Department for Transport, Energy and Infrastructure standards for the recycled material (DPTI 2011)for base material which is 300 MPa as a minimum.

As the percentage of RAP in the blend increases from 20% to 60%, the effect of load duration increases (Mousa 2007). The reason for that is the viscoelastic behavior of the asphalt material; i.e., RAP behaves as elastic material at the fast moving loads while it behaves as a viscous material at slow moving loads (Khan 2015).

A model proposed that correlate CBR with resilient modulus by (Mousa 2007) as shown below.

$$\mathrm{MR} = 1400(CBR)^{-0.32}$$

$$\mathrm{MR} = 1392.36(CBR)^{-0.31}$$

In both equations, MRis expressed in MPa while the CBR is expressed in percentage.

2.6 Californian bearing ratio (CBR)

The CBR of un stabilized RAP is significantly lower than that of the crushed aggregate (about 86%). Stabilizing RAP with a high carbon/high calcium fly ash, however, significantly increased the CBR and the MR and lowered the plastic strain of this material (nearly five folds) (Felipe F. Camargo 2012).

CBR of CSA-RAP blends decreases with increasing RAP content ((Bennett 2005), (Guthrie 2007), (P. K. Cosentino 2012). CBR of RAP ranges from 11 to 33% (J. Thakur 2011). In general, the soaked CBR values dramatically decreased with the increase of RAP content in the blend. This may be owing to the reduction in the angle of internal friction of the mixture due to the asphalt-coated particles of the RAP. Furthermore, the CSA-RAP blends have lower fines content compared to the Virgin crushed aggregate. This may lead to further decrease in the shear strength of the blend (Mousa 2007).

CBR improves by adding fine sand (i.e. material passing the #40 sieve size) instead of increasing density by doubling compaction.

2.7 Unconfined compressive strength

Crushed standard aggregate samples have lower unconfined compressive strength (UCS) than blends containing 25% or 50% RAP (Guthrie 2007). UCS decreases with increasing RAP content ((Guthrie 2007), (Ganne 2009)). Conversely, (Yuan 2010) and (Hoyos 2011) reported that UCS increases with an increasing RAP content. Blends containing coarse RAP aggregates have higher UCS than those containing fine RAP aggregates (Ganne 2009). UCS increases by increasing stabilizing agent (i.e., cement, fly ash) content and curing period, and decreases with RAP content (Wen 2010).

2.8 Permeability

Permeability is an important property of the base material. The permeability test takes a direct way to characterize the moisture susceptibility of a compacted material (saturated or unsaturated) by measuring the speed of water flows through pore spaces in the material. Moisture trapped between the particles in the base course can lead to base course destruction due to loss of support. In asphalt wearing courses, the water content can leak into the base course from surface cracks over time (A.Gunes 2018).

(Trzebiatowski 2005)Found that the RAP hydraulic conductivity ranged from 4.5×10-8 to 1.7×10-6 m/s. This permeability values are similar to the permeability of traditional granular base materials. In similar studies, (Gupta 2009) evaluated the hydraulic conductivity of blends of RAP and crushed-stone aggregate. The authors found that the RAP percentage in the blend did not significantly affect the hydraulic conductivity. Conversely, ((M. W. Wu 2012), (Bennert 2005)) noted that the permeability of a base material decreased as the RAP percentage in the blend increased.

In general, the permeability of the blends increased with the decrease of RAP content. The results indicate that adding RAP yields lower porosity (interconnected voids) in the specimen (Mousa 2007).

Moreover, the level of compaction of the material will largely affect the conductivity of the sample. When performing conductivity tests, it is imperative to ensure the densities are the same to ensure consistent results. (McGarrah 2007)

2.9 Permanent deformation

Permanent deformation affected by angularity (e.g., shape, hardness, and roughness) and maximum size of aggregates, compaction method (Wirtgen. 2010).

High angular and coarse aggregates provide resistant to deformation. As gradation becomes finer, permanent strain increases. Greater compaction effort creates denser material with less permanent deformation (Bennett 2005). Permanent deformation increases with increasing RAP contents. RAP can be blended with Crushed standard aggregate or stabilized by cement and fly ash to increase its strength and to reduce its creep and permanent deformations (J. a. Thakur 2015).

2.10 Durability

There are no durability concerns regarding the use of RAP in granular base, since quality of RAP aggregates usually exceeds the requirements for granular aggregates. However, the thin film of asphalt on the aggregates has some effect on the performance of RAP, as aggregate in unbound pavement layers (Yuan 2010).RAP from pavements that have exhibited stripping have low strength (Saeed 2008).

2.11 Index properties of RAP

Specific gravity values decreases with the increase in the percentage of the RAP replacement in the blend due to the presence of low specific gravity of asphalt (Mousa 2007). According to (Mousa 2007), the water absorption, LL, PI and LAA of the RAP and Virgin crushed aggregates comply with the Egyptian standards for the base materials. The RAP found to be non-plastic and seems to have abrasion resistance less than the Virgin crushed aggregate (Mousa 2007).

The pH values for RAP and Crushed standard aggregate were 9.5and 7.8, respectively, which indicated that the RAP is more alkaline than the neutral level of deionized water of pH equals 7. This also indicated that corrosion of samples was moderate (Mousa 2007).

2.12 Design Recommendation

The percent by total weight allowed for RAP blended with dense graded aggregate base course should be limited to 50%. At percentages greater than 50%, permeability and CBR greatly reduce despite occasional increases in resilient modulus and accumulated permanent deformation (Bennett 2005). The asphalt binder content of total blend should not exceed 1.5% by weight (P. K. Cosentino 2012).

2.13 Benefits of using Recycled asphalt pavement (RAP)

Using RAP materials in road construction reduces both the depletion rate of natural resources and the amount of construction debris disposed in urban landfills (Hoyos 2011). RAP base materials yield considerable savings in overall costs of pavement construction projects. Using between 20%- 50% RAP can result in a cost savings of between 14%- 34% per tonnage (TFHRC. 2010). RAP is used in new bituminous materials by either a hot-mix or cold-mix recycling process. However, a large quantity of RAP materials remains unused, which can be reduced by using RAP as base and subbase aggregate materials (J. a. Thakur 2015).

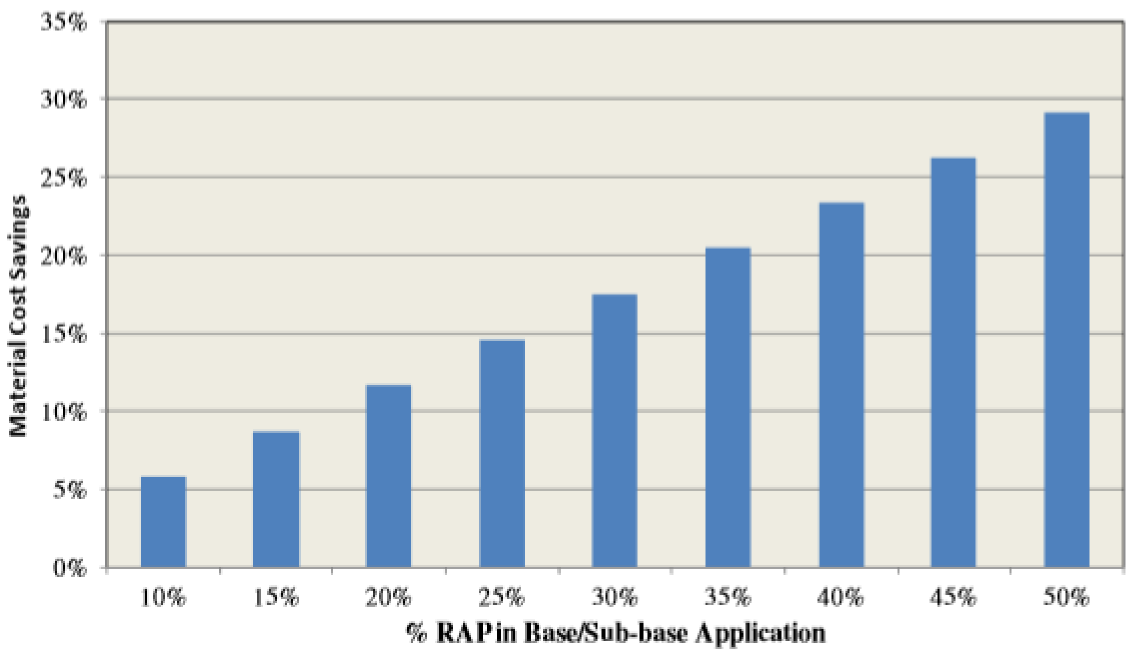

Figure 2-1: Potential material cost savings from RAP use as base and subbase applications **(Edward J. Hoppe 2015)**

CHAPTER 3:

3. MATERIAL and METHODOLOGY

3.1. Material Source Location

Addis - Adama expressway is an asphalt concrete road, which consists of wearing and binder course surfacing, high modulus asphalt macadam (HMAM) base layer, graded macadam subbase layer, and capping layer. As shown in table 3.1 below the thickness of surface course is the same throughout the segment.

Table 3-1: Pavement Layer Thickness (Pavement Report of Addis Ababa-Ababa Toll Motorway Project)

No	Structural Layer Name		Pavement Layer Thickness (cm)	
			Pavement Section 1	Pavement Section 2
			(2+800-52+600) (47.8km)	(52+600-77+500) (24.9km)
1	Surface Course	Wearing course	4	4
2		Binder course	6	6
3	Base course	HMAM	17	16
4	Subbase course	Graded macadam	32	32
5	Improved subgrade	Capping layer	30	30
Total thickness				

Addis -Adama toll motorway road subjected to early failure and frequent maintenance that is a critical case in our country. The most significant failure type observed in Addis -Adama is fatigue cracking of the asphalt layer. Parameters that cause flexible pavements to failure can be the stresses, strains, and deflections developed due to the combined effect of vehicular loading, material characteristics of the layers, and environmental conditions (Almeshet 2019). As a result, maintenance of the wearing course 4cm thick carried out by removing through milling and replacing with new HMA frequently, producing reclaimed asphalt pavement (RAP). The RAP dumped at dumping site near south Bishoftu entrance.

Figure 3-1: Cracked surface and Milling machine extracting the RAP near IT park.

Figure 3-2: Quary site near South Bishoftu entrance

At the time this research work conducted, the RAP material at dumping site of South Bishoftu entrance covers approximate length of 900m and width of 200m and average the height of 10m. Using area of pyramid, volume equal to one-third base area multiply with height. V= 1/3*B*L*H=1/3*900m*200m*10m=600,000m3.

This study were conducted on Recycled asphalt pavement (RAP) samples that have been collected from Addis-Adama express way dumping site around South Bishoftu entrance and Crushed standard aggregate (CSA) collected from IT Park base course stoke place around Koye feche, Addis Ababa. In addition, volcanic ash used as filler collected from nearby Adama west entrance of expressway. These locations selected due to their accessibility and availability of transportation.

3.2. Study design

The researcher designed the paper to answer research questions and meet its objectives based on experimental findings.

The first phase of this experimental investigation includes characterizing Crushed standard aggregate (CSA) and Recycled asphalt pavement (RAP) separately where as in the second phase physical and mechanical properties of CSA- RAP- filler blend examined through conducting laboratory tests. Recycled asphalt pavement were mixed with Crushed standard aggregate with a quality of GB1 material at replacement rate of 0%, 20%, 30% and 40% by mass of total aggregate. In addition, the researcher added 4% volcanic ash as filler by total weight of the blend to improve gradation, compaction characteristics, strength and bond between the particles. The flow chart below shows entire research process.

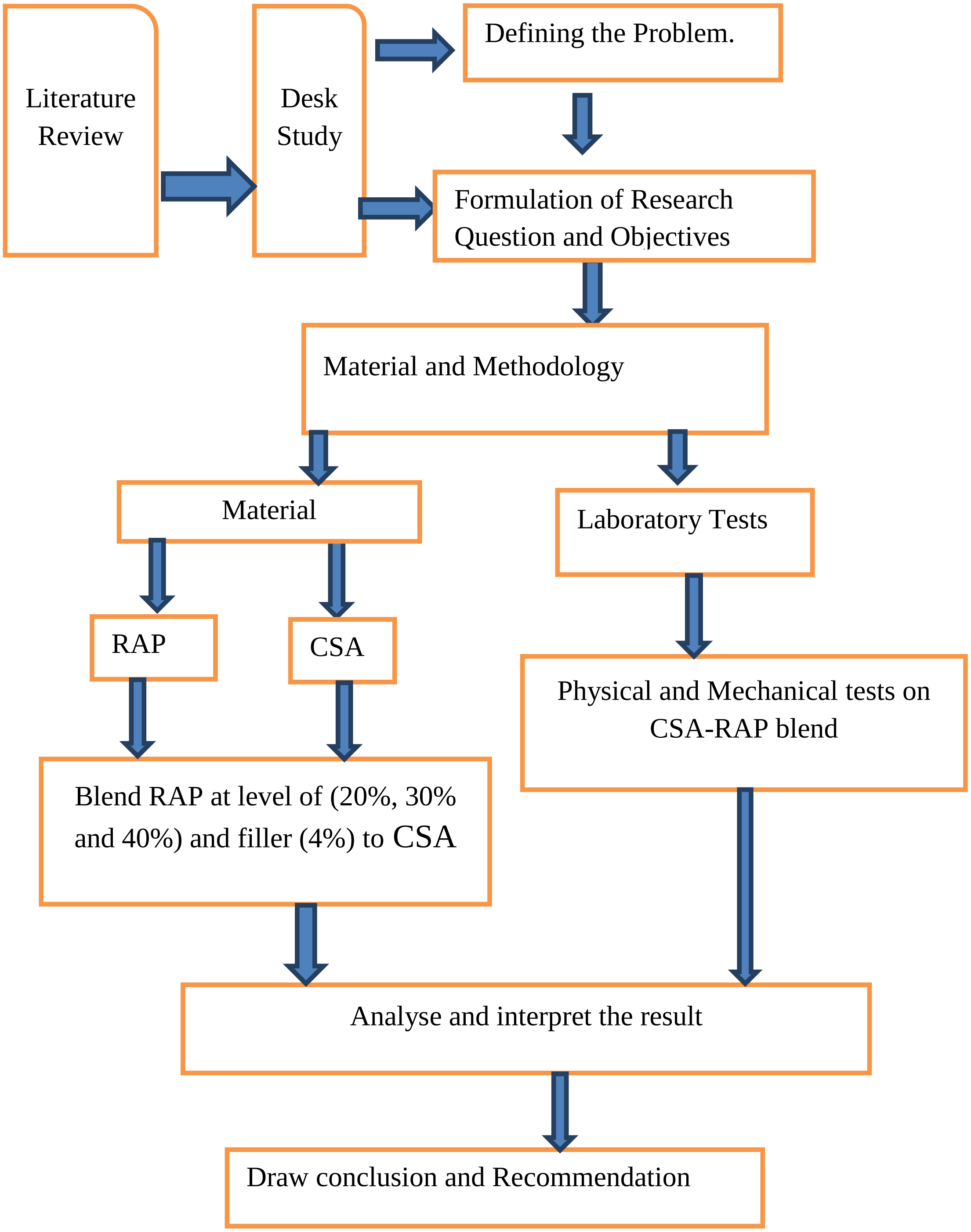

Figure 3-3: Flowchart showing the general outline of the research

3.3. Sampling technique

.Representative Samples collected accordingly in reference to AASHTOO T-2 methodology for sampling from stockpiles. Sufficient amount of samples required for all tests brought to laboratory from respective stockpiles accordingly.

3.4. Preparation of Specimen

In order to have uniform and representative sample for all tests, mechanical splitter according to AASHTO T-248 is used. The test specimen of the blend were prepared by blending Recycled asphalt pavement (RAP) with Crushed standard aggregate(CSA) in ratio of 20/80, 30/70 and40/60 percentage of RAP to crushed aggregate and 4%volcanic ash filler material passing sieve size 0.425mm by total mass added to the blend samples only.

3.5. Laboratory Tests

To determine mechanical and physical properties of Recycled asphalt pavement (RAP), Crushed standard aggregate (CSA) and the blend, the following tests conducted on respective samples.

Particle size distribution (Gradation);

Modified Proctor;

Californian Bearing Ratio (CBR);

Aggregate Crushing Value (ACV);

Aggregate Impact Value (AIV);

Ten percent Fines Value (TFV);

Loss Angeles Abrasion Resistance (LAA);

Flakiness Index;

Specific Gravity and water Absorption and

Atterberg limit.

The blend was designed to be used as GB1 material for heavily trafficked road according to ERA specification for un bound base course material. On this research throughout AASHTO, BS and ASTM test procedures used and all tests conducted with the guidance of technicians and material engineers, moreover all test equipment calibrated every two weeks to insure accuracy. All tests conducted in ERA research center laboratory around Kality, Addis Ababa. Accordingly, all specimens were air dried before proceeding to any test to evaporate moisture and quartered to get representative samples.

CHAPTER 4:

4. RESULT and DISCUSSION

In this portion of the thesis, discussion of test procedures followed in conducting the laboratory tests, result and discussion of the test presented in detail. In order to investigate the effect of replacing some percentage by weight of CSA with RAP and determine the optimum blend proportions, physical tests conducted on different blend ratios selected according to previous works on using RAP as discussed in the literature review. Three blend proportions (replacement ratios) were prepared for testing, which are 20%RAP -80% CSA¸ 30%RAP – 70CSA and 40% RAP- 60%CSA. Test results on CSA, RAP and CSA-RAP blends in the above replacement level presented in the following sections.

4.1 Particle size Distribution and Gradation

Gradation test performed using AASHTO T-11 & T-27. The Sample were mixed thoroughly and reduced to a mass required for testing (i.e.10 kg for nominal size of 25mm) according to AASHTO T-248 and Oven dried to a constant mass and its mass were measured to nearest 0.1 gram. Then the sample placed on sieves nested in decreasing order and shaken sufficiently to ensure all materials having dimensions less than sieve size passes. The mass retained on each sieve measured to nearest 0.01 gram and percent passing on each sieve calculated and checked with the specification of ERA 2013.

For base course, the individual grading of each aggregate size used and the combination of these is essential to the production of the material and its ability to withstand and distribute loads during its time in service. Gradation of aggregates affects the compaction characteristics and shearing resistance of the compacted base course layer. (Ethiopian Roads Authority. 2013).

As shown in figure 4.1 and table 4.1, the CSA and CSA-RAP blends had nominal particle size of 37.5mm whereas the RAP samples had nominal particle size of 28mm. Despite the fact that RAP sample had nominal dimension of 28mm, specification limit of GB1 with nominal dimension of 37.5mm used for all samples for comparison. Determining the type of RAP and its gradation prior to approving its use as a base course material would ensure more consistent test results (McGarrah 2007) .

As shown in table 4.2 and figure 4.1 the CSA sample used satisfy the specification of ERA except for fines passing 0.075mm sieve size and this occurred due to gradation test performed in dry bases, fine particles attached on the course one. Whereas the RAP samples used did not comply with ERA specification limit except on sieve size of 5mm and 2.36mm as illustrated on figure 4.2 and in table 4.1. It could be due to the original gradation and milling process during extraction (E. Mousa 2007). As a result, the reclaimed asphalt pavement required blending with other material to have good compaction, bearing capacity and comply with base course specification. Therefore, the researcher blended the RAP with CSA at different proportion and 4% volcanic ash filler by total mass in order to fit in specification for base course and to have good compaction, bearing capacity and denser material.

All the CSA-RAP blend material gradation in comparison with the specification presented on figure 4.3 lies between upper and lower limit except at 0.2mm sieve, which satisfy the requirement of GB1 material.

Table 4-1: Gradation summary of CSA, RAP and their blends

Particle Size Distribution for crushed aggregate						
Test Method AASHTO T-11 & T-27						
Nominal particle size 37.5mm	% passing					Specification
Sieve size (mm)	crushed aggregate	100% RAP	20% RAP	30% RAP	40% RAP	
50	100	100	100	100	100	100
37.5	98.5	100	98.8	99.1	99.1	95-100
20	72	95.8	77.7	82.3	82.3	60-80
10	45.3	61.4	50.6	53.7	53.7	40-60
5	29.1	28.7	31.9	31.8	31.8	25-40
2.36	18.4	17.6	21.5	21.4	21.4	15-30
0.425	8.1	2.3	10.7	9.5	9.5	7-19
0.075	2	0.3	2.6	2.3	2.3	5-12
pan						

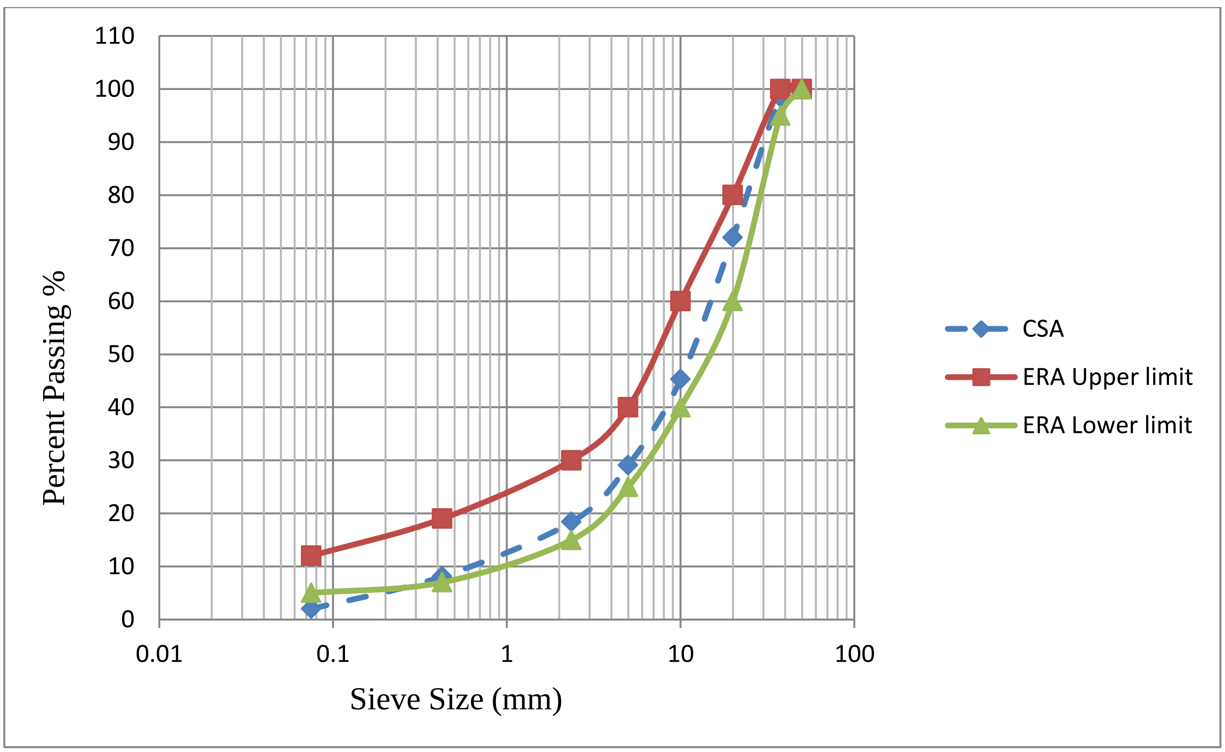

Figure 4-1 : Gradation curve of Crushed standard aggregate (CSA)

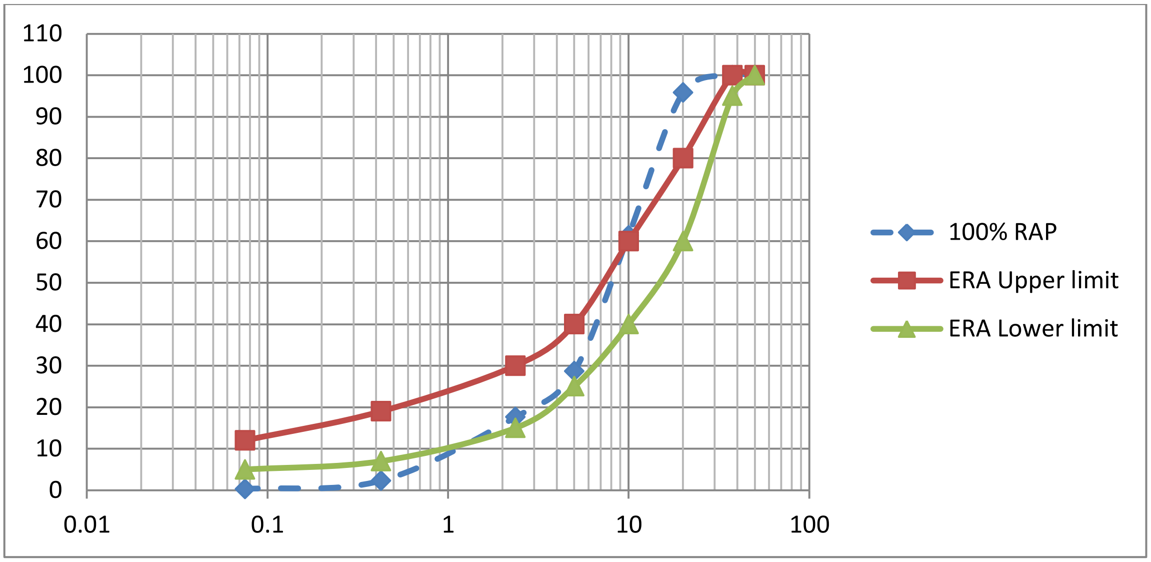

Figure 4-2: Gradation curve of 100% Recycled Asphalt Pavement.

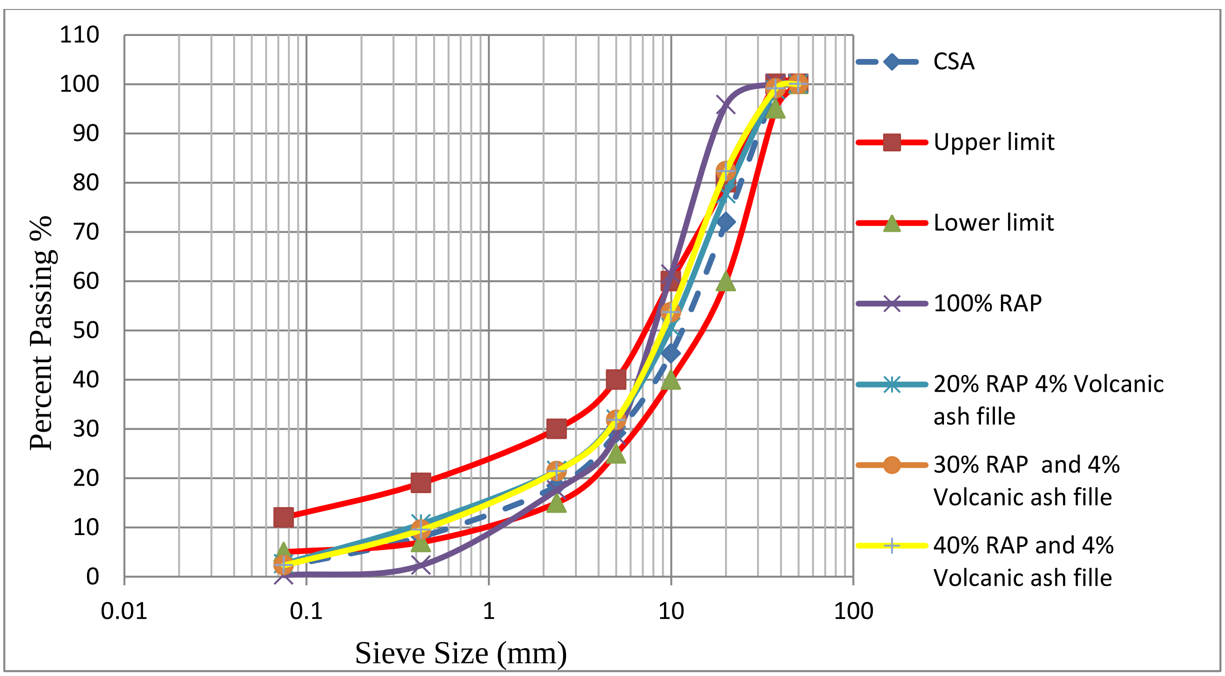

Figure 4-3: Gradation curve for different CSA-RAP blends

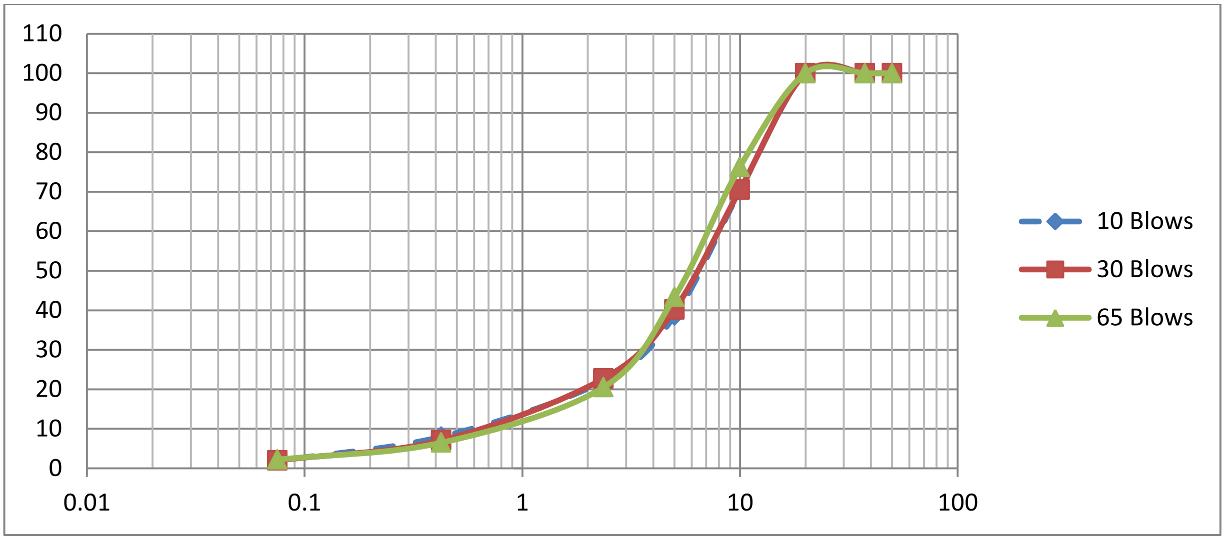

Figure 4-4: Gradation curve for 40% RAP after compaction

To check change of particle size at different compaction level the researcher checked gradation after compaction for 40% RAP content. As shown in figure 4.4 below the presence of RAP and compaction does not affect gradation of the material. The 40% RAP content blend selected due to the maximum allowable RAP content used as unbound base course material.

4.2 Moisture Density Relationship

Procter test performed to determine moisture density relationship of aggregate samples in specified compaction effort. There are two methods to determine moisture density relationship light and heavy compaction for fine and coarse-grained materials, respectively. As this materials aimed for base course and coarse material, heavy compaction method is appropriate. The compaction test performed using the modified proctor testing procedure stated in AASHTO T-180Method D. As the test works for material passing sieve size 19mm, proportional replacement of material passing sieve size 19mm and retain on sieve size 4.75mm made to consider courser material for CSA and CSA-RAP blends. However, having small amount retained on sieve size 19mm for RAP samples, no replacement required.

Modified proctor test conducted on CSA gives values of 2.37 g/cc and 7.1% for maximum dry density (MDD) and optimum moisture content (OMC) respectively as depicted in figure 4.5. These values are common for crushed aggregates with dense gradation and angular particles. As shown on figure 4.6, the RAP samples had lower dry density and moisture content which is 1.9g/cc and of 6.3 respectively. This is due to open gradation nature and lack of filler materials which could increase grain to grain contact in addition to presence of coated aggregates hindering moisture absorption (Soleimanbeigi 2014).Thus, the addition of CSA and filler would make it much easier to compact RAP as a base material ((Taha 1999), (Guthrie 2007) and (Ganne 2009)).

Compaction effort and addition of filler (i.e. passing the 0.425mm sieve size) contributes more for maximum dry density. However, excessive fines can result in long-term total and differential settlement, leading to collapse (Rathje, 2001). For these reason four percent (4%) by mass of total sample non-plastic filler of volcanic ash added to the CSA-RAP blends in this study.

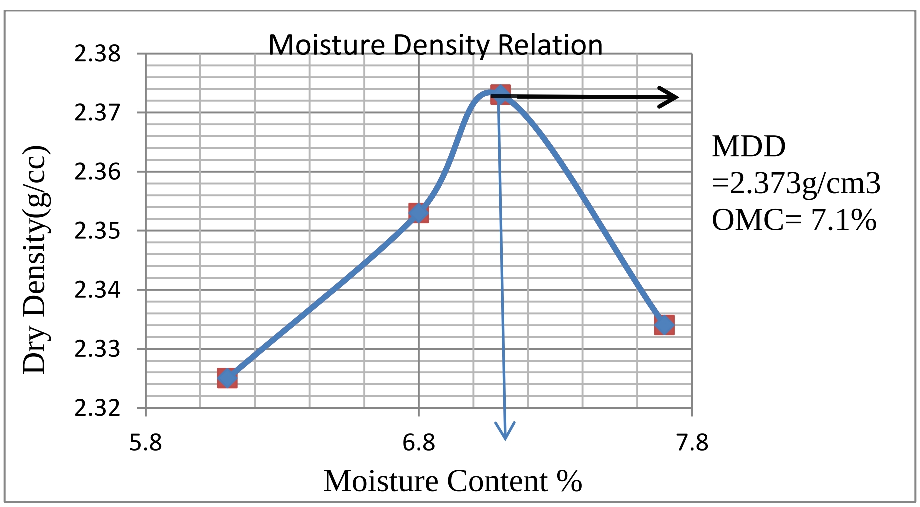

Figure 4-5: Dry density-moisture relation curve of the Crushed standard aggregate (CSA)

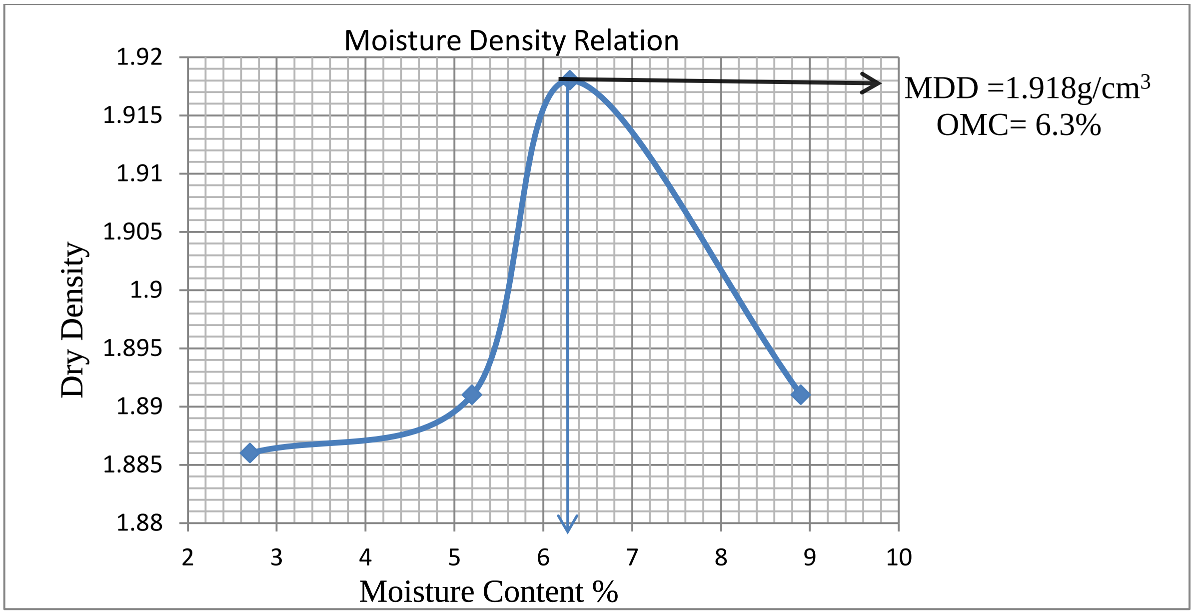

Figure 4-6: Dry density-moisture relation curve of the Recycled asphalt pavement (RAP)

Table 4-2: Maximum dry density vs optimum moisture content for different proportion of RAP

	CSA	20%RAP and 4% volcanic ash	30%RAP and 4% volcanic ash	40%RAP4% volcanic ash	RAP
OMC	7.1	7.8	7.6	8.3	6.3
MDD	2.372	2.28	2.243	2.203	1.918

As illustrated in table 4.2, the CSA-RAP blends shows lower maximum dry densities and higher optimum moisture contents than the CSA due to higher fine content and the absorptive capacity of these fines (M. Alireza 2014). However, CSA-RAP blends shows higher maximum dry densities and lower optimum moisture contents than the RAP. From table 4.2, we can conclude that as RAP level increases optimum moisture content and dry density decreases, with exception at 40% RAP where moisture content is higher. This could be due to the binding effect of bitumen in the RAP, reduce the amount of water needed to achieve the required compaction level of the RAP blends (A.Gunes 2018). The detail test result of CSA-RAP blends listed in Appendix.

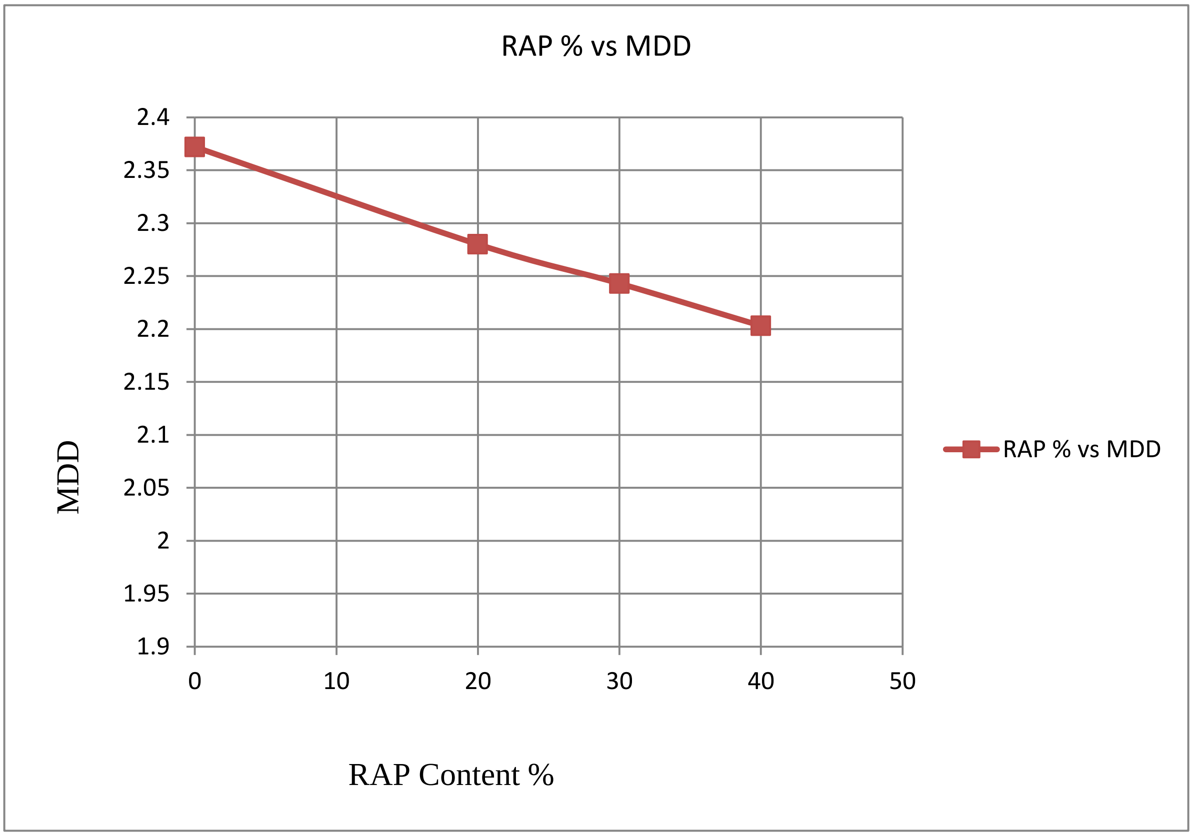

Figure 4-7: Maximum dry density vs RAP content

4.3 California Bearing Ratio (CBR)

CBR is a measure of the resistance of a material to penetration of a plunger under controlled density and moisture conditions. The CBR value for a soil depends upon its density, molding moisture content and moisture content after soaking.

The method uses material passing 19 mm size and provides the CBR value of material at optimum water content. To represent course material retained on 19mm sieve in the field, replaced with an equal amount of material passing 19mm and retain on 4.75mm sieve. The specimen shall be soaked before penetration. A surcharge load of 5Kg placed on the surface to represent the mass of pavement material above base course. The samples were soaked in distilled water for four days to simulate weakest condition in the field. Expansion of the samples measured during soaking to check for potential swelling.

To determine the strength and swelling potential of the samples, a three-point CBR and loaded Swell testing procedure used. The material strength used for design purpose by interpolating the CBR values at different compaction levels, with 10, 30 and 65 blows and compacting in five layers by heavy compaction. This procedure is necessary to obtain 98% of dry density as determined by for proctor test. Water added calculated from proctor test results, which is the OMC, obtained at MDD and by considering the natural moisture content of the material on the test. Stress strain graph drawn and the initial upward concavity of the graph corrected by drawing straight-line tangent to the maximum curvature, extend to cross the abscissa, and shifted the origin to determine corrected value.

A standard piston used to penetrate the sample at a standard rate 1.27 mm/min up to a penetration of 10mm. The CBR value determined using the corrected forces needed to penetrate the plunger 2.54 mm, and 5.08 mm into the compacted specimens. CBR value is the ratio in percent of the load needed to penetrate 2.54mm and 5.08mm to the load required to penetrate standard crushed aggregate respective depth, which is 6.9KN, and 10.34KN respectively.

CBR test measures the bearing capacity and shearing resistant of soil and aggregate masses. The result of this test used as a criterion for checking their suitability of base course aggregates for estimated level of traffic.

Table 4-3: Swell potential and CBR of the Crushed standard aggregate (CSA)

Swell (%)			
Number of Blow	10	30	65
Height of specimen (mm)	117		
RDG (Before Soaking)	366	1380	135
RDG (After Soaking)	366	1380	138
Percent Swell	0	0	0.03
Average Percent Swell	0.01		
Note:- Bottom Penetrated	Dry Density (g/cc)	CBR (%)	98% MDD
10 blows	2.08	46.42	
30 blows	2.145	94.78	
65 blows	2.329	135.4	2.32456

As shown in table 4.3 the swell potential of CSA sample was 0.01% which is small, so the materials swell potential is none. According to ERA, for base course material 98% laboratory maximum dry density is required for the determination of CBR. Therefore, 98% of 2.373 equal to 2.3245 and at this dry density, the CBR value read from the curve as 130%. This value satisfies the requirement of ERA for GB1 material.

Due to less shearing resistant exhibited by mass of RAP aggregates resulting from weak grain to grain contact and interlock between the coarser particles and gap gradation, much lower value about 14% CBR than the CSA at 98% of MDD obtained as shown in figure 4.9.

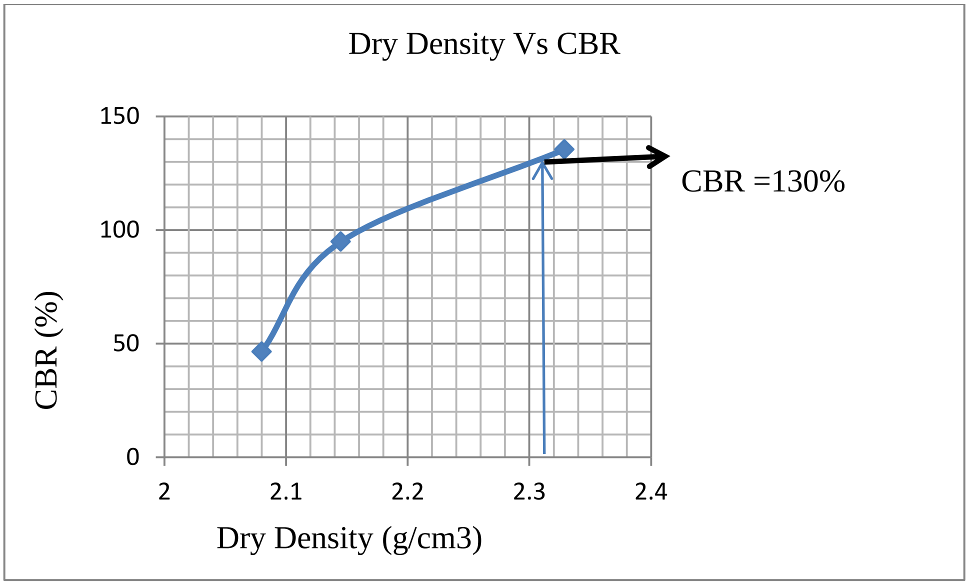

Figure 4-8: Dry density-CBR relation curve of the Crushed standard aggregate (CSA)

Table 4-4: Swell potential and CBR of the Recycled asphalt pavement (RAP)

Swell (%)			
No.of Blow	10	30	65
Height of specimen (mm)	116		
RDG (Before Soaking)	310	911	110
RDG (After Soaking)	310	911	110
Percent Swell	0	0	0
Average Percent Swell	0		
Note:- Bottom Penetrated	Dry Density (g/cc)	CBR (%)	98% MDD
10 blows	1.707	4.64	
30 blows	1.844	11.61	
65 blows	1.983	20.31	1.87964

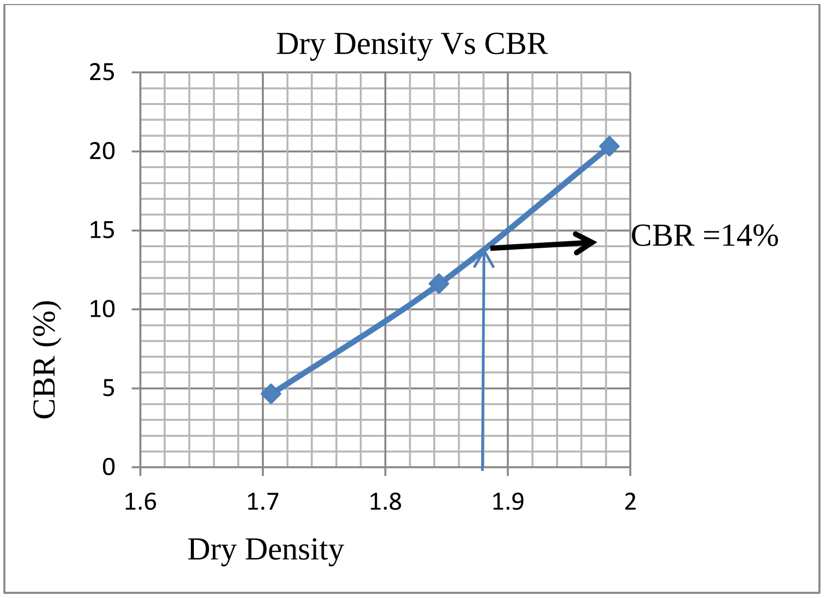

Figure 4-9: Dry density-CBR relation curve of the Recycled asphalt pavement (RAP)

Table 4-5: CBR and 98% MDD value vs RAP content

	CSA	20%RAP and 4% volcanic ash	30%RAP and 4% volcanic ash	40%RAP4% volcanic ash	RAP
CBR	130	112	100	72	14
98% MDD	2.325	2.234	2.198	2.159	1.880

The CBR value of the CSA-RAP blends at replacement level of 20%, 30% and 40% of RAP were 112,100 and 72 respectively, which is lower than CSA as shown in table 4.5 and Figure 4.10 due to bitumen coated aggregate of RAP. However, the CSA-RAP blend showed much higher CBR value than the RAP alone samples due to blending with the CSA and addition of volcanic ash filler (Felipe F. Camargo 2012). In addition, the CBR values decreases with increase of RAP content, because asphalt coated particle reduce angle of internal friction of the mixture and with lower fines shear strength of the mix decreases (Mousa 2007).

Up to replacement level of 30% RAP, the CSA-RAP blends show satisfactory result greater than equals to 100. CBR value at 40% replacement is 72%, which is below the specification for unbound granular materials (Ethiopian Roads Authority. 2013).Thus, replacing up to 30% by weight of CSA with RAP and 4% volcanic ash filler gives satisfactory result for use as unbound granular base course (GB1) material. The detail of the test result shown in Appendix.

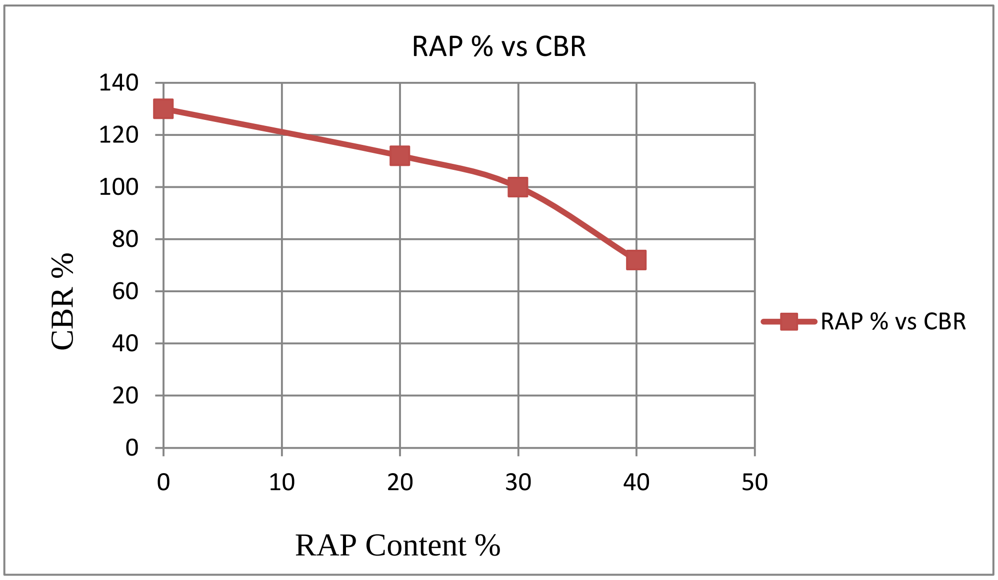

Figure 4-10: Graph of CBR value vs RAP content

4.4 Loss Angeles Abrasion resistance (LAA) test

Abrasion is a measure of resistance to wear or hardness of course aggregates used in pavement design. The LAA value that expressed as the percentage of fine material passing the 1.18mm, BS sieves an estimate of the abrasion resistance of the aggregate.

The Los Angeles Abrasion test is very widely accepted as a suitable test to assess the hardness of aggregates used in pavement construction. AASHTO T96-94 test procedures followed in executing LAA test in this thesis. Clean oven-dried sample sieved through a 1.18 mm sieve, weighed, and placed in the cylinder machine set with a rotation of 500 revolutions at a speed of 30 to 33 revolutions per minute. The material discharged and sieved through 1.18 mm size sieve and material retained on sieve size 1.18 mm 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. LAA value calculated using the following formula.

$$LAA\ Value\ \% = \frac{(\mathrm{M1} - \mathrm{M2})}{\mathrm{M1}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots equation\ 4.1$$

Where M1=mass of a sample before a test in gm.

M2= the mass of sample retained on sieve 1.18mm in gm after the test.

LAA test has four grades A, B, C and D based on sieve size and number of the steel balls used. In this research grade A used for CSA and RAP samples and grade B used for the CSA-RAP blend samples due to gradation and to save sample amount.

Table 4-6: Loss Angeles Abrasion Resistance Test Result of the Recycled Asphalt Pavement (RAP)

Test Method: AASHTO T96-94				
Sieve sizes	1 1/2-1"	1 -3/4"	3/4-1/2"	1/2-3/8"
Grade	A			
Number of Balls	12 Balls			
Wt. of indicated size	1250±25	1250±25	1250±25	1250±25
Weight of tested sample	1249.8	1250.2	1250.3	1249.8
Number of Revolution	500			
Total weight of sample Tested (g)	5000.1			
wt. of tested sample retained	3555.4			

on No. 12 sieve (g)	
Percent loss (%)	29

Table 4-7: Summary of LAA test result vs RAP content

	CSA	20%RAP	30%RAP	40%RAP	RAP
LAA	14	15	19	21	29

As shown in table 4.7, Loss angeles abrasion value of the CSA determined as 14% indicating its durability under vehicular loading on the pavement structure. As shown in table 4.6, the test result of Loss angeles abrasion value of the RAP sample was 29% due to weak bond between bitumen coating and aggregate particles that break apart as a result of impact load from steel balls used for the test there by produced more finer materials. As shown in table 4.7, the LAA value of CSA-RAP blends with proportion of 20%, 30% and 40% by mass of RAP obtained to be 15, 19 and 21 respectively. It shows increasing as RAP content increases due to bitumen coated aggregate crushed apart. However, CSA, RAP and all the CSA-RAP blends satisfies requirement of ERA and British standard (maximum value of 40%).

4.5 Aggregate Crushing value test

Aggregate crushing values test indicates the ability of the aggregates used in road construction to withstand the stresses induced by moving vehicles in the form of crushing and due to the roller during construction. ACV is determined by measuring the material passing a 2.36 mm Sieve after crushing under gradually increasing a applied load to reach 400KN in 10 minutes. The test samples pulverized in compression testing machine after 4 hours of drying in an oven and letting them cool. Detailed test procedures stated in BS 812: part 110.

The aggregate crushing value computed from the ratio of a weight of fines passing 2.36 mm sieve to the total weight of the sample expressed as the percentage.

ACV calculate using the following formula

$$ACV = \frac{(\mathrm{M2})}{\mathrm{M1}} \ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{equation}\ 4.2$$

Where: W1= Total weight of dry sample taken (in gm).

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

If the aggregates are weak, the integrity of the pavement structure is likely to affect adversely, breaking down on aggregate increase fines and decrease coarse particles of a compacted mass, which alters the gradation of the material and cause decrease in the stability, and bearing capacity of road layers constructed by compacting unbound granular materials (AH 2010).

Particles of CSA and RAP used in this research found to be strong and tough as measured by ACV test with an ACV of 15% and 16.5% respectively as illustrated in table 4.9.

As shown in table 4.9, the aggregate crushing value of all the CSA-RAP blends obtained to be 16%, which is a little higher than CSA that could be attributed to ageing (degradation) and fracture of bitumen coating up on loading of particles. The RAP content did not affect aggregate crushing value because the two materials have approximately the same crushing resistance. Therefore, replacing CSA with RAP does not affect particle strength of the blended material. The entire CSA-RAP blend material, RAP and CSA sample satisfies ERA and British standard (BS 812 Part 110: 1990) with maximum aggregate crushing value of 30% for unbound base course.

Table 4-8: Aggregate crushing value result of Recycled asphalt pavement (RAP)

Test Method: BS 812 Part 110: 1990		
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Load applied (KN)	400kn	400kn
Weight of sample before test , passing 14mm and retained on 10mm sieves m1 (g)	2651.5	2675
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	430.9	446.8
Aggregate Crushing value (ACV) % = M2/M1*100	16.3	16.7
Average Aggregate Crushing value	16.5	

Table 4-9: Summary of Aggregate crushing value vs RAP content

	Crushed aggregate	20%RAP	30%RAP	40%RAP	100%RAP
ACV	15	16	16	16	16

4.6 Ten Percent Fines Value test

The most appropriate method of test for aggregates is TFV test. TFV gives a relative measure of the resistance of an aggregate to crushing under a gradually applied load. It is determined by measuring the load required to crush samples prepared in the same way as for ACV test discussed above with the exception that the load required to produce percent passing sieve size 2.36mm 7 to 12. The detail test procedures stated in BS standard (BS 812: part 11, 1990).

The trials will be acceptable if 7%-12% of materials passing 2.36mm sieve produced, otherwise the test should be repeat by decreasing or increasing the load. Ten percent fines value computed using equation 3.3 below.

$$TFV = \frac{(14 * f)}{(M + 4)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; equation\ 4.3$$

Where: f: is the maximum load required to produce (7 -12) % of materials passing 2.36mm after compression test.

M: is percentage of materials passing 2.36 mm sieve after compression test (should be in the range of 7-12%).

Table 4-10: Ten percent fines value of the Recycled asphalt pavement (RAP)

Test Method: BS 812 Part 111: 1990		
Material Condition	Dry	
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Load achieved at required penetration of plunger (f)(KN)	215.6	215.1
Duration of testing (min)	10±30sec	10±30sec
Penetration plunger (mm)	20	20
Weight of sample tested , m1 (g)	2675.5	2649.1
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	236.5	258.2
Percent fine =, m (%) =M2/M1*100	8.8	9.7
Force required to produce 10% fine (TFV) IN KN	235.1	219.1
Average force TFV in KN	227	

Ten percent fines value on CSA and RAP samples determined 256KN and 227KN respectively as shown in table 4.11. The CSA-RAP blend samples in the level of 20, 30 and 40 percent of RAP, ten percent fines values determined 262, 266 and 269 respectively. The CSA, RAP and entire CSA-RAP blend samples have TFV higher than the minimum value according to ERA and BS standard (BS 812 Part 111: 1990) for unbound base course material that is 110 KN.

Table 4-11: Summary of Ten percent fines value vs RAP content

	Crushed aggregate	20%RAP	30%RAP	40%RAP	100%RAP
TFV	256	262	266	269	227

4.7 Aggregate Impact Value test

The resistance of the aggregates to fracture under repeated impacts evaluated from aggregates impact value test. During service period the aggregates faces impact load due to moving vehicles as a result, the aggregates breaks into smaller pieces. Therefore, a test designed to evaluate the toughness of aggregates used in the pavement (AH 2010).

Aggregate passing 14mm sieve and retained on a 10mm sieve filled in 75 mm internal diameter detachable metal cylinder cup, and compacted by a steel tamping rod 16 mm diameter 25 blows. The test applies impact load of 14Kg falling freely from height of 38cm on to the compacted aggregate samples with 15 numbers of blows and remove from the cylinder cup sieved on 2.36 mm sieve until no significant amount passes and the fraction passing the sieve is weighted accurately to 0.1g. The aggregate impact test conducted as per BS 812: part112: 1990.

The aggregate impact value (AIV) calculated as a percentage of the first decimal place for each test specimen from the following expression and the average value taken as AIV of the sample.

Table 4-12: Aggregate Impact Value Test Result of the Crushed standard aggregate (CSA)

Test Method: BS 812 Part 110: 1990		
Trial	1	2
Size of Aggregate (mm)	14-10	14-10
Weight of sample before test , passing 14mm and retained on 10mm sieves m1 (g)	357.8	362
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	39.7	42.2
Aggregate Impact value (AIV) % = M2/M1*100	11.1	11.7
Average Aggregate Impact value	11	

As shown in table 4.13, the CSA, RAP and CSA-RAP blend samples impact value were 11%, 17% and 13% respectively. AIV tests conducted on CSA-RAP blends indicate there was 2% increase in AIV as result of replacing 20 % of CSA with RAP (i.e. 80-20 blend) which remains constant for the other two blends containing 30 and 40% RAP showing that RAP content had less effect on aggregate impact value. Like aggregate crushing value test, the bitumen in the RAP binds together the broken aggregate as a result the value at different percentage is the same except the RAP alone. All the test results were lower than the maximum value of 30% for base course material specification according to BS standard and ERA for unbound base course material. Thus, the entire samples used in this research were tough enough to resist the impact load.

Table 4-13: Summary of Aggregate Impact value vs RAP content

	CSA	20%RAP	30%RAP	40%RAP	RAP
AIV	11	13	13	13	17

4.8 Flakiness Index Test

Flaky material in base course and wearing course is undesirable due to the possibility of breaking down under load, poor of interlocking ability and difficulty of compaction to required density. Therefore, the amount of flaky material should be limited (AH 2010). Flakiness index of an aggregate determined from the ratio of the mass of flaky particles to the total mass of the sample expressed in percentage.

As per BS 812: section 105.1: 1989 test procedure, samples passing 63.0 mm sieve and retained on a 6.3mm sieve tried to pass through measuring gauge of standard sized slots shown in figure 4.11 and weight of particles passed and retained recorded. Then flakiness index value calculated from the equation 4.4below and expressed to the nearest whole number percentage.

$$\text{Flakiness Index (FI)} = \frac{(M3)}{(M2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{equation } 4.4$$

Where: M1= Total mass retained on sieve size 6.3mm and pass 63 mm

M2= Remaining mass after removing those fractions having mass 5% or less of mass M1

M3= Combined weight of all particles passing on the Gauge

M4= Combined weight of all particles retain on the gauge

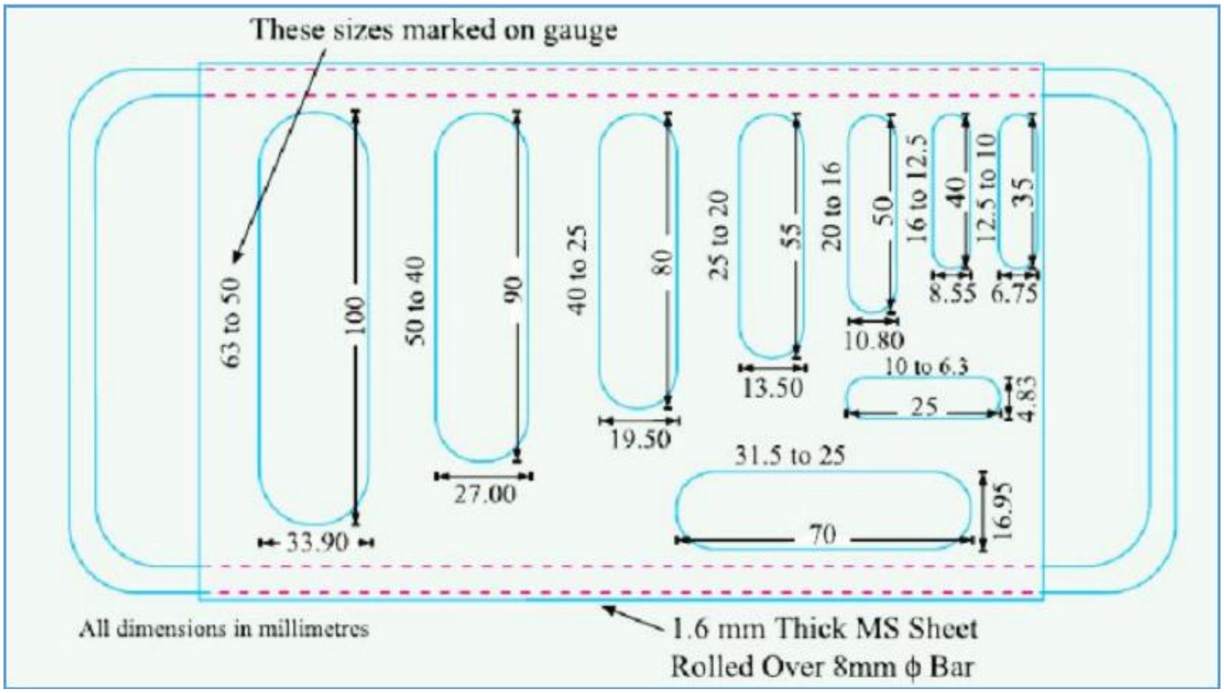

Figure 4-11: Dimension of thickness and length gauges

The Flakiness index test result shows that CSA contains more flaky materials than RAP aggregates with a flakiness index of 27% higher than RAP aggregates having an index of 14%. While the flakiness index value of the CSA-RAP blends found 24, 23 and 22 at 20, 30 and 40 percent of RAP content correspondingly as shown in table 4.15.

As RAP content increases, flakiness index decreases and all the CSA-RAP blends, RAP and CSA materials satisfy the requirement regarding maximum limit of percentage of flaky aggregates, which is 35% for unbound base course as per ERA and British Standard 812 part 105.1, 1989).

Table 4-14: Flakiness index test result of the Recycled asphalt pavement (RAP)

Test Method : BS 812 Part 105.1					
Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Thickness Gauge	Weight of Aggregate
				Width of slot) (mm)	Passed Through the Gage (g)
28	0	0	100	50-37.5	
20	73.7	4.7	95.3	37.5-28	0
14	123.8	7.8	87.5	28-20	0
10	250.6	15.8	71.7	20-14	18.7
6.3	435.2	27.5	44.2	14-10	32.7
Pass 6.3	699.4	44.2	0	10-6.3	61.9
Total	1582.7			Total (M3)	113.3
FI (%) =	M3/M2*100	14		M2	809.6

Table 4-15: Summary of Flakiness index vs RAP content

	CSA	20%RAP	30%RAP	40%RAP	RAP
Flakiness	27	24	23	22	14

4.9 Specific gravity and water absorption test:-

Specific gravity is the ratio of the mass (or weight, in air) of a unit volume of material to the mass of the same volume of water at the stated temperature to the weight in air of an equal volume of gas-free distilled water at the same temperature. Specific gravity has three types i.e.

Bulk specific gravity, surface dry specific gravity and apparent specific gravity. Apparent specific gravity is the ratio of the weight in air of an equal volume at a given temperature of impermeable portion of aggregate to distilled water. Bulk specific gravity is the ratio of the weight in air of an equal volume at a given temperature of an aggregate (excluding voids between particles) to distilled water. Surface dry specific gravity is the ratio of the weight in air of unit volume at a given temperature of aggregate including the water filled in the voids to distilled water. The water Absorption is 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.

A sufficient amount of course aggregate sample retained on sieve size 4.75mm washed thoroughly and oven dried at a temperature of 110 ± 5^0C for 24 hours then cooled in air at room temperature for 4 hours and immersed in water at room temperature for 15hours to 19 hours. Then immersed aggregate allowed to surface dry in air by checking the slump, measure the mass as surface dry, insert into container surface dry samples and measure its mass in water as submerged mass and then oven dried and cooled to room temperature and its mass measured as dry mass. Apparent, bulk and surface dry specific gravities and water absorption calculated as shown in table 4.16 below. Specific gravity and water absorption test performed according to AASHTO T85 test procedure.

As illustrated in table 4.17, the CSA had apparent specific gravity value 2.91, Bulk specific gravity value 2.775, Surface dry specific gravity value 2.82 and water absorption of 1.7. Whereas the RAP samples had apparent specific gravity value 2.69, Bulk specific gravity value 2.56, Surface dry specific gravity value 2.61 and water absorption of 1.85. The RAP samples had lower apparent specific gravity, Bulk specific gravity and Surface dry specific gravity than CSA samples. This is due to presence of low specific gravity of asphalt (Mousa 2007). However, RAP samples showed higher water absorption value than CSA. As RAP content increases apparent specific gravity, Bulk specific gravity and Surface dry specific gravity decreases and water absorption showing increasing tendency.

Table 4-16: Specific Gravity and Water Absorption Test result for Coarse Recycled asphalt pavement (RAP)

Test Method: AASHTO T85			
Sample No.		A	B
	Aggregate Size	>4.75mm	>4.75mm
A	Dry Weight (g)	2916.5	3433.6
B	Saturated Surface Dry Weight (g)	2971.5	3495.8
C	Weight in Water (g)	1833.1	2156.2
D	(A-C) (g)	1083.4	1277.4
E	(B-C) (g)	1138.4	1339.6
Apparent Specific Gravity	A/D	2.69	2.69
	Average	2.69	
Surface Dry Gravity	B/E	2.61	2.61
	Average	2.61	
Bulk Gravity	A/E	2.56	2.56
	Average	2.56	
Water Absorption (%)	(B-A)/A*100	1.89	1.81
	Average	1.85	

Table 4-17: Summary of Specific Gravity and Water Absorption Test result of CSA-RAP blends.

	CSA	20% RAP	30% RAP	40% RAP	100% RAP
Apparent Specific Gravity	2.91	2.87	2.84	2.82	2.69
Surface Dry Gravity	2.82	2.78	2.76	2.74	2.61
Bulk Gravity	2.775	2.73	2.71	2.69	2.56
Water Absorption (%)	1.7	1.73	1.75	1.76	1.85

4.10 Plastic limit test

Plastic limit test performed on fine samples passing 0.425mm sieve size of CSA and volcanic ash and determined as non-plastic. However, RAP samples do not have particle passing sieve size 0.425mm as depicted in the gradation due to bonding effect of bitumen in the RAP. As a result, the RAP considered non-plastic material (Mousa 2007). Therefore, CSA, RAP and volcanic ash satisfies requirement of ERA for GB1 material (non-plastic) and AASHTO (maximum of 6%).

4.11 Comparison with Related Works

In this part, the current research work compared with similar researches done in Ethiopia to identify the trends as follow.

As shown in the table, RAP and CSA material used in previous research had higher CBR value and lower maximum dry density than the current respective material. Higher MDD and OMC are due to the volcanic ash filler in the current research (Wen 2010). However, particle strength and load bearing capacity for CSA sample in current research is stronger and RAP samples shows lower result than the respective samples in the previous research except, TFV for RAP sample shows higher result in the current research.

Despite the CBR value for CSA-RAP blend in the previous research shows higher value than the current research due to individual aggregate properties of RAP and CSA, the rate of decrease of CBR value with increase in RAP content is lower for CSA-RAP blends in the current research than previous research due to volcanic ash filler (Wen 2010).

Table 4-18: Test result value comparison

Test	Current research (with 4%volcanic filler)					Previous research (Yomiyu Reta,2018)				
	CSA	RAP	20% RAP	30% RAP	40% RAP	CSA	RAP	20% RAP	30% RAP	40% RAP
MDD	2.37	1.92	2.28	2.24	2.205	2.22	1.83	2.17	2.09	2.05
OMC	7.1	6.3	7.78	7.6	8.3	7.46	6.64	7.21	7.13	6.94
CBR	130	14	112	100	72	177	42	129	107	98
LAA	27	29	15	19	21	14	7.8	21.5	16.5	15.9
ACV	15	16	16	16	16	20	7.9	16.3	15.7	14.2
TFV	256	227	262	266	269	171	71	136	114	111
AIV	11	17	13	13	13	19	9.5	14.2	12.8	13.7
Flakines	27	14	24	23	22	14	Not determined			

In this study, it is possible to replace CSA with RAP up to 30% and with addition of 4% volcanic ash filler shows a satisfactory result as unbound base course material for highly trafficked road.

CHAPTER 5:

5. CONCLUSION and RECOMMENDATION

5.1 Conclusion

In Ethiopia due to lack of regular over load control mechanism and increasing of vehicle number, many roads fail before end of design period, producing Recycled asphalt pavement (RAP) wasted along the road side without any use. This research aimed to use this wasted material in road construction as un bound base course through blending with virgin crushed aggregate(CSA) and volcanic ash filler to comply with ERA specification. Based on laboratory test conducted on RAP, CSA and RAP-CSA blend samples the following conclusions made.

The test results of neat RAP aggregate shows good particle strength with high resistance against roller compaction during construction, impact loading, crushing and break apart of particle by moving vehicle at time of service, having LAA of 27%, AIV of 17%, ACV of 16%, TFV of 227KN, and flakiness of 29%. In addition, the neat RAP aggregate is non-plastic, satisfying ERA specification for GB1. However, the neat RAP aggregates particle size distribution does not comply with ERA gradation envelope, produce loose layer under compaction having maximum dry density, CBR value and specific gravity 1.918g/cc, 14% and 2.56 respectively which is lower than conventional un bound base course material for high traffic (GB1) and higher water absorption value of 1.85%. Therefore, RAP aggregate alone cannot be used as un bound base course for high traffic road (GB1 material).

The CSA-RAP blend in the replacement level 0f 20%, 30%and 40% by mass of RAP and 4% volcanic ash filler are durable and strong with LAA 15, 19 and 21%, AIV of 13%, ACV of

16%, TFV 262KN, 266 KN and 269KN, and flakiness index 24, 23 and 22%. And also produce dense layer under compaction having maximum dry density 2.281, 2.43and 2.203g/cc, CBR value 112, 100 and 72%, specific gravity 2.73, 2.71 and 2.69g/cc, with the corresponding level of replacement of RAP 20%, 30% and 40% by mass of RAP. Except the CBR value at 40% of RAP, all the results satisfy ERA specification for un bound base course (GB1).

For the studied CSA and RAP, it is possible to replace CSA with RAP up to 30% by total mass of aggregate to use as un bound base course (GB1) material. Hence, using RAP for road construction preserves natural resource and reduces waste of RAP that could create disposal problem.

5.2 Recommendation

On this research work, RAP material collected from Addis – Adama Express way around south Bishoftu Entrance used to replace CSA and 4% volcanic ash filler to be used as un bound base course for high traffic road (GB1). Due to financial, laboratory equipment, machinery availability and time limitation this work did not conduct resilient modulus test, field density, field performance, bitumen content in the RAP, etc that could be done to characterize well. Therefore, the following points should be considered in using RAP as un bound base course for high traffic road (GB1).

1. As particle size, bitumen content, milling process and contamination of the particle greatly varies; Variability of RAP material needs consideration.
2. Performance of CSA-RAP blends material affected by properties of CSA and RAP materials. Thus, Particle size, aggregate strength, and CBR value have to consider.

3. Even though volcanic filler improves compaction characteristics, excessive amount of fine material passing 0.425mm sieve could result in plastic deformation. Therefore, for different RAP and CSA material optimum amount of filler should be determined before use.

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APPENDIX

APPENDIX A: TEST RESULT of CSA

Table A-1: Grading limit for crushed stone Base course material (GB1**)**

Test sieve (mm)	Percentage by mass of total aggregate passing test sieve		
	Nominal maximum particle size		
	37.5mm	28mm	20mm
50	100	-	-
37.5	95-100	100	-
28	-	-	100
20	60-80	70-85	90-100
10	40-60	50-65	60-75
5	25-40	35-55	40-60
2.36	15-30	25-40	30-45
0.425	7_19	12_24	13_27
0.075	5_12	5_12	5_12

Table A-2: Gradation Test result of Crushed standard aggregate (CSA)

Test Method AASHTO T-11 & T-27				
Nominal particle size 37.5mm	Weight retained (g)	% retained	% passing	Specification
Sieve size (mm)				

50	0	0	100	100
37.5	203.6	1.5	98.5	95-100
20	3501.5	26.5	72	60-80
10	3530.9	26.7	45.3	40-60
5	2148.5	16.2	29.1	25-40
2.36	1417.4	10.7	18.4	15-30
0.425	1368.3	10.3	8.1	7_19
0.075	807.3	6.1	2	5_12
pan	251.5	1.9		
Dry total Weight	13229			

TableA-3: Determination of Dry density and Moisture content of Crushed standard aggregate (CSA)

Test Method: AASHTO T180 Method D					
	Trial Number	1	2	3	4
	Weight of Sample (g)	6000	6000	6000	6000
	Water Added (ml)	300	375	450	525
	Weight of Soil+ Mold (g)	10022	10120	10181	10122
	Weight of Mold (g)	4785	4785	4785	4785
	Weight of Soil (g)	5237	5335	5396	5337
	Volume of Mold (cc)	2123.06	2123.06	2123.06	2123.06
Density	Wet Density of Soil g/cc	2.467	2.513	2.542	2.514

	Container Number	B10	B-O	B-S	K-9
	Weight of Wet Soil+ Container (g)	962.3	1004.4	968	980.7
	Weight of Dry Soil+ Container (g)	911.2	945.3	908.4	915.7
	Weight of Water (g)	51.1	59.1	59.6	65
	Weight of container (g)	78.8	70.3	68.1	67.1
	Weight of Dry soil (g)	832.4	875	840.3	848.6
	Moisture Content %	6.1	6.8	7.1	7.7
Moisture	Dry Density (g/cc)	2.325	2.353	2.373	2.334

Table A-4: Density determination for CBR of CSA

California Bearing Ratio Work Sheet						
Test Method : AASHTO T-193						
Density determination						
	10 blows		30 blows		65 blows	
4 Day soaking Condition	Before	After	Before	After	Before	After
Mold Number	1	1	130	130	59	59
Weight of Soil+ Mold (g)	11014	11073	11082	11111	11412	11436
Weight of Mold (g)	6335	6335	6279	6279	6180	6180
Weight of Soil (g)	4679	4738	4803	4832	5232	5256
Volume of Mold (cc)	2107.04	2107.04	2107	2107	2107	2107.04
Wet Density of Soil g/cc	2.221	2.249	2.28	2.293	2.483	2.494
Dry Density of Soil g/cc	2.08	2.103	2.145	2.149	2.329	2.351

Table A-5: Moisture determination for CBR of CSA

Moisture determination									
	10 blows			30 blows			65 blows		
4 Day soaking Condition	Before	After		Before	After		Before	After	
Container Number	HT	TOP	BOTTOM	B5	TOP	BOTTOM	BX	TOP	BOTTOM
Weight of Wet Soil+ Containe (g)	666.7	944.5	996.3	667.4	1159.2	925	773.7	1055	812.6
Weight of Dry Soil+ Container (g)	628.5	889.1	936	631.7	1091	871.8	730.4	995.6	771.8
Weight of Water (g)	38.2	55.4	60.3	35.7	68.2	53.2	43.3	58.9	40.8
Weight of container (g)	65.7	81.9	76.2	68.2	69	71.5	76.8	77.9	71.6
Weight of Dry soil (g)	562.8	807.2	859.8	563.5	1022	800.3	653.6	917.7	700.2
Moisture Content %	6.8	6.9	7	6.3	6.7	6.6	6.6	6.4	5.8
Avg. Moisture Content %		6.95			6.7			6.1	

Table A-6: Penetration test result for CBR of CSA

Penetration test data												
Ring factor	44.306 KN/Div	cor.factor	1.0003									
		10 blows				30 blows				65 blows		
penetration(mm)	Dial RDG	load(KN)	Cor. Load(KN)	CBR	Dial RDG	load(KN)	Cor. Load(KN)	CBR	Dial RDG	load(KN)	Cor. Load(KN)	CBR
0	0	0			0	0			0	0		
0.635	15	0.338645			11	0.24834			35	0.790172		
1.27	33	0.74502			40	0.903054			93	2.099601		
1.91	59	1.332005			107	2.41567			165	3.725099		
2.54	89	2.009296	2.2	31.89	145	3.273572	4.6	66.67	245	5.531207	6.6	95.66
5.08	210	4.741035	4.8	46.42	385	8.691897	9.8	94.78	603	13.613542	14	135.4

7.62	325	7.33 7315			585	13.2 0716 8			980	22.1 2482 8	

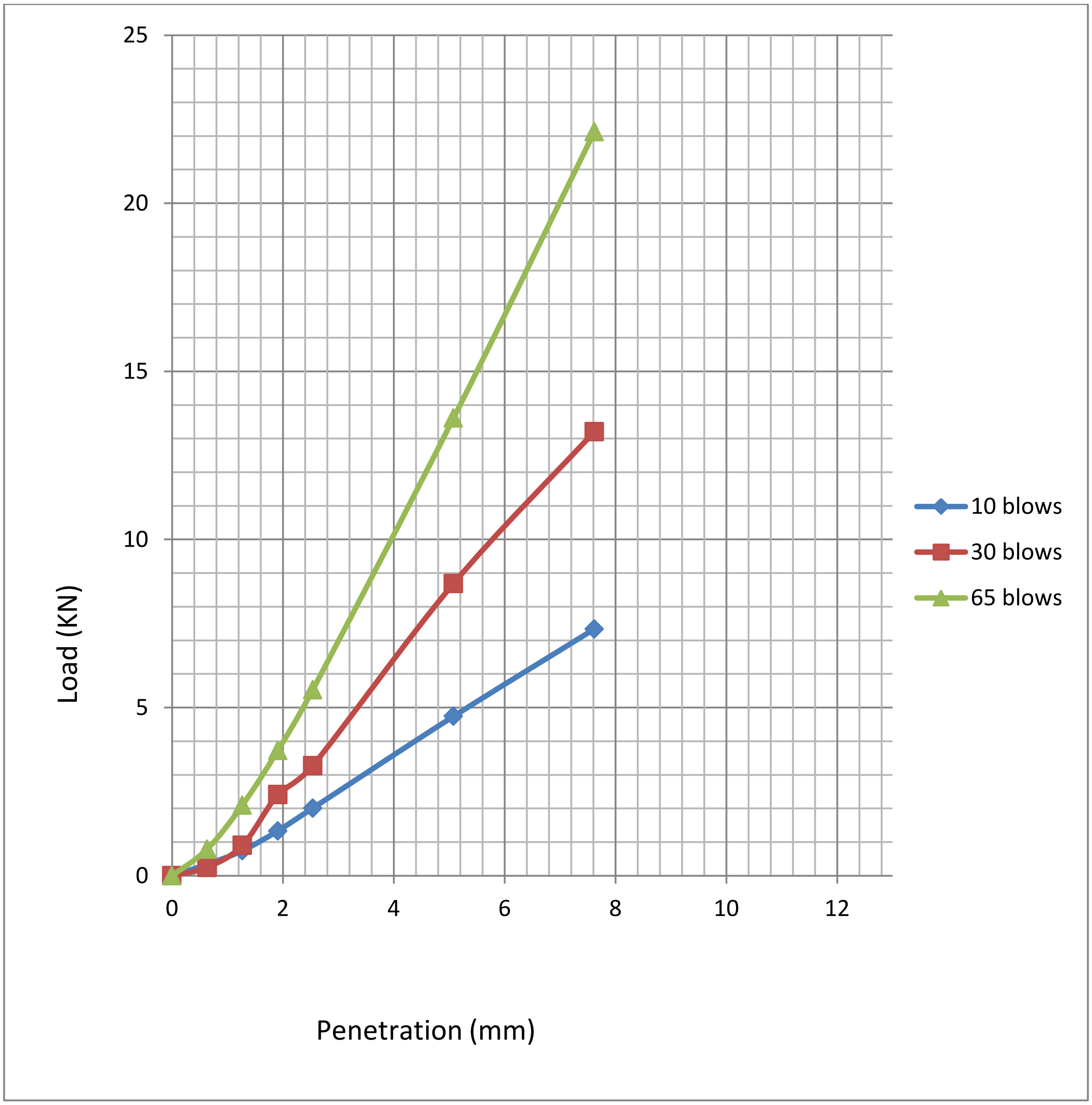

Figure A-1: Graph of Load vs penetration at different compaction level for CSA

Table A-7: Loss angeles abrasion result of the Crushed standard aggregate (CSA)

Test Method: AASHTO T96-94				
Sieve sizes	1 1/2-1"	1 -3/4"	3/4-1/2"	1/2-3/8"
Grade	A			
Number of Balls	12 Balls			
Wt. of indicated size	1250+25	1250+25	1250+25	1250+25
Weight of tested sample	1250.6	1250.1	1250	1250.1
Number of Revolution	500			
Total weight of sample Tested (g)	5000.8			
wt. of tested sample retained on No. 12 sieve (g)	4275.7			
Percent loss (%)	14			

Table A-8: Aggregate crushing value result of Crushed standard aggregate (CSA)

Test Method: BS 812 Part 110: 1990		
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Load applied (KN)	400kn	400kn
Weight of sample before test , passing 14mm and retained on 10mm sieves m1 (g)	2950.9	2946.6
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	447.2	453.3

Aggregate Crushing value (ACV) % = M2/M1*100	15.2	15.4
Average Aggregate Crushing value	15	

Table A-9: Ten percent fines value of the Crushed standard aggregate (CSA)

Test Method: BS 812 Part 111: 1990		
Material Condition	Dry	
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Load achieved at required penetration of plunger (f)(KN)	232.2	230.7
Duration of testing (min)	10+30sec	10+30sec
Penetration plunger (mm)	20	20
Weight of sample tested , m1 (g)	2952.8	3022.3
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	253.6	264.1
Percent fine m(%) = M2/M1*100	8.6	8.7
Force required to produce 10% fine (TFV) IN KN	258.2	253.5
Average force TFV in KN	256	

Table A-10: Flakiness index test result of the Crushed standard aggregate (CSA)

Test Method : BS 812 Part 105.1: 1989					
Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Thickness Gauge	Weight of Aggregate
				Width of slot) (mm)	Passed Through the Gage (g)
63	0	0	100		
50		0	100		
37.5	203.5	3	97	63-50	
28	436.3	6.4	90.6	50-37.5	
20	1195.8	17.6	73	37.5-28	0
14	927.9	13.7	59.3	28-20	276.8
10	965.5	14.2	45.1	20-14	354.6
6.3	804.3	11.8	33.3	14-10	268
Pass 6.3	2260.5	33.3	0	10-6.3	279.42
Total	6793.8			Total (M3)	1178.82
Flakiness Index (%) =	M3/M2*100	27		M2	4329.8

Table A-11: Specific Gravity and Water Absorption Test result for coarse CSA

Test Method: AASHTO T85			
Sample No.		A	B
	Aggregate Size	>4.75mm	>4.75mm
A	Dry Weight (g)	3591.3	3811.5
B	Saturated Surface Dry Weight (g)	3654	3873.1
C	Weight in Water (g)	2352	2504.9
D	(A-C) (g)	1239.3	1306.6
E	(B-C) (g)	1302	1368.2
Apparent Specific Gravity	A/D	2.9	2.92
	Average	2.91	
Surface Dry Gravity	B/E	2.81	2.83
	Average	2.82	
Bulk Gravity	A/E	2.76	2.79
	Average	2.775	
Water Absorption (%)	(B-A)/A*100	1.75	1.62
	Average	1.7	

APPENDIX B: TEST RESULT of RAP

Table B-1: Gradation Test result of Reclaimed Asphalt Pavement (RAP)

Test Method AASHTO T-11 & T-27				
Nominal particle size 28mm				
Sieve size (mm)	Weight retained (g)	% retained	% passing	Specification
50	0	0	100	100
37.5	0	0	100	95-100
20	245.8	4.2	95.8	60-80
10	2007.3	34.4	61.4	40-60
5	1904.9	32.7	28.7	25-40
2.36	648	11.1	17.6	15-30
0.425	890.3	15.3	2.3	7-19
0.075	114.4	2	0.3	5-12
pan	21.7	0.4		
Dry total Weight	5832.4			

Table B-2: Determination of Dry density and Moisture content of Recycled Asphalt Pavement (RAP)

Test Method: AASHTO T180 Method D					
Density	Trial Number	1	2	3	4
	Weight of Sample (g)	6000	6000	6000	6000

	Water Added (ml)	100	150	200	250
	Weight of Soil+ Mold (g)	5756	5808	5858	5878
	Weight of Mold (g)	3820	3820	3820	3820
	Weight of Soil (g)	1936	1988	2038	2058
	Volume of Mold (cc)	999.65	999.65	999.65	999.65
	Wet Density of Soil g/cc	1.937	1.989	2.039	2.059
Moisture	Container Number	B13	B15	B0	W3
	Weight of Wet Soil+ Container (g)	657.9	758.5	643.2	687.4
	Weight of Dry Soil+ Container (g)	642.3	724.3	609.2	637.2
	Weight of Water (g)	15.6	34.2	34	50.2
	Weight of container (g)	67.4	71.6	70.2	70.1
	Weight of Dry soil (g)	574.9	652.7	539	567.1
	Moisture Content %	2.7	5.2	6.3	8.9
	Dry Density (g/cc)	1.886	1.891	1.918	1.891

Table B-3: Density determination for CBR of RAP

Test Method : AASHTO T-193						
Density determination						
	10 blows		30 blows		65 blows	
4 Day soaking Condition	Before	After	Before	After	Before	After
Mold Number	56	56	57	57	ERA 156	ERA 156
Weight of Soil+ Mold (g)	9847	9916	10288	10408	10608	10735
Weight of Mold (g)	6120	6120	6180	6180	6232	6232
Weight of Soil (g)	3727	3796	4108	4228	4376	4503
Volume of Mold (cc)	2105.42	2105.42	2110.36	2110.36	2111.56	2111.56
Wet Density of Soil g/cc	1.77	1.803	1.947	2.003	2.072	2.133
Dry Density of Soil g/cc	1.707	1.698	1.844	1.883	1.983	1.981

Table B-4: Moisture determination for CBR of RAP

Moisture determination									
	10 blows			30 blows			65 blows		
4 Day soaking Condition	Before	After		Before	After		Before	After	
Container Number	TK	TOP	BOTTOM	W1	TOP	BOTTOM	C1	TOP	BOTTOM
Weight of Wet Soil+ Containe (g)	598.2	710.4	578.5	563.4	679.4	650.5	511.1	757.2	795.5
Weight of Dry Soil+ Container (g)	579.5	665.7	554.5	537.1	637.6	620.6	492	700.8	753.3
Weight of Water (g)	18.7	44.7	24	26.3	41.8	29.9	19.1	56.4	42.2
Weight of container (g)	73.6	70.6	67.2	69.5	68.3	78	69.9	79.2	78.8
Weight of Dry soil (g)	505.9	595.1	487.3	467.6	569.3	542.6	422.1	621.6	674.5
Moisture Content %	3.7	7.5	4.9	5.6	7.3	5.5	4.5	9.1	6.3
Avg. Moisture Content %		6.2			6.4			7.7	

Table B-5: Penetration test result for CBR of RAP

Penetration test data												
Ring factor	44.306 KN/Div	cor.factor	1.000268									
		10 blows				30 blows				65 blows		
penetration(mm)	Dial RDG	load(KN)	Cor. Load(KN)	CBR	Dial RDG	load (KN)	Cor. Load(KN)	CBR	Dial RDG	load (KN)	Cor. Load(KN)	CBR
0	0	0			0	0			0	0		
0.635	2.5	0.056441			5	0.112882			5.3	0.119655		
1.27	4	0.090305			9	0.203187			14	0.316069		
1.91	6	0.135458			13	0.293493			25	0.564409		
2.54	8	0.180611	0.2	2.9	18.4	0.415405	0.46	6.67	37	0.835325	0.9	13.05
5.08	19	0.428951	0.48	4.64	49	1.106241	1.2	11.61	90	2.031872	2.1	20.31

7.62	33	0.74 502			84.6	1.90 996			147	3.31 8724		

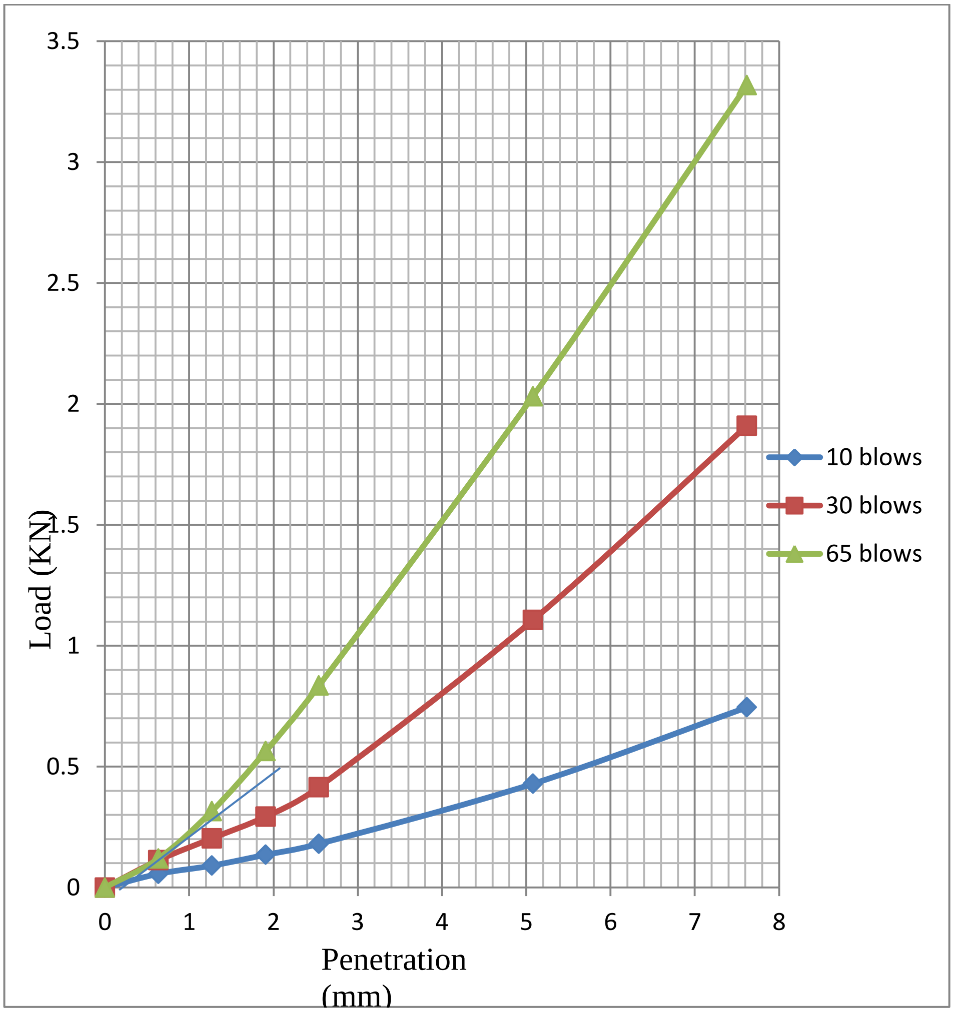

Figure B-1: Graph of Load vs penetration at different compaction level for RAP

Table B-6: Aggregate Impact Value Test Result of the recycled asphalt pavement (RAP)

Test Method: BS 812 Part 110: 1990		
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Weight of sample before test , passing 14mm and retained on 10mm sieves	317.4	319.1

m1 (g)		
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	54.3	54.4
Aggregate Impact value (ACV) % = M2/M1*100	17.1	17
Average Aggregate Impact value	17	

APPENDIX C: TEST RESULT of RAP-CSA BLENDS

Table C-1: Test result of Particle size distribution of 20% RAP

Particle Size Distribution				
Test Method AASHTO T-11 & T-27				
Nominal particle size 37.5mm				
Sieve size (mm)	Weight retained (g)	% retained	% passing	Specification
50	0	0	100	100
37.5	203.6	1.5	98.8	95-100
20	3501.5	26.5	77.7	60-80
10	3530.9	26.7	50.6	40-60
5	2148.5	16.2	31.9	25-40
2.36	1417.4	10.7	21.5	15-30
0.425	1368.3	10.3	10.7	7_19
0.075	807.3	6.1	2.6	5_12
pan	251.5	1.9		
Dry total Weight	13229			

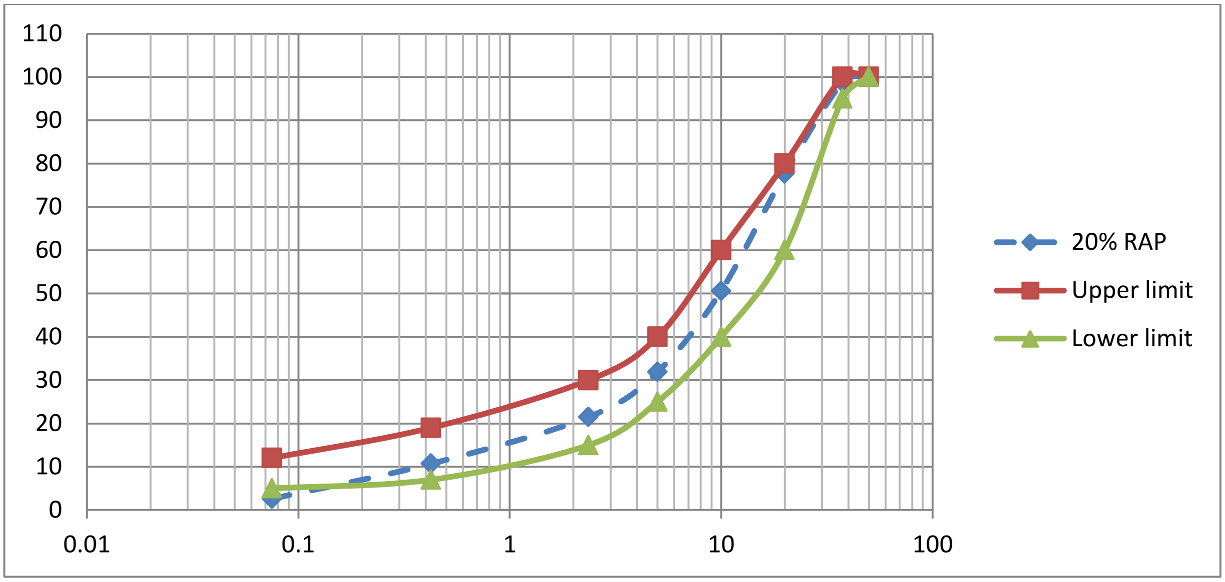

Figure C1: Gradation curve of 20% RAP

Table C-2: Determination of Dry density and Moisture content of 20% RAP

Test Method: AASHTO T180 Method D					
	Trial Number	1	2	3	4
	Weight of Sample (g)	6000	6000	6000	6000
	Water Added (ml)	250	325	400	475
	Weight of Soil+ Mold (g)	9633	9807	1002	9940
	Weight of Mold (g)	4785	4785	4785	4785
	Weight of Soil (g)	4848	5022	5217	5155
	Volume of Mold (cc)	2123.06	2123.06	2123.06	2123.06
Density	Wet Density of Soil g/cc	2.283	2.365	2.457	2.428
	Container Number	W3	B10	K9	B9
	Weight of Wet Soil+ Container (g)	815.4	892.1	1098	1318.4
	Weight of Dry Soil+ Container (g)	776.7	839.6	1023.6	1214.6
	Weight of Water (g)	38.7	52.5	74.4	103.8
	Weight of container (g)	70.2	70.3	67	68.7
	Weight of Dry soil (g)	706.5	769.3	956.6	1145.9
	Moisture Content %	5.5	6.8	7.8	9.1
Moisture	Dry Density (g/cc)	2.164	2.214	2.279	2.225
MDD:	2.280 g/cm3				
OMC	7.8				

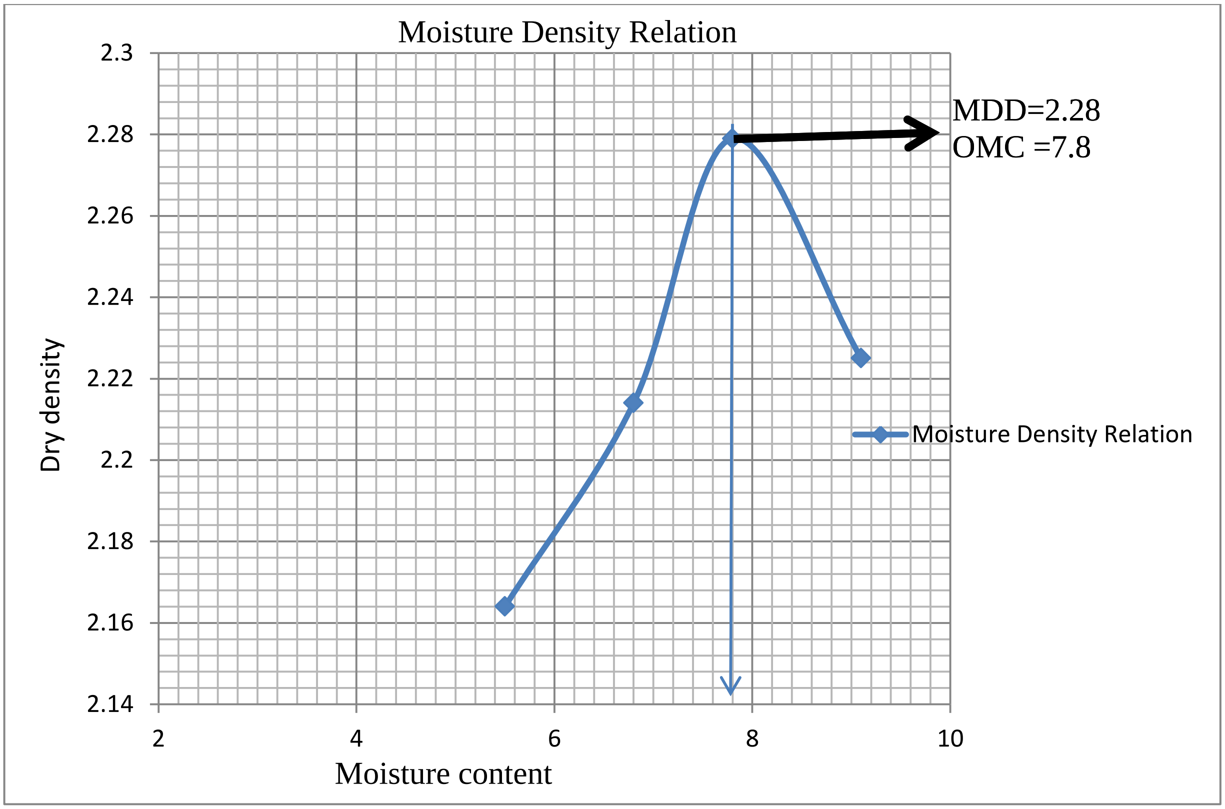

Figure C-2: Dry density-moisture relation curve of 20% RAP

Table C-3: Density determination for CBR of 20% RAP

Test Method : AASHTO T-193						
Density determination						
	10 blows		30 blows		65 blows	
4 Day soaking Condition	Before	After	Before	After	Before	After
Mold Number	ERA 130	ERA 130	4	4	56	56
Weight of Soil+ Mold (g)	10795	10890	11290	11335	11206	11231
Weight of Mold (g)	6279	6279	6475	6475	6120	6120
Weight of Soil (g)	4516	4611	4815	4860	5086	5111
Volume of Mold (cc)	2104.75	2104.75	2090.79	2090.79	2105.42	2105.4
Wet Density of Soil g/cc	2.146	2.191	2.303	2.324	2.416	2.428
Dry Density of Soil g/cc	1.998	2.013	2.134	2.164	2.258	2.269

Table C-4: Moisture determination for CBR of 20% RAP

Moisture determination									
	10 blows			30 blows			65 blows		
4 Day soaking Condition	Before	After		Before	After		Before	After	
Container Number	GW	TOP	BOTTOM	C1	TOP	BOTTOM	TK	TOP	BOTTOM
Weight of Wet Soil+ Container (g)	672.3	921.4	546.9	490.8	894.3	688.7	637	733	777.8
Weight of Dry Soil+ Container (g)	631	851.9	508.6	460.1	835.3	647.4	600	688.9	732.6
Weight of Water (g)	41.3	69.5	38.3	30.7	59	41.3	37	44.1	45.2
Weight of container (g)	71.3	81.9	68.9	69.8	72.2	68.3	73.5	79.2	70.1
Weight of Dry soil (g)	559.7	770	439.7	390.3	763.1	579.1	526.5	609.7	662.5
Moisture Content %	7.4	9	8.7	7.9	7.7	7.1	7	7.2	6.8
Avg. Moisture Content %		8.85			7.4			7	

Table C-5: Penetration test result for CBR of 20% RAP

Penetration test data												
Ring factor	44.306 KN/Div	cor.factor	1.000268									
		10 blows				30 blows				65 blows		
penetration(mm)	Dial RDG	load(KN)	Cor. Load(KN)	CBR	Dial RDG	load(KN)	Cor. Load(KN)	CBR	Dial RDG	load(KN)	Cor. Load(KN)	CBR
0	0	0			0	0			0	0		
0.635	10	0.225764			39	0.880478			24	0.541833		
1.27	25	0.564409			79	1.783532			72	1.625498		
1.91	40	0.903054			125	2.822044			130	2.934926		
2.54	56	1.264276	1.6	23.19	179	4.041168	4.6	66.67	193	4.357237	5.6	81.16
5.08	127	2.867197	3.2	30.95	376	8.48871	9	87.04	472	10.65604	12.2	117.99

7.62	203	4.58 3			586	13.2 2974 4			750	16.9 3226 7		

Table C-6: Swell potential and CBR of the Recycled asphalt pavement (RAP)

Swell (%)			
No.of Blow	10	30	65
Height of specimen (mm)	116		
RDG (Before Soaking)	310	839	954
RDG (AfterSoaking)	314	841	956
Percent Swell	0.04	0.02	0.02
Average Percent Swell	0.027		
Note:- Bottom Penetrated	Dry Density (g/cc)	CBR(%)	98% MDD
10 blows	1.998	30.95	
30 blows	2.134	87.04	
65 blows	2.258	117.99	2.2344
Remark :- The material has CBR of 112%			

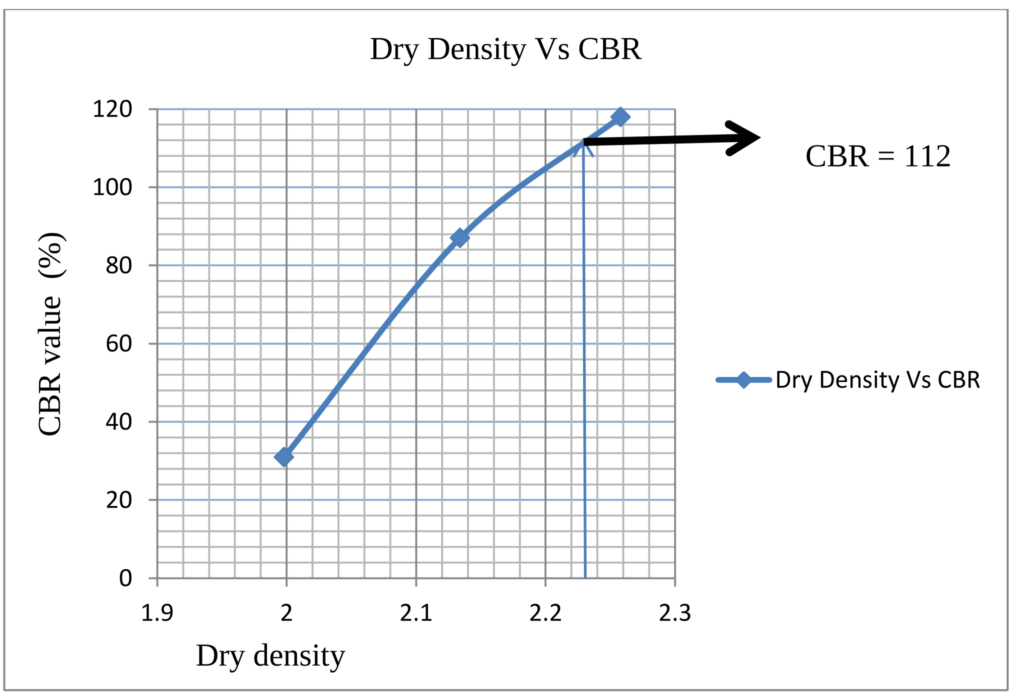

Figure C-3: Dry density-CBR relation curve of 20% (RAP)

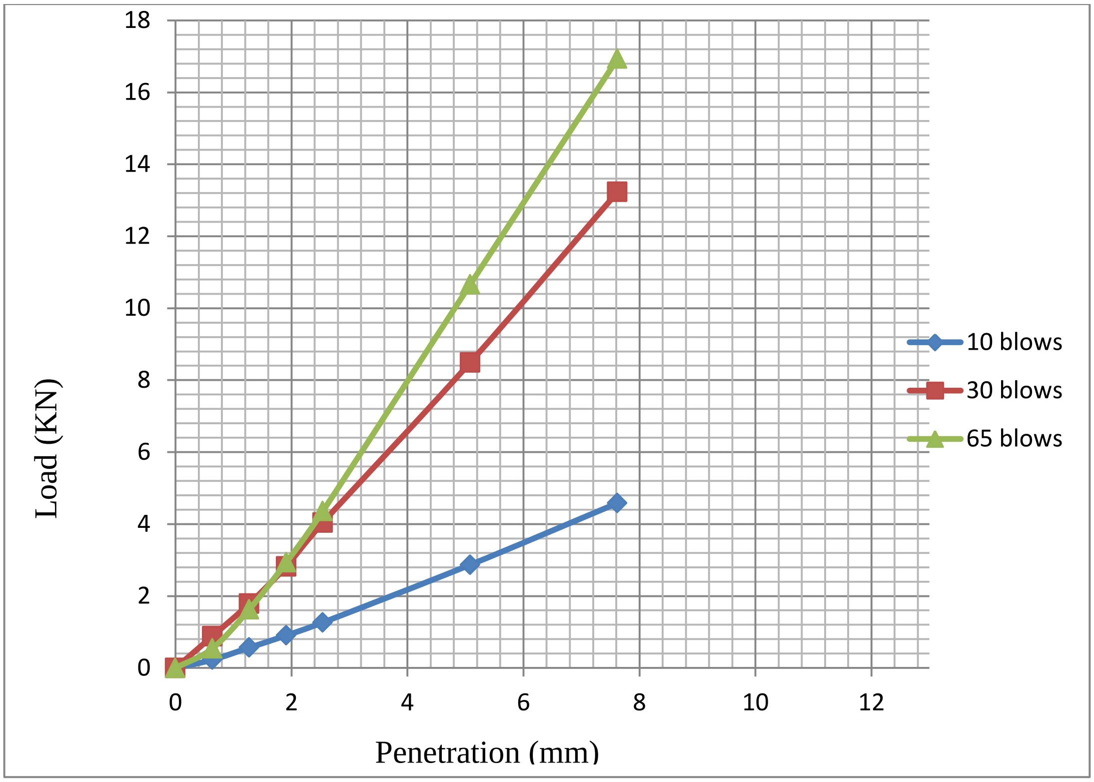

Figure C-4Graph of Load vs penetration at different compaction level for 20% RAP)

Table C-7: Loss Angeles Abrasion Resistance Test Result of 20% RAP

Test Method: AASHTO T96-94		
Grade	B	
Number of Balls	11 Balls	
Sieve sizes	3/4-1/2"	1/2-3/8"
Wt. of indicated size	2500+10	2500+10
Weight of tested sample	2500.3	2500.1
Number of Revolution	500	
Total weight of sample Tested (g)	5000.4	
wt. of tested sample retained on No. 12 sieve (g)	4275.7	
Percent loss (%)	14.5	
Remarks: The material has LAA of 15%		

Table C-8: Aggregate crushing value Test Result of 20% RAP

Test Method: BS 812 Part 110: 1990		
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10

Load applied (KN)	400kn	400kn
Weight of sample before test , passing 14mm and retained on 10mm sieves m1 (g)	2905	2961.4
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	481.6	461.2
Aggregate Crushing value (ACV) % = M2/M1*100	16.6	15.6
Average Aggregate Crushing value	16.1	
Remark:- The material has ACV of 16%		

Table C-9: Ten percent fines value Test Result of 20% RAP

Test Method: BS 812 Part 111: 1990		
Material Condition	Dry	
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Load achieved at required penetration of plunger (f)(KN)	242.6	246.8
Duration of testing (min)	10+30sec	10+30sec
Penetration plunger (mm)	20	20
Weight of sample tested , m1 (g)	2931	2936.2
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	225.5	243.6
Percent fine =, m(%) M2/M1*100	7.7	8.3
Force required to produce 10% fine (TFV) IN KN	263.6	261.3
Average force TFV in KN	262	
Note:- percent passing 2.36mm should be between 7.5% and 12.5%		
F=14*f/(m+4)		
penetration of plunger		
15mm rounded or partially rounded aggregate		
20mm for normally crushed aggregates		
24mm for vesicular (hone combed) aggregate		

Table C-10: Aggregate Impact value Test Result of 20% RAP

Test Method: BS 812 Part 110: 1990		
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Weight of sample before test , passing 14mm and retained on 10mm sieves m1 (g)	336.6	340.8
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	43	44.3
Aggregate Impact value (ACV) % = M2/M1*100	12.8	13
Average Aggregate Impact value	13	

Remark:- The material has AIV of 13%

Table C-11: Flakiness index Test Result of 20% RAP

Test Method : BS 812 Part 105.1					
Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Thickness Gauge	Weight of Aggregate
				Width of slot) (mm)	Passed Through the Gage (g)
63	0	0	100		
50		0	100		
37.5	162.8	2.8	97.2	63-50	
28	349.04	6.1	91.1	50-37.5	
20	971.38	16.9	74.2	37.5-28	0
14	767.08	13.3	60.9	28-20	198.441
10	822.52	14.3	46.6	20-14	264.421
6.3	730.48	12.7	33.9	14-10	197.941
Pass 6.3	1948.28	33.9	0	10-6.3	212.917
Total	5751.58			Total (M3)	873.72
Flakiness Index (%) =	M3/M2*100	24		M2	3640.5
Note:- M1= Total mass retained on sieve size 6.3mm and pass 63 mm					
M2= Remaining mass after removing those fractions having mass 5% or less of mass M1					
M3= Combined weight of all particles passing on the Gauge					
M4= Combined weight of all particles retain on the gauge					
Remark:- The material has Flakiness index of 24%					

Table C-11: Test result of Particle size distribution of 30% RAP

Particle Size Distribution				
Test Method AASHTO T-11 & T-27				
Nominal particle size 37.5mm				
Sieve size (mm)	Weight retained (g)	% retained	% passing	Specification
50	0	0	100	100
37.5	203.6	1.5	99.1	95-100

20	3501.5	26.5	82.3	60-80
10	3530.9	26.7	53.7	40-60
5	2148.5	16.2	31.8	25-40
2.36	1417.4	10.7	21.4	15-30
0.425	1368.3	10.3	9.5	7_19
0.075	807.3	6.1	2.3	5_12
pan	251.5	1.9		
Dry total Weight	13229			

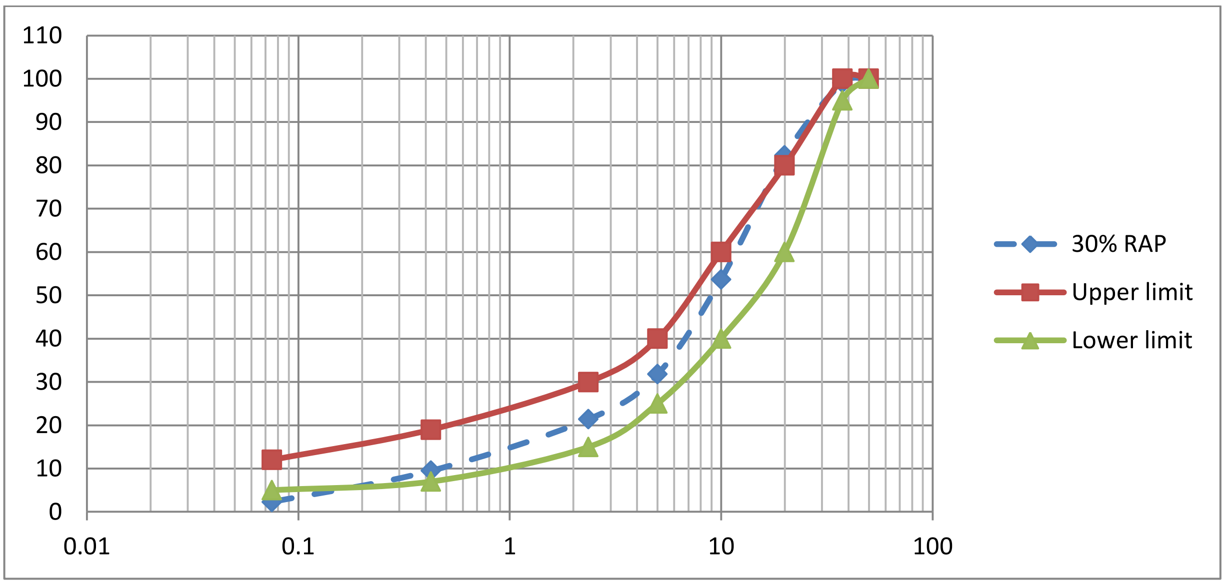

Figure C5: Gradation curve of 30% RAP

Table C-12: Determination of Dry density and Moisture content of 30% RAP

Test Method: AASHTO T180 Method D					
	Trial Number	1	2	3	4
	Weight of Sample (g)	6000	6000	6000	6000
	Water Added (ml)	200	300	400	500
	Weight of Soil+ Mold (g)	9531	9773	9923	9902
	Weight of Mold (g)	4785	4785	4785	4785
	Weight of Soil (g)	4746	4988	5138	5117
	Volume of Mold (cc)	2126.06	2126.06	2126.06	2126.06
Density	Wet Density of Soil g/cc	2.232	2.346	2.417	2.407
	Container Number	W1	HT	W3	BX
Moisture	Weight of Wet Soil+ Container (g)	1146.4	997.1	973.7	1365.3

	Weight of Dry Soil+ Container (g)	1096	940.9	909	1247.9
	Weight of Water (g)	50.4	56.2	64.7	117.4
	Weight of container (g)	69.5	65.8	71.1	76.9
	Weight of Dry soil (g)	1026.5	875.1	837.9	1171
	Moisture Content %	4.9	6.4	7.7	10
	Dry Density (g/cc)	2.128	2.205	2.244	2.188
MDD:	2.243 g/cm3				
OMC	7.7				

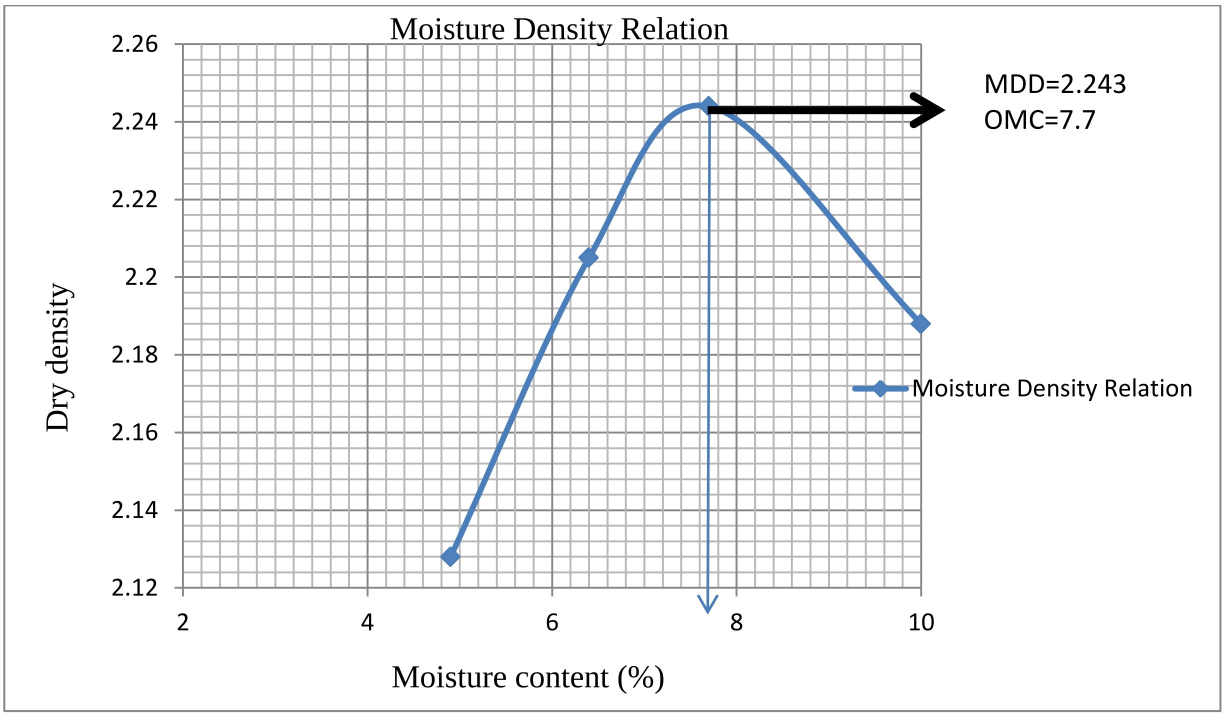

Figure C-6: Dry density-moisture relation curve of 30% RAP

Table C-13: Density determination for CBR of 30% RAP

Test Method : AASHTO T-193						
Density determination						
	10 blows		30 blows		65 blows	
4 Day soaking Condition	Before	After	Before	After	Before	After
Mold Number	57	57	4	4	63	63
Weight of Soil+ Mold (g)	10515	10608	11266	11329	10670	10705
Weight of Mold (g)	6180	6180	6475	6475	5715	5715
Weight of Soil (g)	4335	4428	4791	4854	4955	4990

Volume of Mold (cc)	2110.36	2110.36	2090.79	2090.79	2116.77	2116.77
Wet Density of Soil g/cc	2.054	2.098	2.291	2.322	2.341	2.357
Dry Density of Soil g/cc	1.932	1.95	2.155	2.164	2.211	2.207

Table C-14: Moisture determination for CBR of 30% RAP

Moisture determination									
	10 blows			30 blows			65 blows		
4 Day soaking Condition	Before	After		Before	After		Before	After	
Container Number	R8	TOP	BOTTOM	K9	TOP	BOTTOM	BO	TOP	BOTTOM
Weight of Wet Soil+ Containe (g)	711.4	1038.6	820.4	581.5	783.9	682.5	584.7	889.9	744.8
Weight of Dry Soil+ Container (g)	673.1	967.7	770.4	550.9	730.6	645.8	556.2	834.8	704.8
Weight of Water (g)	38.3	70.9	50	30.6	53.3	36.7	28.5	55.1	40
Weight of container (g)	65.7	81.9	76.2	67	70.6	81.6	70.3	68.6	75
Weight of Dry soil (g)	607.4	885.8	694.2	483.9	660	564.2	485.9	766.2	629.8
Moisture Content %	6.3	8	7.2	6.3	8.1	6.5	5.9	7.2	6.4
Avg. Moisture Content %		7.6			7.3			6.8	

Table C-15: Penetration test result for CBR of 30% RAP

Penetration test data												
Ring factor	44.306 KN/Div	cor.factor	1.000268									
		10 blows				30 blows				65 blows		
penetration(mm)	Dial RDG	load(KN)	Cor. Load(KN)	CBR	Dial RDG	load(KN)	Cor. Load(KN)	CBR	Dial RDG	load(KN)	Cor. Load(KN)	CBR
0	0	0			0	0			0	0		
0.635	12	0.270916			25	0.564409			27	0.609562		
1.27	27	0.609562			59	1.332005			69	1.557769		
1.91	42	0.948207			102	2.302788			126	2.844621		

2.54	57	1.286852	1.287	18.66	152	3.431606	4	57.97	183	4.131473	5.4	78.27
5.08	130	2.934926	2.9345	28.38	345	7.788843	8.5	82.21	450	10.15936	10.6	102.51
7.62	187	4.221778			529	11.942892			696	15.713143		

Table C-16: Swell potential and CBR of 20% RAP

Swell (%)			
No.of Blow	10	30	65
Height of specimen (mm)	116		
RDG (Before Soaking)	327	107	159
RDG (AfterSoaking)	329	111	159
Percent Swell	0.02	0.04	0
Average Percent Swell	0.02		
Note:- Bottom Penetrated	Dry Density (g/cc)	CBR(%)	98% MDD
10 blows	1.932	28.38	
30 blows	2.155	82.21	
65 blows	2.211	102.51	2.19814

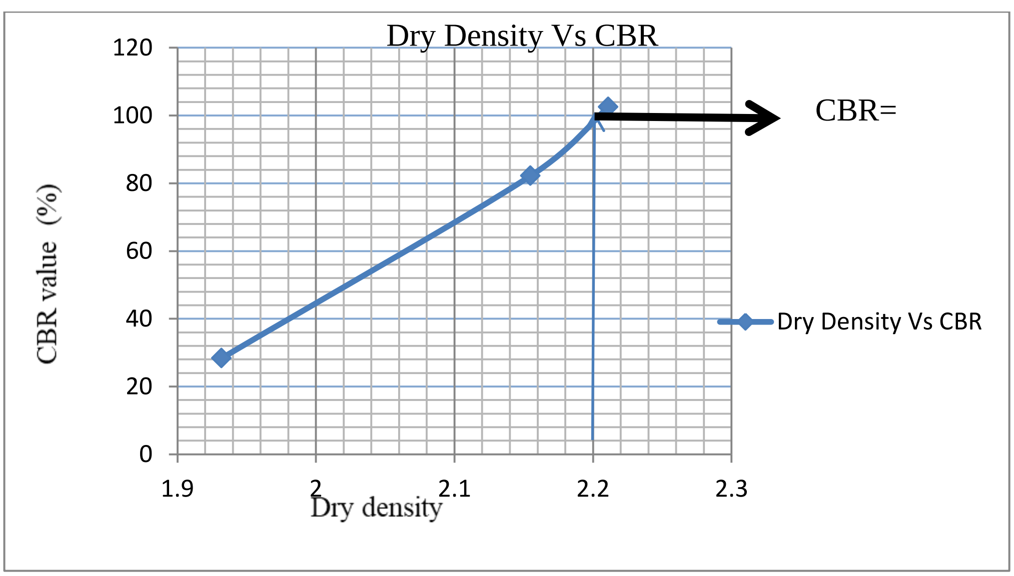

Figure C-7: Dry density-CBR relation curve of 30% (RAP)

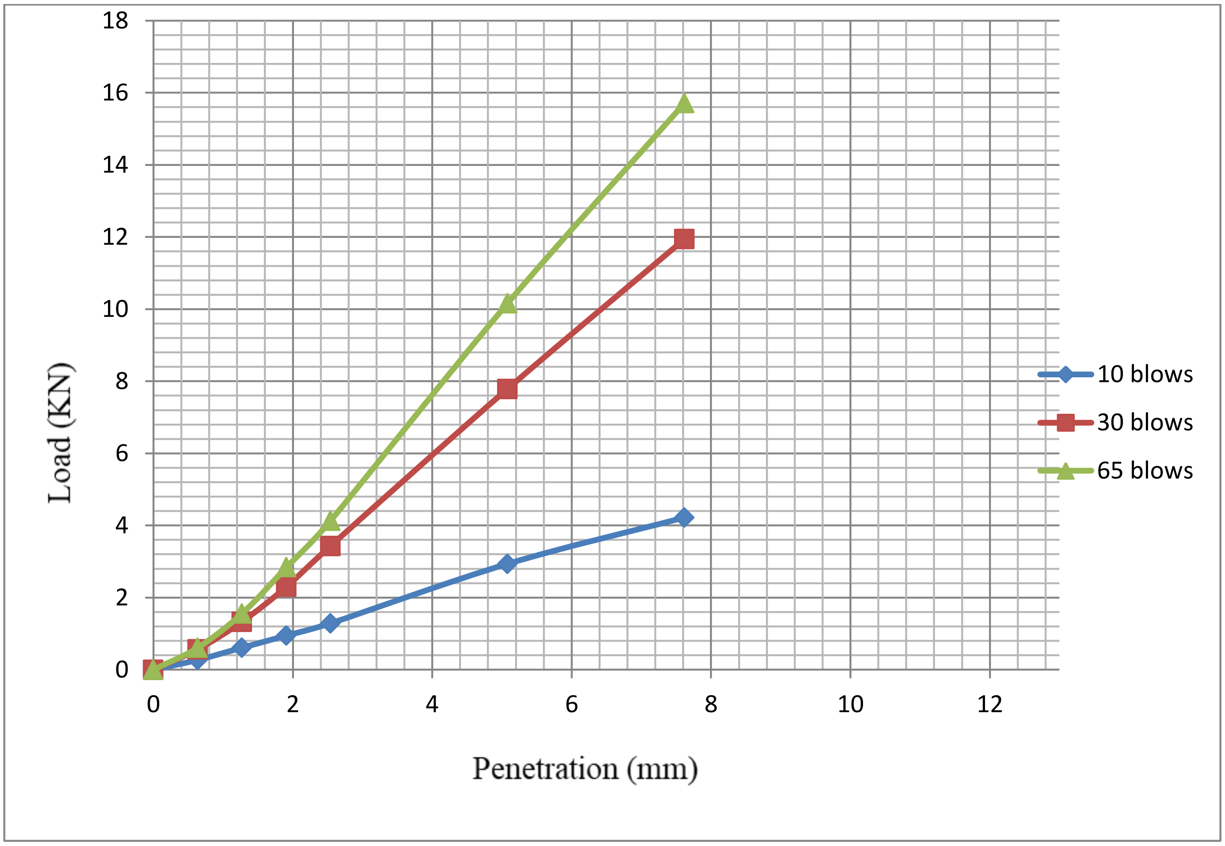

Figure C-8 Graph of Load vs penetration at different compaction level for 30% RAP)

Table C-17: Loss Angeles Abrasion Resistance Test Result of 30% RAP

Test Method: AASHTO T96-94		
Grade	B	
Number of Balls	11 Balls	
Sieve sizes	3/4-1/2"	1/2-3/8"
Wt. of indicated size	2500+10	2500+10
Weight of tested sample	2500.3	2500.1
Number of Revolution	500	
Total weight of sample Tested (g)	5000.4	
wt. of tested sample retained on No. 12 sieve (g)	4053.3	
Percent loss (%)	18.9	
Remarks: The material has LAA of 19%		

Table C-18: Aggregate crushing value Test Result of 30% RAP

Test Method: BS 812 Part 110: 1990		
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Load applied (KN)	400kn	400kn
Weight of sample before test , passing 14mm and retained on 10mm sieves m1 (g)	2905	2961.4
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	481.6	461.2
Aggregate Crushing value (ACV) % = M2/M1*100	16.6	15.6
Average Aggregate Crushing value	16.1	
Remark:- The material has ACV of 16%		

Table C-19: Ten percent fines value Test Result of 30% RAP

Test Method: BS 812 Part 111: 1990		
Material Condition	Dry	
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Load achieved at required penetration of plunger (f)(KN)	227.6	236.8
Duration of testing (min)	10$\pm$30sec	10$\pm$30sec
Penetration plunger (mm)	20	20
Weight of sample tested , m1 (g)	2851	2851.9
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	225.5	243.6
Percent fine =, m(%) M2/M1*100	7.9	8.5
Force required to produce 10% fine (TFV) IN KN	267.6	264.3
Average force TFV in KN	266	
Note:- percent passing 2.36mm should be between 7.5% and 12.5%		
F=14*f/(m+4)		
penetration of plunger		
15mm rounded or partially rounded aggregate		
20mm for normally crushed aggregates		
24mm for vesicular (hone combed) aggregate		

Table C-20: Aggregate Impact value Test Result of 30% RAP

Determination of Aggregate Impact Value (AIV) test		
Test Method: BS 812 Part 110: 1990		
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Weight of sample before test , passing 14mm and retained on 10mm sieves m1 (g)	329.1	338.6
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	45.3	43.5
Aggregate Impact value (ACV) % = M2/M1*100	13.8	12.8
Average Aggregate Impact value	13	
Remark:- The material has AIV of 13%		

Table C-21: Flakiness index Test Result of 30% RAP

Test Method : BS 812 Part 105.1					
Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Thickness Gauge	Weight of Aggregate
				Width of slot) (mm)	Passed Through the Gage (g)
63	0	0	100		
50		0	100		
37.5	142.45	2.7	97.3	63-50	
28	305.41	5.8	91.5	50-37.5	
20	859.17	16.4	75.1	37.5-28	0
14	686.67	13.1	62	28-20	169.52
10	751.03	14.4	47.6	20-14	235.5
6.3	693.57	13.3	34.3	14-10	178.24
Pass 6.3	1792.17	34.3	0	10-6.3	167.5
Total	5230.47			Total (M3)	750.76
Flakiness Index (%) =	M3/M2*100	23		M2	3295.85
Note:- M1= Total mass retained on sieve size 6.3mm and pass 63 mm					
M2= Remaining mass after removing those fractions having mass 5% or less of mass M1					
M3= Combined weight of all particles passing on the Gauge					
M4= Combined weight of all particles retain on the gauge					
Remark:- The material has Flakiness index of 14%					

Table C-22: Test result of Particle size distribution of 40% RAP

Particle Size Distribution				
Test Method AASHTO T-11 & T-27				
Nominal particle size 37.5mm				
Sieve size (mm)	Weight retained (g)	% retained	% passing	Specification
50	0	0	100	100
37.5	203.6	1.5	99.1	95-100
20	3501.5	26.5	82.3	60-80
10	3530.9	26.7	53.7	40-60
5	2148.5	16.2	31.8	25-40
2.36	1417.4	10.7	21.4	15-30
0.425	1368.3	10.3	9.5	7_19
0.075	807.3	6.1	2.3	5_12
pan	251.5	1.9		
Dry total Weight	13229			

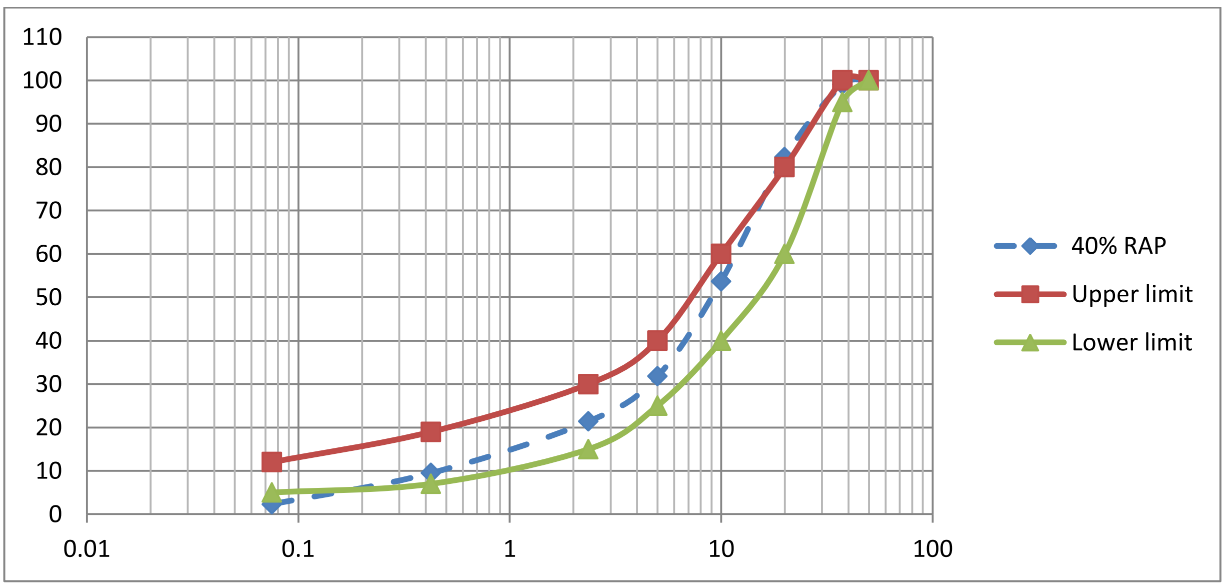

Figure C9: Gradation curve of 40% RAP

Table C-23: Determination of Dry density and Moisture content of 40% RAP

Test Method: AASHTO T180 Method D					
	Trial Number	1	2	3	4
	Weight of Sample (g)	6000	6000	6000	6000
Density	Water Added (ml)	275	350	425	500

	Weight of Soil+ Mold (g)	9562	9725	9851	9886
	Weight of Mold (g)	4785.6	4785.6	4785.6	4785.6
	Weight of Soil (g)	4776.4	4939.4	5065.4	5100.4
	Volume of Mold (cc)	2123.06	2123.06	2123.06	2123.06
	Wet Density of Soil g/cc	2.25	2.327	2.386	2.402
	Container Number	K9	B7	B0	B10
	Weight of Wet Soil+ Container (g)	870.8	1035	1195.2	1455.8
	Weight of Dry Soil+ Container (g)	826.1	971.2	1109	1334.4
	Weight of Water (g)	44.7	63.8	86.2	121.4
	Weight of container (g)	67	81.2	70.3	78.6
	Weight of Dry soil (g)	759.1	890	1038.7	1255.8
	Moisture Content %	5.9	7.2	8.3	9.7
Moisture	Dry Density (g/cc)	2.125	2.171	2.203	2.19
MDD:	2.203 g/cm3				
OMC	8.3				

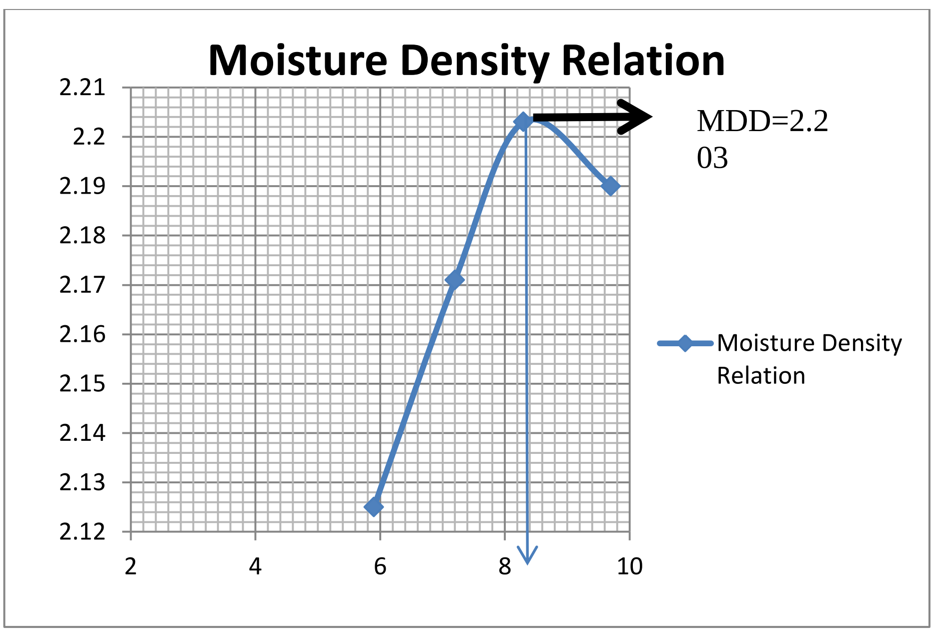

Figure C-10: Dry density-moisture relation curve of 40% RAP

Table C-24: Density determination for CBR of 40% RAP

Density determination						
	10 blows		30 blows		65 blows	
4 Day soaking Condition	Before	After	Before	After	Before	After
Mold Number	2	2	56	56	50	50
Weight of Soil+ Mold (g)	10612	10663	10857	10891	11093	11096
Weight of Mold (g)	6145	6145	6120	6120	6115	6115
Weight of Soil (g)	4467	4518	4737	4771	4978	4981
Volume of Mold (cc)	2113.99	2113.9	2105.42	2105.42	2109.45	2109.45
Wet Density of Soil g/cc	2.113	2.137	2.25	2.266	2.36	2.361
Dry Density of Soil g/cc	1.967	1.979	2.091	2.114	2.179	2.202

Table C-25: Moisture determination for CBR of 40% RAP

Moisture determination									
	10 blows			30 blows			65 blows		
4 Day soaking Condition	Before	After		Before	After		Before	After	
Container Number	BZ	TOP	BOTTOM	K9	TOP	BOTTOM	B9	TOP	BOTTOM
Weight of Wet Soil+ Containe (g)	806.6	894.8	798.7	821.5	856.7	1102.2	687.8	921.1	797
Weight of Dry Soil+ Container (g)	756.6	834.7	744.2	768.5	806.4	1028.9	640.4	859.6	752.5
Weight of Water (g)	50	60.1	54.5	53	50.3	73.3	47.4	61.5	44.5
Weight of container (g)	81.2	74	69.9	67	69.9	70.1	68.7	68.6	77.2
Weight of Dry soil (g)	675.4	760.7	674.3	701.5	736.5	958.8	571.7	791	675.3
Moisture Content %	7.4	7.9	8.1	7.6	6.8	7.6	8.3	7.8	6.6
Avg. Moisture Content %		8			7.2			7.2	

Table C-26: Penetration test result for CBR of 40% RAP

Penetration test data												
Ring factor	44.306 KN/Div	cor.factor	1.000268									
		10 blows				30 blows				65 blows		

penetration(mm)	Dial RDG	load(KN)	Cor. Load(KN)	CBR	Dial RDG	load (KN)	Cor. Load(KN)	CBR	Dial RDG	load(KN)	Cor. Load(KN)	CBR
0	0	0			0	0			0	0		
0.635	10	0.225764			9.5	0.214475			14.7	0.331872		
1.27	23	0.519256			27	0.609562			44	0.99336		
1.91	38	0.857902			54	1.219123			79.5	1.79482		
2.54	53	1.196547	1.2	17.4	85	1.91899	2.3	33.33	124	2.799468	3.1	44.93
5.08	128	2.889773	2.9	28.05	227	5.124833	5.9	57.06	318	7.179281	7.9	76.4
7.62	205	4.628153			364	8.217793			527	11.897739		

Table C-27: Swell potential and CBR of 40% RAP

Swell (%)			
No.of Blow	10	30	65
Height of specimen (mm)	116		
RDG (Before Soaking)	366	866	891
RDG (AfterSoaking)	369	868	894
Percent Swell	0.03	0.02	0.03
Average Percent Swell	0.027		
Note:- Bottom Penetrated	Dry Density (g/cc)	CBR(%)	98% MDD
10 blows	1.967	28.05	
30 blows	2.091	57.06	
65 blows	2.179	76.4	2.15894

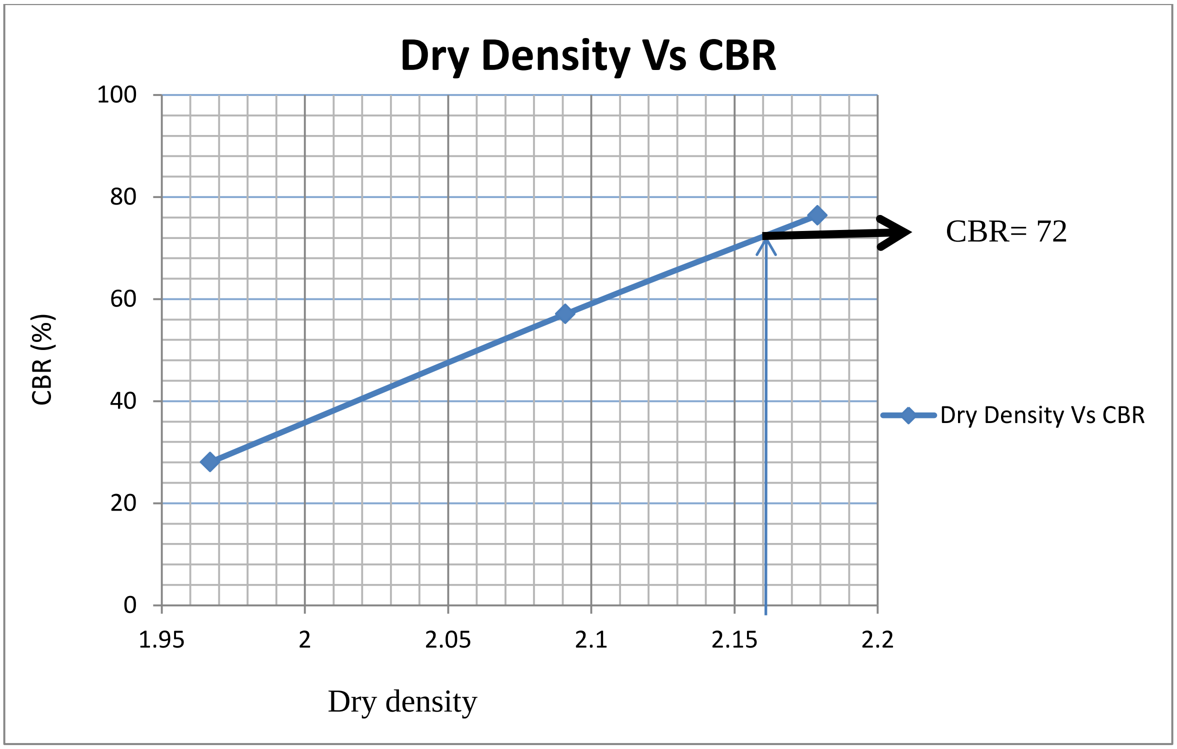

Figure C-11: Dry density-CBR relation curve of 40% (RAP)

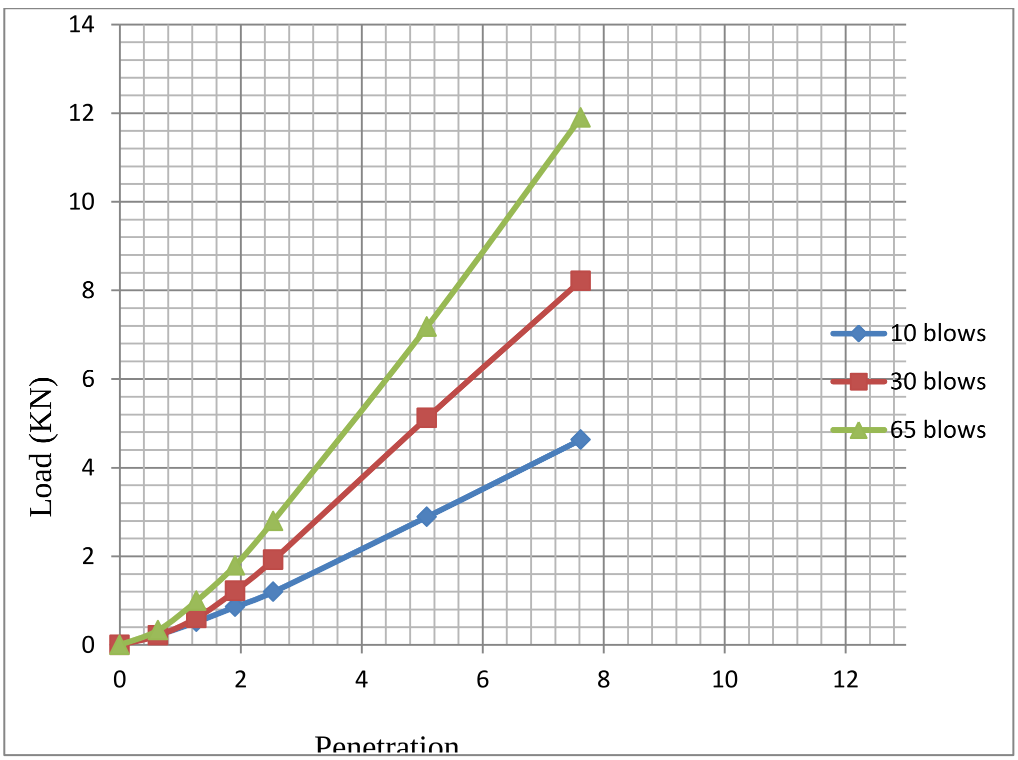

Figure C-12 Graph of Load vs penetration at different compaction level for 40% RAP)

Table C-28: Loss Angeles Abrasion Resistance Test Result of 80% RAP

Test Method: AASHTO T96-94		
Grade	B	
Number of Balls	11 Balls	
Sieve sizes	3/4-1/2"	1/2-3/8"
Wt. of indicated size	2500+10	2500+10
Weight of tested sample	2500.1	2500.4
Number of Revolution	500	
Total weight of sample Tested (g)	5000.5	
wt. of tested sample retained on No. 12 sieve (g)	3966.6	
Percent loss (%)	20.7	
Remarks: The material has LAA of 21%		

Table C-29: Aggregate crushing value Test Result of 40% RAP

Test Method: BS 812 Part 110: 1990		
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Load applied (KN)	400kn	400kn
Weight of sample before test , passing 14mm and retained on 10mm sieves m1 (g)	2651.5	2675
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	430.9	446.8
Aggregate Crushing value (ACV) % = M2/M1*100	16.3	16.7
Average Aggregate Crushing value	16.5	
Remark:- The material has ACV of 16%		

Table C-30: Ten percent fines value Test Result of 40% RAP

Test Method: BS 812 Part 111: 1990		
Material Condition	Dry	
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Load achieved at required penetration of plunger (f)(KN)	230.36	233.14
Duration of testing (min)	10±30sec	10±30sec
Penetration plunger (mm)	20	20
Weight of sample tested , m1 (g)	2912.08	2954.14
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	242.36	255.9

Percent fine =, m(%) M2/M1*100	8.3	8.7
Force required to produce 10% fine (TFV) IN KN	270.2	268.1
Average force TFV in KN	269	
Note:- percent passing 2.36mm should be between 7.5% and 12.5%		
F=14*f/(m+4)		
penetration of plunger		
15mm rounded or partially rounded aggregate		
20mm for normally crushed aggregates		
24mm for vesicular (hone combed) aggregate		

Table C-31: Aggregate Impact value Test Result of 40% RAP

Test Method: BS 812 Part 110: 1990		
Sample No.	1	2
Size of Aggregate (mm)	14-10	14-10
Weight of sample before test , passing 14mm and retained on 10mm sieves m1 (g)	336.6	334.9
Weight of sample after compression pass on 2.36mm sieve size ,m2(g)	45.3	42.7
Aggregate Impact value (ACV) % = M2/M1*100	13.5	12.8
Average Aggregate Impact value	13	
Remark:- The material has AIV of 13%		

Table C-32: Flakiness index Test Result of 40% RAP

Test Method : BS 812 Part 105.1					
Sieve Size (mm)	Weight Retained (g)	Retained (%)	Passing (%)	Thickness Gauge	Weight of Aggregate
				Width of slot) (mm)	Passed Through the Gage (g)
63	0	0	100		
50		0	100		
37.5	122.1	2.6	97.4	63-50	
28	261.78	5.6	91.8	50-37.5	
20	746.96	15.9	75.9	37.5-28	0
14	606.26	12.9	63	28-20	144.146
10	679.54	14.4	48.6	20-14	210.12
6.3	656.66	13.9	34.7	14-10	152.866
Pass 6.3	1636.06	34.7	0	10-6.3	142.24
Total	4709.36			Total (M3)	649.372

Flakiness Index (%) =	M3/M2*100	22	M2	2951.2
Note:- M1= Total mass retained on sieve size 6.3mm and pass 63 mm				
M2= Remaining mass after removing those fractions having mass 5% or less of mass M1				
M3= Combined weight of all particles passing on the Gauge				
M4= Combined weight of all particles retain on the gauge				