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ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Utilization of Reclaimed Asphalt As An Effective Unbound Base Course Material, A Case In Addis Ababa

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A Thesis in Road and Transport Engineering

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A Thesis

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The undersigned have examined the thesis entitled **Utilization of Reclaimed Asphalt As An Effective Unbound Base Course Material, A Case In Addis Ababa** presented by **Tasebe Fisha**, a candidate for the degree of Master of Science and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that this research work titled "Utilization of Reclaimed Asphalt As An Effective Unbound Base Course Material, A Case In Addis Ababa" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

The motive to conduct this study was initiated from repeated observations of excessive wastes of asphalt surface and road maintenance techniques in Addis Ababa. The study was focused on determining the materials property of recycled granular materials containing different percentages of recycled asphalt pavement (RAP) to use as an unbound base course material.

Laboratory tests and field implementation were carried out to determine the physical and mechanical properties of virgin aggregates and various aggregate-RAP blends at different percentages. The results were used to evaluate the strength of granular layer for pavement construction through proper compaction and control of RAP usage. The tests were also conducted to check the standards and requirements specified by the Addis Ababa City Roads Authority (AACRA) and Ethiopian Roads Authority (ERA) using the procedures of the American Association of State Highway and Transportation Officials (AASHTO) testing manual.

The sieve analysis test results showed that gradation of material RAP 1 and RAP 2 are better than the virgin aggregate gradation currently used by AACRA. Both standard and modified proctor compaction tests were carried out to evaluate the effect of variable compaction; the results also showed that the dry density of materials resulted from standard compaction is lower than the result in modified compaction of the same material. The laboratory CBR results showed that the blends with high content of virgin aggregate achieved high bearing capacities. Low CBR values was achieved by neat RAP materials of 100% RAP 1 and 100% RAP 2 materials. The blends containing 75% VA in all material types resulted in higher CBR values. RAP materials implemented in field as an unbound base course material for trial did not show any of early pavement distresses in one year service time.

Beyond determining materials property the study review and asses current material production and road maintenance activity to consider major economic and environmental benefits emanated from using the recycled materials instead of virgin aggregate productions. In this regard, the economic benefits by using RAPs resulted in 50% saving of virgin aggregate production costs annually. In addition to economic benefits, reuse of RAPs may reduce road construction wastes generated from road maintenance and rehabilitation activity by 23% which is needless for the city, Addis Ababa.

Key words: Recycled Asphalt Pavement (RAP), CBR, proctor compaction, aggregate blends.

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ACRONYMS

AACRA:	Addis Ababa city Road Authority
AASHTO:	American Association of State Highway and Transportation Officials
ASTM:	American Society of Testing Materials
CBR:	California Bearing Ratio
DD:	Dry Density
DGABC:	Dense Graded Aggregate Basecourse
DOT:	Department of Transportation
ERA:	Ethiopian Roads Authority
ETB:	Ethiopian Birr
FDT:	Field Density Test
HMA:	Hot Mix Asphalt
MDD:	Maximum Dry Density
MDUW:	Maximum Dry Unit Weight
Mr:	Resilient Modulus
OMC:	Optimum Moisture content
PA:	Pure Aggregates
VA:	Virgin Aggregate
RAP:	Reclaimed Asphalt Pavement
RCA:	Reclaimed Concrete Aggregate

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CHAPTER ONE

INTRODUCTION

1.1 Background

The reutilization of asphalt pavement has become a common practice in the transportation industry. Motivations for recycling typically include the environmental, economic, and social benefits. Recycled Asphalt Pavement (RAP) is one of the most commonly used recycled materials. RAP is the term given to removed and/or reprocessed pavement materials containing asphalt and aggregates. RAP is generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. RAP consists of high-quality, well-graded aggregates coated by asphalt cement. The use of RAP in roadway construction fits with the global objective of sustainable development by the prudent use of natural resources. RAP recycling activities address the issues of reducing use of declining virgin aggregate sources and material storage and disposal of reclaimed asphalt material from paving projects. Further, energy savings can be realized through the use of RAP in roadway construction by reducing the processing and haulage of virgin aggregate materials. Other factors include potentially faster project completion and reduction in construction-related traffic, resulting in less disruption to the traveling public.

In most engineering applications, RAP has performed satisfactorily when it is blended with conventional aggregates as granular base/sub base. Some of the benefits of RAP aggregates that have been properly incorporated into granular base applications include: adequate bearing capacity, acceptable resilient modulus, good drainage and durability (Cong Luo, 2014).

In Ethiopia, there is no written standard and guideline to utilize asphalt pavement wastes by reprocessing to different pavement layer structures, even if there is limitation on recommended specifications some recommendations of RAP usage were presented on Ethiopian Roads Authority (ERA, 2013) Pavement Design Manual. In Addis Ababa, all new and existed road networks construction and asset control owned and administered by a governmental institution named Addis Ababa City Roads Authority, AACRA. The Authority has a standard and specification manual for the city road design, construction, maintenance and material controls lastly modified in 2004. However in this manual, there is no specifications and directions to use recycled materials; even, there is no a clear experience of utilizing RAP as an important construction material. Typically in Addis Ababa, yearly on average more than 25,000m^3 of asphalt concrete wastes were removed

from an existing pavement due to maintenance reasons that will be for patching or rehabilitation (AACRA Annual maintenance report, 2018/19). These is one cause of a need higher road maintenance or/and construction cost and increasing construction wastes in and around the city.

Environmental and economic efficiency use of RAP as base course material by blending with virgin aggregates will result in a material with high bearing capacity and strength. This study was designed for experimental investigation of utilizing RAP as an unbound base course material by blending with a virgin aggregate material to evaluate environmental, economic, social and engineering benefits in road constructions that is owned, controlled and administered by AACRA. The experimental approaches for engineering aspect determinations such as: Gradation analysis, proctor compaction tests, California Bearing Ratio (CBR) test and field implementations were conducted in laboratory and fields, yet they were not quite enough for detail investigations.

1.2 Statement of the Problem

Large amount of construction waste is produced each year and becomes more difficult to find appropriate locations for waste area and landfill. Recycled materials offer viable solutions to the concern, which is beneficial to both environment and economy.

Many researches and transportation authority's manuals shows that utilizing RAP as an unbound base course has a lot of benefits on environmental, economic and engineering aspects. 'When thick bituminous surfaces become worn out, the recycling of such materials can reduce costs and damage to the environment by reducing the exploitation of local natural resources. Age-hardened asphalt can be recycled as an unbound granular material. It may be produced as millings, crushed asphalt from lumps or as granulated asphalt. The RAP can be mixed with fresh aggregate to produce a particle size distribution appropriate to the layer in which it will be used (ERA, 2013).

Rather, environmental and economic efficiency use of RAP as base course material by blending with pure or virgin aggregates will result in a material with high bearing capacity and strength (Tutumluer, 2013). Fifty percent (50%) RAP content blended with Virgin aggregates will result in strengths two times greater than using pure aggregate base. Nowadays, AACRA faces with problems of quarry sites for material production and waste area or landfills for material disposals during construction. For the last two years; maintenance, rehabilitations and constructions of roads in the city done by the Authority's own force were delayed and by different administrative and

technical reasons; from those reasons scarcity of base course materials appeared when it was needed (AACRA Annual maintenance report, 2019).

Because of absence of regular and sufficient waste disposal area, scarified asphalt wastes were dumped everywhere in the city (at places like; center of roundabouts, medians, on any free spaces owned by government, along riversides, on right-of-way restrained for future use and other different places). This act becomes familiar and major factor for bad aesthetics image of the city. Likewise, RAP stockpiles (excavated and milled) in Addis Ababa have been growing ultimately into different dumping sites in the city. Currently, there is no clear guideline and even no experience to utilize RAP as unbound material by applying proper blending with the virgin aggregates.

This study is conducted to investigate the effectiveness in strength of RAP as a base course material by blending with pure aggregates in different percentages and content that aims reducing energy usage, cost of using virgin aggregate and avoiding over wastes in Addis Ababa.

1.3 Objectives

1.3.1 General Objective

The general objective of this research is to evaluate the effectiveness of utilizing RAP as an unbound base course material to ensure better performance in strength resulting in economic environmental benefits.

1.3.2 Specific Objectives

Specific objectives of this thesis are to:

- Carry out laboratory tests on selected RAP and virgin aggregates, VA to explore the way of producing better base course material;
- Determine the cost-effectiveness of utilizing RAP than producing and using virgin aggregate;
- Recommend viable suggestions on RAP usage as unbound material to benefit the Country in general and Addis Ababa in particular, if implemented.

1.4 Research Questions

This research will mainly focus to answer the following questions:

- Was there any experience of asphalt recycling in Addis Ababa?
- What are the properties of reclaimed asphalt as an unbound base course material?
- Does RAP base course perform well in road construction?
- Do the tests truly evaluate the strength of the material?
- What will be the extent of RAP to blend with virgin aggregate to achieve better performance and strength?
- Does variation in compaction application affect the RAP performance?
- How much cost can be reduced by utilizing RAP instead of using virgin aggregate? And
- How much asphalt waste is reduced if RAP is reused for base course layer?

1.5 Scope and limitations of the Study

Utilizing virgin aggregates needs a quarry site with its cost, transportation cost, crushing plant cost, operational cost and others. With the ever-increasing amounts of stockpiled RAP material, the search for potential alternative recycling applications should be intensified, since its ultimate effect will be visible if there is a provision of appropriate land fill. This study is envisaged to result in a high performance base course material by blending asphalt waste and virgin aggregate with reducing a cost required to produce pure base course and avoiding environmental wastes. That will give a direction for potential alternative recycling applications and methods for any responsible bodies in Addis Ababa city, AACRA and others.

The scope of this research is limited with investigation of the property of RAP materials and their blend with virgin aggregates to substitute usage of virgin aggregates as base course materials in Addis Ababa city road regarding rehabilitation and maintenance activity. In this regard, laboratory tests were carried out by using two different RAP samples blended with virgin aggregates and field implementation was done for analysis of some physical behaviour. In addition economic benefit of using RAP instead of virgin aggregate materials is also contrasted. However, there is a limitation in this test which reduces the study effectiveness in detail and modified investigations;

The limitations are:-

- Before starting to conduct this research, different laboratory tests were proposed to evaluate the effectiveness of RAP materials. From those proposed testes the major one is resilient modulus test. But unexpectedly, the triaxial chambers for Mr test available in some institutions were only used for fine grained soil materials, not used for granular materials. In the study, it was tried to correlate the Mr value with for RAP materials derived from the CBR results. However, many researchers have confirmed that the Mr value for RAP materials derived from the CBR result were found very different and so not recommended to draw the Mr value of RAP from CBR results. This was because; the study was limited to investigating material characterization and performance related tests.
- Even though it was not proposed earlier to compare the laboratory and field density results as well as to investigate the properties and behavior of RAP during construction, the study implemented a small construction area of an asphalt pavement by using RAP materials as an unbound base course material. Because of some administrative and technical difficulties in that specific period, the study did not deal with field density (FDT). Instead the visual evaluation on identification of early pavement distresses and investigations were reported.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Over the years, the spiraling costs of asphalt pavement manufacturing have resulted in the increased demand for recycling. Since the 1970s, different countries have been promoting efficient re-use of RAP materials. During rehabilitation or reconstruction, the existing asphalt concrete layers are removed partial-depth or full-depth. In response to the shrinking supply of raw materials and the rising costs of virgin aggregates, RAP is considered to be an alternative to virgin materials. The principal factors behind recycling efforts include reduction of construction waste, preservation of non-renewable natural resources, and lower energy costs.

Typically, economic savings and environmental benefits of using recycled materials are balanced by the performance requirements of pavement design. It is commonly acknowledged that the use of recycled construction materials to the maximum extent possible should be carried out in the overall context of maintaining a cost-effective, high-quality, well-performing, and environmentally sound pavement infrastructure. In principle, the same materials used to build the original highway system can be re-used to repair, reconstruct, and maintain it. Integral to pavement maintenance is the milling of the aged asphalt pavement during resurfacing, rehabilitation, and reconstruction operations. The RAP produced in the milling operations is a granular material consisting of the original aggregates from the mixture along with aged asphalt binder.

In tropical countries, the types of asphalt concrete that are most likely to be available for recycling are those that have become severely age-hardened and cracked or surfaces that have failed through plastic deformation. Of these types of failure, the former is more common, with plastic deformation failures occurring locally where traffic is slow moving such as at junctions and on climbing lanes. Aged asphalt is brittle, containing very hard bitumen. In contrast, asphalt that has deformed plastically is likely to contain bitumen that has suffered very little age hardening. These two types of material present different problems for recovery, stockpiling and re-use (ERA, 2013).

2.2 Current and previous use of RAP as an unbound Base course material

The predominant recycling practice is mixing the reclaimed asphalt pavement (RAP) into new hot-mix asphalt mixture. However, reclaimed asphalt pavement is not totally utilized for recycling in Hot Mix Asphalt (HMS). At the same time, the increasing need for rehabilitation of old pavement contributes to the shortage of virgin aggregate. Furthermore, engineers need an alternative economic way to deal with increasing landfill cost of disposing demolished pavement materials due to the availability of landfill space. Recent research on the potential use of RAP as a base material indicates that RAP is a viable substitute for conventional aggregate base.

In Ethiopia, such recycling and usage of RAP is not familiar because of different reasons of potentiality of RAP materials, absence of clear specifications and construction laws on its usage, and absence of RAP processing machineries and units. But the revised ERA (2013), flexible pavement design manual indicates somehow on usage of recycled materials as follows: 'When thick bituminous surfacing become worn out the recycling of such materials can reduce costs and damage to the environment by reducing the exploitation of local natural resources. This is particularly true for areas where there is a shortage of road-building aggregate or where there are no indigenous oil reserves. It is possible to ensure that there are benefits both for client and contractor from recycling operations; but recycling is unlikely to become widespread until certain conditions are met. These include:

- Sufficient potential for recycling to justify the purchase of specialist plant;
- Pressure from government agencies to implement recycling;
- Suitable specifications and/or working methodologies for contractual use; and
- A good understanding of material properties and methods of modification and application'

The use of RAP as a base course material offers economic and environmental benefits. The Wisconsin Department of Transportation (WSDOT) in the United States currently allows up to 20 percent RAP to be blended with virgin crushed aggregates to form the base course materials. McGarrah (2007) conducted a survey of current practices regarding the use of RAP as base course material and contacted seven (7) states in the United States of America (USA). Whether RAP may be used as base course material is decided on a project-by-project basis instead of being stated in the standard specifications, and the maximum percentage of RAP used as base course material may reach 60% (As cited by Cong Luo, 2014).

The maximum percentage of RAP used as base course was selected on the basis of the research conducted by Mokwa and Peebles (2005), proved that the blending of RAP with virgin aggregate only caused minor changes to the engineering properties of the mixed base course material.

Collins (1994) noted that highway agencies have been proactive in the recycling of reclaimed and byproduct materials into construction materials, with RAP being the material most frequently used. In addition to its use in asphalt mixtures, they identified unbound base and subbase as proven applications for RAP, with grading identified as the limiting factor for use.

In current pavement engineering practice, the shortage of natural aggregate supplies along with the increase in processing cost has encouraged the use of various reclaimed materials from old structures as a source of construction material. This technology reduces both the cost of highway construction and protects the environment by reducing construction waste. RAP had been used as aggregate for pavement construction for some time. In California, considerable saving was made using RAP as a base course for the construction of a thoroughfare. RAP is also widely used in many highway construction projects in Ontario, Canada (Cong Lou, 2014).

In the European practice, recycled unbound aggregates must comply in general with the same criteria as the virgin aggregates, with most countries having no specific requirements for these materials (Thogersen et al, 2013). In USA, many state DOTs actively promote the use of recycled materials, allowing the use of RAP in unbound base and subbase layers (Saeed, 2007). RAP materials are often, but not always, subjected to the same tests and specifications as virgin aggregates. It may be argued that RAP material has already passed various quality control tests, although the aggregate can be somewhat degraded and the binder is aged. At a minimum, it may be prudent to enforce limits on grain size distribution and the percentage of deleterious matter. Following down experience of RAP usage in different selected US state departments and countries were discussed (As cited by Edward et al, 2015).

France

The use of RAP in unbound layers is not a common practice in France When used in granular base materials, RAP content is typically kept below 30% by weight. Specifications for unbound mixtures, as defined in NF EN 13285 (European Committee for Standardization, 2010), are followed. RAP is widely used in bound pavement layers, including HMA and warm-mix asphalt, and in cold processes involving foam and emulsion.

Germany

Current practice in Germany focuses on RAP recycling in HMA layers. The use of RAP in unbound base layers is allowed, up to 30% by weight (Road and Transportation Research Association, 2012). RAP materials with binders containing coal tar are excluded. Field compaction is usually tested using the lightweight deflectometer or intelligent compaction method.

Idaho Transportation Department

The Idaho Transportation Department (2012) specifies that RAP can be mixed in approximately equal proportions with granular borrow for subbase applications. RAP is defined as salvaged bituminous pavement that may have minor coatings of dust or aggregate particles adherent from the reclamation process, with no discernible seams, pockets, or amounts of untreated aggregate or soil. Field compaction is governed by the use of the roller pattern. In-place, uncorrected density readings are obtained from a nuclear gauge. The required compaction is achieved when the final roller pass adds no more than 0.5 lb/ft3 to the previous in-place density. For payment, RAP is measured as a portion of granular subbase (no additional compensation).

Iowa Department of Transportation

For the Iowa DOT (2014), the processing requirements for aggregates produced from reclaimed materials are essentially the same as for virgin aggregates. Up to 50% RAP is allowed in the granular subbase. In practice, relatively small quantities of RAP material are actually used in unbound layers, as the contractors prefer to blend it back into HMA mixtures.

New York State Department of Transportation

New York State DOT (2008) Standard Specifications allows “Alternate C” subbase construction using at least 95% reclaimed bituminous material with a maximum top size of 2 in. No soundness or plasticity index tests are required for this alternate. RAP is approved based on a visual inspection by the regional geotechnical engineer. Testing may be required if there is evidence of a substantial amount of flat or elongated particles. Material with a greater than 30% content of flat or elongated particles is rejected. Grain size distribution requirements are waived when the material consists solely of RAP. RAP is not allowed on roads with a high percentage of truck traffic, defined as 10% or more, unless Portland cement concrete pavement is used.

Texas Department of Transportation

Texas DOT (TxDOT-2004) specifications allow up to 20% RAP by weight in flexible bases. RAP material must pass the 2 in sieve. The compaction specifications call for 100% maximum density. The field density of granular materials is verified by a nuclear density gauge. More common, TxDOT uses RAP in cement-treated base layers, where up to 50% RAP by weight is allowed.

The Netherlands

In the Netherlands, with a landfill ban on construction and demolition waste, almost 100% of RAP is recycled in road construction. The recycling is focused primarily on base asphalt pavement layers. Current practice does not allow for use of RAP in unbound granular subbase and base layers In contrast, the RCA is commonly used in unbound layers.

United Kingdom

In the United Kingdom, the requirements for unbound mixtures are listed in Series 800 of Specification for Highway Works (Department for Transport, 2014). Up to a maximum of 50% RAP by weight is permitted in unbound subbase mixtures. Up to 100% RAP is allowed in unbound aggregate mixture. The compaction requirements are defined in terms of a number of passes of a specified type of compaction equipment (type and mass) over a specified loose layer. Contractors are allowed to use an alternative method of compaction if they can prove at site trials that the results are equivalent to or better than those using the specified method. The moisture content of the compacted material is specified within the range of 1% above to 2% below the optimum value. Specification for Highway Works is primarily used for main roads, but it is widely adopted by local highway authorities.

Florida Department of Transportation, USA

The Florida DOT (FDOT) specifications allow the use of up to 100% RAP only for non-traffic base applications, primarily at paved shoulders and bike paths. The use of RAP in roadway base is not allowed. FDOT's main concerns are low bearing capacity and a high potential for long term creep deformations. Some districts reported excessive settlements when large trucks were parked on the shoulder overnight. FDOT specifies the use of the nuclear gauge for compaction acceptance of RAP layers. Moisture content is obtained by use of the Speedy moisture tester.

2.3 Effects of Using RAP as a Base Material

In contrast to usage of pure aggregate materials for base course, different researchers made their own conclusions drawn from laboratory and field tests. Although there are obvious advantages of utilizing RAP as base materials, the application is still limited due to the lack of systematic laboratory evaluation study. Since the mid 1990's, series of standard tests and traffic-type tests have been conducted to study the design criteria of RAP base. Those tests indicated RAP has good behavior in early stage of pavement life. Most test results reported the resilient modulus of RAP is slightly larger than that of aggregates (Bennert, 2000).

Garg and Thompson (1996) reported average California Bearing Ration (CBR) value of RAP base is less than CBR of aggregates. Rapid shear testing was also employed to investigate RAP's Mohr-Coulomb failure envelope. The test results indicated similar friction angle of RAP and aggregate. RAP exhibits lower cohesion value than aggregates.

Several methods were employed to improve the quality of RAP base. Bennert (2000) used standard tests to characterize RAP, recycled concrete aggregate (RCA) and dense-graded aggregate base aggregate (DGABC). Traffic-type loading tests were also conducted to analyze RAP, RCA and DGABC blends. The 100% RAP and 100% RCA obtained higher resilient value than 100% DGABC's which is currently used in pavement design in New Jersey. Conversely, the 100% RAP accumulated largest permanent strain. The result appears to be a discrepancy; the possible reason is the breakdown of the asphalt binder under the larger loading during the permanent deformation test. RAP shows the trend to accumulate large permanent deformation (Bennert et al, 2000).

The significant cost reduction due to RAP application in base is attractive too. Some counties in US charge high fee for generating construction debris to encourage recycling and to save space due to the rapidly diminishing landfills. The unit bid price for the reclaimed asphalt decreased significantly as a sign of the contactor's confidence. The use of reclaimed asphalt pavement as base avoided all disposal charges and save the valuable resources. In certain regions where engineers experience virgin aggregate shortage, RAP could be economically reused as base or sub base aggregate. The use of RAP in base and sub base is recommended as a viable and cost-effective material for pavement design (Wenbin, 2006).

2.4 Processing and storing of RAP

RAP can be produced by milling, ripping, breaking, crushing, or pulverizing types of equipment, with milling being the most common method. Usually, the milling depth depends on the size of surface cracks and/or the depth of weak layers or interfaces, which is established through visual examination of cores. During the removal of these distressed or weak layers, the milled material should not be contaminated with other debris. The milled surface should be inspected for uniform texture, which helps achieve long-term performance of a pavement overlay. The gradation of RAP is mainly affected by milling and the composition of these layers (Saeed, 2008).

ERA (2013) flexible pavement design manual directs three Methods of obtaining RAP; from those methods milling is particularly useful where traffic access must be retained during the removal of damaged asphalt. Either method is suitable when the road is closed to traffic during the rehabilitation work.

Asphalt millings: Asphalt millings are obtained by planning in a layer by layer fashion, using a mobile plant and are typically consistent in their lump-size distribution. They can normally be used as granular material, as won, or with minimum screening to remove any over-size material.

Crushed asphalt: Crushed asphalt is commonly obtained by using horizontal impact crushers or hammer mill impact crushers. Jaw/roll combination crushers are not suitable for processing RAP which contains 'soft' bitumen because 'pancaking' can occur on warm days and the material will remain agglomerated.

Granulated asphalt: Granulated asphalt is produced in a specialized plant, known as a granulator, or in milling/grinding units. These units are not crushers and are designed only to break the bitumen-asphalt bond.

Storing or the stockpiling of RAP is a very important part of the recycling process. The full benefits of comprehensive testing of the in situ asphalt layers can easily be lost if equally meticulous control of the stockpiling process is not put in place. Depending upon the variability found during testing, it may be necessary to build separate stockpiles of materials taken from different sections of the road. The tendency for RAP to agglomerate will be affected by both the hardness of the bitumen in the RAP and the ambient temperature. The most effective method of stockpiling must be established by trial and error. Experience has shown that RAP in large piles does not tend to

agglomerate. Stockpiled RAP destined to be used as unbound granular material may be watered to prevent agglomeration of particles in warm weather and this also aids compaction on site.

Some agencies allow only RAP from their projects to be recycled. This limitation is used to control aggregate and binder quality. Most agencies allow the use of RAP from multiple sources, including 'unclassified RAP' that has been combined and processed into a single stockpile. This practice is usually allowed with the stipulation that appropriate aggregate properties meet the required specifications. Some agencies also impose a requirement that no additional material can be added to a stockpile once it is built and tested.

A more common approach is to allow stockpiles to be continuously replenished with new material. Delivery of consistent material over time requires regular testing and analysis of RAP samples. Typically, millings from a single project are consistent in gradation, asphalt content, aggregate properties, and binder properties. Currently, there are processes and techniques available to achieve uniform RAP composition from multiple sources. As with virgin aggregates, there is the potential for segregation of RAP material placed on stockpiles. This is a common problem when stockpiles are built using fixed conveyors that six (6) allow particles to drop long distances. The problem can be minimized by using indexing-type conveyors that extend and raise the discharge point as the size of the stockpile increases (Edward et al, 2015).

2.5 Application and usage of RAP

Although some disadvantages were recognized, reduced costs, environmental benefits and other advantages lead to increased interests in utilizing RAP as base materials for highway construction. Generally, three main methods have been reported in different manuals and literatures to improve the quality of RAP base. These are:

i. Mixing virgin aggregate with RAP (Adam Schneider et al 2016, Cong Luo 2014);
ii. Recycling existing AC by pulverizing and mixing with underlying poor quality base material to yield new base material; and
iii. Cement stabilized RAP base (Li 2004, Dulal Chandra Saha 2017 as cited by Adam et al 2016).

In this study, the strength and financial performance of RAP mixing with virgin/pure aggregates like in number one (i) above was evaluated.

If it can be shown that an unbound material containing RAP meets the specifications for grading, density and CBR which are normally applied to fresh materials, then it should be acceptable to use the RAP as road base. A limiting factor will be the hardness of the bitumen in the RAP; 'softer' bitumen in agglomerations of bitumen and fines may prevent the achievement of the required density. In these circumstances, the proportion of RAP used in the new layer will have to be restricted to a level at which thorough compaction can be achieved. The road base is an important load bearing layer and it is therefore advisable to restrict the general use of RAP in this layer until experience of its performance has been acquired. Inclusion of RAP in a lower road base layer or under an Asphalt Concrete surfacing on more lightly trafficked roads provides an appropriate method of acquiring this experience (ERA, 2013).

In most engineering applications, when used as unbound granular material (UGM), RAP is usually milled or crushed down to 37.5 mm or less, with a maximum allowable top size of approximately 50 mm. RAP has performed satisfactorily in many cases when it is blended with conventional aggregates as granular base and sub base. Some of the benefits of RAP that have been properly incorporated into granular base and sub base applications include: adequate bearing capacity, acceptable resilient modulus, good drainage characteristics and durability (Cong Lou, 2014).

As with virgin or pure aggregates, there is the potential for segregation of RAP material placed on stockpiles. This is a common problem when stockpiles are built using fixed conveyors that allow particles to drop long distances. The problem can be minimized by using indexing-type conveyors that extend and raise the discharge point as the size of the stockpile increases.

Once processed, RAP can be handled and stored as a conventional aggregate material in horizontal stockpiles and left uncovered. When large quantities of RAP from different sources are available, it is advisable to keep stockpiles separated by the source (Chesner et al, 1998)

Cosentino (2013) concluded that blends of 50% RAP and 50% limerock can be effectively stabilized with asphalt liquid emulsion. The resulting mixture had soaked limerock bearing ratio strengths exceeding 100 and acceptable 30-year creep deformations. Similar results were achieved with Portland cement stabilization. The addition of 2% to 3% of cement by weight yielded satisfactory strength and deformation properties of the stabilized RAP. The asphalt binder content of a blend stabilized with asphalt emulsion not exceeding 3.5% by weight. If Portland cement is used as a stabilizer, its content should not exceed 2% by weight.

There are wide variations in the amount of RAP allowed in unbound layers by various transportation agencies. Although the use of 100% RAP is not isolated, the general state of the practice appears to be trending toward 50% as the maximum allowable content. Many agencies set limits at well below 50% by weight. The large variability in RAP content in unbound layers allowed by various agencies may indicate that this particular application is not the main focus of RAP recycling efforts. It can be argued that RAP material is too valuable a resource to be used in large quantities in applications other than recycling in bound asphalt mixtures (Edward et al, 2015).

2.6 Properties of RAP

Extensive research has shown that RAP has good drainage characteristics, adequate shear strength and stiffness. Thus, by properly blending it with natural aggregate, RAP can also be used in granular base/sub base courses. However this application is still controversial because RAP is difficult to compact during construction, has low bearing strength and exhibits creep deformation over time. Cosentino et al (2008), reported on laboratory tests, comparing the performance of pure RAP with 20, 40, 60 and 80% natural aggregates in the blends. His results show that the 100% RAP produces the lowest bearing strength, with the California Bearing Ratio (CBR) being only 11. Thus, he suggests that the maximum content of RAP should be limited to 60% in sub base and 10% in granular base.

Bennert and Maher (2005) discussed the performance when RAP is blended with natural aggregates in Jersey-Georgia, USA. He concluded that when the amount of RAP content is limited to 50% by weight, the blends meet the requirements for base course materials. McGarrah (2007) as cited by Cong Luo (2014), evaluated the current practices of RAP/natural aggregate as base course material in the United States. The findings from his literature review drew attention to the effect of RAP content on both physical and mechanical properties in the blends, including data on: density, moisture content, permeability, permeability, CBR, and resilient modulus Table 2-1.

Table 2-1: Effect of increasing RAP content on material properties

Report	Dry density	Moisture content	Permeability	CBR	Resilient modulus
Bennert, 2005	Decreased	Decreased	Decreased	---	Increased
Taha, 1999	Decreased	No change	Increased	Decreased	---
Guthrie, 2007	Decreased	Decreased	---	Decreased	---
Macgregor, 1999	---	---	No change	---	Increased
Papp,1998	Decreased	Decreased	---	---	Increased

Source: Cong Lou, (2014); Granular base incorporating reclaimed pavement, p-11

Some findings show that the improper processing or compaction of RAP may result in poor pavement performance. With an increased RAP content, granular base/subbase tends to have a reduced bearing capacity or the California Bearing Ratio (CBR). The experience of Ontario shows that CBR is reduced below the expected value for conventional granular base when the amount of RAP exceeds 20 to 25% (Senior et al, 2008).

Existing laboratory studies indicate that as the RAP content increases in the RAP and virgin aggregate blend, the permeability increases, the resilient modulus increases, and the shear strength decreases. There is a clear trend showing that large strains (CBR) lead to substantial permanent deformations, whereas the resistance to small strains (resilient modulus) increases in a RAP blend. Notably absent in these studies are the measurements of actual stress levels in unbound base layers. It is possible that for some pavement sections the resulting traffic-induced stresses in base and subbase materials are inconsequential and the rutting potential may be minimal. The depth of the pavement section and the relative layer stiffness affect RAP material performance in the field (Edwards et al, 2015).

The pavement design method currently used in AASHTO is not capable of capturing the performance of base material containing RAP (Wu M, 2011). Only the resilient modulus value is used in design. The MEPDG procedure includes a prediction model for fatigue, rutting, and other performance distresses and can be used to predict the performance of a pavement containing RAP

base material (AASHTO, 2008). Thus, a life cycle cost analysis is possible to evaluate the cost-effectiveness of using RAP. However, the characteristics of RAP are different from those of traditional materials. For instance, the rutting potential of virgin aggregates is negatively correlated with their stiffness. This is not the case for RAP materials. Therefore, the rutting prediction model for granular materials in the MEPDG is not directly applicable to base materials containing RAP (Wu M, 2011).

2.7 Experiments for RAP as a base course material

Currently, there are no clear and accepted national specifications for the use of RAP as unbound base material in different countries.

ERA (2013) Flexible Pavement Design Manual, recommended that an unbound material containing RAP meets the specifications for grading, density and CBR which are normally applied to fresh materials then it should be acceptable to use the RAP as road base.

Saeed and Hammons (2008) recommended the following tests to characterize the field performance of RAP mixtures:

- Screening tests (sieve analysis and moisture-density relationship);
- Toughness (Micro-Deval test);
- Stiffness (resilient modulus test);
- Shear strength (static triaxial and repeated loading at OMC and saturated conditions); and
- Frost susceptibility (tube suction test).

The materials may be either unbound granular or bound, depending on the requirements for the layer. Base course material, consisting of a specific type of aggregate, is placed on top of the subbase. It supports the bound pavement layer.

According to Tutumluer (2013), some of the most important material characteristics affecting the unbound aggregate behavior include the following:

- Mineralogy;
- Particle size distribution (grading) and fines content;
- Particle shape, surface texture, and angularity; and
- Durability (soundness, abrasion resistance).

These characteristics play out during construction by affecting the workability of the mixture and controlling the degree of compaction (density) and pore structure of the layer. These in turn impact the layer strength, stability (resistance to deformation), and modulus (stiffness) properties that are relevant to performance and design. Standard methods such as sieve analysis, sulfate soundness, and Los Angeles impact and abrasion are used to assess the suitability of materials for use in granular base applications, but grading is the only universally common method applied by the various states. Generally, subbase materials tend to be more coarse-graded than granular base. Both materials are designed to provide the required bearing capacity and drainage for the pavement structure. They are essential to long-term pavement performance. Index tests such as the California bearing ratio (CBR) and the Hveem R-value are commonly used to characterize the shear strength, resilient modulus, and deformation characteristics of granular layers. Different researches and transportation department manuals recommended the following major tests to be done in evaluating the RAPs performance as a granular base course material (Tutumluer, 2013).

2.7.1 Gradation

Gradation seems to play the most significant role among the aforementioned factors. In pavement surface layers, gradation plays an effective role in load tolerance, in addition to load distribution on a broader basis.

If it can be shown that an unbound material containing RAP meets the specifications for grading, density and CBR which are normally applied to fresh materials then it should be acceptable to use the RAP as road base. A limiting factor will be the hardness of the bitumen in the RAP; 'softer' bitumen in agglomerations of bitumen and fines may prevent the achievement of the required density. In these circumstances, the proportion of RAP used in the new layer will have to be restricted to a level at which thorough compaction can be achieved. The road base is an important load bearing layer and it is therefore advisable to restrict the general use of RAP in this layer until experience of its performance has been acquired. Inclusion of RAP in a lower road base layer or under an AC surfacing on the more lightly trafficked roads provides an appropriate method of acquiring this experience (ERA, 2013). Table 2-2 below shows granular base course gradation specification in respect of the ERA requirements.

Table 2-2: Granular base course/GB1 gradation specification (ERA requirement)

Test sieve (mm)	Percentage by mass of total aggregate passing test sieve		
	Nominal maximum particle size		
	37.5 mm	28 mm	20 mm
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 (1)	5 – 12	5 - 12	5 – 12

Source: ERA (2013); Flexible pavement design manual volume I, page 6-2

If the amount of fine aggregate produced during the crushing operation is insufficient, non-plastic angular sand may be used to make up the deficiency. In constructing a crushed stone base course, the aim should be to achieve maximum impermeability, good compaction and high stability.

AACRA (2004) standard specification number 302 states, that the granular base material should meet the material property requirements specified in Table 2-3 below.

Table 2-3: AACRA standards of base course material grading

Sieve Size (mm)	Alternate Grading (% passing)		
	A Crushed	B Crushed	C Uncrushed
50	100		100
37.5	97-100	100	85-100
25		97-100	
19	67-81		60-90
9.5		56-70	
4.75	33-47	39-53	30-65
2.0			20-50
0.425	10-19	12-21	10-30
0.075	4-8	4-8	5-15
PI	6 max	LA	50% max
LL	25 max	CBR	80% min
LS	5 max	Compaction	98% min

Source: AACRA (2004); standards for road and bridge designs, section 300 page 302-3

2.7.2 Moisture-density relationship

Bennert (2005) determined OMC and MDUW for samples containing different percentages of RAP using modified proctor compaction method. The results indicated that the increasing percentage of RAP caused a decrease of OMC and MDUW. Adam Schneider et al (2016), found that RAP had a lower MDUW comparing to aggregate samples, based on results from both proctor compaction tests and tests using gyratory compactor at 50 gyrations. For the gyratory compaction, increasing RAP decreased OMC whereas for standard proctor compaction, OMC increased with the increase of RAP percentage. It was concluded that increasing RAP increased MDUW but decreased OMC.

Both Standard and Modified Proctor compaction tests were conducted, according to AASHTO T-99 and T-180, respectively, to determine the optimum water contents and maximum dry densities by applying different compaction effort, that compaction effort has less effect on the moisture content than on the maximum dry density for the materials used in this study. The maximum dry density increases and optimum water content decreases as the compaction effort is increased, as is expected. Thus, it is clear that the change of compaction method can make significant difference in density, and consequently result in different material performances, because of this conducting Moisture-density relationship test is necessary (Cong Lou, 2014).

The standard and modified maximum dry density Proctor tests are used to determine the optimum moisture content and maximum compacted dry density for each material. The difference between the two methods lies in the number of layers in which the material is compacted (three layers for the standard Proctor and five layers for the modified Proctor), the drop height for the Proctor hammer (305 mm for the standard test and 457 mm for the modified test) and the weight of the hammer (2.5 kg for the standard test and 4.5 kg for the modified test). All these factors typically contribute to lower optimum moisture contents and higher compacted densities under the modified Proctor test relative to the standard Proctor results. In Ontario, the standard maximum dry density Proctor test is typically conducted on pavements such as roads, highways and parking lots, whereas modified maximum dry density Proctor tests are typically conducted on pavements such as major airports and port facilities (Adam et al, 2016).

2.7.3 California Bearing ratio test

California bearing ratio (CBR): is an index that is used to evaluate the potential strength/stiffness of subgrade, subbase, and base course materials, as well as recycled materials. It is commonly used to characterize the shear strength, resilient modulus, and deformation characteristics of granular layers. However, many manuals promote particle size grading to provide an empirical estimate of layer properties for design purposes (Tutumluer, 2013).

California Bearing Ration (CBR) Tests were conducted in accordance with different standards such as ASTM D 1883. "Standard test method for CBR (California Bearing Ratio) of laboratory compacted soils" on Reclaimed Asphalt Pavement (RAP), Crushed Stone, and RAP-Crushed Stone blends in various composition to determine loading resistance of materials (Dulal, 2013).

In pavement engineering, CBR is generally used as a parameter to evaluate the suitability of a soil as pavement construction material. It is also used to estimate the resilient modulus and strength of subgrade, subbase, and base course materials. The CBR value is important for pavement design when selecting the materials. Usually the higher CBR values have the better performance with regard to both stiffness and strength (Cong Luo, 2014).

2.7.4 Resilient modulus test

The AASHTO T307-99 designation was followed in all resilient modulus tests. After a test specimen was fabricated and placed in the triaxial chamber, the recording devices for load cell were adjusted as needed before conditioning (750 cyclic axial stress of 93.1 KPa applying on the sample at 103.4 KPa confining pressure). The purpose of sample conditioning was to eliminate the effects of the interval between compaction and loading and to eliminate any initial loading versus reloading. During the cyclical loading stage, the drainage valve remained open to minimize the buildup of excess pore pressure (Cong Lou, 2013).

Common flexible pavement design methodologies are largely calibrated to empirical studies while their formulation is informed by commonly measured mechanical properties, especially resilient modulus and various measurements that correlate with resilient modulus. Hence, studies to support the incorporation of RAP into pavement designs have focused on characterizing its mechanical properties. The mechanical properties of RAP are expected to largely mimic those of crushed stone aggregate due to its similar composition with the notable exception of residual

asphalt binder and particle-size gradation. Several authors have performed laboratory studies of RAP, focusing on tests of interest to pavement base construction, including Proctor compaction, California Bearing Ratio (CBR), and resilient modulus.

2.8 Economical and Environmental Benefit of Using RAP in Addis Ababa

This study briefly discussed regarding the advantages of RAP utilization based on data's from AACRA on virgin or pure aggregate base course annual production, distribution and demand. In addition, the environmental benefits with regard to waste disposal are also assessed.

Many studies show that some of the environmental and economic benefits of using RAP as a sustainable construction material are: the use of already existing materials, the elimination of disposal problems, conservation of natural resources, reduction of inconvenience attributable to traffic caused by haulage of materials and major energy savings including those related to avoiding processing of additional virgin material and the reduced haulage of materials.

2.8.1 Economic benefit of using RAPs

Currently, AACRA owns two crushing plants for subbase and base course materials which are found around 'Kality' at the gorge of great Akaki River at the back of 'Klinto Industrial Park'. It is currently involved with low quality quarry raw materials. So, the plant is mostly operational in processing crushed subbase materials. The second source of unbound base course material is found at Bole-Bulbula, particularly named the "Reventi" crushing plant.

By considering operational costs of plants, vehicles and machineries, salaries of workers and other administrative costs, AACRA set a unit price of ETB 388.89 for one metric cube ($1.0m^3$) of crushed aggregate base course materials. Table 2-4 below shows the last two years production volume and distribution costs of aggregate base course material.

Table 2-4: Yearly production of base course aggregates at AACRA quarries

Year (E.C.)	2010	2011
Production (m^3)	61,621.00	41,854.00
Cost of production (ETB)	23,963,790.69	16,276,602.06
Average two years productions		51,783 m^3

Source: AACRA, Quarry control; Annual office report of 2011 EC, page 2

Yearly average production of both crushing plants was 51,783 m^3. Based on a unit price for 1 m^3 of material, the yearly average financial need came to be Birr 20,120,390.00

On the contrary, during the two successive years of 2010 E.C and 2011 E.C, 28,042m^3 and 23,899m^3 of asphalt layers were excavated respectively. Out of the 23,899m^3 asphalt layer of 2011 E.C, 568m^3 was milled using milling machine and the remaining 23,331m^3 was scarified and excavated by excavators and disposed as regular wastes of soil and rock. Currently, AACRA owns two new milling machines which can produce the required RAP materials. However in year 2011E.C, they only produced 568m3 of RAPs. This is because of no regulations, experiences and awareness of producing and using RAPs as a construction material to fill the scarcity of pavement layer constituents.

Based on the excavation, waste, asphalt overlay, asphalt base and surface patching were reported that annually from road maintenance, they can produce around 31,000$m^3$of RAP materials on the average. Based on the current production and distribution of base course aggregates from quarries, if 50% of pure aggregated were substituted by RAPs, Birr 10 million ETB can be saved annually, based on current quarry productions.

Since operational costs and manpower and dump trucks requirement of milling activity and familiar excavation by other machineries are similar, there is no extra financial expense for RAP productions. In addition, there is a need for hauling of virgin aggregate materials from quarries to construction site and milled RAP materials to construction location or to RAP stockpile area; the difference in transportation costs requirement is variable. Because of this, the difference in transportation cost was not accounted for in economic value of RAP as a substitute of virgin aggregates.

2.8.2 Environmental Benefit

In addition to filling the scarcity of granular base course materials and cost saving, recycled materials are important environmental benefits associated with reducing the quantity of wastes which requires more waste dumping area or landfill. Currently, AACRA temporarily uses two waste dumping areas, around ‘Gerji’ and ‘Torhayloch’ which are not sufficient, since the available free spaces are narrow and their location is within the City, Addis Ababa, close to residential and commercial areas. Sometimes, there are restrictions by the agents of the Municipality of Addis Ababa to dump wastes because of many administrative reasons. Table 2-5 below shows the

excavation and cart away of wasted materials from the reports of two successive years from AACRA Own Force Maintenance Directorate.

Table 2-5: Annual excavation and cart away volumes on maintenance task only

Year (E.C)	**2010**	**2011**
Total Excavation, including Asphalt surface (m^3)	120,248	101,025
Cart away (m^3)	99,015	116,347
Excavated asphalt surface only (m^3)	28,042	23,899

Source: AACRA, Road maintenance directorate annual reports of 2010 & 2011 E.C.

From Table 2-5, excavation and cart away reports of the above table can be understood and that almost all the excavated materials were removed as a waste material including asphalt surfaces. This shows that there is no further activity of recycling done using any of the materials used before. If the asphalt surfaces were reused as a RAP material, more than 23% of total waste will be reduced and this will be better in environmental protection rather than saving costs for cart away hauling. Therefore environmentally, the use of already existing materials is helpful by elimination of disposal problems, conservation of natural resources, reduce haulage of materials and reduction of inconvenience attributable to traffic caused by haulage of materials.

Generally, the use of RAP in base course application is attractive for a number of reasons:

- It reduces the cost of material production by eliminating quarrying, crushing, and screening operations;
- For repaving projects, it reduces handling and transportation costs since RAP is retained onsite for reuse;
- It reduces the consumption of natural resources and energy, as reflected in the reduced costs in the above two points; and
- It reduces the need for waste dumping area or landfill and are used to keep the city streets and spaces clean from construction wastes.

CHAPTER THREE

METHODOLOGY AND EXPERIMENTAL STUDIES

3.1 Introduction

This chapter describes the methodology of this research such as: locations, testing program, sampling techniques the tested materials, equipment, and laboratory testing and field implementation procedures. Since the study was conducted in Addis Ababa all those procedures were based on the standards specified by AACRA, ERA and AASHTO manuals.

3.2 Study area

The study is conducted in Addis Ababa city based on AACRA's construction, maintenance and rehabilitation method, specification and trend along different road sections. Currently in the city, more than 5,400km road is on service under different standards and categories. Out of this, 2,442km is covered by asphalt pavement; the rest: 1984km, 509km and 220km were covered with Cobble, Gravel and Stone chipping surface layered roads respectively. AACRA have been removing more than 25,000m^3 of asphalt waste yearly on average for the last three years (2009, 2010 and 2012 EC). This implies that there was a huge volume of RAP materials that were wasted like any unwanted waste. Besides this, the Authority utilizes more than 50,000m^3 of virgin aggregate for base course materials for maintenance and rehabilitation purpose by own force (AACRA Quarry control, 2018/19).

3.3 Study Design

Experimental study design was used to achieve the ultimate goal of the research. The experimental study design consisted of two tasks; field work and laboratory tests. The field work extends from detail observation of RAP and Virgin aggregate production, stockpiling and usage, taking sample from different places within the study area to investigate the engineering properties of those materials. In laboratory tests, the samples taken from the study area were tested to measure the physical and mechanical properties such as: checking moisture content, grain size distribution, density, CBR test and other necessary laboratory tests were conducted. In addition to laboratory tests, field implementation was performed to evaluate the compaction and to check out early distresses resistance of the material.

3.4 Materials and Sampling

The materials considered for this study were three: RAP 1 (RAP taken by crushing from "Bashawolde" dumping site), RAP 2 (taken from Anfo area stock pile) and the crushed virgin aggregate (VA) taken from "Bulbula" (AACRA aggregate crushing plant). The samples were taken by considering the present available RAP materials, the difference in RAP production process, location gap or distance, layer structures of pavement and suitability of sampling.

3.4.1 Sampling of materials

RAP 1: This sample was particularly taken to discover the granular properties of RAP material processed by crushing existing asphalt wastes were excavated by heavy machineries; mainly, an excavator from road sections located at the central part of Addis Ababa. In this study, test specimens were prepared by crushing largely scarified asphalt layer with hand hammer. Most of the excavated asphalt wastes in this dumping area were with very thick layer measured between 10 cm to 20cm, which was because of repeated overlay maintenance. Figure 3-1(a) down shows the excavated asphalt surfaces disposed as waste materials and Figure 3-1(b) shows laboratory test materials assigned as the RAP 1.



(a) (b)

Figure 3-1: Sample of material RAP 1 at waste area and in laboratory

RAP 2: This was taken from the Stockpile of RAP material processed by milling operation (see Figure 3-2 below). The samples were taken using the procedures recommended by AACRA standards of material sampling division 802 of section 800. The sample represents various gradations and physical conditions since it was taken during dumping of trucks in stockpile area and the other sample after three days stocking. The milled materials were produced in the western part of the City on the road sections from 'Alembank' Round about to 'Tatek Ambo/ YeshiDebele' Round about. Unlike sample RAP1, the exiting asphalt surface was not repeatedly maintained and overlaid. The only layers were wearing course and binder course. Figure 3-3 below shows the milled stockpiles around 'Anfo' area and samples were assigned as RAP 2 taken from.



Figure 3-2: Asphalt milling operation around 'Anfo' round about



Figure 3-3: RAP 2 temporary stockpiles 'Anfo' project, AACRA

Virgin/Pure aggregate: AACRA uses crushed basaltic rock for unbound base course layer. The Authority currently owns two crushing plants: the first located around 'Kality' at the gorge of Great Akaki River, at the back of 'Klinto industrial park'. It is currently faced with a quality quarry raw materials of basaltic rocks; due to this, the plant is mostly operational processing crushed subbase materials. The second source of unbound base course material is at 'Bole-Bulbula'; particularly named the 'Reventi' crushing plant. This plant currently covers 70% unbound base course consumptions for AACRA own force road construction and maintenance uses (AACRA, Quarry control, 2019). The virgin aggregate sample for this test was taken from this plant stocks because of the above reasons. Figure 3-4 below shows a sample taken that represents virgin aggregate material for base course.



Figure 3-4: Samples representing virgin aggregates, VA

3.5 Experimental program

'If it can be shown that an unbound material containing RAP meets the specifications for grading, density and CBR which are normally applied to fresh materials, then it should be acceptable to use the RAP as road base' (ERA 2013, flexible pavement design Manual p G-6). In this study to investigate the behaviour of granular materials containing RAP, the tests were divided into two categories: physical property tests and mechanical behaviour tests. The physical property tests were performed to determine the basic material properties (including gradation, optimum water content and maximum dry density) through sieve analysis and Proctor compaction tests. The CBR test was carried out to evaluate the strength/stiffness characteristics of the materials.

To obtain an improved understanding for proper use of RAP in granular base/subbase layer and the behaviour of aggregate-RAP blends under various conditions, the following tasks were performed and the test matrix and the corresponding testing designations are summarized and shown in Table 3-1 and Table 3-2 below respectively. Clearly, thorough pre-crushing of the RAP would make it easier to place and compact the material and vibratory rollers should also be effective in breaking down agglomerations. Fresh aggregate could, if necessary, be blended with the RAP to modify the particle size distribution.

Preparation of aggregate-RAP blends with 0%, 25%, 50%, 75% and 100% RAP content are stated below:

- 0% RAP with 100% crushed rock or virgin aggregate (used as a control mix);
- 25% RAP blended with 75% virgin aggregate;
- 50% RAP blended with 50% virgin aggregate;
- 75% RAP blended with 25% VA; and
- 100% RAP material.

For the study the following strength related tests were conducted, which are: physical property and mechanical behavioral test which includes sieve analysis test, Proctor compaction and CBR tests.

Field implementation/construction of aggregate-RAP blend was also done as a base course layer for early analysis of rutting, bleeding and compaction characteristics.

Table 3-1: Summary of test matrix carried out in this study

Material/Test	Physical property tests			Mechanical Behaviour tests	
	Sieve Analysis	Standard Proctor Compaction	Modified Proctor Compaction	CBR test	Field Implementation
100% VA	Yes	Yes	Yes	Yes	Yes
100% RAP 1	Yes	Yes	Yes	Yes	No
100% RAP 2	Yes	No	Yes	Yes	Yes
75% VA & 25% RAP 1	No	No	Yes	Yes	No
50% VA & 50% RAP 1	No	Yes	Yes	Yes	No
25% VA & 75% RAP 1	No	No	Yes	Yes	No
75% VA & 25% RAP2	No	No	Yes	Yes	No
50% VA & 50% RAP 2	No	No	Yes	Yes	Yes
25% VA & 75% RAP 2	No	No	Yes	Yes	No

Table 3-2: Summary of laboratory tests and standards used in this study

Laboratory test	**AACRA Test no.**	**Test method**
Sieve analysis of fine and coarse aggregates	S-4	AASHTO T27
Moisture-density relations of soils using standard compaction (2.5-kg(5.5-lb) Rammer and 305mm(10-in) drop height)	S-35	AASHTO T99
Moisture-density relations of soils using modified proctor compaction a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.)	S-11	AASHTO T180
Standard method of test for the California bearing ratio	S-12	AASHTO T193

3.5.1 Gradation test

Sieve analysis, AASHTO T27 used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. A grain size analysis was used to determine various amounts of material contained in standard size segments from the largest to the smallest within a given sample of the aggregate.

Since removed asphalt surface aggregates are made up of a grain of many different sizes, the size used in a base course layer should be processed to coarse and fine aggregate size. Grain-size analysis of aggregate containing relatively large particles was accomplished using sieves. It is an apparatus having openings of equal size and shape through which grains smaller than the size of the opening will pass, while larger grains are retained. Sieve analysis involves a nested column of sieves with punch plate, woven wire mesh and or cloth screens nested in decreasing order and the sample is shaken through the sieve until no more will pass and the retained portion on each sieve is weighed and recorded. The calculation is commonly performed to represent the results expressed as percentage passing a particularly selected sieve. This procedure was typically performed on a sample in dry state. However, wash Sieve analysis is the name of the operation of dividing a sample of aggregate into fractions, each consisting of particles of the same size.

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. Almost all other tests were conducted based on the gradation of the material under study and it was necessary to accurately conduct this test with good precision. In this study, AASHTO T27 was used as referenced by AACRA test number S-4. Sieve analysis laboratory test results are attached in Appendix A.

3.5.2 Density and optimum moisture content

In this case, the laboratory test was performed to determine the relationship between the moisture content and the dry density of material in a specified compaction effort. The compaction effort is the amount of mechanical energy that is applied to the soil mass. This laboratory test was conducted to determine the optimal moisture content at which a given material will become denser and achieve its maximum dry density. An essential task of material engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density (as a percentage of the "maximum" density measured in a standard laboratory test) and the water content.

The optimum water content is the water content that results in the greatest density in a specified compaction level. Compacting at water contents higher than (wet of) the optimum water content results in a relatively dispersed soil structure (parallel particle orientations) that is weaker, more ductile, less previous, softer, more susceptible to shrinking and less susceptible to swelling than soil compacted dry of optimum to the same density. The soil/material compacted lower than (dry off) the optimum water content typically results in a flocculated soil structure (random particle orientations) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density.

Two methods are outlined namely; light and heavy compaction for fine and coarse-grained materials, respectively. Since the materials were tested to be used as base course materials, heavy compaction method is appropriate. In this study, the compaction test was performed through both standard and modified proctor compaction testing procedure stated in AACRA test number S-35 and AASHTO T-99 for standard compaction (2.5kg Rammer and 305mm drop height) and AACRA test number S-11 and AASHTO T-180 for modified proctor compaction (4.54kg Rammer and 457mm drop height). The reason for using both of standard and modified proctor compaction tests is to evaluate the effect of variable compaction outcome on each variable RAP and RAP-VA blend materials. All the materials were air-dried before the tests. Appendix B shows laboratory results of proctor compaction tests in detail.

3.5.3 California Bearing Ratio (CBR) test

CBR is an index that is used to evaluate the potential strength/stiffness of subgrade, subbase, and base course materials, as well as recycled materials. It is a measure of the resistance of a material to penetration of a plunger under controlled density and moisture conditions. The results obtained from these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used methods for the design of flexible pavement. The CBR value for a soil depends upon its density, molding moisture content and moisture content after soaking. The CBR test is a long established, very extensively applied test yielding an empirical measure of the quality of granular road materials. The CBR-test was developed initially for the evaluation of the laboratory and in-situ subgrade strength. Presently, the laboratory CBR-test is used globally as a quick means of characterizing qualitatively the bearing capacity of soils and unbound base and subbase materials.

A standard piston is used to penetrate the soil at a standard rate. The pressure up to a penetration of 10mm and its ratio to the bearing value of a standard crushed rock is termed as the CBR. The principle is to determine the relationship between force and penetration when a cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. It pushed with a constant 1.25 mm/min displacement rate in a sample contained in a steel cylinder with a diameter of 152.4 mm. Although vast experience is built up with this specific test, it is actually at best a strength test which gives some information on the shear resistance of the material about its degree of compaction and moisture content. The CBR value is determined by the force needed to penetrate the plunger 2.54 mm, and 5.08 mm into the three specimens of each material in 10, 30 and 65 blow compaction using the procedures in AASHTO T193. The method uses material passing 19 mm size and provides the CBR value of material at optimum water content. The specimen shall be soaked before penetration. A surcharge is placed on the surface to represent the mass of pavement material above base course. The sample is soaked to simulate its weakest condition in the field. Expansion of the sample is measured during soaking to check for potential swelling. To determine the strength and swelling potential of the samples, the test was carried out after 96 hours soaking.

In this study, three point CBR was used using pre-examined moisture density relationship. All specimens were compacted into 5 layers of 10, 30 and 65 blows in three different molds for each materials in accordance to the AACRA test number S-12 and AASHTO T193 (i.e. Standard

method of test for the CBR at optimum water content). Water to be added was calculated from compaction test results which is the OMC obtained at MDD and by considering the natural moisture content of the material on the test. The results of the CBR tests for each blows and CBR density relationship for each material blends are summarized and presented in Appendix C. Figure 3-5 below shows sample procedures and tools in CBR test of this study.



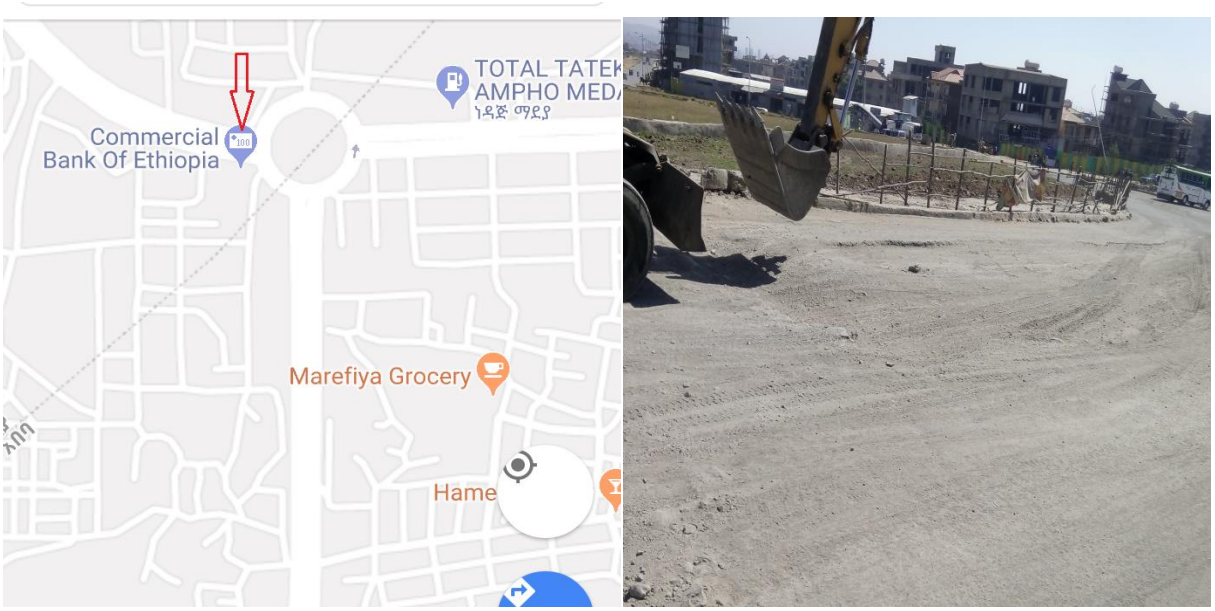
Figure 3-5: Sample procedures and tools in CBR test of this study

3.5.4 Field implementation and construction

To compare the field density test (FDT) of the base course material and laboratory compaction results and to examine some unexpected behaviour of RAP materials used as granular base course during and after construction, field implementation was done. This implementation was proposed to reduce limitations in necessary laboratory tests like modulus of resilient and other deformation tests besides common tests of granular materials. Even though no scientific measures and standards were used finally, because of factors explained under the Scope and Limitation part of Chapter One, this study was conducted to show the performance of pavement constructed for trial using RAP and blends on a major route in western Addis Ababa within ‘Kolfe Keranyo’ Subcity along the New Ambo Road, around ‘Yeshi Debele’ area and is depicted in Figure 3-6(a) below particularly indicated by the arrow.

From the five major trunk roads that connect the Capital Addis Ababa with other parts of Ethiopia, this road section serves high number of vehicle movements. Heavy trucks and trailers which

transport construction materials, containers and others use the road section frequently and repeatedly. The existed road is a six-lane two-way flexible asphalt concrete pavement with different structural failures that needs rehabilitation/maintenance (see Figure 3-6 (b) below).



(a) (b)

Figure 3-6: Road section location and the distress before maintenance

In these implementation activity materials of 100% RAP 2, 100% VA and 50% of RAP 2 and VA blends were used. Other procedures and results will be discussed in the next chapter.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

The previous chapters provided information on RAP usage experiences in different countries; advantages of recycling, RAP usage suitability in the Ethiopian context, pavement maintenance trend in Addis Ababa city, RAP usage recommendations in different transportation and road authorities' manuals, properties of RAP materials and recommended tests to evaluate the performance of RAPs. This chapter summarizes the results of all laboratory tests and materials (both virgin aggregates and blends with different RAP contents) using the methods recommended by AACRA standards as outlined in Chapter Three. The presentations of the test results are organized as follows:

- Gradation tests for RAP and virgin aggregate base course material as a control test;
- Moisture density relationship with different compaction effects;
- CBR test results of variable percentage RAP blends; and
- Onsite implementation of RAP with one year performance visual inspection results.

4.2 Gradation test results

Strength is highly dependable on gradation of materials that needs compaction to fill out voids. Therefore, the use of well-graded coarse-grained aggregates could significantly increase the strength. In special cases, the increase in strength is very crucial and materials with highest values of technical specifications must be used. Therefore, in circumstances where the road is under special utilization conditions, the aggregate base course and sub-base course need to have top technical specifications in regard to gradation. Because of this, the study conducted the test based on the standards and specifications described under methodology and experiments. The samples were taken from three different locations and gradations. The samples were separated in the laboratory using mechanical sample splitter and the sieves were arranged according to AACRA standards from the lowest pan and increased to the highest as follows: 0.075mm, 0.425mm, 2mm, 4.75mm, 9.5mm, 19mm, 25mm and 37.5mm.

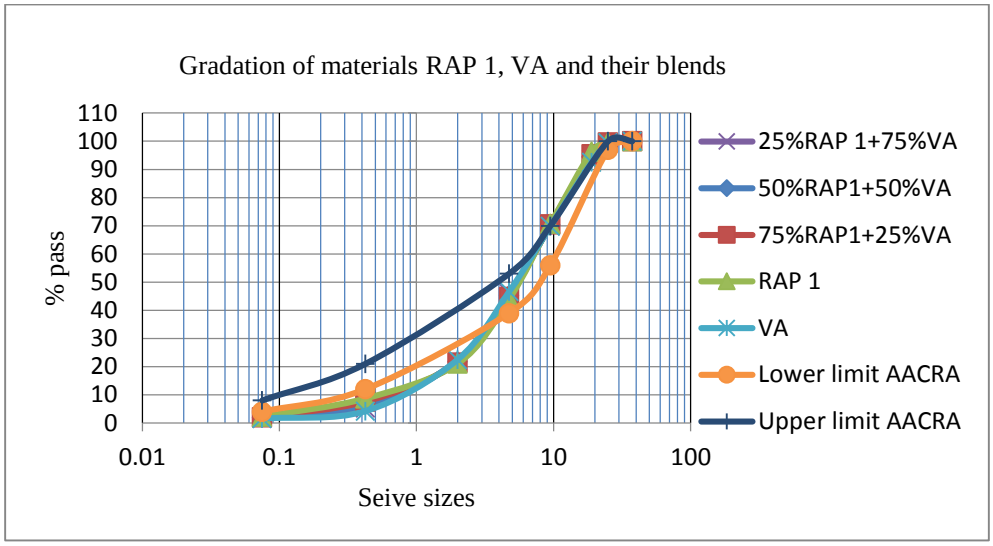
The laboratory test was then conducted based on the procedures of AASHTO T27 and finally the sieve result of three representative materials RAP 1, RAP 2, VA and their blend in different percentage were summerised as depicted in Table 4-1 below. Sieve analysis laboratory data and estimations are attached in Appendix A.

Table 4-1: Gradation Summery of Materials RAP 1, RAP 2, VA and their blends

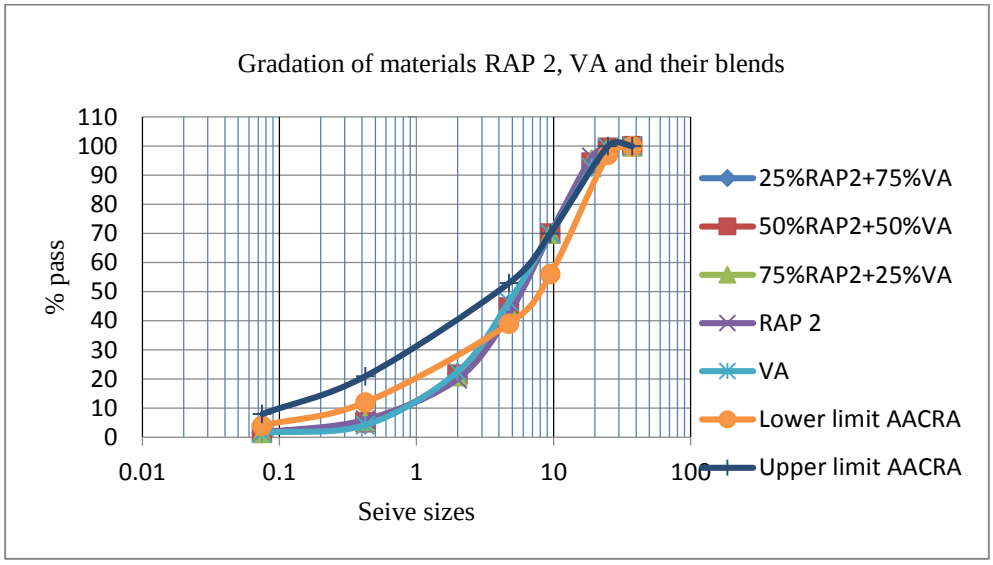
Sieve (mm)	**RAP1**	**RAP2**	**VA**	**25%RAP1 + 75%VA**	**50%RAP1 + 50%VA**	**75%RAP1 + 25%VA**	**25%RAP2 + 75%VA**	**50%RAP2 + 50%VA**	**75%RAP2 + 25%VA**
37.5	100	100	100	100	100	100	100	100	100
25	99.63	99.49	99.48	99.52	99.55	99.59	99.48	99.48	99.49
19	96.36	96.3	92.59	93.53	94.47	95.42	93.52	94.44	95.37
9.5	70.7	70.11	69.84	70.05	70.27	70.48	69.91	69.97	70.04
4.75	44.04	42.55	46.63	45.98	45.34	44.69	45.61	44.59	43.57
2	21.13	20.05	22.52	22.17	21.82	21.48	22.02	21.51	21
0.425	8.74	6	4.207	5.34	6.47	7.61	4.66	5.11	5.55
0.075	2.26	1.57	1.533	1.71	1.89	2.08	1.54	1.55	1.56

As we see from Table 4-1, the materials gradation looks well graded with similar distribution with each other. But, after 0.425mm sieve, the amount of materials got lower compared with the gradation requirement of AACRA. From those, three materials of RAP 1 have finer particles in some amount than RAP 2 and control test material of VA; this may be because of the samples of RAP 1 were taken from asphalt wastes with thick and multi layered asphalt concrete surface. For each material, three tests were conducted in order to keep data accuracy and the average of them was taken as a material representative gradation. The gradation of each blends in different percentage of those three materials were show no significant change on particles distribution. This is because of the similarity in particles size distribution of the materials RAP 1, RAP 2 and VA. However, the presence of high percentage of RAP 1 materials blended with VA shows some

changes particle size distribution RAP 1 + VA blends in different percentage, this improves the gradation of virgin aggregates by providing additional finer particles in blended mix. The results are illustrated in Figures 4-1(a) and 4-1(b) below in logarithmic gradation curves. Figure 4-1(a) shows gradation of RAP 1 materials and blends in different percentage with virgin aggregate used as a control test on logarithmic curves; Figure 4-1(b) shows the gradation logarithmic curve of RAP 2 materials and blends with VA. Both curves shows this results with AACRA base course gradation requirement boundaries.



(a)



(b)

Figure 4-1: Particle size gradation of materials RAP 1, RAP 2, VA and their blends

To clearly layout and compare the particle size distribution of those materials, their results were plotted on a common logarithmic chart as shown in Figure 4-2 below. However, except the increments in fine particles of RAP 1 after sieve size of 2mm, the particle gradation of all the three materials of RAP 1, RAP 2 and VA were almost similar and well graded.

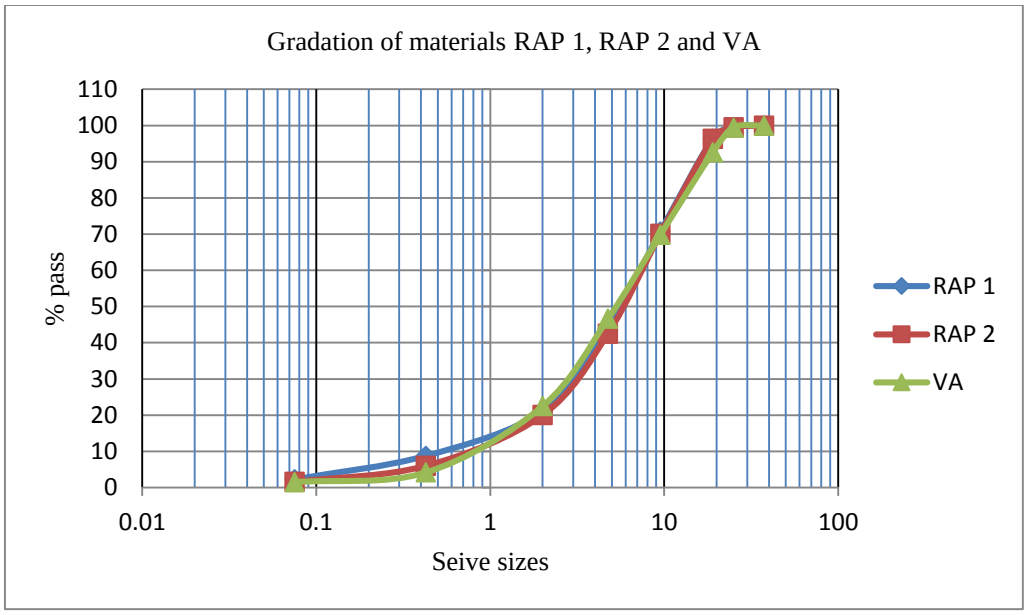


Figure 4-2: Particle size gradation of materials RAP 1, RAP 2 and VA

Tables 4-2 and Figure 4-3 below present the particle size distribution requirement of unbound crushed base course material as recommended by AACRA standards-2004.

Table 4-2: Gradation requirement of granular base course recommended by AACRA

Sieve Size (mm)	Alternate Grading (% passing)		
	A Crushed	B Crushed	C Uncrushed
50	100		100
37.5	97-100	100	85-100
25		97-100	
19	67-81		60-90
9.5		56-70	
4.75	33-47	39-53	30-65
2.0			20-50
0.425	10-19	12-21	10-30
0.075	4-8	4-8	5-15

Source: AACRA (2004); Standards for Road and Bridge designs, section 300 page 302-3

To evaluate whether or not the study materials gradation were found in the range between the above requirements are clearly indicated in the Figure 4-3 below.

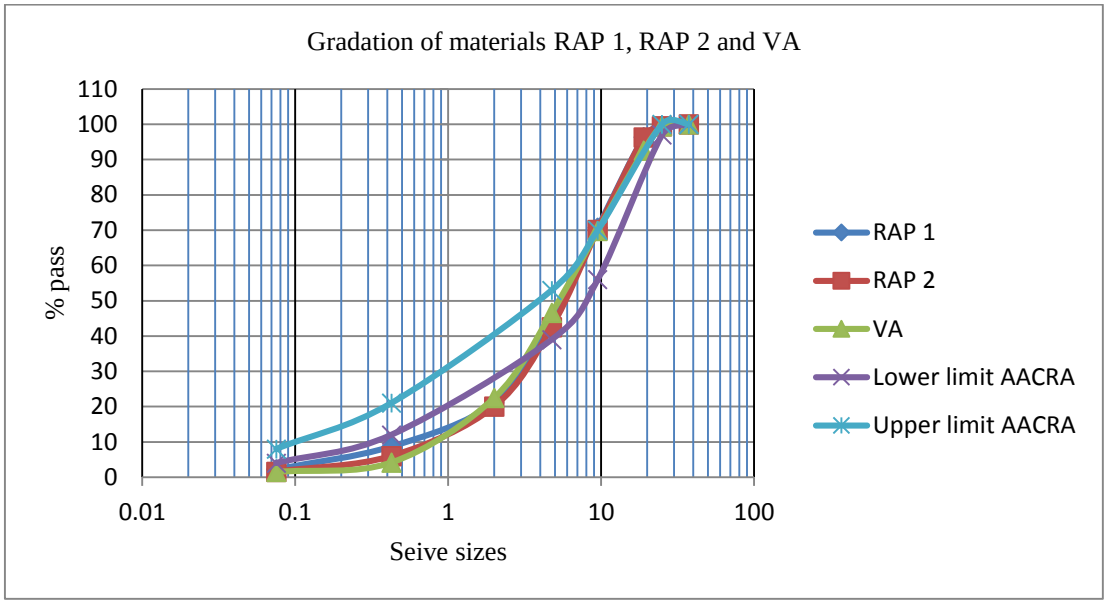


Figure 4-3: Granular materials gradation requirement range in logarithmic chart

Table 4-2 above shows the AACRA standards of base course material gradation for different nominal maximum aggregate sizes categorized as A, B and C in each column. In this study, all test samples passed sieve 37.5mm (1$_{1/2}$ in) and the maximum sized aggregate is retained on 25mm sieve with a little percentage of the whole sampled quantity. Because of this, the material is classified under gradation category 'B' above in Table 4-2, but the sieve analysis results of RAP 1, RAP 2 and VA materials show that the fine grained filler materials which should pass on sieve sizes 0.45mm (No.40) and 0.075mm (No.200) were insufficient to satisfy the required gradation requirement. Figure 4-3 above shows that the logarithmic gradation curve of tested materials and AACRA's requirement ranges, that the materials percentage passing should be placed between the upper and lower limit. The chart shows that, after sieve size of 1mm the materials percentage pass is reduced and the curve of all the three materials: RAP 1, RAP 2 and VA are going out of the requirement boundary. This shows that there is a particle size distribution gap of fine grained materials, this have an effect on compaction and expected laboratory and field density of the materials.

From those results, we can say that gradation of material RAP 1 and RAP 2 is better than the virgin aggregate gradation, currently used by AACRA as a base course material. Likewise, the presence

of those RAP materials in road construction as a base course layer will be important in improving materials performance with respect to gradation and compaction by blending with virgin materials in addition to getting an alternative base course material.

4.3 Standard and modified proctor measurement results

The standard and modified maximum dry density Proctor tests are used to determine the optimum moisture content and maximum compacted dry density for each material. The difference between the two methods lies in the number of layers in which the material is compacted (three layers for the standard Proctor and five layers for the modified Proctor), the drop height for the Proctor hammer (305 mm for the standard test and 457 mm for the modified test) and the weight of the hammer (2.5 kg for the standard test and 4.5 kg for the modified test). All these factors typically contribute to lower optimum moisture contents and higher compacted densities under the modified Proctor test relative to the standard Proctor results, the standard maximum dry density Proctor test is typically conducted on materials which have higher plasticity and for different functional roads pavement materials whereas modified maximum dry density Proctor tests are typically conducted to determine moisture density relationship of coarser materials and for pavements of major roads, major airports and port facilities.

The modified Proctor test was included in this test in order to further characterize the test mixes and their responses to greater compacted effort. The standard Proctor test was conducted in accordance with the AACRA test number S-35 or AASHTO T99 Method-A for Moisture-Density Relationship of Soils Using 2.5 kg Rammer and 305 mm Drop, and the modified Proctor test was conducted in accordance with AACRA test number S-11 or AASHTO T180 Method-D for Moisture-Density Relationship of Soils Using 4.5 kg Rammer and 457 mm Drop. For the purposes of these tests, manual Proctor hammer apparatus was used to aid in ensuring consistent compaction of the test materials at 25 and 56 blows per layer under both the standard and modified conditions respectively.

Tests and samples from both RAP 1 and RAP 2 materials were mixed with virgin aggregate in different percentages as shown in Table 4-3 below in respect of 100%, 75% 50%, 25% and vice versa for each RAP materials were used to determine the optimum water contents and maximum dry densities. Since the gradation of RAP 1 and RAP 2 materials are the same the study considered their densities mainly affected and varied by compaction. Because of this, standard proctor

compaction was done for RAP 1 material to compare the effected compaction on density and moisture content. Both RAP 1 and RAP 2 materials were used for modified proctor test. The standard and modified Proctor test results for each test mix are summarized in Table 4-3 below.

The laboratory test results reflect the general expectation that greater compaction efforts seen in the modified Proctor test yield lower optimum moisture contents and higher compacted dry densities relative to the standard Proctor test. It can also be noted from Table 4-3 that laboratory optimum moisture content and dry density results vary significantly between RAP1, RAP2 and VA, this is to be anticipated as the physical characteristics of the materials, the individual test blend gradations, the RAP processing mechanism and existed/recycled asphalt layer condition.

Table 4-3: Moisture-density relationship using standard and modified proctor test

Materials	Standard Optimum Moisture Content	Standard Maximum Dry Density	Modified Optimum Moisture Content	Modified Maximum Dry Density
	(%)	g/cm^3	(%)	g/cm^3
100% VA	10	1.88	9.0	2.11
75% VA and 25% RAP 1			8.2	2.18
50% VA and 50% RAP 1	10.5	1.74	7.6	2.09
25% VA and 75% RAP 1			7.8	2.07
100% RAP 1	10	1.72	7.4	2.02
75% VA and 25% RAP 2			8	2.14
50% VA and 50% RAP 2			6.5	2.15
25% VA and 75% RAP 2			7.5	2.07
100% RAP 2			7.2	2.03

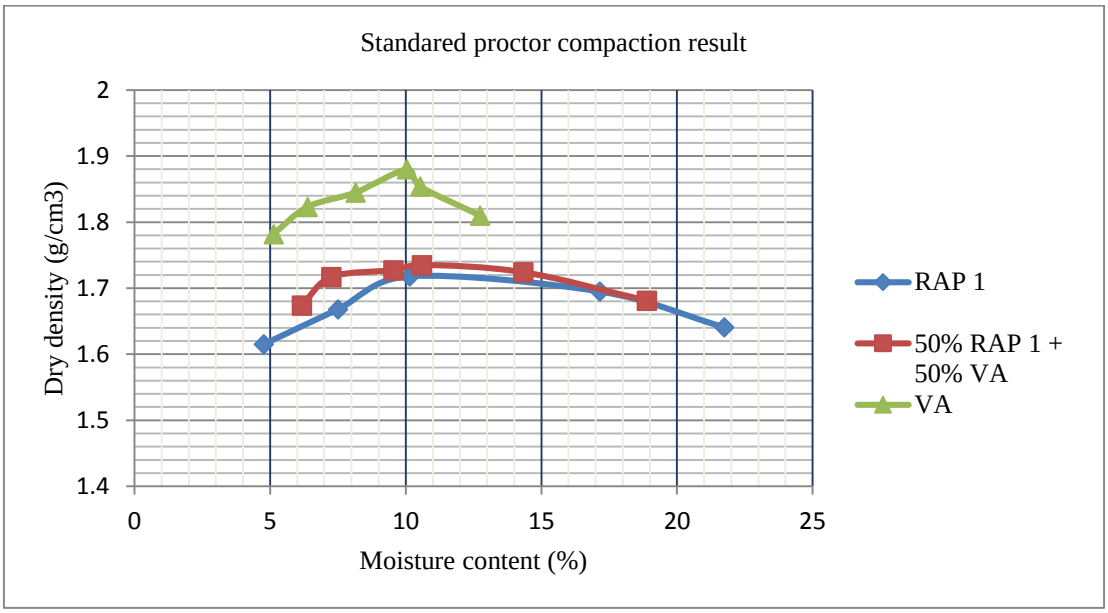
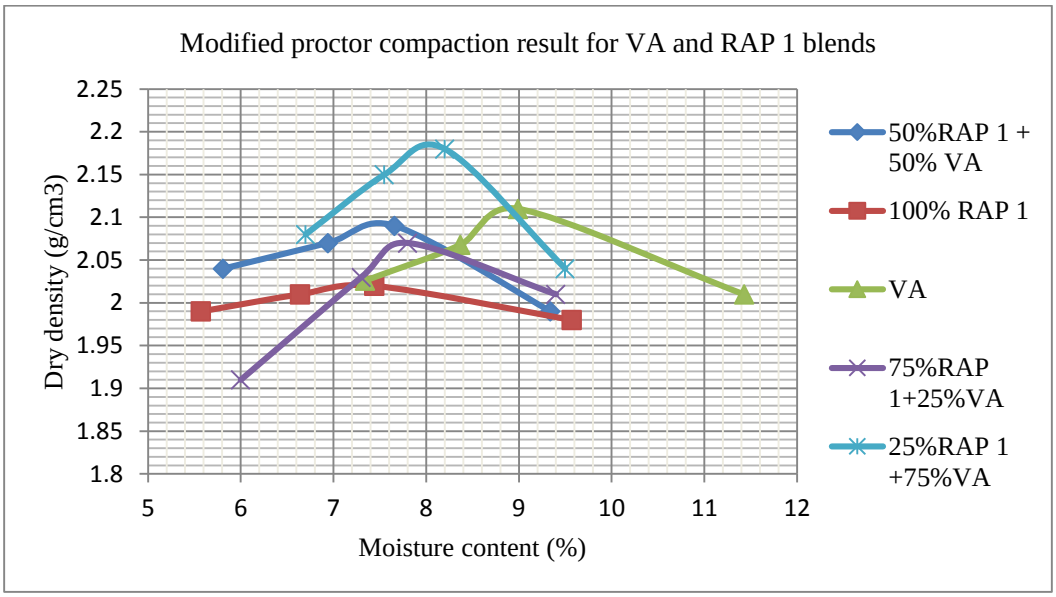
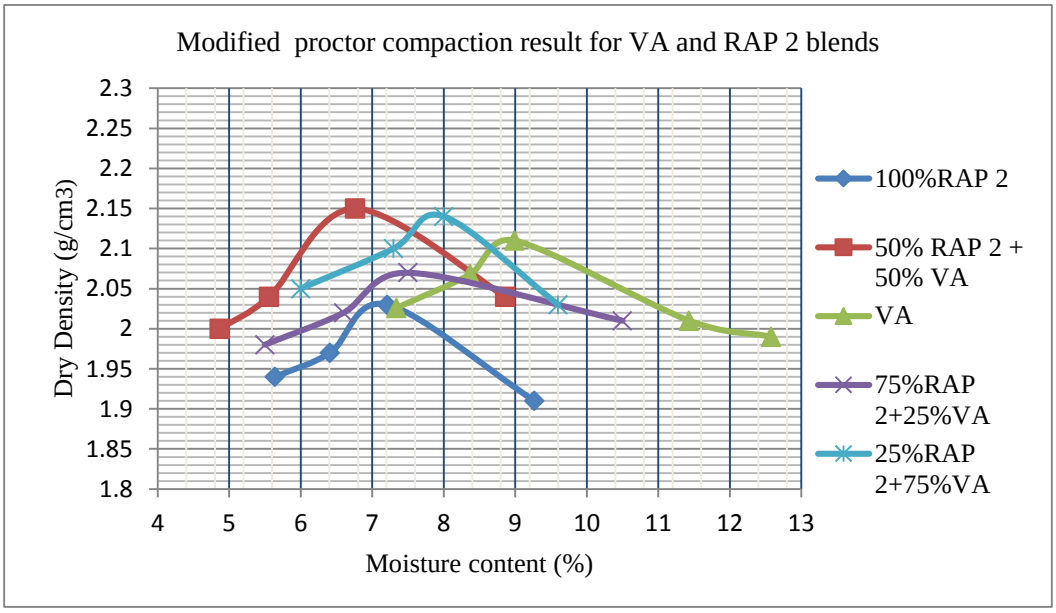


Figure 4-4: Moisture-Density relationship using standard proctor test

The standard proctor compaction result showed that the dry density of VA material is greater than RAP and the RAP blend materials. However, the optimum moisture content at which all materials achieve the dry density is nearly the same. This shows that moisture requirement of RAP material to use as a base course would be similar with little variable effect. Figure 4-5 below, modified proctor result, shows that Dry density of materials increased with slight decrement in optimum moisture content. A material of both RAP 1 and RAP 2 mixes with high content of virgin aggregates, VA such as blend of 75% VA and 50% VA developed high densities relative to other mixes. The change in density between standard and modified compaction results indicated that the number of compaction drops and number of compacted layers have an effect in achieving expected dry density. Figures 4-5 (a) and (b) illustrates the moisture-density relationships developed using modified proctor test.



(a)



(b)

Figure 4-5: Moisture-Density relationship using modified proctor test

Figure 4-4 and Figure 4-5 above summarized the dry density-water content curves obtained from both Standard and Modified Proctor compaction tests. For all materials, the maximum dry density increases and optimum water content decreases as the compaction effort is increased. Thus, it is clear that the change of compaction method can make significant difference in density, and consequently result in different material.

4.4 California Bearing Ratio test results

Three different specimens were prepared for each material blends and compacted in five layers with 10, 30 and 65 blows to each layer. The test machine used the load with penetration rate of 1.25 mm/min. The load readings at penetrations of 0.64, 1.27, 1.91, 2.54, 3.18, 3.81, 4.45, 5.08, 7.62, 10.16 and 12.7 mm were recorded and the results of stress versus penetration depth were plotted to determine the CBR for each materials blend on variable dry density and compaction conditions. Table 4-4 below shows the results of experiments conducted to determine the CBR of each materials blend.

Table 4-4: Results of CBR test for VA and RAP blends

Sample Designations	Compaction test			CBR test results			CBR @ 98% of MDD/@
	OMC (%)	MDD (g/cm^3)	98% MDD	# of blow	DD (g/cm^3)	CBR %	
VA	9	2.11	2.07	10	1.89	39.3	85
				30	2.02	62.1	
				65	2.09	96	
75% VA & 25% RAP 1	8.2	2.18	2.14	10	1.87	53.4	97.5
				30	2.04	65.8	
				65	2.18	112	
50% VA & 50% RAP 1	7.6	2.09	2.05	10	1.8	32	80
				30	2	67.2	
				65	2.10	95	
25% VA & 75% RAP 1	7.8	2.07	2.03	10	1.82	29.5	68.5
				30	2.02	65	
				65	2.06	91.5	
100% RAP 1	7.4	2.02	1.98	10	1.75	31.5	70
				30	1.91	48	
				65	2.02	83.3	
75% VA & 25% RAP 2	8	2.14	2.10	10	1.86	35	94.5
				30	2.05	68.5	
				65	2.12	109.4	
50% VA & 50% RAP 2	6.5	2.15	2.12	10	2.02	41.3	89.5
				30	2.07	55.7	
				65	2.13	97.3	
25% VA & 75% RAP 2	7.5	2.07	2.03	10	1.83	27.8	64
				30	2.01	57.1	
				65	2.08	83.8	
100% RAP 2	7.2	2.03	1.99	10	1.78	23.4	54.5
				30	1.98	50.1	
				65	2.04	82.7	

The data summerised in Table 4-4 shows Dry density results of materials of each blend increasing as compaction application increases. Except materials, 75% VA + 25% RAP 2, 25% VA + 75% RAP 1 and 50% VA + 50% RAP 2 blends the dry density of other materials increased at 65 blows of compaction than the maximum dry density determined by proctor compaction. The result show that CBR values of RAP were ranging from 54.5% to about 97.5%. From compaction laboratory test result, it can be observed that there is a big difference between 100% RAP material and virgin aggregates at the same compaction effort. More specifically, the maximum dry densities of compacted RAP was observed at 2.02 g/cm^3 with that of VA it was observed at 2.11 g/cm^3. These indicate that the RAP materials property is highly affected and improved by compaction applications. Since dry density and CBR values are directly proportional to the increments in dry density by applying more compactions effects will increase the CBR value of materials. Depending on the dry densities and CBR values, the DD-CBR relation graph was plotted and the governing CBR value was determined at 98% of MDD curve. Figure 4-6 below illustrates the CBR at 98% MDD from CBR-Dry density graph.

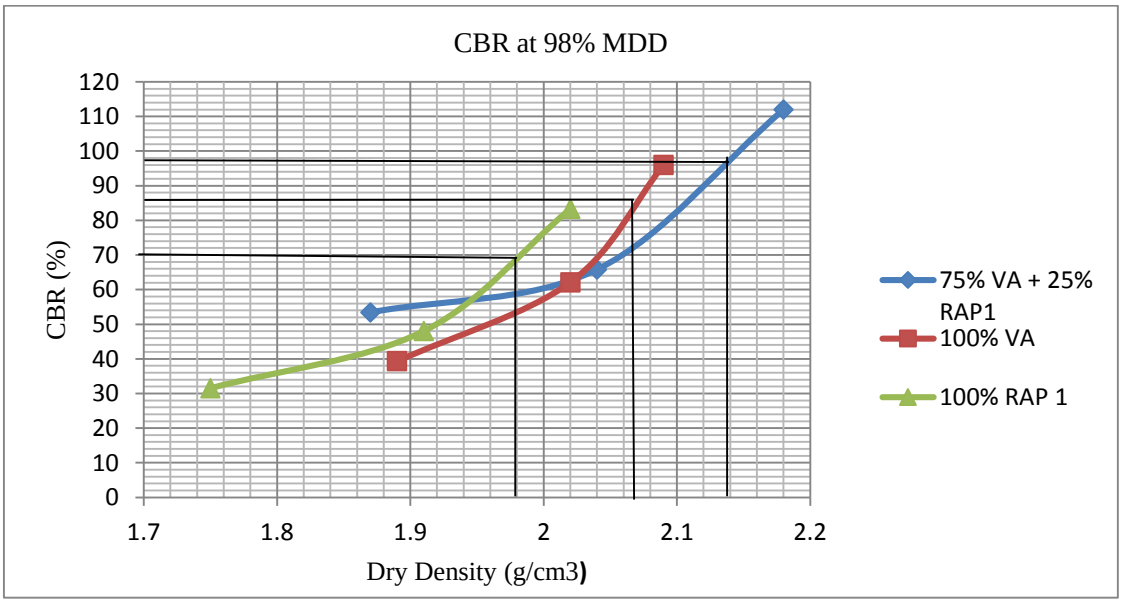


Figure 4-6: CBR at 98% MDD from CBR-Dry density graph

A sample density-CBR relation graph of three materials is shown in Figure 4-6 above. This relation was derived from the results of densities determined at 10, 30 and 65 blow compactions CBR values. For each compacted specimen, CBR values at load penetration of 2.54 and 5.08 were determined and dry densities were estimated at each specimen before soaking. Those results were

used to construct a relationship graph CBR versus dry densities. As shown above from three materials, the curve for 100% RAP 1 shows a lower value of CBR density relation. Unlikely, the materials with the higher contents of VA exhibited great CBR values relatively. Even though, the dry densities in each compaction samples are important in estimation of CBR value, 98% of maximum dry density which was taken from proctor test results is major determinants of CBR value of each material from the CBR versus density graph. Figure 4-7 below shows the CBR values of blended material with 75% VA and 25% RAP 1 which were taken from the chart. Recorded data and analysis results of CBR for all material blends are provided Appendix C.

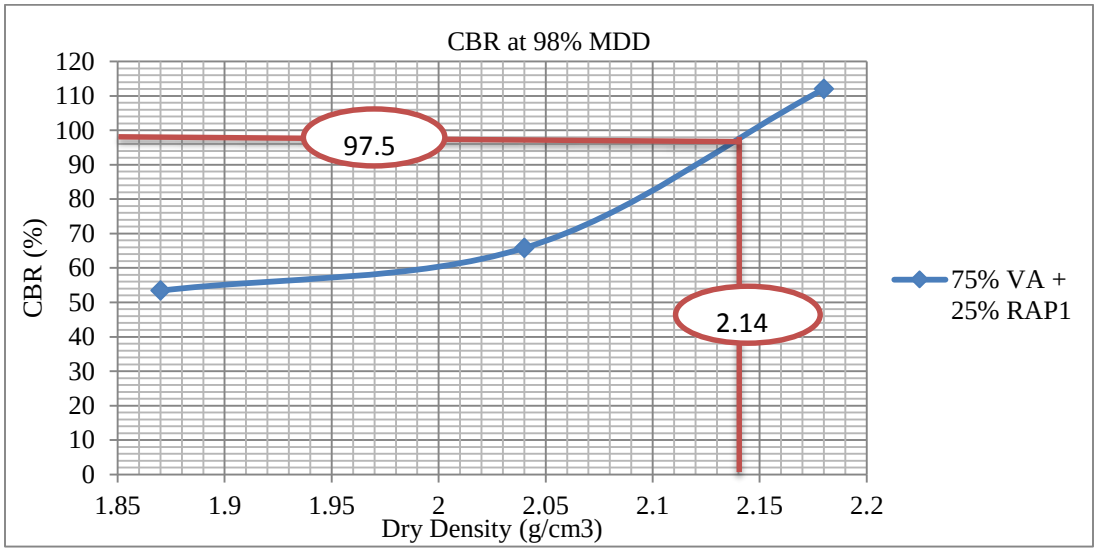


Figure 4-7: CBR value of 75% VA and 25% RAP 1 blend @98% of MDD

The CBR values seen are all relatively good, achieving above 80% for most of test blends. Furthermore, the blends with high content of virgin aggregate, VA achieved high bearing capacities which were similar and above the control mix. This indicate that the introduction of RAP with a fixed amount improve the performance of the base course material. However, one key observation is the lower CBR values achieved by neat RAP materials of 100% RAP 1 and 100% RAP 2 materials. The blends containing 75% RAP also showed lesser values of CBR which is below the required specifications of the AACRA base course material.

As summary of CBR tests in this study, it is known that higher RAP contents show lower CBR value; this is because of RAP particles characteristically tend to attract and hold moisture, which in turn causes RAP particles and fragments to come together to form larger conglomerates. At high RAP concentrations, this can result in segregation and heterogeneity in the mix, leading to

problems with constructability and the consequent development of inconsistent strength properties in the compacted granular material.

4.5 Field implementation observation and results

The trial implementation was done using the materials named as 'RAP 2' and processed by milling operation. The milling activity is conducted around a section 200m away from the rehabilitation project. The asphalt layer which was milled had two layers of binder and wearing courses with thicknesses of 5.5cm and 3.3cm respectively. The defect or distresses seen on the pavement layer were alligator crack and layers fragmentation.

Materials designations in this field implementation of constructing a base course using RAP materials are shown below in Table 4-5 with the area covered by and thicknesses used.

Table 4-5: Material designations for field implementations

Materials	Area covered (m^2)	Thickness used (m)
100% RAP 2	90	0.2
100% VA	163	0.2
50% VA+50% RAP 2	117	0.2

All the materials in the above designations were placed, mixed and distributed using an equipment, Grader [see Figure 4-8(a)] and compacted using 14 ton single drum Roller by applying variable vibratory effects and repeated passes.

After placement of a base course layer on that day, prime coat (medium curing bitumen, MC-30) was applied [see Figure 4-8(b)]. After three days of prime coat applications, the Asphalt Maintenance Team of AACRA placed asphalt concrete binder coarse layer by correcting the recent MC-30 coat with a rough distribution of RC-70 (rapid curing bitumen). Since the road sections were opened for traffic (not recommended) on the last days after RAP base construction, the base course layers using 100% VA shows some segregations and disturbance in compacted layers. This was seen also on 50% RAP 2 and 50% VA mix layers to a little extent. But the base course layer which was constructed by 100% RAP 2 materials showed a very strong surface not susceptible to segregations, and even it developed a strong bond between aggregate particles using aged bitumen and prime coat applications by the effect of temperature [see Figure 4-9(a)]. Figure 4-8 below shows the RAP base course placemen and prime coating.



(a) (b)

Figure 4-8: RAP base course placement and prime coating

On November 2018, the asphalt layer binder course was placed with 8cm thickness before compaction and it has been serving to-date without additional construction of wearing coarse layer. Currently in September 2019, the condition of the road visually is excellent; doesn't show any of distresses that may be expected in early period of service life such as; rutting, deformations, bleeding and others [see Figure 4.9(b)]. More current and recent pictures of the pavement condition were shown in Appendix D.



(a) (b)

Figure 4-9: During maintenance and current condition of pavement constructed by RAP 2

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Even though, the study dealt with limited laboratory tests, its intention is to help extend the use of RAP which is cheap and environment friendly material, particularly for application in unbound granular base layers. The study gained advanced understanding of physical and mechanical behaviour of granular materials (i.e. virgin aggregates, RAPs and various aggregate-RAP blends) under different laboratory tests. Based on the results of the conducted tests, the following conclusions were drawn.

- The result from sieve analysis shows that there is a particle size distribution gap of fine grained materials; this has an effect on compaction and expected laboratory and field density of the materials. Besides, gradation of material RAP 1 and RAP 2 was better than the virgin aggregate gradation, currently used by AACRA as a base course material. Likewise, the presence of those RAP materials in road construction as a base course layer will be important in improving materials performance with respect to gradation and compaction by blending with virgin materials, in addition to getting an alternative base course material.
- Dry density of materials was increased with slight decrement in optimum moisture content. Materials of both RAP 1 and RAP 2 mixed with high content of virgin aggregates, VA such as blend of 75% VA and 50% VA developed a high density relatively with other mixes. The change in density between standard and modified compaction results indicate that the number of compaction drops and the number of compacted layers have an effect in achieving the expected dry density. For all materials, the maximum dry density increased and optimum water content decreased as the compaction effort increased. Thus, it is clear that the change of compaction method can make significant difference in density, and consequently result in different material especially on materials of higher RAP content.
- The CBR value results were relatively good, achieving above 80% for most of the test blends. Furthermore, the blends with high content of virgin aggregate, VA achieved high bearing capacities which were similar and above the control mix. This indicates that the

introduction of RAP with fixed amount improves the performance of the base course material. However, one key observation was the lower CBR values achieved by neat RAP materials of 100% RAP 1 and 100% RAP 2 materials. The blends containing 75% RAP also show lesser values of CBR which is below the required specifications of AACRA base course material.

- The trial implementation done by using the materials 100% VA shows some segregations and disturbance in compacted layers. The same thing happens at 50% RAP 2 and 50% VA mix layers in a little extent. But, the base course layer constructed by 100% RAP 2 develops a strong bond between aggregate particles. Then currently, the pavement structure of the trial section serving well and free from defects and distresses in one year service time after construction. This indicates that the effect of aged bitumen content in RAP materials didn't cause early pavement distresses.
- Based on the results from a complete CBR results the bearing resistance of materials which have a blend equal and lower than 50% of RAP content are sufficient enough to use as a granular base course material. But from the five types of blending percentages tested in this study; the better strength achieved in blend of 25% RAP and 75% virgin aggregates, so it is highly recommendable to use this amount in weight.

When the asphalt pavements are badly deteriorated, overlay may not be economical and reconstruction can be a feasible solution by removing these pavement surfaces. By processing, these removed surfaces into recycled asphalt pavement material, the amount of using freshly crushed aggregate will have reduced, which implies that the additional cost expended on virgin aggregate are reduced when the optimum amount of RAP is mixed with virgin aggregates. Disposed asphalt surfaces as base course material will help the Government to build more road networks by eliminating extra costs of hauling virgin aggregates from far distant places. Utilization of RAP materials was not familiar with road construction industries in Addis Ababa as well as in Ethiopia due to lack of knowledge on the technology. When mechanically blended with VA, RAP gives better properties to fill the scarcity of unbound materials and replace usage of pure aggregate in partial percent. The use of RAP in road base layer is technically viable. Therefore; AACRA should prepare a guideline to use RAP materials in order to save costs and protection of the environment.

5.2 Recommendations

Based on the outputs of the study, the following recommendations are forwarded for consideration by pertinent policy makers:

i. AACRA should develop a guideline and standards to recycle and use RAP materials as a constituent of pavement materials through conducting different repetitive and variable researches.
ii. Until the preparation of significant specification and Guideline for RAP usage, AACRA can produce and use RAP and aggregate-RAP blend materials in low volume road sections of the city by evaluating field densities during construction.
iii. If RAP is produced in huge quantity in milling operation, proper stockpiles locations should be made and isolated based on locations and milled pavement condition to stock separately.
iv. It is possible to RAP materials as a granular subbase material by considering the gradation requirement and permeability behaviour; hence the bearing capacity is sufficient enough for subbase structure.
v. The physical and mechanical behaviour of pure aggregate materials currently used by ACCRA is relatively lower than materials used in this standard and required specifications. Therefore, materials produced in quarries should be checked and tested periodically.

5.3 Proposed Future Research Works

It should be noted that the conclusions as summarized above are based on test results on limited number of variables and tests. The following research areas are commendable for future considerations:

- Resilient modulus and permanent deformation tests are critical and important tests to characterize such kind of materials to determine the formation of distresses in life time of the pavement. Future study need to explore those tests.
- Since the property of RAP is different in laboratory and in field due to the effect of temperature, future researches should conduct field density and related test effectively.

- Age of recycled asphalt, bitumen content, distress type on recycled asphalt, permeability tests and other variables influence the performance of RAP materials. Therefore, future study should explore the effects of those variables.
- Different researchers conduct a study on RAP usage by incorporating cement as a constituent of the material blend or mix. The results drawn from the test shows the materials perform well than pure aggregate-RAP blend. Since one of the aims of such kind of study is to find out best performing materials, future researches may try the effect of the presence of cement in the mix.
- This study reviews economical and environmental benefits of using RAP as a constituent of base course layer based on the current virgin aggregate production and asphalt waste excavated for maintenance and rehabilitation activity by AACRA. However, in future study it is better to include values of transportation costs, energy consumption costs, environmental effects related to natural resource consumption, pollution and other factors which is related to economical and environmental benefits to apply recycling.

REFERENCE

AACRA, (2004) Addis Ababa City Road Authority, Standard specification for Road and Bridge design works, soils and materials manual section 300, Addis Ababa

AACRA, (2018) Addis Ababa City Road Authority, Own force road maintenance directorate. Annual report of 2010 E.C prepared by office engineering team, Addis Ababa

AACRA, (2018/19) Addis Ababa City Road Authority, quarry selector and controlling team yearly performance report of material productions for 2010 and 2011 EC page 2-7, Addis Ababa

AACRA, (2019) Addis Ababa City Road Authority, Own force road maintenance directorate. Annual report of 2011 E.C prepared by office engineering team, Addis Ababa

AACRA, (2019) Addis Ababa City Road Authority, Own force road maintenance directorate. Half year work progress evaluation meeting presentation by Lot-1 project office engineering team, Addis Ababa

AASHTO, (2008) American Association of State Highway and Transportation Officials. Mechanistic-Empirical Pavement Design Guide: A Manual of Practice. Washington, DC, 2008.

AASHTO, (2010) American Association of State Highway and Transportation Officials. AASHTO T 180-10: Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in) Drop. Washington, DC.

AASHTO, (2010) American Association of State Highway and Transportation Officials. AASHTO T 99: Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5kg Rammer and 305mm drop height, Washington, DC

AASHTO, (2008) American Association of State Highway and Transportation Officials. AASHTO T 193-93: Standard Method Test for California bearing ratio, CBR. Washington, DC

Adam Schneider, Hassan Baaj v, Stephen Senior (2016) Testing and Evaluation of Reclaimed Materials as Aggregate for OPSS Granular B Type II, Paper prepared for presentation at the Green Technology in Geotechnical and Materials Engineering Session Canada, Ontario

Bennert, T., W. J. Papp, Jr. A. Maher, and N. Gucunski, (2000) "Utilization of Construction and Demolition Debris Under Traffic-Type Loading in Base and Subbase Applications", Transportation Research Record, n 1714, Nov, 2000, p 33-39

Bennert, T., and Maher, (2005) The development of performance specification for granular base and subbase material. Technical Report, FHWA-NJ-2005-003, p 55. New Jersey Department of Transportation, Federal Highway Administration, U.S. Department of Transportation, Washington DC

Chesner, W.H., Collins, R.J., and MacKay M.H., (1998) User Guidelines for Waste and Byproduct Materials in Pavement Construction.FHWA-RD-97-148. Washington, DC

Collins, R.J., and Ciesielski, S.K. (1994) Recycling and Use of Waste Materials and By-Products in Highway Construction. NCHRP Synthesis 199.Transportation Research Board of the National Academies, Washington, DC

Cong Luo, (2014) High Performance Granular Base and Subbase Materials Incorporating Reclaimed Asphalt Concrete Pavement, McMaster University

Cosentino, P. J., Kalajian E. H., Dikova, D., Patel, M., and C. Sandin, (2008) Investigating the statewide variability and long-term strength deformation characteristics of RAP and RAP–soil mixtures.Technical Report, FL/DOT/ RMC/06650-7754 BDB 809.Florida Department of Transportation, Tallahassee

Cosentino, P.J. (2013) Improving the Properties of Reclaimed Asphalt Pavement for Roadway Base Applications through Blending and Chemical Stabilization. Presented at the Annual Meeting of the Transportation Research Board, Washington

Dulal Chandra Sahaa, J. N. Mandal, (2017) Transportation Geotechnics and Geoecology, TGG 2017, Russia Laboratory investigations on Reclaimed Asphalt Pavement (RAP) for using it as base course of flexible pavement, Saint Petersburg

Edward J. Hoppe, Ph.D., P.E, D. Stephen Lane, G. Michael Fitch, Ph.D. and Sameer Shetty, (2015) Final report feasibility of reclaimed asphalt pavement (RAP) use as road base and subbase

material. Virginia Center for Transportation Innovation and Research (A partnership of the Virginia Department of Transportation and the University of Virginia, Virginia

ERA, (2013) Federal Democratic Republic of Ethiopia, Ethiopian roads authority, pavement design manual volume 1 flexible pavements, Appendix G- Recycled materials. Addis Ababa.

ERA, (2013) Federal Democratic Republic of Ethiopia, Ethiopian roads authority, pavement design manual volume 1 flexible pavements, section 6 unbound pavement materials, Addis Ababa

Garg, N., Thompson, M. R. (1996) "Lincoln Avenue reclaimed asphalt pavement base project" Transportation Research Record, n 1547, Nov, 1996, p 89-95

Mokwa, R.L., and Peebles, C.S, (2005) Evaluation of the Engineering Characteristics of RAP/Aggregate Blends. Montana State University, Bozeman

Saeed, A. (2007) Appendixes to NCHRP Report 598.NCHRP Web-Only Document 119. Transportation Research Board of the National Academies, Washington, DC

Saeed, A. (2008) Performance-Related Tests of Recycled Aggregates for Use in Unbound Pavement Layers. NCHRP Report 598. Transportation Research Board of the National Academies, Washington, DC

Saeed, A. and Hammons, M.I. (2008) Minimum Standards for Using Recycled Materials in Unbound Highway Pavement Layers in Airfield and Highway Pavements. American Society of Civil Engineering, Reston

Senior, S. A., Gorman, B., and Szoke, S. I. (2008) Recycling road building materials and experience with full depth reclamation in the Ontario provincial highway system. Proc.2008 Annual Conference of the Transportation Association of Canada, Toronto

Thøgersen, F., Gregoire, C., Stryk, J., Hornych, P., Descantes, Y., Chazallon, C., Blasi, A., Broere, P., Bizjak, K.F., Hellman, F., and Arm, M. (2013) Recycling of Road Materials in to new Unbound Road Layers – Main Practice In Selected European Countries. Road Materials and Pavement Design, Vol. 14, No. 2, pp. 438-444.

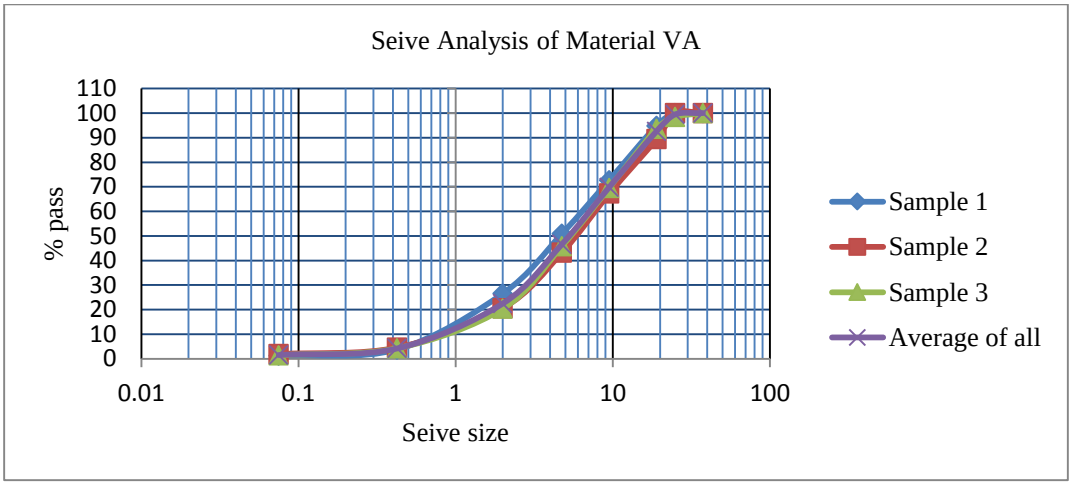
Tutumluer E, (2013) Practices for Unbound Aggregate Pavement Layers. NCHRP Synthesis 445.Transportation Research Board of the National Academies, Washington, DC

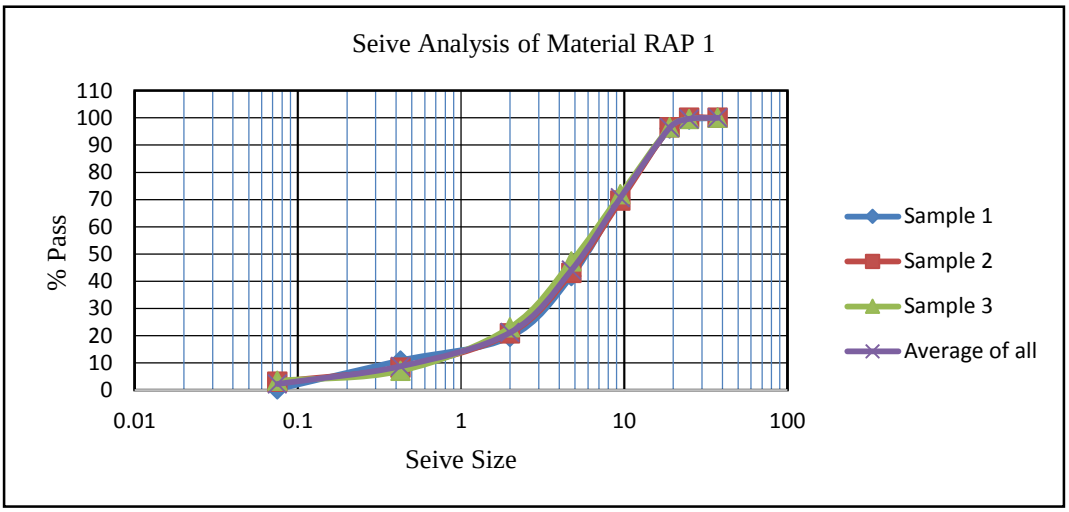
Wenbin He., (2006) Laboratory Evaluation of Unbound RAP as a Pavement Base Material, University of Tennessee, Knoxville

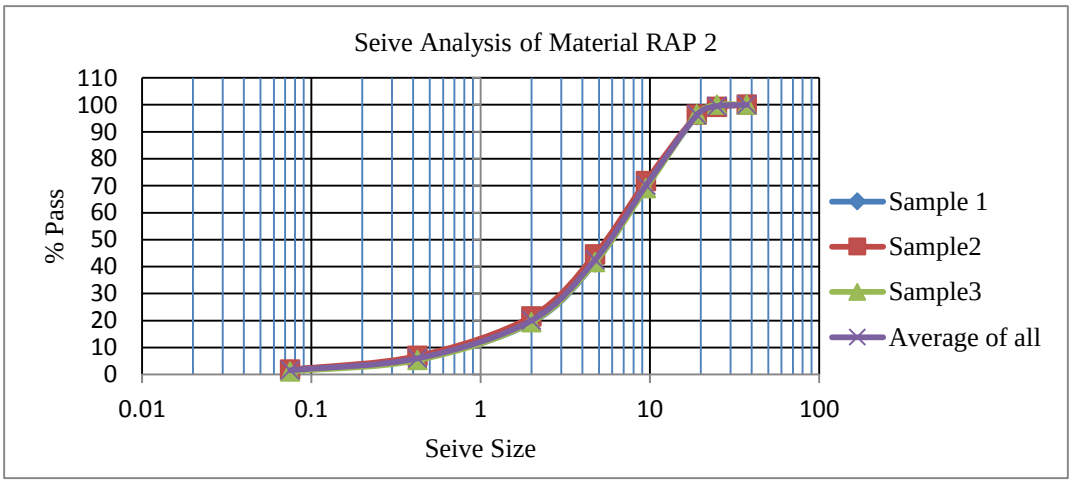
Wu, M. (2011) Evaluation of High Percentage Recycled Asphalt Pavement as Base Course Materials. M.S Thesis, Washington State University, Pullman

APPENDIX A

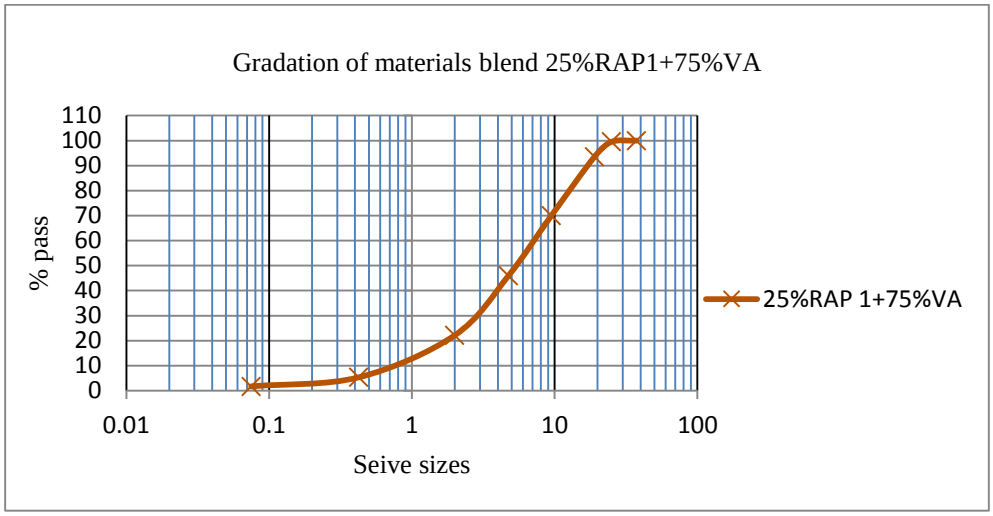
Sieve analysis laboratory results for materials VA, RAP 1 and RAP 2

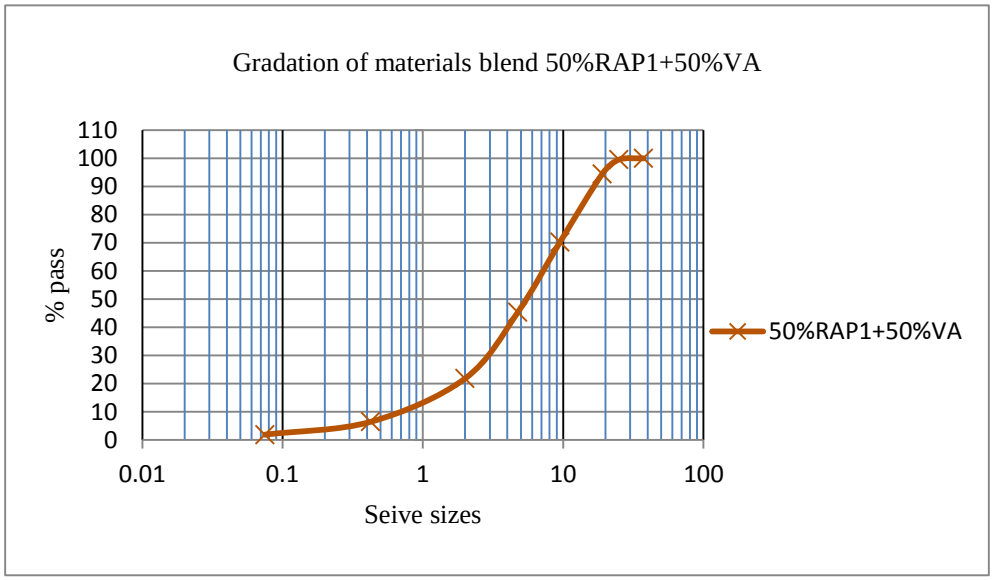


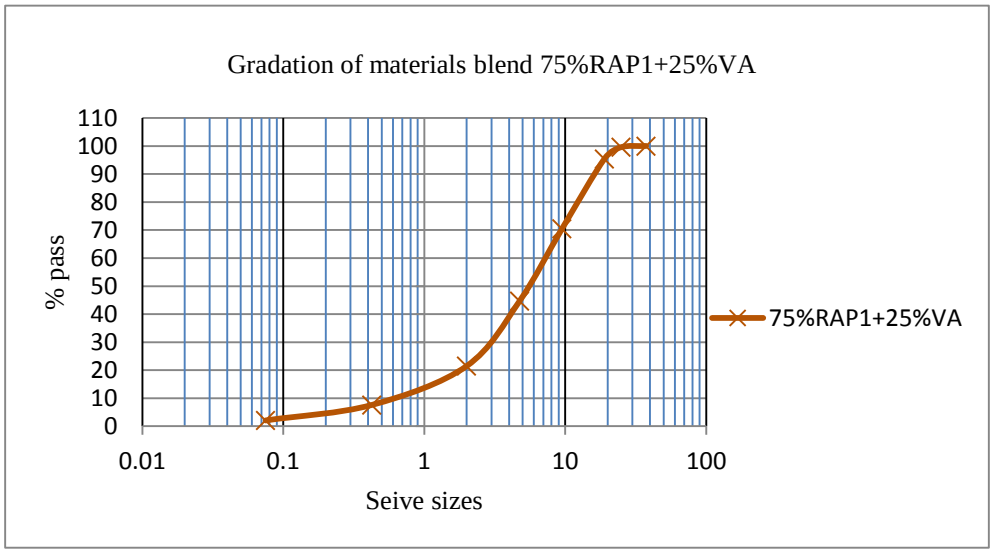


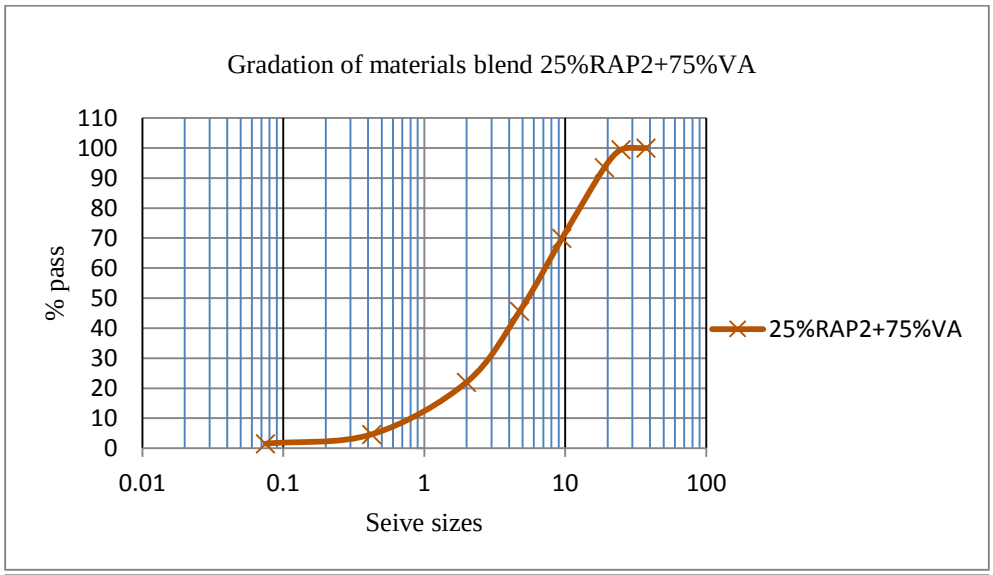


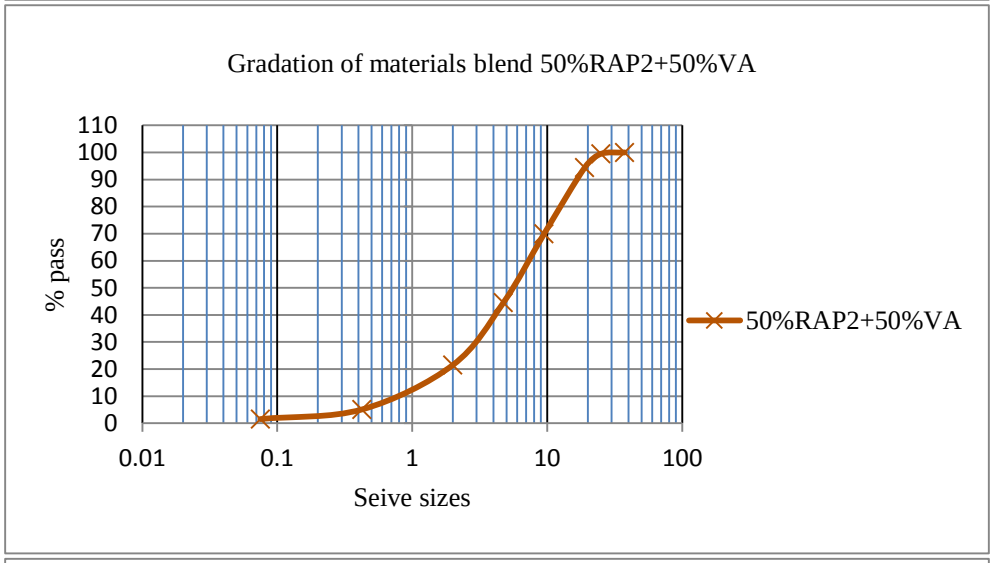
Gradation of blends in different percentage for RAP 1, RAP 2 and VA

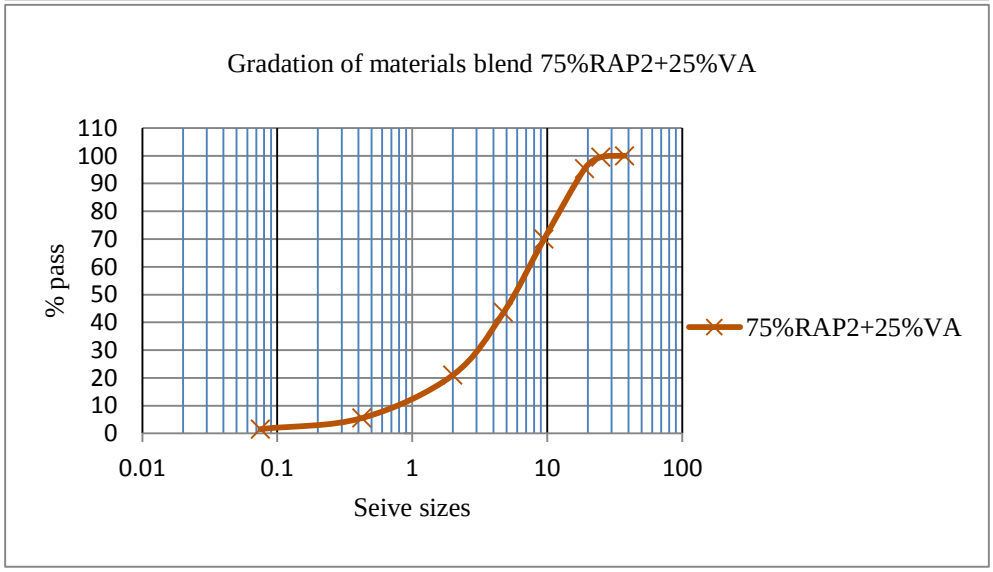







Gradation of materials blend 25%RAP2+75%VA
% pass
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Seive sizes
25%RAP2+75%VA


Gradation of materials blend 50%RAP2+50%VA
% pass
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Seive sizes
50%RAP2+50%VA


Gradation of materials blend 75%RAP2+25%VA
% pass
110
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Seive sizes
75%RAP2+25%VA

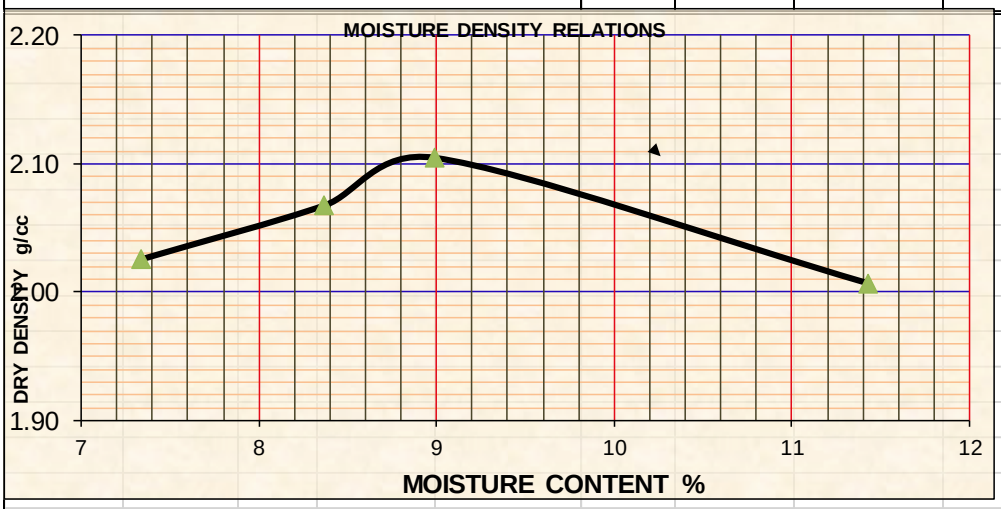
APPENDIX B

Laboratory results of maximum dry density and optimum moisture content using modified proctor compaction test.

MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D)

Representing Station		Source :	Bulbula
Sampled at:	Quarry	Lab job No.	
Sampling date :	4/11/2010	Visual Discription	Crushed Base Course
Testing date :	12/11/2010		
Contractor/Centeral	For Thesis purpose	Tested By:	
Material for :	VA/virgin aggregate basecourse	Cons. Representative	For Thesis Purpose

DENSITY	TRIAL NUMBER		**1**	**2**	**3**	**4**	**5**
	Sample weight	(g)	**9000**	**8390**	**7798**	**7196**	**6589**
	Natural moistur content	(%)	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**
	Add water required	(%)	**4.00**	**6.00**	**8.00**	**10.00**	**12.00**
	water added	(g)	**180.00**	**335.60**	**467.88**	**575.68**	**658.90**
	WEIGHT OF SOIL + MOLD	(g) W_1	12785.0	12935.0	13055.0	12925.0	12952.0
	WEIGHT OF MOLD	(g) W_2	7880	7880	7880	7880	7880
	VOLUME OF MOLD	(Cm^3) V	2256	2256	2256	2256	2256
	WEIGHT OF WET SOIL	(g) $W_3 = W_1-W_2$	4,905	5,055	5,175	5,045	5,072
	WET DENSITY OF SOIL	(g/Cm^3) $W_d = W_3/V$	2.174	2.241	2.294	2.236	2.248
MOISTURE	CONTAINER NUMBER		**1**	**5**	**8**	**10**	**9**
	WET SOIL + CONTAINER	(g) a	610.0	592.0	602.0	607.0	612.0
	DRY SOIL + CONTAINER	(g) b	575.0	554.0	561.0	555.0	555.0
	WEIGHT OF CONTAINER	(g) c	98.0	100.0	105.0	100.0	102.0
	WEIGHT OF WATER	(g) d = a-b	35.0	38.0	41.0	52.0	57.0
	WEIGHT OF DRY SOIL	(g) e =b-c	477.0	454.0	456.0	455.0	453.0
	MOISTURE CONTENT (d/e)*100	**(%) m=**	7.34	8.37	8.99	11.43	12.58
DRY DENSITY OF SOIL		**(g/Cm3) $D_d = W_d/(100+m)*100$**	2.026	2.068	2.105	2.007	1.997

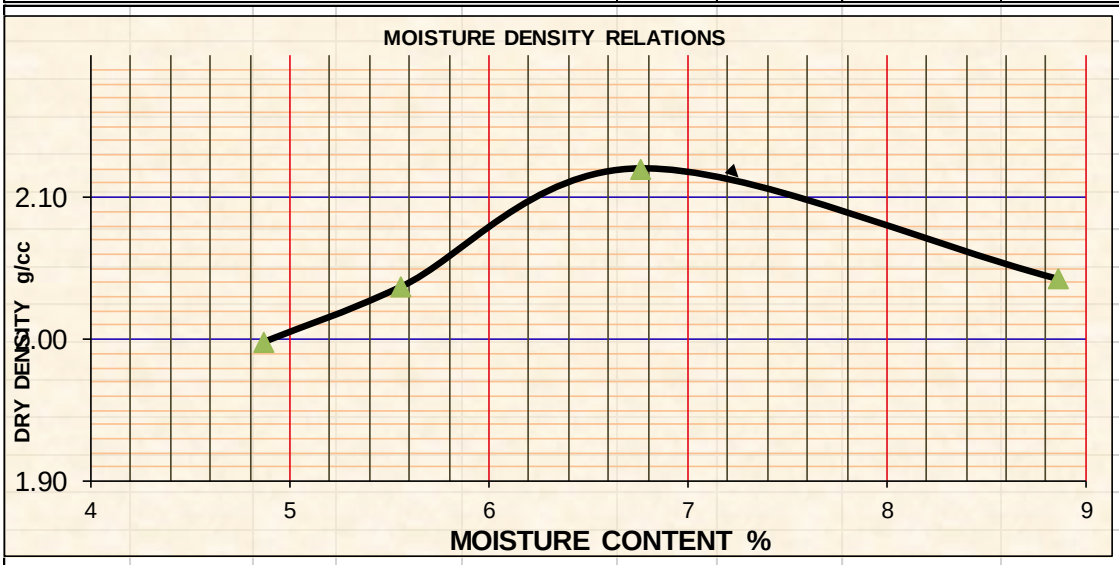


MDD :	**2.11**	**g/cm^3**
OMC :	**9.00**	**%**

MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D)

Representing Station		Source :	-
Sampled at:	Stoke	Lab job No.	
Sampling date :	12/5/2011	Visual Discription	Blended aggregates
Testing date :	16/05/2011		
Contractor/Centeral	For Thesis purpose	Tested By:	
Material :	50% RAP2 and 50% VA	Cons. Representative	For Thesis Purposes

DENSITY	TRIAL NUMBER	**1**	**2**	**3**	**4**	
	Sample weight (g)	9000	8548	8073	7615	
	Natural moistur content	2.00	2.00	2.00	2.00	
	Add water required	4.00	6.00	8.00	10.00	
	water added (g)	180.00	341.92	484.38	609.20	
	WEIGHT OF SOIL + MOLD (g) W_1	12613.0	12735.0	12991.0	12901.0	
	WEIGHT OF MOLD (g) W_2	7885	7885	7885	7885	
	VOLUME OF MOLD (Cm^3) V	2256	2256	2256	2256	
	WEIGHT OF WET SOIL (g) $W_3 = W_1-W_2$	4,728	4,850	5,106	5,016	
	WET DENSITY OF SOIL (g/Cm^3) $W_d = W_3/V$	2.096	2.150	2.263	2.223	
MOISTURE	CONTAINER NUMBER	**2**	**3**	**4**	**6**	
	WET SOIL + CONTAINER (g) a	552.0	575.0	560.0	530.0	
	DRY SOIL + CONTAINER (g) b	531.0	550.0	531.0	495.0	
	WEIGHT OF CONTAINER (g) c	100.0	100.0	102.0	100.0	
	WEIGHT OF WATER (g) d = a-b	21.0	25.0	29.0	35.0	
	WEIGHT OF DRY SOIL (g) e =b-c	431.0	450.0	429.0	395.0	
	MOISTURE CONTENT (%) m= (d/e)*100	4.87	5.56	6.76	8.86	
DRY DENSITY OF SOIL (g/Cm3) $D_d = W_d/(100+m)*100$		1.998	2.037	2.120	2.042	



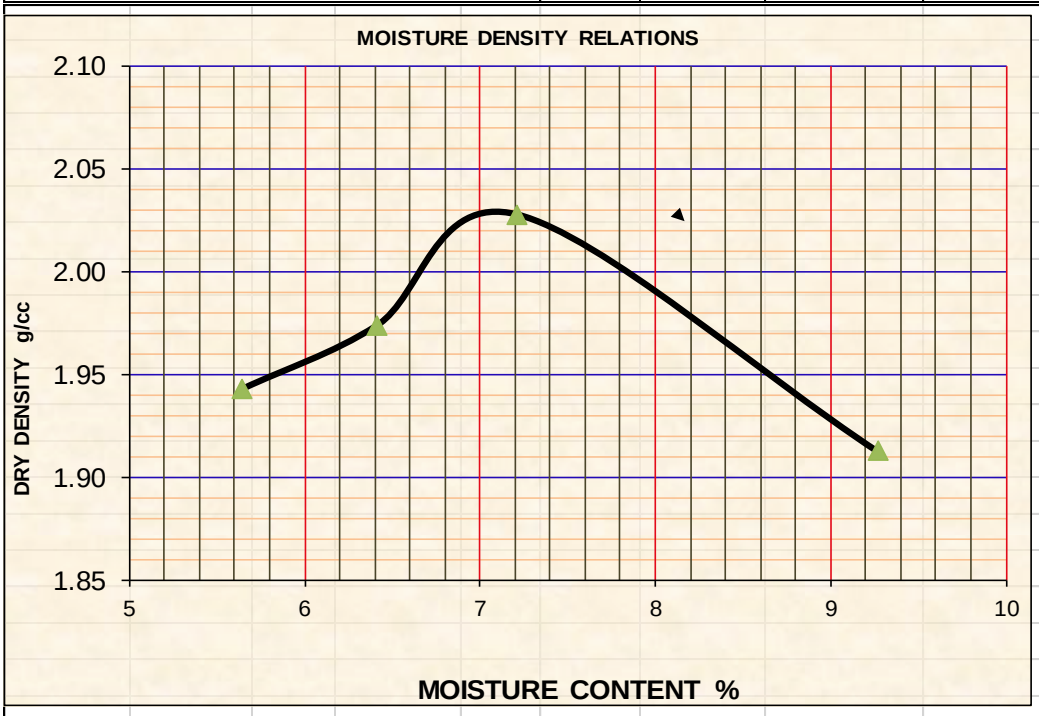
MDD :	**2.12**	**g/cm^3**
OMC :	**6.80**	**%**

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MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D)

Representing Station	Anfo- Zenebework RA	Source :	Anfo
Sampled at:	Temporary stock	Lab job No.	
Sampling date :	12/5/2011 EC	Visual Discription	Milled asphalt particl
Testing date :	15/05/2011 EC		
Contractor/Centeral	For Thesis Purpose	Tested By:	
Material :	RAP 2 100%	Cons. Representative	For Thesis purpose

DENSITY	TRIAL NUMBER			1	2	3	4	
	Sample weight	(g)		9000	8548	8073	7615	
	Natural moistur content	(%)		1.50	1.50	1.50	1.50	
	Add water required	(%)		3.50	5.50	7.50	9.50	
	water added	(g)		180.00	341.92	484.38	609.20	
	WEIGHT OF SOIL + MOLD	(g)	W_1	12501.0	12608.0	12774.0	12585	
	WEIGHT OF MOLD	(g)	W_2	7870	7870	7870	7870	
	VOLUME OF MOLD	(Cm^3)	V	2256	2256	2256	2256	
	WEIGHT OF WET SOIL	(g)	W_3 =	4,631	4,738	4,904	4,715	
	WET DENSITY OF SOIL	(g/Cm^3)	W_d	2.05	2.10	2.17	2.09	
MOISTURE	CONTAINER NUMBER			8	20	a	c	
	WET SOIL + CONTAINER	(g)	a	633.5	667.0	874.0	819	
	DRY SOIL + CONTAINER	(g)	b	605.0	633.0	822.0	758	
	WEIGHT OF CONTAINER	(g)	c	100.0	102.5	101.0	100	
	WEIGHT OF WATER	(g)	d =	28.5	34.0	52.0	61.0	
	WEIGHT OF DRY SOIL	(g)	e =b	505.0	530.5	721.0	658.0	
	MOISTURE CONTENT (d/e)*100	**(%)**	**m=**	5.64	6.41	7.21	9.27	5.6
DRY DENSITY OF SOIL $W_d/(100+m)*100$		**(g/Cm3)**	**D_d =**	1.94	1.97	2.03	1.91	1.94

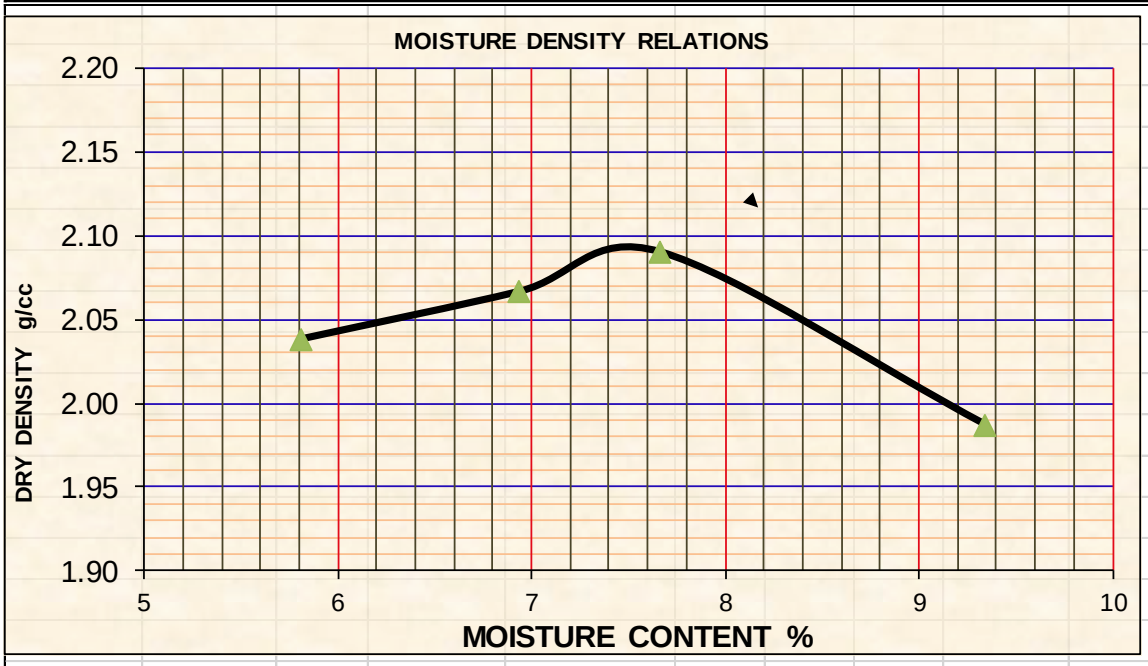


MDD :	**2.03**	**g/cm^3**
OMC :	**7.20**	**%**

MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D)

Representing Station		Source :	waste area and quarry
Sampled at:	Stoke	Lab job No.	
Sampling date :	04-06/11/2010 EC	Visual Discription	Blended aggregates
Testing date :	12/11/2010		
Contractor/Centeral	For Thesis Purpose	Tested By:	
Material for :	50% RAP 1 & 50 % VA	Cons.	For Thesis Purpose

DENSITY	TRIAL NUMBER		**1**	**2**	**3**	**4**	
	Sample weight (g)		9000	8465	7887	7282	
	Natural moistur content (%)		2.00	2.00	2.00	2.00	
	Add water required (%)		4.00	6.00	8.00	10.00	
	water added (g)		180.00	338.60	473.22	582.56	
	WEIGHT OF SOIL + MOLD (g)	W_1	12735.0	12855.0	12946.0	12771.0	
	WEIGHT OF MOLD (g)	W_2	7870	7870	7870	7870	
	VOLUME OF MOLD (Cm^3)	V	2256	2256	2256	2256	
	WEIGHT OF WET SOIL (g)	$W_3 = W_1-W_2$	4,865	4,985	5,076	4,901	
	WET DENSITY OF SOIL (g/Cm^3)	$W_d = W_3/V$	2.156	2.210	2.250	2.172	
MOISTURE	CONTAINER NUMBER		**9**	**2**	**6**	**3**	
	WET SOIL + CONTAINER (g)	a	535.0	578.0	625.0	615.0	
	DRY SOIL + CONTAINER (g)	b	511.0	547.0	588.0	571.0	
	WEIGHT OF CONTAINER (g)	c	98.0	100.0	105.0	100.0	
	WEIGHT OF WATER (g)	d = a-b	24.0	31.0	37.0	44.0	
	WEIGHT OF DRY SOIL (g)	e =b-c	413.0	447.0	483.0	471.0	
	MOISTURE CONTENT (%)	**m= (d/e)*100**	5.81	6.94	7.66	9.34	
DRY DENSITY OF SOIL	**(g/Cm3)**	**$D_d = W_d/(100+m)*100$**	2.038	2.066	2.090	1.987	

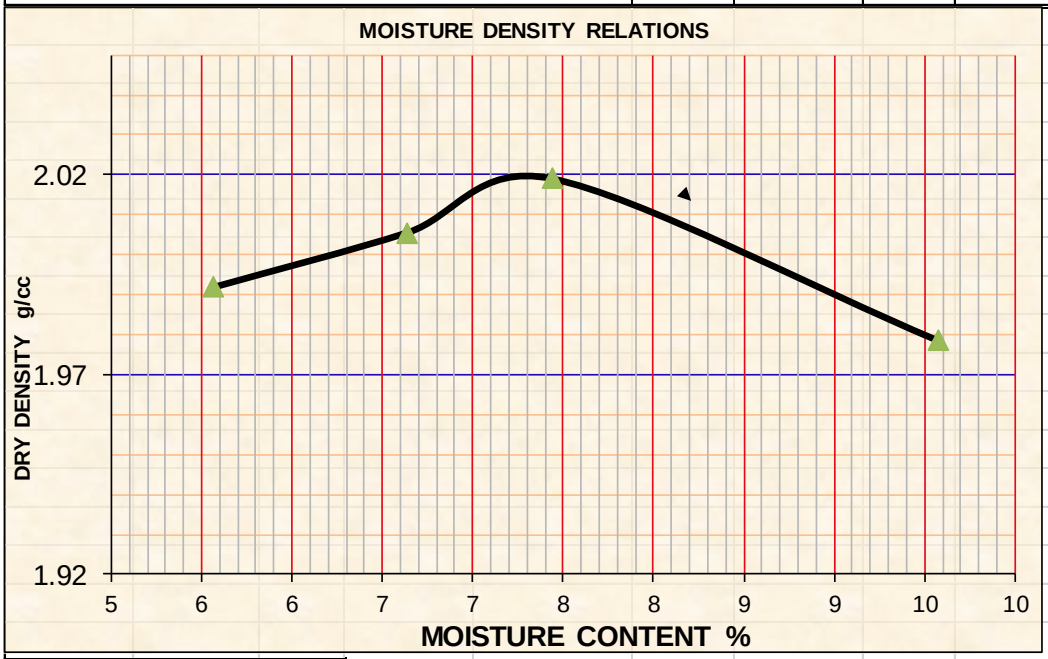


MDD :	**2.09**	**g/cm^3**
OMC :	**7.60**	**%**

MOISTURE DENSITY RELATIONSHIP OF SOIL (TEST METHOD: AASHTO T-180 METHOD D)

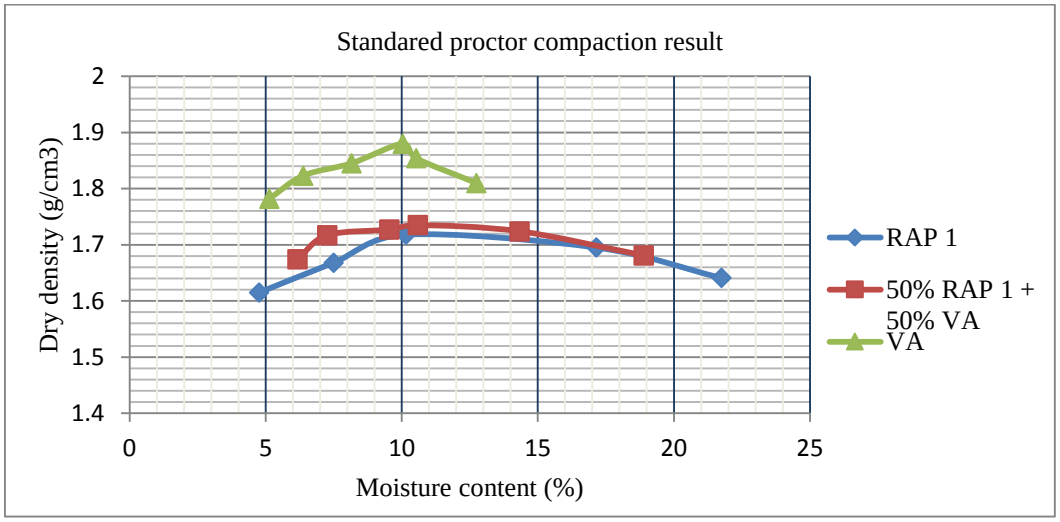
Representing Station :	Asphalt wastes in centeral AA	Source :	"Basha wolde"
Sampled at:	Waste area	Lab job No.	
Sampling date :	6/11/2010	Visual Discription	Crushed aged asphalt
Testing date :	11/11/2010		
Contractor/Centeral	For Thesis purpose	Tested By:	
Material for :	100% RAP 1	Cons.	For thesis purpose

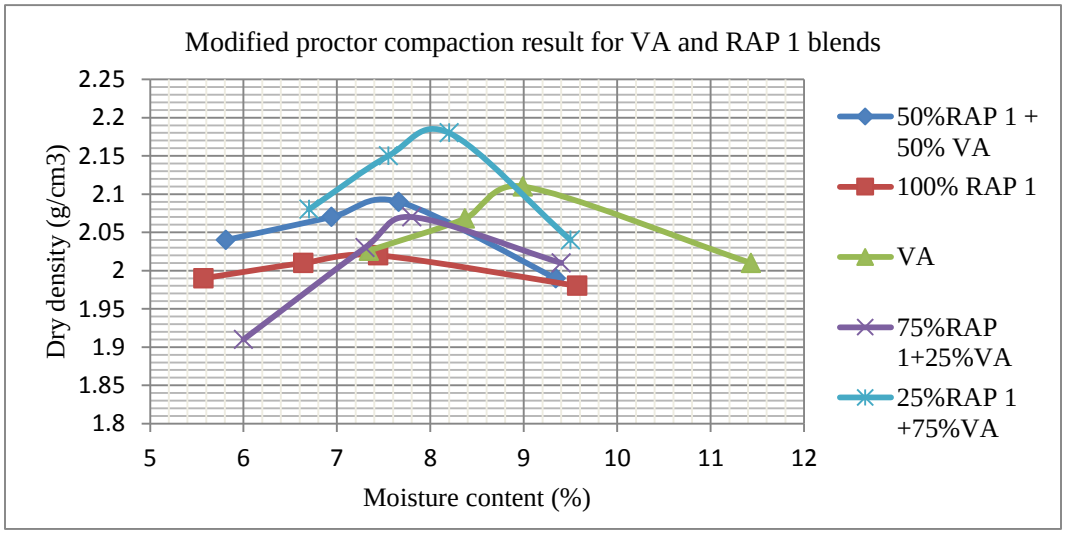
DENSITY	TRIAL NUMBER		**1**	**2**	**3**	**4**	**5**
	Sample weight (g)		9000	8390	7792	7167	6552
	Natural moistur content (%)		1.50	1.50	1.50	1.50	1.50
	Add water required (%)		3.50	5.50	7.50	9.50	11.50
	water added (g)		180.00	335.60	467.52	573.36	655.20
	WEIGHT OF SOIL + MOLD (g)	W_1	12624.0	12705.0	12774.0	12771.0	12755.0
	WEIGHT OF MOLD (g)	W_2	7880	7880	7880	7880	7880
	VOLUME OF MOLD (Cm^3)	V	2256	2256	2256	2256	2256
	WEIGHT OF WET SOIL (g)	$W_3 = W_1-W_2$	4,744	4,825	4,894	4,891	4,875
	WET DENSITY OF SOIL (g/Cm^3)	$W_d = W_3/V$	2.103	2.139	2.169	2.168	2.161
MOISTURE	CONTAINER NUMBER		**7**	**10**	**9**	**4**	**1**
	WET SOIL + CONTAINER (g)	a	610.0	598.0	625.0	615.0	612.0
	DRY SOIL + CONTAINER (g)	b	583.0	567.0	589.0	570.0	558.0
	WEIGHT OF CONTAINER (g)	c	98.0	100.0	105.0	100.0	102.0
	WEIGHT OF WATER (g)	d = a-b	27.0	31.0	36.0	45.0	54.0
	WEIGHT OF DRY SOIL (g)	e =b-c	485.0	467.0	484.0	470.0	456.0
	MOISTURE CONTENT (%) (d/e)*100	**m=**	5.57	6.64	7.44	9.57	11.84
DRY DENSITY OF SOIL (g/Cm3)		**$D_d = W_d/(100+m)*100$**	1.992	2.006	2.019	1.979	1.932

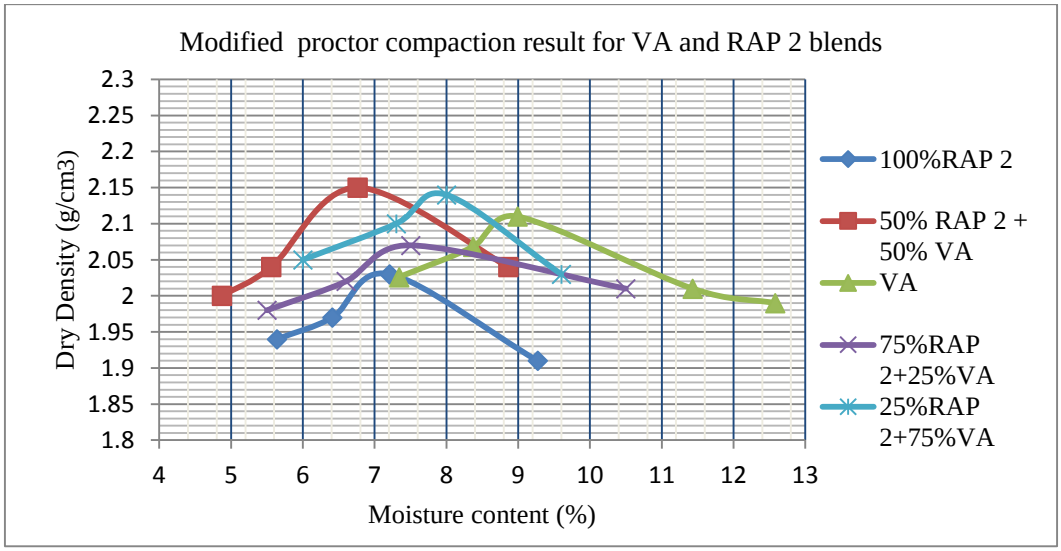


MDD :	**2.02**	**g/cm^3**
OMC :	**7.40**	**%**

Moisture Density relation results together with other blends







APPENDIX C

Sample laboratory test data record sheet and CBR analysis; Laboratory CBR test experiment for 100% PA.

RESEARCH TECHNOLOGY TRANSFERE AND LABORATORY DIRECTORATE [CENTERAL LABORATORY]

CALIFORNIA BEARING RATIO TEST (TEST METHOD AASHTO T-193)

Repres. Section:	PA 100%	**Source :**	Bulbula
Sampled at :	Quarry site	**Date Submited:**	-
Visual Descri. :	Crushed Aggregate	**Lab. Job No**	
Material For :	100% PA	**Soaking date :**	13/11/2010
Sampling date :	4/11/2010	**Testing date :**	17/11/2010
Contractor/Centeral Lab.	For Thesis	**Cons.Repres.:**	For Thesis

DENSITY DETERMINATION

SOAKING CONDITION		10 Blows		30 Blows		65 Blows	
		BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
MOLD NUMBER		60		18		50	
WEIGHT OF SOIL +MOLD (g)	W_1	12109	12200	12398	12485	12603	12705
WEIGHT OF MOLD (g)	W_2	7678	7678	7678.5	7678.5	7796	7796
VOLUME OF MOLD (Cm^3)	V	2124	2124	2124	2124	2124	2124
WEIGHT OF WET SOIL (g)	$W_3 = W_1 - W_2$	4431	4522	4720	4807	4807	4909
WET DENSITY OF SOIL (g/cm3)	$W_d = (W_3/V)$	2.09	2.13	2.22	2.26	2.26	2.31
DRY DENSITY OF SOIL (g/cm3)	$D_d = W_d/(100+m)*100$	1.89	1.90	2.02	2.04	2.09	2.10

MOISTURE DETERMINATION

SOAKING CONDITION		10 Blows			30 Blows			65 Blows		
		BEFORE	AFTER		BEFORE	AFTER		BEFORE	AFTER	
			TOP 1 in.	AVG.		TOP 1 in.	AVG.		TOP 1 in.	AVG.
CONTAINER NUMBER		6		11	10		14	88		26
WET SOIL +CONTAINER (g)	a	625		633	595		821.5	788		830
DRY SOIL +CONTAINER (g)	b	576		576	550		751	736		765
WEIGHT OF CONTAINER (g)	c	105.5		106	99.0		103.5	101.0		106.5
WEIGHT OF WATER (g)	d = a - b	49.0		57.0	45.0		70.5	52.0		65.0
WEIGHT OF DRY SOIL (g)	e = b - c	470.5		470	451		647.5	635		658.5
MOISTURE CONTENT (%)	m =(d/e)*100	10.41		12.13	9.98		10.89	8.2		9.9
AVG. MOIST. CONTENT (%)										

PENETRATION TEST DATA

PENETRATION (mm)	10 Blows				30 Blows				65 Blows			
	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		
0.64	1.4	0.4			2.2	0.7			5.0	1.6		
1.27	2.4	0.7			3.2	1.0			8.9	2.8		
1.91	3.8	1.2			5.8	1.8			16.2	5.0		
2.54	7.4	2.3	2.29	17.38	14.4	4.5	4.46	33.82	27.0	8.4	8.37	63.4
3.18	9.2	2.9			15.2	4.7			30.0	9.3		
3.81	10.4	3.2			19.4	6.0			42.5	13.2		
4.45	12.6	3.9			28.5	8.8			53.4	16.6		
5.08	15.4	4.8	4.77	23.9	40.0	12.4	12.40	62.0	61.8	19.2	19.16	95.8
7.62	17.6	5.5			46.6	14.4			74.8	23.2		
10.16												
12.7												

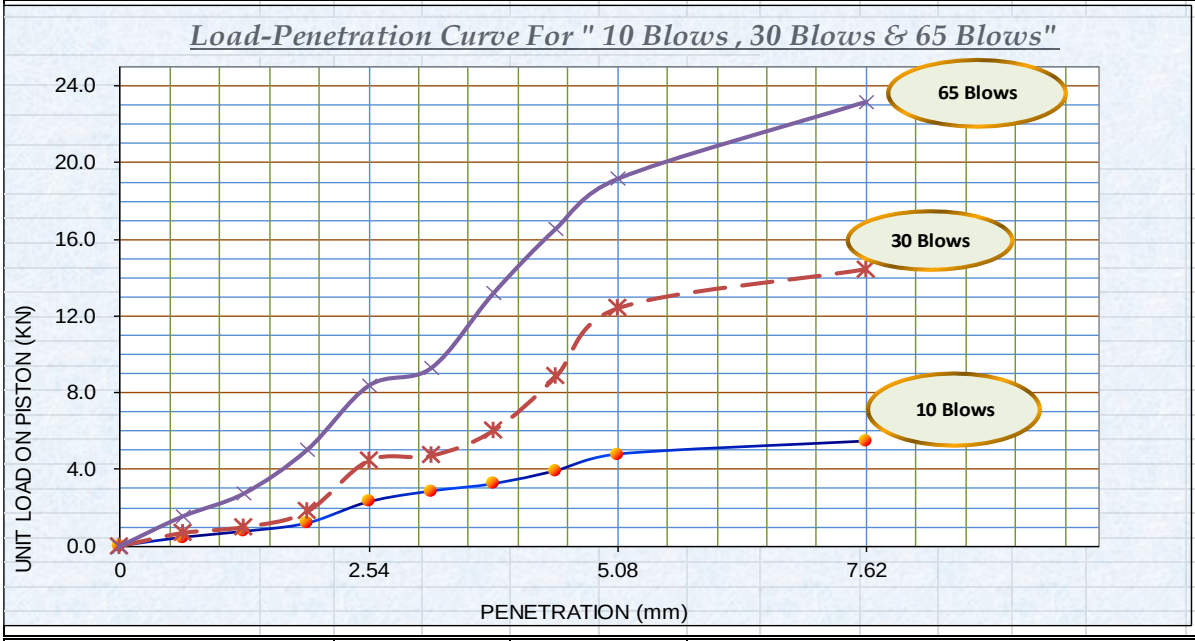
SWELL			
No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING)	0.15	0.15	0.15
RDG (AFTER) SOAKING)	0.15	0.15	0.15
PERCENT SWELL	0.00	0.00	0.00
AVERAGE PERCENT SWELL :		0.00	

RING FACTOR		
0.31000 KN/Divis.	MDD (gm/cc)	2.11
	98% of MDD	2.07
	C.B.R.at 98%of MDD	**85.00**

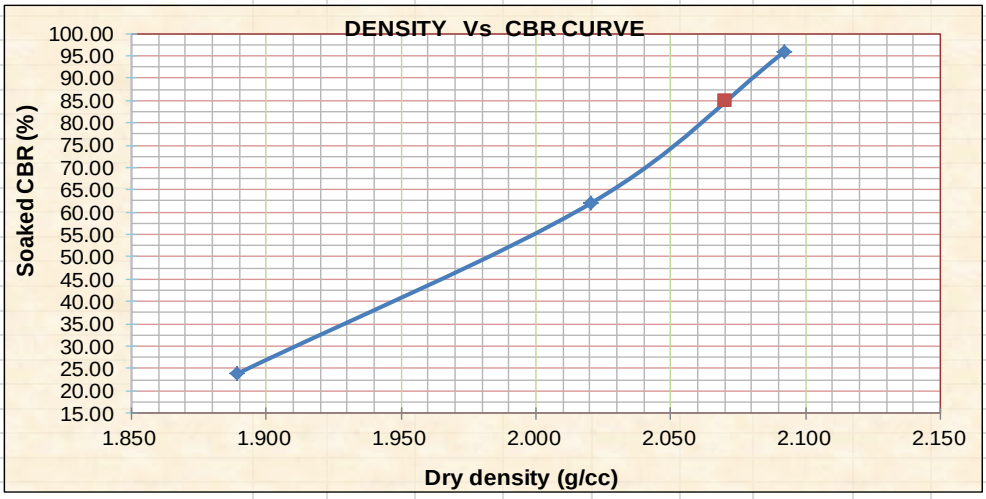
RESEARCH TECHNOLOGY TRANSFERE AND LABORATORY DIRECTORATE [CENTERAL LABORATORY]

CALIFORNIA BEARING RATIO TEST (TEST METHOD AASHTO T-193)

Repres. Section:	PA 100%	**Source :**	Bulbula
Sampled at :	Quarry site	**Date Submited:**	-
Visual Descri. :	Crushed Aggregate	**Lab. Job No**	-
Material For :	100% PA	**Soaking date :**	13/11/10
Sampling date :	4/11/2010	**Testing date :**	17/11/10
Contractor/Centeral Lab. Representative :	For Thesis	**Cons.Repres.:**	For Thesis



BLOWS	LOAD (KN)		CBR(%)		DRY DENSITY Vs SOCKED C.B.R.			
	2.54mm	5.08mm	2.54mm	5.08mm				
10	2.29	4.77	17.4	23.9	**No # OF BLOWS**	**10**	**30**	**65**
30	4.46	12.40	33.8	62.0	**DRY DENSITY**	1.89	2.02	2.09
65	8.37	19.16	63.4	95.8	**SOAKED C.B.R.**	23.9	62.0	95.8

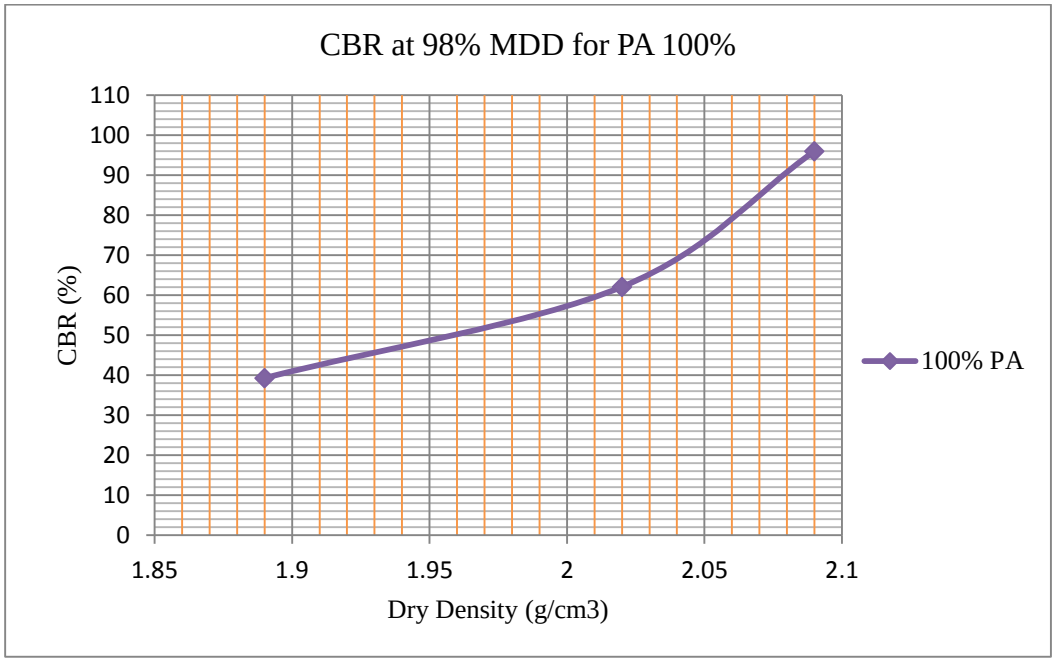


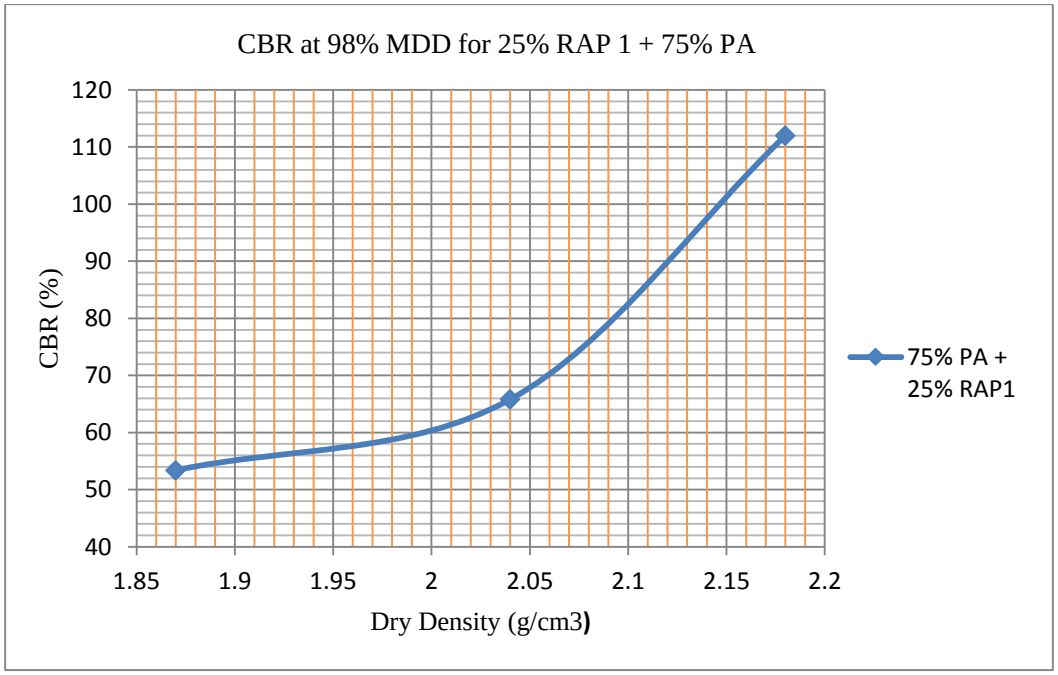
MDD (g/Cm^3) :	**2.11**	**98% of MDD(g/Cm^3)**	**2.07**	**CBR at 98% of M**	**85.00**

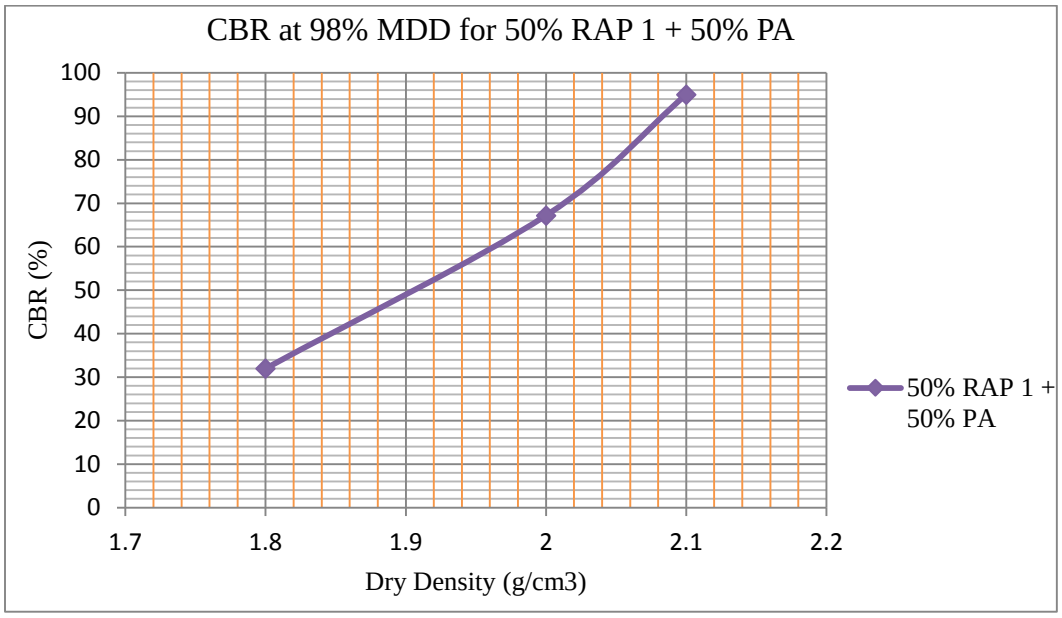
CBR value results summary derived from penetration and from Dry density versus CBR curves of each blow specimens.

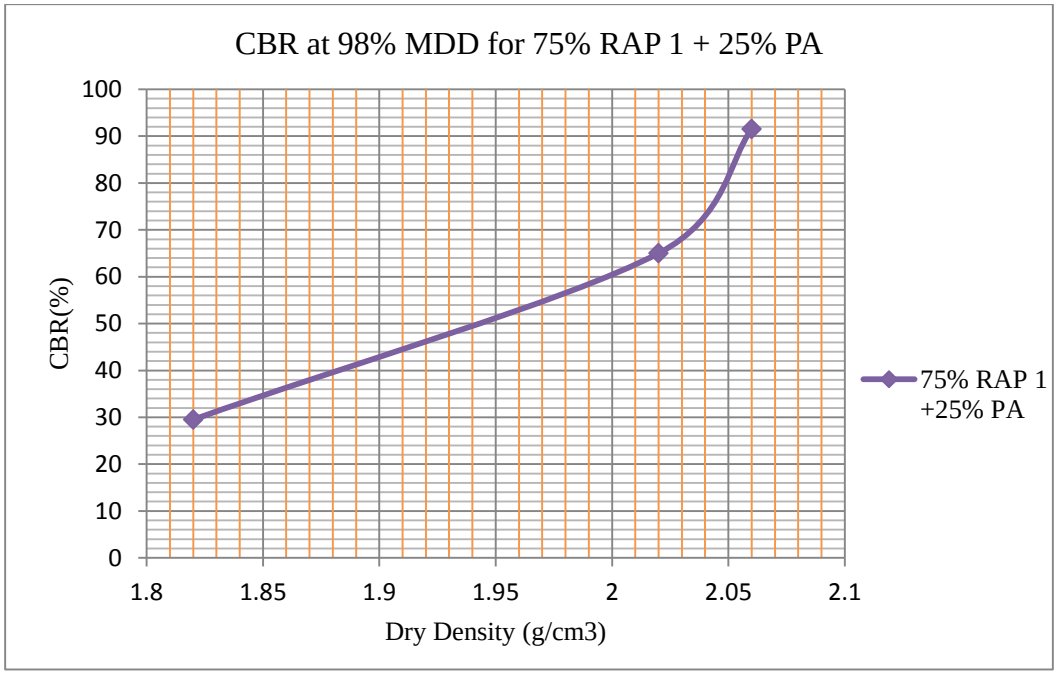
Material blend	Dry density and CBR on each blow					
		10	30	65	98% MDD	CBR (%) @ 98% MDD
100% PA	DD	1.89	2.02	2.09	2.07	85
	CBR	39.3	62.1	96		
25% RAP 1	DD	1.87	2.04	2.18	2.14	97.5
	CBR	53.4	65.8	112		
50%RAP	DD	1.8	2	2.1	2.05	80
	CBR	32	67.2	95		
75%RAP 1	DD	1.82	2.02	2.06	2.03	68.5
	CBR	29.5	65	91.5		
100%RAP 1	DD	1.75	1.91	2.02	1.98	70
	CBR	31.5	48	83.3		
25%RAP 2	DD	1.86	2.05	2.12	2.1	94.5
	CBR	35	68.5	109.4		
50% RAP 2	DD	2.02	2.07	2.13	2.12	89.5
	CBR	41.3	55.7	97.3		
75% RAP 2	DD	1.83	2.01	2.08	2.03	64
	CBR	27.8	57.1	83.8		
100% RAP 2	DD	1.78	1.98	2.04	1.99	54.5
	CBR	23.4	50.1	82.7		

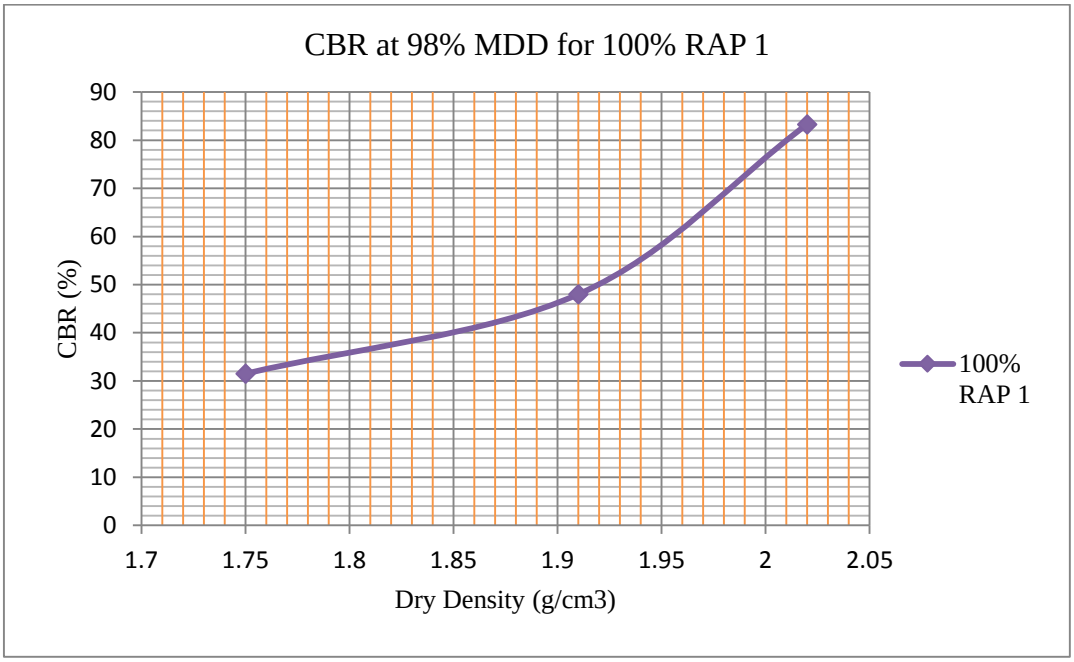
The following curves down shows, CBR values versus dry density relations for each material blend.

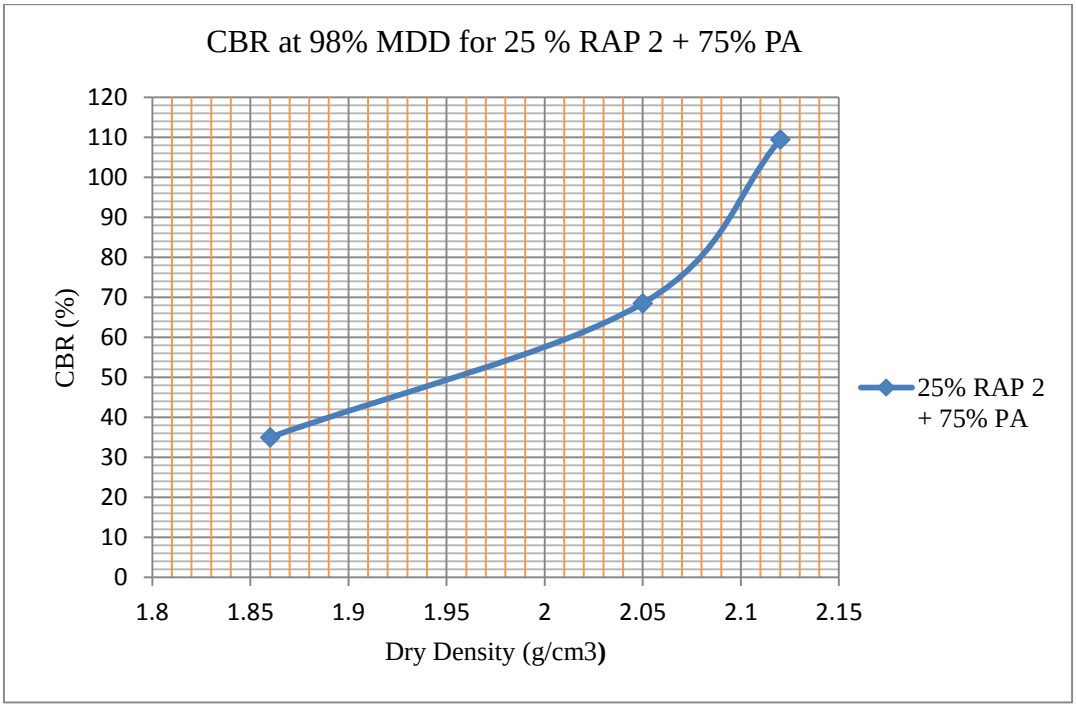


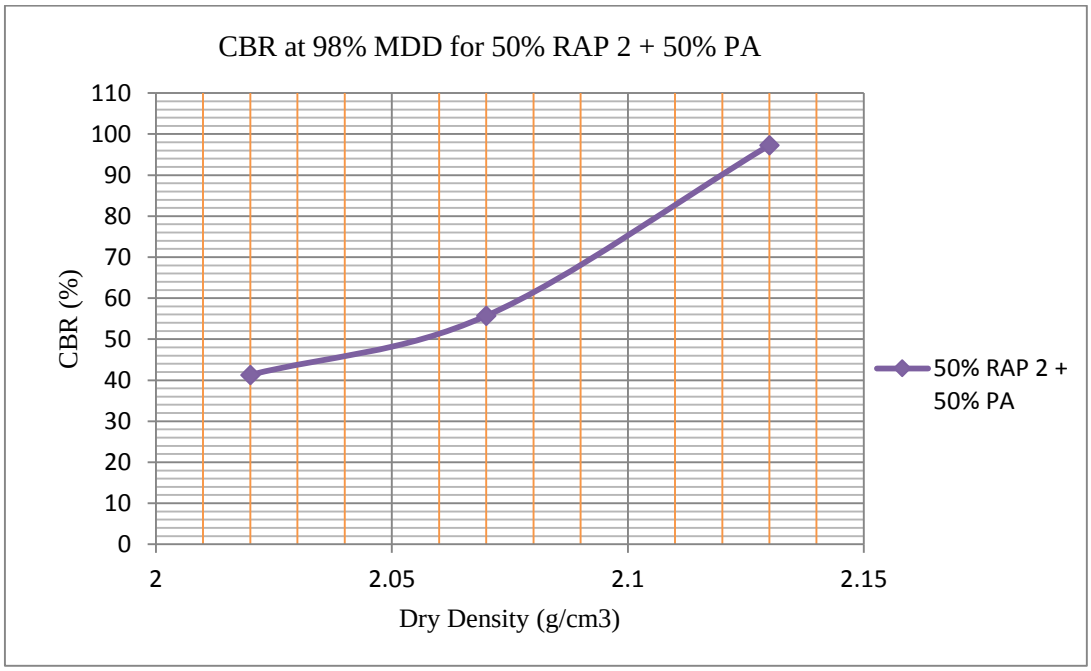


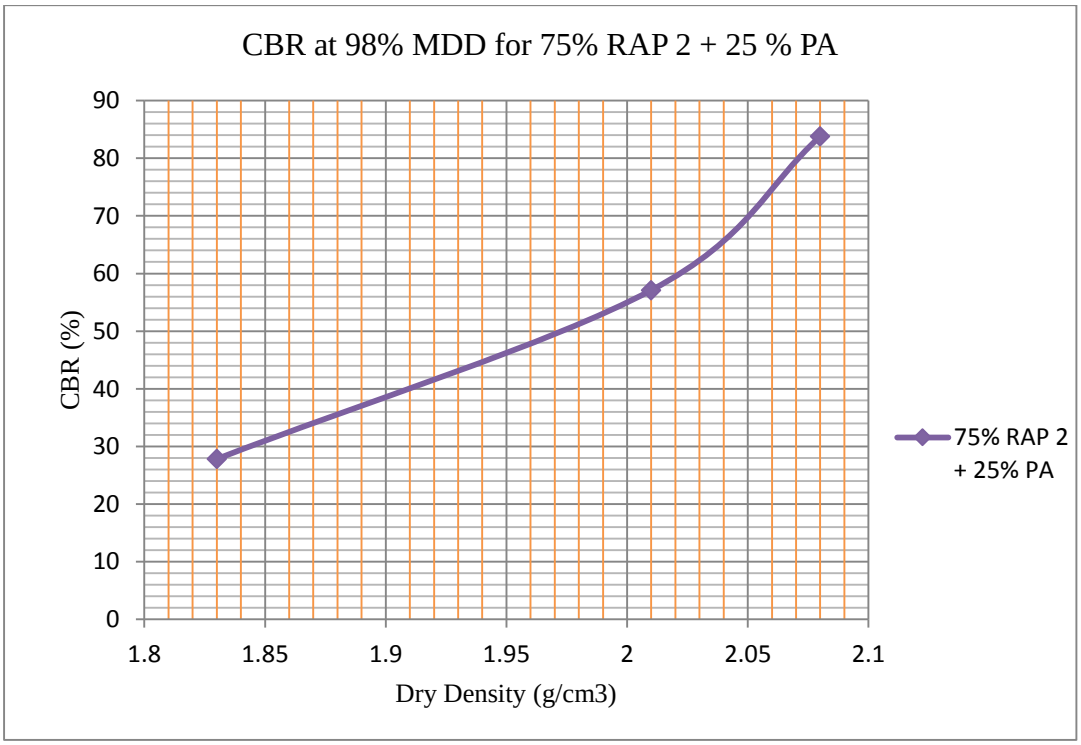

CBR at 98% MDD for 50% RAP 1 + 50% PA
CBR (%)
100
90
80
70
60
50
40
30
20
10
0
1.7
1.8
1.9
2
2.1
2.2
Dry Density (g/cm3)
50% RAP 1 + 50% PA

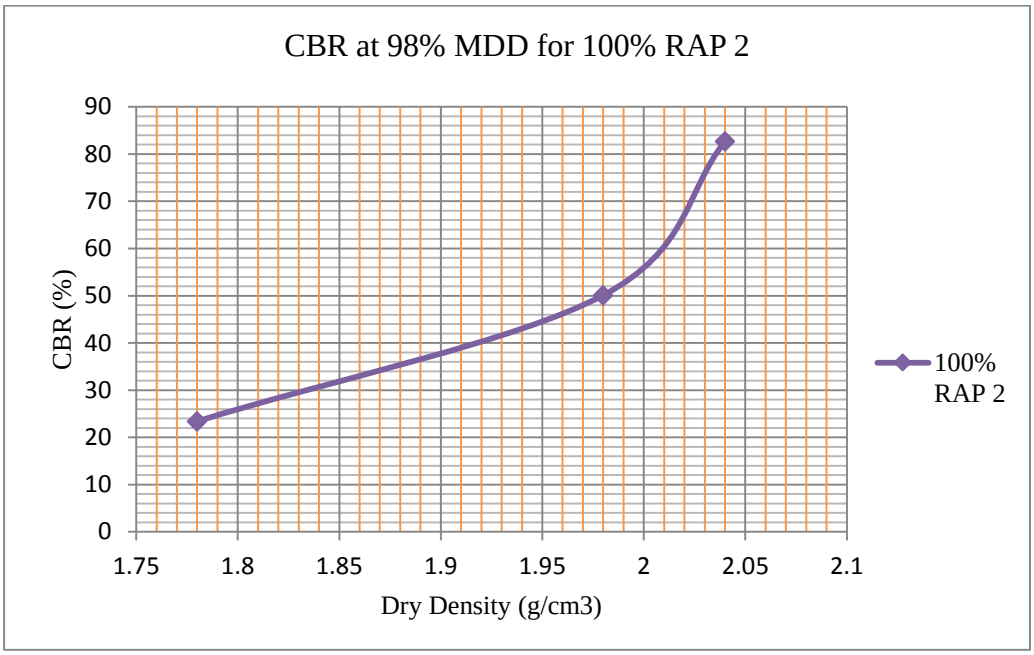

CBR at 98% MDD for 75% RAP 1 + 25% PA
CBR(%)
100
90
80
70
60
50
40
30
20
10
0
1.8
1.85
1.9
1.95
2
2.05
2.1
Dry Density (g/cm3)
75% RAP 1 +25% PA


CBR at 98% MDD for 100% RAP 1
CBR (%)
90
80
70
60
50
40
30
20
10
0
1.7
1.75
1.8
1.85
1.9
1.95
2
2.05
Dry Density (g/cm3)
100% RAP 1


CBR at 98% MDD for 25 % RAP 2 + 75% PA
CBR (%)
120
110
100
90
80
70
60
50
40
30
20
10
0
1.8
1.85
1.9
1.95
2
2.05
2.1
2.15
Dry Density (g/cm3)
25% RAP 2 + 75% PA


CBR at 98% MDD for 50% RAP 2 + 50% PA
CBR (%)
110
100
90
80
70
60
50
40
30
20
10
0
2
2.05
2.1
2.15
Dry Density (g/cm3)
50% RAP 2 + 50% PA


CBR at 98% MDD for 75% RAP 2 + 25 % PA
CBR (%)
90
80
70
60
50
40
30
20
10
0
1.8
1.85
1.9
1.95
2
2.05
2.1
Dry Density (g/cm3)
75% RAP 2 + 25% PA


CBR at 98% MDD for 100% RAP 2
CBR (%)
90
80
70
60
50
40
30
20
10
0
1.75
1.8
1.85
1.9
1.95
2
2.05
2.1
Dry Density (g/cm3)
100% RAP 2

APPENDIX D

Pictures taken from the trial section that shows the pavement condition before maintenance, during RAP base course placement and current condition after one year service time.








CAT











