JIMMAUNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

MASTER OF SCIENCE IN HIGHWAY ENGINEERING

APPLICATION OF LOCALY PRODUCED GRAVEL AS SURFACE MATERIAL FOR URRAP GRAVEL ROAD CONSTRUCTION IN KENBATA TENBARO ZONE; CASE OF KACHIBER WOREDA.

BY:-WOGAYEHU MASEBO

A FINAL THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN HIGHWAY ENGINEERING

NOVEMBER, 2016

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BY:-

WOGAYEHU MASEBO

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NOVEMBER, 2016

JIMMA, ETHIOPIA

DECLARATION

I, the undersigned, declare that this thesis: in titled Application of locally produced gravel as surface material for URRAP gravel road construction in Kenbata Tenbaro Zone; case of Kachiber Woreda is my own work, and it has not been presented for any degree in any other University. It is being submitted for the degree of Master of Science in Highway Engineering, and all sources of materials used for this thesis have been fully acknowledged.

Wogayehu Maseboa	________________	________________
Name	Signature	Date

This thesis has been submitted for examination with my approval as University Supervisor

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ABSTRACT

Surfacing material for gravel road construction should pass the required blended material from the specification. Coarse aggregate and fine aggregate, as part of surfacing material, should be in there intended and accepted gradation. The specification requires suitable material in term of two basic soil parameters; namely shrinkage product and grading coefficient which can be taken particle size distribution and linear shrinkage.

The general objective of this study was to evaluate the application of locally produced gravel material for URRAP road construction. Laboratory experiment was done to check the engineering properties of the gravel surfacing material. The result was compared with ERA and AASHITO standard specification. Interview and observation were made to determine the performance of the URRAP road.

Gravel material was taken from three quarry sites using random selection and select the material which pass the graduation requirement. Out of the three sites, gravel from Chacha was selected for further laboratory experiment.

The maximum dry density of the material was 1.632g/cc and optimum moisture content was 23.7%. The CBR test result was 49.0 percent and swell factor was found to be 0.2 percent. The plasticity Index was 8.5, plastic product was 153.0 and Los Angeles Abrasion value was 80.60 percent. +Other factors which are relevant on the design of gravel road was taken also like rainfall data and traffic data which are 177.9 mm and 69veh/day. The cost comparison was made for gravel surfacing material and macadam pavement which is found to be 23,6000birr and 4M birr respectively.

It was found out that the localy produced gravel was partially suitable for gravel surfacing material as compared with ERA and AASTHO specification because 75 percent pass the required specification. All results pass except the LAA value and plasticity product. With regard to economical aspect, in rural road construction, gravel road is preferable.

It was recommended the applicability of the locally produced gravel for URRAP road construction. In this way it can help the local community reduce the unemployment and help the local government increase their income. It was also suggested to perform stabilization to improve the LAA value and plasticity product.

Key word: URRAP, Gravel Material, Engineering Property, Cost Effectiveness

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ABREVIATIONS

ADT	Average daily traffic
ASTM	American standard test manual
AASHTO	American Association State Highways and Transport Organizat
CBR	California bearing ratio
DC	Design Code
ERA	Ethiopian Road Authority
GC	Grading Coefficient
GM	Grading Modulus
ILO	Internationally Labor Organization
LVR	Low Volume Road
MDD	Maximum dry density
NMT	Non-Motorized Traffic
OMC	optimum moisture content
PM	Plasticity Modulus
PI	Plasticity Index
PP	Plasticity Product
RRGAP	Rural road gravel assessment program
RRST	Rural Road Surfacing Trials
SNNPR	South Nation Nationality People Region
SRA	South Road Authority
ToR	Term of reference
TRL Ltd	Transport research laboratory limited
URRAP	Universal Rural Road Access Program
USCS	Unify Soil Classification Specification
VPD	Vehicle per day

CHAPTER ONE

INTRODUCTION

1.1. Background

Roads are clearly a critical enabling condition for improving living conditions in rural areas. However, the distribution of socio-economic benefits resulting from rural road is a separate issue, and there are no guarantees or inherent mechanisms to ensure that these benefits will be distributed equitably between the poor and average individual in communities.

Ethiopia is implementing the Universal Rural Road Access Program (URRAP): its vision is to free the country's rural peoples from their access constraints, reduce rural poverty, improve welfare and opportunity, stimulate agro-productivity and share growth - a growth in which poor people benefit. And its mission is to connect all Kebele by all-weather roads. Road infrastructure will be of appropriate standards to meet the needs of the rural communities and will be affordable to build and maintain.

Gravel surfacing material should contain the appropriate blend of material. Coarse aggregate and fine aggregate, as parts of the surfacing material, should be to their intended mix. The proper blend of different size aggregate on the road produces a surface that can be used in all types of weather (Local Technical Assistance Program, 2000). From the perspective of gravel surfacing material, the material should satisfy some important criteria. According to ERA (ERA., 2002), the surfacing material should have sufficient cohesion to prevent raveling and corrugating, especially in dry conditions, and the amount of fines, particularly plastic fines, should be limited to avoid a slippery surface under wet conditions.(ERA, 2011a).

Gravel roads are heavily affected by their environment. Road environment can be classified into two: man–made environment includes traffic, historical events, political decision, and economics and natural environment includes; topography, climate, and geology. Topography to which the gravel road constructed on, can be related to alignment of the roads, drainage and gravel loss. Gravel roads in contrast to sealed roads, when they are designed and constructed, they tend to follow the natural contour. In highly contoured terrain, gravel roads are likely to be steeper and more sharply curved than their paved counterpart. The effects of topography on gravel roads alignment therefore are higher. Topography also affects the drainage capability of the roads. If the roads have flat terrain water may accumulate on the road and facilitate the deterioration of the road. If the roads have mountainous terrain, since it increases the flow of water, the consequence become erosion and gravel loss of the surfacing material. Traffic in terms of composition, volume and axle load, should be considered to identify the defects on gravel roads (U.S. Department of Transport and Administration, 1998).

Most of the deteriorations observed on gravel roads are caused by the combination of those factors. It is rare that the particular type of defects to be caused by the single deteriorating agent. Traffic, for example, in combination with other factors, can be the cause of corrugation, potholes, ruts, dust, loose gravel, loss of gravel and stoniness (P.Paige-Green, 2000). But, from the maintenance point of view the most expensive type of defect is loss of surfacing material of the gravel roads. Since the lost gravel should be replaced, it becomes the challenge of many road agencies regarding the amount of gravel to be replaced and the limited budget allocation for maintaining the whole road network (Henning T. F. P. *et al.*, 2008).

Graveled Roads are built and designed to certain engineering principles, including the supply, where warranted, of gravel wearing surface. Construction of these roads also involves a defined cross section, drainage and structures like bridges and culverts. This research focused on the study of the engineering property of locally produced gravel material and the performance of Shinshicho–Angacha gravel road fond in SNNPR Regional State Kambatta Tambaro Zone.

The case study site location and the material property with the climate condition of the area with the grading and plasticity components of the gravel material property were check and compared with specification.

1.2. Statement of the Problem

Different factors affect the overall performance of roads whether they are asphalt surfaced or gravel surfaced. A road is designed for parameters like traffic, surrounding atmospheric condition, and material property based on certain design principles and the standard for the intended use of the road.

Under low volume road context and other higher standard roads to have better performing and long lasting nature of the road is basically depends on the material it wears; therefore studying the performance of the road surface material is key to the selection of alternative gravel wearing materials with better load bearing capacity and longevity. The application of locally produced gravel surface material as surface material in URRAP construction road is important method for minimizing the construction cost related with other material because to construct the surface with other material many problem is happen like surface deterioration, maximum construction cost and less durability of surfacing for this case to minimizing this problem to use locally produced gravel material as surface material is safe and economical because increasing the living standard of rural people sustainable development of the country economy. In order to increasing the living standard of rural people and the sustainable development of the country economy. (Adewole S.Oladele et al., 2014).

This research was focused on the study of the application of gravel wearing material for URRAP road construction in Kambatta, Tambaro Zone. The engineering property and performance were check and compared with the ERA and AASHTO specification

1.3. Objective of the study

1.3.1. General objective

The general objective of this research was to evaluate the application of localy produced gravel as surface material for URRAP road construction.

1.3.2. Specific objective

- To check the engineering property of the gravel materials used in URRAP road construction in the study area
- To compare the engineering properties of locally produced gravel with ERA and AASHTO standard specification
- To evaluate the performance and cost effectiveness locally produced gravel material as surface material.

1.4. Research Question

- What are the engineering property of surfacing material in URRAP road construction in the study area?
- Is the gravel material accepted with ERA and AASTHO specifications?
- What are the performance and cost effectiveness of locally producer gravel material as surface material in the study area?

1.5. Significance of the Study

The developing application of locally producer gravel material could be used for many purposes. Application of locally producer gravel material as surface material could benefits road agencies in determining maintenance and rehabilitation requirement of the surfacing material because in order to update predicting the residual life of gravel road and evaluating the trade-offs between different maintenance and construction policies cycle and also determining re-gravelling frequency and gravel materials characteristics and specification

.this application used to know specific traffic, climatic conditions, effectiveness of construction method and cost effectiveness and environmental and man-made factors. This will help the URRAP decide on the selecting the quarry site.

1.6. Scope of the Research

The scope of this research was limited to the evaluation of engineering property of locally produced gravel material as surface material , service life and determination of design period attainability of the specific of for URRAP Gravel Road Construction in Kambata-Tambaro zone road on the basis of the sampled sub base materials used as the wearing course of gravel surface of the road, measured laboratory tests result and road users performance rating assessment to investigate how the road is performing. The riding comfort or quality of the road depends on the erodability of surface materials by erosion and other forces; presence of surface distresses which are directly depends on the material strength of the wearing course sub base materials.

CHAPTER TWO

LITERATURE REVIEW

Ethiopia is a country of great geographical, geological and climatic diversity. Altitudes range from the highest peak at Ras Dashen (4,620m above sea level) down to the Afar Depression (110m below sea level). The high plateaus and mountain, ranges usually above 1500m are characterized by precipitous edges and dissection by numerous rivers and streams. These areas constitute about 45 percent of the total area and are inhabited by close to 80 percent of the population (ERA, 2011b).

In Ethiopia road transport plays a significant role in every aspect of activities. It facilitates economic development by benefiting the population of the country. The benefits can be observed in economic, social and political activities with in the country. In early modernization theory, roads were considered to be the important catalysts of economic development. Although the theory that building a road leads to development becomes the controversial issue, the modernization theory still works to the present time (Deborah, 2006).

Gravel roads are considered as low volume roads in Ethiopia. Low volume roads are defined as those roads carrying up to about 300 vehicles per day and Less than about 1 million equivalent standard axles. These roads contain mainly collector and feeder roads in Ethiopia. Low volume roads (LVR) are categorized in design code (DC) of 4 up to 1 (ERA, 2011b).

Investment in transport, and particularly road transport, improves the wellbeing of the poor. Provision of all-weather roads:

- Improves the quality of universal education – it makes it possible to recruit and retain qualified teachers and assistants;
- Improves access by the poor to human, natural, social and financial resources that they need to raise living standards and welfare;
- Provides opportunities for the poor to participate more fully in development opportunities it gives access to markets, jobs, schools, social and health facilities;
- Provides both short (road building) and long-term (road maintenance) employment opportunities; and
- Reduces the negative impacts of natural disasters and shocks and provides the links needed to manage it.

The greatest returns for agricultural productivity, food security and poverty reduction often come from appropriate investments in roads.

Table 2.1Road classes in Ethiopia

Road Functional Classification						Geometric Standards	Level of Service	AADT
				TRUNK	HIGH VOLUME	DC8	A	>10,000
			LINK	TRUNK	HIGH VOLUME	DC7	A	3,000 - 10,000
			LINK	TRUNK	HIGH VOLUME	DC6	B	1,000 - 3,000
		MAIN ACCESS	LINK	TRUNK	HIGH VOLUME	DC5	B	300 - 1,000
	COLLECTOR	MAIN ACCESS	LINK	TRUNK	LOW VOLUME	DC4	C	150 – 300
FEEDER	COLLECTOR	MAIN ACCESS			LOW VOLUME	DC3	C	75 – 150
FEEDER	COLLECTOR				LOW VOLUME	DC2	C	25 – 75
FEEDER					LOW VOLUME	DC1	D	<25
FEEDER					LOW VOLUME	Track	D	

Source: ERA, Low volume road design, (ERA, 2011b)

Table 2.2 shows that, the growth of each type of roads in the region and in the country was different. In the federal road network, asphalt road has grown in average of 6% and the gravel road has grown in average of 3%. This shows that the federal road authority was mostly concentrated on construction of asphalt roads than gravel roads. Observing the gravel road growth in the region, since it is the only types of their road asset, the network has grown higher than the gravel roads in the federal road network (7.65%).

Table 2.2 Road network development in Ethiopia

Federal Road Network (km)							Regional roads	
Year	Asphalt (km)	Growth rate (%)	Gravel (km)	Growth rate (%)	Total (km)	Growth rate (%)	Gravel (km)	Growth rate (%)
1997	3708		12162		15870		10680	
1998	3760	1.38	12240	0.81	16000	1	11737	10
1999	3812	1.36	12250	0.39	16062	0.4	12600	7
2000	3824	0.31	12250	0.07	16074	0.1	15480	23
2001	3924	2.55	12467	1.93	16391	2	16480	6
2002	4053	3.18	12564	1.36	16617	1	16680	1
2003	4362	7.08	12340	0.51	16702	1	17154	3
2004	4635	5.89	13905	9.91	18540	11	17956	5
2005	4972	6.78	13640	0.39	18612	0.4	18406	3
2006	5002	0.60	14311	3.63	19313	4	20164	10
2007	5452	8.25	14628	3.82	20080	4	22349	11
2008	6066	10.12	14363	1.71	20429	2	23930	7
2009	6938	12.57	14234	3.51	21172	4	25640	7
2010	7476	7.20	14373	3.10	21849	3	26944	5
2011	8295	9.87	14136	2.59	22431	3	30712	14
2012	9875	16	14675	8.63	24550	9	31550	2.7
%	40	6.21	60	2.82		3		.65

Source: 15 year assessment of RSDP (ERA, 2013).

2.2. Gravel Roads

According to (William, 2001), the term gravel road is generally used to refer to all unpaved roadways. A true gravel road is a roadway whose surface layer is constructed of mineral aggregate materials (such as sand, gravel, pebbles or crushed stone) that are generally obtained from gravel pits and quarries. In line to this definition, Theuns, H. and Peter, K. (Theuns, 2006) defines unsealed roads as a road that has no permanent surface proofing of water in contrast of sealed roads.

Gravel roads are built and designed to certain engineering principles, including the supply, where warranted, of gravel wearing surface. Construction of these roads also involves a defined cross section, drainage and structures (bridges, culverts). Good gravel road is constructed of three different layers. The subgrade or roadbed is the bottom layer made up of the native material (clay, silt or sand) found along the roadway alignment or fill to level a depression. The aggregate base is placed on top of the subgrade and is ideally 45cm to 60cm depth. It should be constructed from free draining and easily compactable aggregate material (gravel or crushed stone) that produces a strong and stable layer. Such aggregate base materials should contain a minimal amount of fines (materials with a very small particle size such as clay or silt) since they tend to inhibit the free drainage of water, which could reduce the strength of the aggregate base. Finally, the surface layer (uniformly graded gravel or crushed stone) is placed on top of the aggregate base and it is at least 20cm in depth. Gravel roads can also be known as unpaved roads. (Transport research Laboratory, 1994) which says, “An unpaved road is a road with a soil or gravel surface.”

The materials for gravel wearing course should satisfy the following requirements that are often somewhat conflicting. They should have sufficient cohesion to prevent raveling and corrugation (especially in dry conditions) and the amount of fines (particularly plastic fines) should be limited to avoid a slippery surface under wet conditions and dust in dry conditions. For an aggregate road surface to shed rain water, it must have an at least 10% fines in the material (Department of Transport, 1990).

According to ERA (2011), great care should be taken in using gravel as a road surface in some circumstances. It is unlikely that it will be suitable due to high costs of replacing the surface material that will be lost due to rainfall or traffic, or dust nuisance in the locations; where

- Traffic is more than 200 motor vehicles per day
- Annual Rainfall is greater than 2,000mm
- Longitudinal slope of road surface is more than 6%

- ❖ Through community settlements
- ❖ The haul distance from the quarry/pit to the road site is more than 10km
- ❖ The road section experiences flooding
- ❖ The gravel is of poor quality.

Gravel roads, due to their nature of construction, are prone to deterioration by different factors. These factors are traffic (speed, volume and axle loads), environmental factors especially climate (temperature and precipitation), surfacing material (type and nature) and geometrical design of gravel roads .Due to these factor, gravel roads deteriorated early than anticipated by their design. Defects on gravel road are potholes, corrugations, ruts, erosion (longitudinal and transversal), dust, loose material, stoniness and last but not least gravel loss (Jones, 2000).

By necessity, general specifications must cover a very wide range of material types and cater for extreme climatic environments. As a consequence they are likely to contain significant in-built factors-of- safety. By implication this means that proven specifications drawn-up for specific materials for particular environments need not be so conservative in approach and hence may allow the use of previously non- conforming or marginal materials. There is a need to shift away from classifying such materials as “marginal” or using the term “marginal” as an all-encompassing descriptor, when in fact there is a real prospect of their effective use within an appropriate design. Marginality in the eyes of engineers infers a substandard product. This need not be the case if materials are appropriately assessed, used and promoted, hence the preferred use of “non- standard” as a description. At the same time there is an apparent need to assess the suitability of these materials in a manner that is technically justifiable. (AASHTO, 2004).

2.3. Sub Base Materials Properties

The engineering property of sub base materials used for the wearing course of gravel road are determined by their components or ingredients of the material, generally the sub-base materials consists of granular material ,gravel, crushed stone, reclaimed(blended) material or a combination of these materials but the material used for gravel road is the natural selected material which fulfills the specification listed under 2002 Pavement design manual of ERA Volume I and 2011 ERA LVR manuals in our country since this materials are used as pavement and pavement is the portion of the highway which is most obvious to the motorist (Department of Transport, 1990). The condition and adequacy of the highway is often judged by the smoothness or roughness of the pavement. Deficient pavement conditions can result in increased user costs and travel delays, braking and fuel consumption, vehicle maintenance repairs and probability of increased crashes (Jones, 2000).

The sub-base material used as wearing course for the surfacing of unsealed road should fulfill the following specification.

Table 2. 3 Specification for sub base materials used as wearing course of unsealed road Sieve size (mm)

Sieve size(mm)	Alternate Grading(% passing)		
	A	B	C
50	100	100	-
25	-	75-95	100
9.5	30-65	40-75	50-85
4.75	25-55	30-60	35-65
2	15-40	20-45	25-50
0.425	8-20	15-30	15-30
0.075	2-8	5-20	5-15
PI	6-12	LA	50% max
LL	-	CBR	30% min
LS	-	Compaction	95% min

Source: Highway material and soil (Atkins, 1997).

The granular material should meet the material property requirement specified above table. For the surfacing of gravel road the material from the quarry run is used. The term “Quarry Run” is used as a general term to cover naturally occurring rock and weathered rock materials excavated from a quarry or borrow area and delivered to site without processing, apart from any required selection or screening for the removal of oversize boulders or cobbles.

In areas where hard rock quarries have been developed primarily for aggregate production, the use of quarry run in rural road construction provides a use for materials that may otherwise be considers as waste for dumping. Provided they are acceptable, this use of these materials, therefore, brings with it an environmental advantage.

This type of material is by its nature highly variable and care should be taken in initially assessing the suitability of the source; in addition and equally importantly supervision resources must be available to ensure the continued consistency of its properties throughout the contract. Even if they meet specified criteria, any materials with excessive variation within the acceptable envelopes should be rejected due to the consequent problems caused in compaction control (Atkins, 1997).

For the purposes of the construction of rural road sub-base the target for acceptable quarry run material will be to meet the established requirements for naturally occurring gravel used for the same purpose according to the gravel road specification.

The materials must comply with specified grading and plasticity criteria as well as compacted strength and particular care must be taken in ensuring the removal of oversize material.

During the construction of gravel road and at the time of Construction and Supervision the following points should be assured.

- ✓ Ensure that any deformations, ruts, soft spots or other defects in the formation have been corrected to the satisfaction of the Engineer i.e. fulfill gravel road specification.
- ✓ Secure lateral support for the sub-base shall be in place prior to the construction of the sub-base layer which is used as wearing course.
- ✓ After ensuring appropriate amounts of quarry run are loaded, spreading and compaction should start immediately as it is generally known that soil or selected material used for the wearing course of gravel road exists in three forms or volumes; bank volume, loose volume and compacted volume. From this three states bank state is the natural state (Dot, 2004). If labor-based methods are a construction option, the workers should use special spreading rakes, appropriate hand tools or hoes to spread the material evenly onto the sub- grade. Work should progress from the center line towards the shoulder, and material should be spread from one side of the center line at a time. Oversize pieces of rock should be removed or crushed, if possible, using sledge hammers.
- ✓ If the material is in a dry condition then water should be added prior to compaction. Make sure that there is a sufficient supply of water, to maintain close to optimal moisture content in the quarry run during compaction.
- ✓ An inspection should be made of the laid out material prior to compaction to identify and remove any oversize to attain the required quality and performance of the road.
- ✓ Compaction should be carried out along the road line starting at the shoulder of the road and gradually working towards the center line, ensuring an adequate overlap between passes.
- ✓ The first passes of the vibrating roller should be done without vibration in order to avoid that the roller getting "bogged down" in loose material.
- ✓ Water should be added as necessary to facilitate compaction.

Make sure that the camber of the road is always maintained for both the base layers as well as the gravel layer (Dot, 2004).

2.4. Environmental Responsibilities

The program puts a strong emphasis on protection of one of the country's most precious resources – its environment.

URRAP appreciates the vital role that the environment plays on the livelihoods of those it sets out to benefit. It is not a free resource in infinite supply. The environment provides a wide range of services which underpin all productive activities and contributes to human welfare in a number of very direct ways. Although it may not be possible to put a "price" on the environment, it has a great value to those who work and live in it.

Responsibilities for applying sound environmental screening are outlined in Table 2.4. In carrying out the program, staff will be guided by the over-arching objective of ensuring that road interventions are designed and implemented according to sound principles which minimize adverse impact and enhance benefits. A variety of procedures are followed at various stages of the project cycle in order to achieve this objective. These procedures normally involve an environmental impact assessment (EIA) or screening that captures identifying and quantifying the full range of potential impacts on the natural and social environments and formulates remedial procedures for avoiding, mitigating and compensating for negative impacts. Remedial measures are reflected within the project and contract documents and the Regional and Wereda Authorities monitor compliance during implementation.

Community involvement in this process is important. Information, views and concerns are fed into the Wereda plan and these are discussed at grass-roots level by the affected community.

Whilst the nature of the roads falling under the program might not, under normal; circumstances merit the same "environmental" attention as say a main road, the magnitude of the program demands a strenuous assessment for both upgrading and new construction works (GTP, 2010-2015).

Table 2.4 Responsibilities for applying sound environmental screening

Project stage	Activity	Objective	Responsible Agency
Project identification	Initial Screening	Register danger signals, Avoid unnecessary investigation where impacts are likely to be minimal	Wereda development committee $wereda road office
Feasibility	Environmental appraisal	Predict impact, Assess importance of effect, Indict key mitigating action required, Present implications to decision maker	Wereda development committee $wereda road office
	Preliminary Screening	Decisions on mitigation $checklist requirement	Regional coordination committee$ Regional Environmental protection office
	Environmental checklist assessment	Predict in detail likely impacts including cost implications Identify specific measures necessary to avoid mitigate or compensate for damage Present predications $ option to decision makers	Wereda road office
	Selection of project	Decision an acceptance	Recommendation by regional Environmental protection office
Design	Environmental Mitigation Plan	ensure environmental mitigation measures are included in the contract documents	Wereda Road Office & Regional Roads Authority
Implementation	Environmental Monitoring	ensure environmental mitigation measures are being complied with during construction	Supervisor & Wereda Road Office
Operations and Maintenance	Environmental audit	Assess the extent of implementation of a project against the requirements derived from the checklist. Ensure lessons learned are incorporated in future projects	Regional Environmental Protection Office and Regional Coordination Committee

Source: (GTP, 2010-2015)

2.5. What is Good Gravel?

The answer to this question will vary depending on the region, local sources of aggregate available and other factors. Some regions of the country do not have good sources of gravel (technically called aggregate in many places). A few coastal regions in the United States use seashells for surface material on their unpaved roads; other regions use materials such as clinker (locally known as "scoria" in some States), slag, reclaimed materials such as recycled asphalt or concrete pavement, and others as applicable in different regions of the country. However, this section of the manual will discuss the most common sources of material. They are quarry aggregates such as limestone, quartzite and granite; glacial deposits of stone, sand, silt and clay; and river gravels that generally are a mix of stone and sand. One thing should be stressed: it pays to use the best quality material available (Department of Transport, 1990).

2.6. Difference between Surface Gravel and Other Base Materials

Too often surface gravel is taken from stockpiles that have been produced for other uses. For instance, the gravel could have been produced for use as base or cushion material for a paved road. There are two major differences between surface gravel and base (cushion) material which are: gravel for base material will generally have larger top-sized stone and a very small percentage of clay or fine material. This is necessary for the strength and good drainage characteristics needed in base gravels. If this material is used as a surface gravel, it will not form a crust to keep the material bound together. It will become very difficult to maintain. Other gravel could have been produced simply as fill material for use at building sites. This material often has a high content of sand-sized particles which make it very drainable. This is a desirable characteristic in fill material since water can quickly flow through it and drain away from under building foundations and parking lots. But, if this material is used on a gravel road, it will remain loose and unstable. A good gravel road needs gravel with sufficient fine material which has a plastic or "binding" characteristic (FHWA, 2000).

2.7. Understanding the Gravel Road Cross Section

Everyone involved in gravel road construction must understand the correct shape of the entire area within the road's right-of-way. Figure 2.1 shows a typical cross section of a gravel road. If States have minimum standards or policies for low-volume roads, they must be follow.

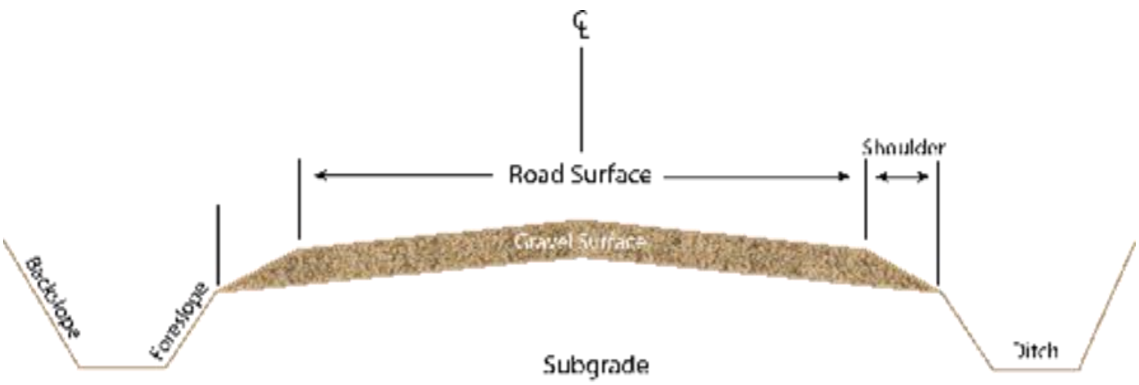


Figure 2.1 The components of the roadway cross section

In order to maintain a gravel road properly, operators must clearly understand the need for three basic elements:

1. A crowned driving surface,
2. A shoulder area that slopes directly away from the edge of the driving surface, an
3. A ditch.

The space for the shoulder area and the ditch of many gravel roads is often minimal. This is particularly true in regions with very narrow or confined rights-of-way. Regardless of the location, the basic shape of the cross section must be correct or a gravel road will not perform well, even under very low traffic (FHWA, 2000).

2.8. Good Gradation

Unfortunately, poor performing gravel will often be blamed on the maintenance operator. But the operator cannot make good gravel out of bad gravel. Bad or poorly graded gravel cannot be changed to good gravel by a motor grader operator. Bad or poorly graded gravel cannot be changed to good gravel by a motor grader operator. Good quality surface gravel may cost more, but it is often well worth the extra cost.

Quality can only be determined by proper field sampling and then testing in a materials lab.

Good surface gravel has the appropriate percentage of stone, or coarse aggregate, which gives strength to support ne aggregate, to fill the void between the stones to provide stability. The final requirement is an appropriate percentage of plastic, very fine particles to bind the material together which allows a gravel road to form a crust and shed water. The simplest definition of coarse and fine aggregate as defined by AASHTO is that material retained on (coarse), or passes through (fine) a No. 4 Sieve in the laboratory testing process. What is referred to as very fine material is that portion of the fine aggregate that passes a No. 200 sieve. These fine particles are extremely small, less than 0.075 mm in size, that cannot be seen individually by the human eye (SDLTAP, 2010).

2.9. The Benefit of Testing Aggregates

It is very important to understand that all gravels are not the same. One can tell a little about them by visual inspection or by running your hands through the material but real quality can only be determined by testing.

The primary concern here should be gradation and plasticity, or cohesive characteristic, of the fine portion of the material. Further testing can provide information on items such as hardness or soundness, gradation, percentage of fractured stone and plasticity index, all of which affect the performance of surface gravel (SDLTAP, 2010).

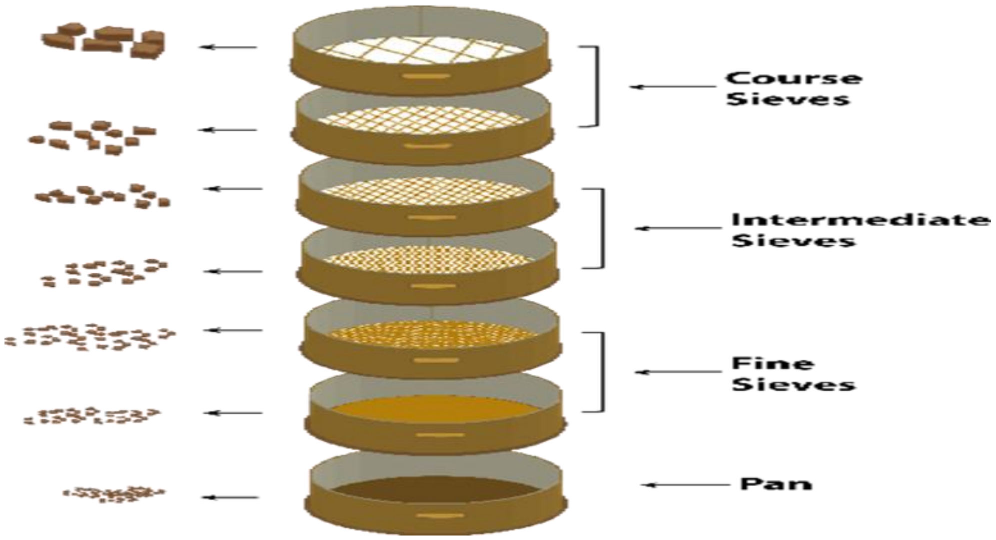


Figure 2.2 Sieve size of gravel particle

2.10. Reasons for Testing

All managers and decision makers in local government need a good understanding of the benefit of testing aggregates in order to work towards better quality in road and street maintenance. Not everyone needs to understand how to do the testing. Testing requires special knowledge and equipment which is generally not available or affordable to most local governments. You simply need to recognize that knowing more about the quality of aggregate that is used in construction and maintenance operations will contribute to better road construction and maintenance. This knowledge gives power to decision makers to specify good materials, to know when to accept or reject materials, and to communicate better with crushing contractors, consultants, commercial suppliers and others involved in the business of constructing and maintaining roads. Often an objection is raised to sampling and testing because the cost is too high. This claim can be countered with the argument that if a few, or many thousand tons of aggregate are going to be purchased, is it not wise to invest a comparatively small amount of money in the testing of the material to insure that good quality aggregate is being purchased? It is a good practice to test the aggregate before placing it on the road. Also, if the tests fail, you can work with the supplier to try to improve or reject the material (Gravel Roads Maintenance and Design Manual, 2000)

2.11. Sampling

Another issue critical to testing aggregate is obtaining a good sample of the material to be tested. Knowing how to get a good representative sample from a crushing operation, a stockpile, a windrow, or from the existing surface is absolutely critical in getting valid test results from a lab.

Poor sampling techniques have led to more controversy in aggregate testing than any other factor. Some common problems are obtaining a sample from only one location in a stockpile or windrow, getting a sample from the discharge conveyor belt that is not representative of the entire stream of material going up the belt, not gathering enough quantity for testing and not getting the sample to the lab in a timely manner.

Every effort must be made to make sure that the sample brought to a lab is truly representative of the material in the field. It is wise to follow national standards such as the ASTM or the AASHTO standard for aggregate sampling. It is always advisable to work with an experienced sampler if you are not familiar with sampling .If your State has a surface gravel or aggregate specification it is highly recommended that specification be used. Local governments are not held to these specifications when doing their own construction and maintenance work without state or federal funding and oversight. Yet, it is wise to be familiar with them and follow them whenever possible. If you choose to modify the specifications to suit a local material source or project, it is best to begin with a State specification characteristics of the material and uniform quality will have a major impact on the performance of the roadway surface. The base course requires 100 percent of the material to pass a 1-inch sieve, but allows up to 20 percent of the stone to be retained on the 3/4 inch sieve. While this could make excellent base gravel, it will likely perform poorly if used as gravel surfacing. There would be too much large stone resulting in very difficult blade maintenance. Also, the high percentage of coarse material would make a rough driving surface. A higher percentage of large stone is needed for strength in the base course, but will be detrimental to surface gravel. Good surface gravel that goes into a tightly bound state will provide a good driving surface (AASHTO, 2004).

Table 2.5 Example of Gradation Requirements and Plasticity for Two Types of Materials

Requirement Sieve	Aggregate Base Course Percent Passing	Gravel Surfacing Percent Passing
1		100
¾	80-100	100
½		68-91
No.4	46-70	50-78
No.8	34-54	37-67
No. 40	13-35	13-35
No. 200	3-12	*4-15
Plasticity index	0-6	4-12

From: South Dakota Standard Specifications

*Sometimes modified to 8-15 for better performance for Roads and Bridge

2.12. Fines and Plasticity Index

Notice also the difference in the fine material and the plasticity index (PI) sometimes referred to as Atterberg Limits. While gravel surfacing allows as little as 4 percent and up to 15 percent (and sometimes modified to 8 to 15 percent) of the material to pass a #200 sieve, base course can have as little as 3 percent, but not more than 12 percent passing the same sieve. More importantly, the PI can be no less than 4 or as high as 12 in. surface gravel. The same index can fall to 0 in base course and rise to no more than 6. There is good reason for this.

Good surface gravel needs a percentage of plastic material, usually natural clays, which will give the gravel a "binding" characteristic and hence a smooth driving surface. This is critical during dry weather.

During wet weather, the surface may rut a bit, but will quickly dry and harden in sunny and windy weather. The same material used as base would lose its strength and stability if it became wet and cause rutting or even failure of the pavement. Too often the same gravel is used for both base work and surface gravel. Generally, it will be good for one purpose or the other, but will not work for both application.

Contains a sample of a complete Screen Analysis and PI Worksheet typical of those used by testers across the country. Once again, it should be stressed that only by sampling and testing the aggregate can one really determine the quality of the material. Simple visual inspection can be misleading. One thing in particular that is very hard to determine without testing is plasticity. This is a laboratory test which, in simplified terms, tells you whether the fines are primarily clays or silts. If you are not familiar with this testing, the whole process may seem very confusing. Yet, it really pays to increase your knowledge of these matters in order to be a better manager. Every local road or street department manager has a big job and there is never enough money to cover all of the needs. It is imperative that money be spent wisely (Millard .R. S, TRL, 91993).

2.13. Establish Specifications

Gravel for local roads is often bought from a local supplier at a negotiated or bid price for an estimated quantity. There may be some assurance that the gravel will perform well on the road based on past experience. However, material sources can change rapidly as the material is removed. The only real assurance of getting good quality material is to establish a specification and then sample and test the product to make sure these specifications are met. If one is confident in knowledge of surface grave and wishes to change the specifications, that is fine; but it is wise to use the State specification a benchmark from which to work. For example, State specifications may show a “Class I Surface Aggregate” designation for surface gravel. You may want a higher minimum requirement for plasticity or perhaps a smaller top size on the rock. State clearly in your specification that you want a “Modified Class I Surface Aggregate” and then clearly indicate what your modifications are. If you have not done so, familiarize yourself with your State specifications (Gravel Roads Maintenance and Design Manual, 2000).

2.14. Handling Gravel

It is not common for maintenance operators or field supervisors to be involved in the actual production process of the gravel that is used on their roads. Yet it is very helpful to understand how the material should be handled from the time it is taken from the quarry face or the gravel bank in a pit. There are certain problems that can arise from the time the material is first removed from the earth until it is finally placed on the road. It may be wise to visit the site where your gravel is being produced to see if it is being handled well.

Source: (SDLTAP, 2010).

Figure 2.3 Example of poor management of a gravel pit

Note top soil was not removed from the top of the working face of the gravel bank and has fallen down into the working area.

This will contaminate the gravel with organic material and could spread noxious weeds

2.15. Pit (Quarry Operations)

It is very important to remove topsoil and vegetation from the surface of the material source before beginning to process the gravel. Topsoil will contain organic matter which is never good for a road surface. Furthermore, in some agricultural regions of the country, the spread of noxious weeds can occur when parts of growing plants and/or the seeds are hauled out with the gravel and spread on rural roads. Several States have laws that allow authorities to quarantine material sources and stockpile sites to prevent the spread of weeds. Under these laws, the gravel cannot be removed even though your agency may already have ownership of it. The solution is to make sure the topsoil is removed and placed well out of the way.

Figure 2.4 Good example of top soil and vegetation stripped

A good example of top soil and vegetation stripped back from the working face of the gravel bank. It is also a good practice to work a broad area of the face of a pit or quarry to blend material and reduce variability as it is fed into the processing plant (Gravel Roads Maintenance and Design Manual, 2000).

Source: (SDLTAP, 2010).

Figure 2.5 Bad example of taking material

A bad example of taking material from a narrow area of the working face of a gravel bank not allowing good blending of material.

2.16. Roadway Preparation

When fresh gravel is to be placed on a road, it is vital to properly shape the road surface first. For example, a washboard area needs to be cut out and reshaped prior to placing new gravel over it. Otherwise, the washboard distress will quickly reflect right up into the new surface and the problem quickly reappears. Another critical matter is to address surface drainage problems. If the road has lost crown, has potholed areas, high shoulders or severe rutting, all of these problems need to be eliminated. Then fresh gravel can be placed at a uniform depth and the road becomes easier to maintain. Generally, it is not wise to simply fill these problem areas with new gravel. It can become very expensive and the gravel will not have uniform layer thickness.

Figure 2.6 Roadway preparation

This road has been damaged by a heavy haul. Reshaping the entire road surface is required before new gravel is placed.

Preparing a road for new gravel can be as simple as cutting out a few potholes or a washboard area to reshaping the entire cross section. Even if the existing road is smooth and hard, it is often wise to lightly scarify the surface to break the crust to get a good bond between new and existing material. One final tip: be sure the crown and shape of the road is as close as possible to the desired shape of the road surface after graveling is finished. That is the only way a completely uniform layer of new gravel can be placed (Gravel Roads Maintenance and Design Manual, 2000).

2.17. Calculating Quantity

The procedure for determining how much gravel needs to be hauled to construct a new gravel layer on a road is not always well understood. One thing that is often overlooked is the shrinkage in volume that occurs from ordinary compaction. Ordinary compaction means the shrinkage that occurs from the material being placed, from routine blade maintenance and absorbing moisture from rainfall and then having traffic passing over it. In many parts of the country this will result in 30 percent or greater reduction in volume (Gravel Roads Maintenance and Design Manual, 2000).

Figure 2.7 Very good practice of measuring and marking spread distance

A very good practice of measuring and marking spread distance for incoming trucks with a measuring wheel and shovel to make a mark on the surface.

Too often the volume of material is calculated in a loose state as it exists in the stockpile or as it is dumped from the truck. Material in the stockpile or in trucks is very loose and has very low density.

Remember to allow for shrinkage when calculating how much gravel depth is needed after the job is compacted and finished. Calculation then should be made for the distance that each truck can spread its load. This is not always done in maintenance operations, but it is recommended. It's the only way to really know for sure how much material is being placed.

2.18. Hauling and Dumping

Once hauling begins, it is wise to have a motor grader present to process and place the gravel immediately. The skill of the truck drivers can really make a re graveling operation work smoothly. When drivers are able to dump the load evenly and within the correct length that was marked, the grader operator's job becomes much easier.

Figure 2.8 Good example of evenly dumping gravel on the road

A good example of evenly dumping gravel on the road. Notice a grader is ready at the hilltop to begin processing the gravel.

2.19. Windrowing, Equalizing and Spreading

Once the gravel is dropped on the road, the grader operator should pick up the material and place it in a windrow. This will usually take more than one pass. It is called equalizing. This accomplishes two important things when handling gravel. It gives a final blending and mixing of the gravel, and it makes a windrow of very uniform volume. Once equalized, the material should be spread by the grader evenly on the roadway. A general rule is the minimum thickness when placing each layer of gravel is twice the thickness of the top-sized stone. Hence, if top-size stone in the gravel is 1-inch, the layer thickness should be a minimum of 2-inches. Care must be taken not to carelessly cast material off the edge of the roadway where it cannot be recovered. When the material is finally placed across the roadway, it leaves a uniform depth of well-blended material that becomes the new gravel surface for the public to drive on. It all works better when everyone understands their job.

While it is not possible everywhere, adding water and using rollers for compaction makes a better gravel road. It is recommended whenever possible.

Source: (SDLTAP, 2010).

Figure 2.9 the motor grader operator

The motor grader operator beginning to process gravel immediately after it is dumped on the road.

Source: (SDLTAP, 2010)

Figure 2.10 windrowing and equalizing the new gravel

This operator had done an excellent job of completely windrowing and equalizing the new gravel.

2.20. Surfacing Material of Gravel Roads

Low-volume road surfaces and structural sections are typically built from native materials that must support light vehicles and may have to support heavy commercial truck traffic.

In addition, low-volume roads should have a surface that, when wet, will not rut and will provide adequate traction for vehicles (Gordon Keller, 2003). Roadway materials, and particularly roadway surfacing materials, such as aggregate or paving, can be half the cost of a road. Selection of materials directly affects the function, structural support, rider comfort, environmental impact and safety of the road user.

The classification systems for gravels used in road construction are generally depends on some measure of grading, maximum particle size, plasticity and bearing capacity (Jenkins, 2004). AASHTO M 145, classification of soil-aggregate mixtures for highway construction purposes, divides soils into the two major groups, namely granular and silt-clay materials. The granular materials are those soils with 35% or less passing the 75 μm (No. 200) sieve .ASTM D 2487, divides soils into three major groups of coarse-grained soils (sands and gravels), fine-grained soils (silts and clays), and highly organic soils (peat and other highly organic soils).

Gravel surfacing material should contain the appropriate blend of material. Coarse aggregate, sand and fine aggregate parts of the surfacing material should be to their intended mix. The proper blend of different size aggregate on the road produces a surface that can be used in all types of weather (Program, 2000). From the perspective of gravel surfacing material, the material should satisfy some important criteria. According to ERA (2002), the surfacing material should have sufficient cohesion to prevent raveling and corrugating (especially in dry conditions) and the amount of fines (particularly plastic fines) should be limited to avoid a slippery surface under wet conditions.

The specifications identify the most suitable materials in terms of two basic soil parameters; shrinkage product (SP) and grading coefficient (GC), which are determined from particle size distribution and linear shrinkage. An alternative to using linear shrinkage and the shrinkage product is to use the plasticity index and the associated plasticity product. For the range of materials likely to be used for gravel wearing course, the plasticity index can be assumed to be 2*linear shrinkage. The linear shrinkage (shrinkage product) is recommended as it is based on one relatively simple test which has good precision limits in the shrinkage ranges of acceptable gravel wearing course material (ERA, 2011b).

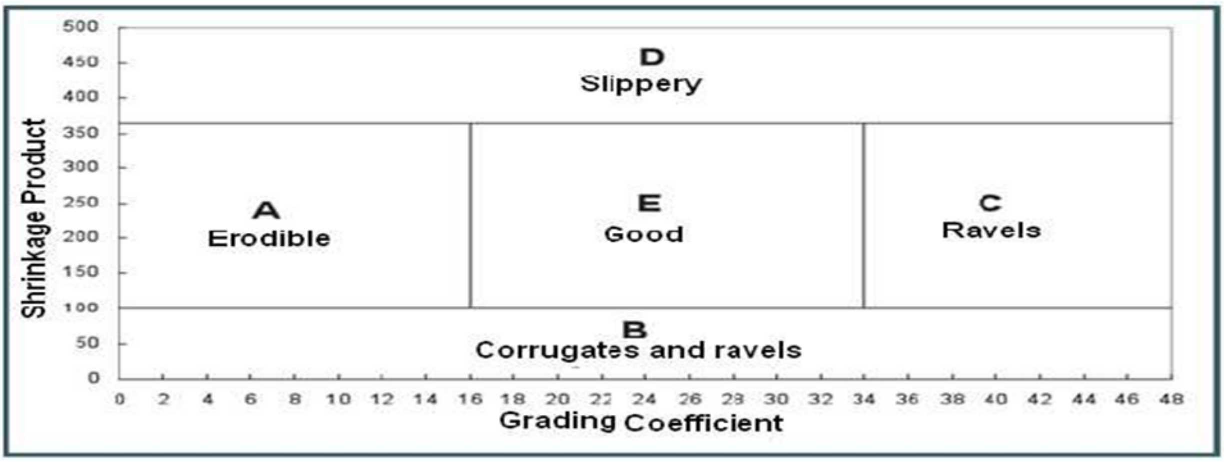


Figure 2.11 Material quality zone

Source: ERA (2011)

Note: SP = (Linear Shrinkage) x (% passing 0.425 mm) particularly prone to erosion. They should be avoided if possible, especially on steep grades and

GC = ((% passing 28 mm) - (% passing 2 mm) x (% passing 5 mm)/10) ERA (2011).

The characteristics of materials in each zone are as follows:

- Zone A material are generally perform satisfactorily but are finely graded and sections with steep cross-falls and super-elevations. Roads constructed from these materials require frequent periodic and labor intensive maintenance over short lengths and have high gravel losses due to erosion.
- Zone B material are materials that generally lack cohesion and are highly susceptible to the formation of loose material (raveling) and corrugations. Regular maintenance is necessary if these materials are used and the road roughness is to be restricted to reasonable levels.
- Zone C materials are generally comprised of fine, gap-graded gravels lacking adequate cohesion and resulting in raveling and the production of loose material.
- Zone D materials with a shrinkage product in excess of 365 tend to be slippery when wet.
- Materials in zone E perform well in general, provided the oversize material is restricted to the recommended limits (ERA, 2002)

In calculating the amount of dust from the surface of gravel roads, clay and silt content (% surface material < 0.075mm), average vehicle weight in tones and surface material moisture content should be considered (Greening, 2011). Some of the factors that are the causes for erosion of surface materials of gravel roads are soil type and condition. Coarse textured sands and gravels are the least erodible, because they are comprised of bigger and heavier particles that are harder to move. Water percolates in sand and gravel at a faster rate, which means there is less storm water to run off. Silts and fine sands are generally the most erodible soils, due to their large part to their small particle size. Smaller particles are lighter and more easily carried away by surface water runoff (District, 2010).

Surfacing material for gravel road should satisfy the criteria that standard sets for the usage of each types of material. Surfacing materials can be classified depending on their physical and chemical behaviors. In the world today, there are many classification systems such AASHTO soil classification and USCS classification systems.

In the AASHTO classification system, road materials are classified in to

- Boulders:-retained on 3 in. square sieve

- Gravel: - material passing sieve with 3 in. square opening and retained on the No. 10 sieve
- Coarse sand:- are material passing No.10 sieve and retained on the No.200 sieve
- Fine sand:- are material passing the No.40 and retained on No.200 sieve
- Combined silt and clay:- materials passing the No.200 sieve

The term clay and silt are also categorized by the use of plasticity index .if the material is silt it has plasticity index of 10 or less and if it is clayey it has plasticity index of 11 or greater. They can also be classified by the use of gradation. If the material has size between (2-75μm) it is silt and if it has a size less than 2μm it is clay AASHTO (2004).

According to Arora K.R. (2004), plasticity of a soil is the ability to undergo deformation without cracking or fracturing. A plastic soil can be molded in to various shapes when it is wet. Plasticity is an important index property of fine grained soil, especially clayey soil. Plasticity in soil is due to the presence of clay material. The clay materials carry a negative charge on their surface.

The clay particles are separated by layers of adsorbed water which allow them to slip over one another. When the soil is subjected to deformation, the particles do not return to original position, with the result that deformations are plastic (irreversible). As the water content of the soil reduces, the plasticity of the soil reduces. Soil becomes dry when the particles are cemented together as a solid mass. The presence of adsorbed water is necessary to impart plasticity characteristics of soil. The soil becomes plastic only when it has clay mineral. If the soil contains only non-clay mineral, such as quartz, it would not become plastic whatever maybe the fineness of the soil. When such soils are ground to very fine size, these cannot be rolled in to the threads (Arora K.R., 2004).

Material selection is one of the most crucial for design and maintenance considerations. Often, alternative surfacing options are considered for poor performing unsealed roads, whilst the problem can be resolved by using quality materials. Gravel loss is the single most important reason why gravel roads are expensive in whole life cost terms and often unsustainable, especially when traffic levels increase. Reducing gravel loss by selecting better quality gravels or modifying the properties of poorer quality materials is one way of reducing long term costs. Gravel losses (gravel loss in mm/year) are determined in relation to the quality of the gravel wearing course (Henning, 2005).

2.20.1. Geometric Design of Gravel Roads (Absolute Gradient)

Geometric design is the process whereby the layout of the road through the terrain is designed to meet the needs of all the road users. It covers road width, cross-fall, horizontal and vertical alignments, sight distance and transverse profile or cross-section (ERA, 2011b). The geometric features influencing gravel loss are horizontal and vertical curvature, the cross section elements and longitudinal grades. Geometric cross-sectional characteristics particularly crown, camber, side- drains and run-off points have pronounced effects on drainage and gravel road deterioration during high rainfall.

Longitudinal-section, in particular the grade above 6%, interacts with rain water to cause gravel loss. Horizontal curvature not in harmony with vehicle speed will create gravel materials whip off, and vertical curvature with steep grades will interact with rain water to erode the gravel materials (Allopi, 2012). Loss of surface material depends on material quality, traffic, rainfall, gradient and maintenance regime (Henning, 2005). In Ethiopia topography is classified in to four.

Table 2.6 Classification of topography

Flat	0 to 10 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally below 3%.
Rolling	11 to 25 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally between 3 and 25%.
Mountainous	26 to 50 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally above 25%.
Escarpment	Escarpments are geological features that require special geometric standards because of the engineering risks involved. Typical gradients are greater than those encountered in mountainous terrain.

Source: ERA (2011)

Roads that are constructed in mountainous and escarpment topography have grater gradient compared to the other classes of topography. In low volume road design, the maximum gradient that can be fixed to the roads ranges 6% to 12%. The higher gradient values corresponds for the roads that have less traffic flow and the roads that are found in mountainous and escarpment parts of the country (ERA, 2011b). According to (200, the slop length and gradient of the road plays a significant role in erosion of the road surface. The long the slop length and the higher the gradient, the impact of the rainfall become devastating.

According to Cook, S.R. and Petta, R.C. (2005), the study indicates that erosion increases significantly between 4% and 6% road gradient. It has been commonly acknowledged that gradients above 6-8% are not usually suitable for gravel surfacing. The table 2.9 shows the magnitude of each ranges of gradient and the associated erosion.

Table 2.7 Gradient and surface erosion relation

	Road Gradient as survey point				
	Flat	> 0-2 %	> 2-4 %	> 4-6%	> 6 %
% slight or no erosion	91	67	47	47	26
% significant erosion	9	23	53	53	74

Source: Vietnam rural road assessment program (Vietnam, 2002 – 2005).

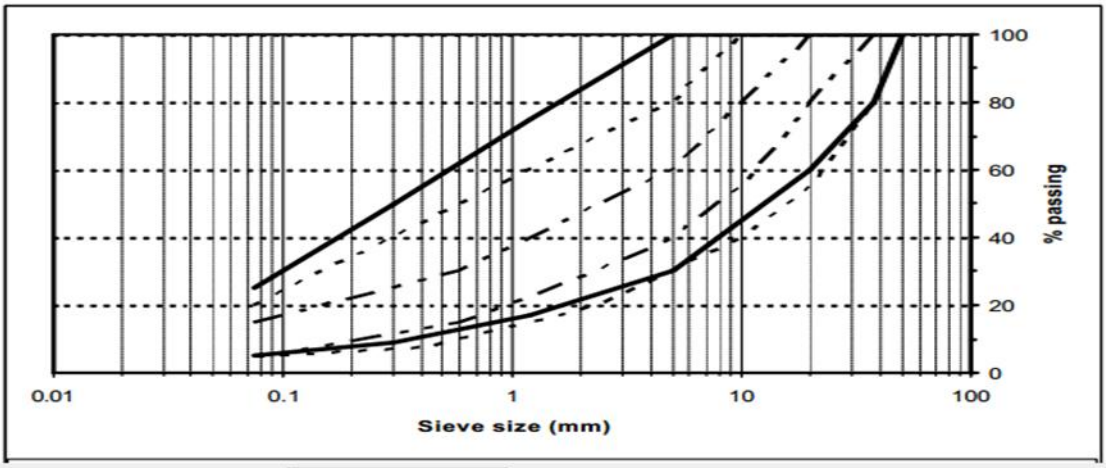
2.20.2. Gravel materials characteristics and specification

The characteristics of gravel materials to lose or retain water for a considerable length of time and its cohesive nature of granular particles can be specified by using performance study. The derivation of appropriate specification for the selection of surfacing materials for unsealed roads can be derived locally from monitoring among other parameters the GL on a range of existing gravel roads, and correlating it with the materials physical characteristics.

The characteristics of a surfacing material which contribute to satisfactory behavior of a gravel road have conventionally been considered to be as follows:

- ✓ It should contain a sufficient quantity of binder in the form of fine grain materials to prevent loosening of the surface, and yet not cause excessive dustiness in dry periods.
- ✓ It should also resist movement of material and thus reduce gravel loss. If the fines content is too high then under wet conditions a substantial loss of strength will occur, leading to excessive deformation and a slippery surface.
- ✓ The material should not contain a large quantity of coarse particles which can become exposed through trafficking and lead to high surface roughness and create a traffic hazard. Large particles may also prevent efficient maintenance reshaping of a road surface and can lead to pothole deformation if they are plucked out by traffic or during grading.
- ✓ They can also prevent compaction forces being transmitted evenly through a layer, which may result in low densities being achieved with a consequent enhanced risk of road deterioration, Vietnam (TRL 52, RT2, 2005).

These characteristics are reflected in the standard specifications for gravel surfacing that exist throughout the world that are normally based on grading envelope and plasticity criteria. In this context it should be noted that the current Vietnam MoT/RT2 specification already allows a wide envelope grading in comparison to other specifications,



Source: Technical Information Note on Laterite Johnston (IFG, 2004)

Figure 2.12 Current MoT in Comparison with other Specifications

Evaluation of the RRGAP test results against this specification are presented on province-by-province basis in Appendix B of this document.

Test results have also been evaluated using other plasticity and particle size indices, such as:

Plasticity Product (PP) Plasticity Index X % material passing 0.075mm sieve

Plasticity Modulus (PM) Plasticity Index X % material passing 0.425mm sieve

Grading Coefficient (GC) (P26.5mm – P2.00mm) X (P 4.74mm)/100

Grading Modulus (GM): (P2.00 + P0.425 + P0.075)/100

Where P= %passing (mm)

Experience has indicated the value of these indices as material assessment criteria and Figure 2.12, which utilizes the plasticity product value has proved useful in other regions. RRGAP data has therefore also been plotted in this format.

There is a significant variability in the nature and performance of the materials being used as unsealed road surfaces in Vietnam. The material loss for the RRGAP sites for each of the 7 principal material groups is presented Figure 2.13 indicates the apparent erosion variability related to material type (IFG, 2004).

2.21. Surfacing Alternatives

Surfacing alternatives have evolved over a long period as new materials and technologies keep emerging.

2.21.1. Factors to be considered when selecting surfacing alternatives

The main factors that need to be considered when deciding between surfacing types are presented below.

- Climate, Geography and Topography
- Environmental and Socio-Economic Impact
- Safety
- Engineering Suitability
- Durability of Surfacing
- Failure Modes of Treatments
- Political and Organizational Issues
- Design Standard

It should be noted that any one, or the combination, of these factors may determine the surface type require (ARRB, 2000).

CHAPTER THREE

RESEARCH METHODOLOGY

In order to achieve the objectives of the research, review of applicable practices, research findings, information on serviceability of road were check. The AASHTO road test and other pavement performance related study and relevant literatures on current design approaches were also reviewed. Moreover, adaption of various models of pavement performance with initial and final serviceability as input for the research work was reviewed.

3.1 Description of the Study Area

The study will be conducted at Kachabirra woreda which is located between 07^{o}4"North to 07^{o}18’ N latitude and 37^{o}42’E and 37^{o}50' E Longitude in Kembata Tembaro Zone of SNNPRS. The woreda is 327 km and 117 km from Addis Ababa and Hawassa respectively. The woreda has 20 rural Kebeles and 2 semi-urban Kebeles. Kachabirra Woreda has limited land holding size, soil infertility, repeated year of drought, and decline livestock holding, have together resulted increased poverty in the area. The Woreda has become an area of acute and chronic food insecurity and in recent years has sought food aid regularly. The altitude of the study area ranges from 1900-2800meter above sea level. The maximum and the minimum temperature is 31°-18°c respectively. The landform consists of 5% plain, 30% plateau, and 65% sloppy and rugged terrain. Kachabirra Woreda has two major Agro ecological zones, 72.53% Dega and 22.47 % Weyna dega. The annual rainfall of the Woreda is 1200-1500 mm. The main soil type of the Woreda is loamy soil. Agricultural activities are planned around the Belg rain that falls between January and May, the summer rain that falls between June-September.

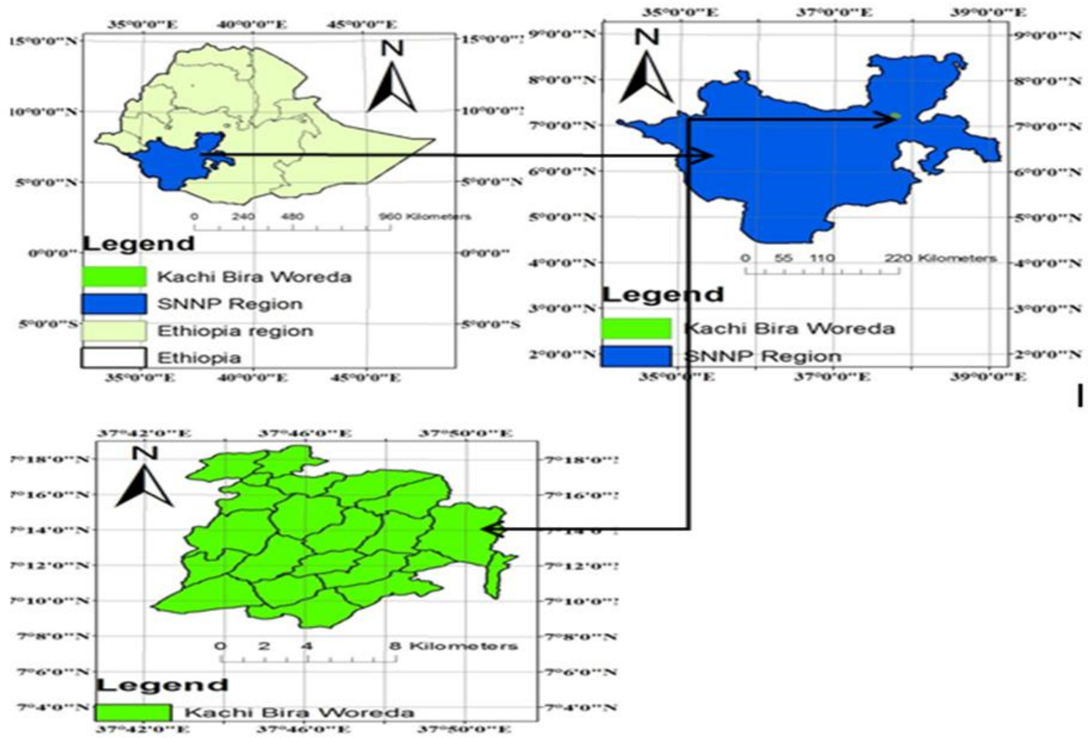


Figure 3.1 Location of the study area

3.2 Research Population and Sampling Method

The study population includes three gravel roads that are located around Kachbira town and Anegacha town. The selected roads were about 23km in length. These roads are Kachbira – Ladda Kebele (5km), Chacha –Durame(10) and Shone Mazoria (8km). All roads are governed by SNNPR Rural Roads Authority.

The sample road segment for economic comparison were 1 km, which was taken from Kachbira town – Anegacha (0.2km), Chacha – Durame – Shone Mazoria (0.8 km) .The selection of the length of the segments from sample road follows no scientific method and it was determined by the difficulty of data collection of the specific road and the weather conditions of the area when the initial observation was conducted.

The gravel materials, 40kg each, were selected from three quarry sites using random collection. Out of the three samples, gradation were performed to select the gravel for further laboratory experiment. Quartering method were performed to select the materials for other laboratory experiment.

Interview were performed randomly out of the population form the local community and URRAP personnel to check the performance and economics of the gravel road

3.3 Research Design

Experimental research design were applied to evaluate the applicability of the gravel materials. Qualitative and quantitative research were applied to check the performance and cost effectiveness of the road in question

The methodologies adopted to achieve the objectives are outlined as follows:

- ✓ Review of applicable practices, research findings and other relevant information on sub base material pavement performance and materials used for the wearing course of gravel road.
- ✓ Relevant literatures on current engineering property of gravel material, performance and serviceability approach various modes of failure and damage propagations have been reviewed.
- ✓ Data collection has been carried out in the study site "Kambat zone URRP gravel road route. The necessary data collected were: Questionnaire had been filled by the users (drivers) on the site. Sample data for CBR test had been collected on site in the case study site for strength test.

Finally the sampled locally produced gravel surfacing material data collected from the field was tested in highway laboratory, and the strength result on the test to indicate performance level of the materials strength.

3.3. Data Collection

Data collected for the analysis were obtained from design documents and through field measurements and have shown different characteristics. Engineering properties of gravel material, cost effectiveness and performance and strength test of subgrade soil data were well collected in the site and laboratory for the analysis of the performance level of the gravel as surfacing material.

3.3.1 Primary data collection

Actual field investigation and measurements or survey works including simple observation of road project at the sites is required to collect the necessary data to know the present condition of the scheme and structure. These include

- ❖ Photograph of the site and structure.
- ❖ Observation and interview on the performance
- ❖ Field dimensions like width, length, slope and shape.
- ❖ Sampling of localy produced gravel from quarry
- ❖ Laboratory experiment results

- Sub grade soil lab test data
- Rainfall data
- Traffic data

3.3.2 Secondary data

The data available for the study is to be collected from the past reports and file kept by responsible organization for further interpretation and analyses. The important data for the study includes:

- Design document of road and structure
- Operation and maintenance costs

3.4. Data Analysis

Data were analyzed using table, graph and word interpretation and compare with references.

3.5 Study variable

3.5.1 Dependent variable

Applicability of localy produced gravel as surface material

3.5.2 Independent variables

- Engineering properties
    - Plasticity Index
    - Plasticity product
    - Compaction
    - Grading
    - Californian Bearing Ratio (CBR)
    - Los Angeles Abrasion
- Cost effectiveness and performance

5.6 Materials used for the study

- Digital video camera, to catch up the structure of road
- CBR Machine
- Sieves stacked on sieve shaker
- Atterberg's Limit apparatus

3.7. Methods and Procedures for Obtaining Traffic Data

One of the basic measures of the traffic demand for a highway is average daily traffic (ADT). The ADT is defined as the total volume during a given time period (in whole period), greater than one day and less than one year, divided by the number of days in the time period (AASHTO, 2004).

The type of traffic in each day was recorded using standard table for traffic count. Since the observation was in summer season, i.e. it starts and ends in summer (July, August and September), traffic volume was collected for about one week for each road section. For the road which is managed by SNNPR Rural Roads Authority, two directional volumes were collected for about one week and for 16 hour in each day. The traffic at the night level was recorded for two days and found to be insignificant and only the day traffic was included in the analysis for the two road section (Kachbira town – Anegacha and Chacha –Durame –Shone Mazoria The table used for data collection was found in appendix B. For the road in federal roads authority (Durami-Shenshicho), ADT for 2011 was obtained from ERA and forecasted for 2014 using growth factor of 6 % (Durami-Shenshicho upgrading project).

3.8. Methods and procedures for obtaining mean monthly precipitation on the roads

The rainfall data of the two towns were collected form Ethiopian Metrological Agency. For Kamebat- Temebaro rainfall history of 2008-2009 was used, since this was the only available historical data obtained from the agency. In case of this research, the three month precipitation (July, August and September), was averages to had single values. This was done to reduce the difficulties that would be encountered in using each month precipitation data in the engineering property of gravel material.

3.9. Methods and procedures for obtaining California bearing capacity (CBR)

California bearing capacity (CBR) is one of the most widely used tests for evaluating the strength of sub grade, sub base and base course support value that is the bearing capacity of the pavement or gravel material (Donald Walker, 2002).

The CBR strength of the material evaluation method covers the laboratory determination of the California Bearing Ratio (CBR) of a Compacted or undisturbed sample of soil. The principle is to determine the relation between force and penetration when a cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. At certain values of penetration the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio (CBR).

Based on ERA manual, for the sub-base material the minimum soaked California Bearing. Ratio (CBR) shall be 30% when determined in accordance with the requirements of AASHTO T-193.

The Californian Bearing Ratio (CBR) shall be determined at a density of 95% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method D (Robert A. Eaton and Ronald E. Beaucham, 1992).

According to ERA specification, all sub-base materials shall have a maximum plasticity index of 6 when determined in accordance with AASHTO T-90. The plasticity product (PP = PI x percentage passing the 0.075mm sieve) shall not be greater than 75 %(Ken Skorseth and Ali A. Selim, Ph.D., P.E, 2000).

Design of the various pavement layers is very much dependent on the strength of the sub grade soil over which they are going to be laid for the thickness of the gravel wearing course the CBR is deterministic strength factor for the sub grade and the top wearing sub base material. Sub grade strength is mostly expressed in terms of CBR (California Bearing Ratio). Weaker sub grade essentially requires thicker layers whereas stronger sub grade goes well with thinner pavement layers. The pavement of the gravel bearing capacity and the sub grade bearing capacity mutually must sustain the traffic volume (Stevens, L.B, 1985).

A minimum CBR of 30 per cent is required at the highest anticipated moisture content when compacted to the specified field density, usually a minimum of 95 per cent of the maximum dry density achieved in the ASTM Test Method D 1557 (Heavy Compaction) for gravel surface wearing course material used according to ERA 2002 manual.

In these circumstances, the bearing capacity should be determined on samples soaked in water for a period of four days. The CBR test should be conducted on samples prepared at the density and moisture content likely to be achieved in the field. In order to achieve the required bearing capacity, and for uniform support to be provided to the upper pavement, limits on soil plasticity and particle distribution may be required, materials which meet the recommendations of the required specification.

Particle size distribution for sub -base materials which will meet the strength requirements to use as wearing course in gravel unsealed road.

Table 3.1 Particle size distribution for sub base materials which will meet the strength requirements to use as wearing course in gravel unsealed road

Test sieve(mm)	Percentage by mass of total aggregate Passing test sieve (%)
50	100
37.50	80-100
20	60-100
5	30-100
1.180	17-75
0.30	9-50
0.0750	5-25

3.10. Methods and Procedures for Obtaining Plasticity Index

The data concerning the surfacing material of the gravel road was obtained by the laboratory test of the sample material. Sample material was obtained from the quarry site of each road. The needed output of the test was plasticity index. Standard procedure, (ASTM, D4318-10) was used to obtain the liquid limit and plastic limit of the sample material of each road. After the plasticity index was obtained, the type of the surfacing material was determined by figure 3.2.

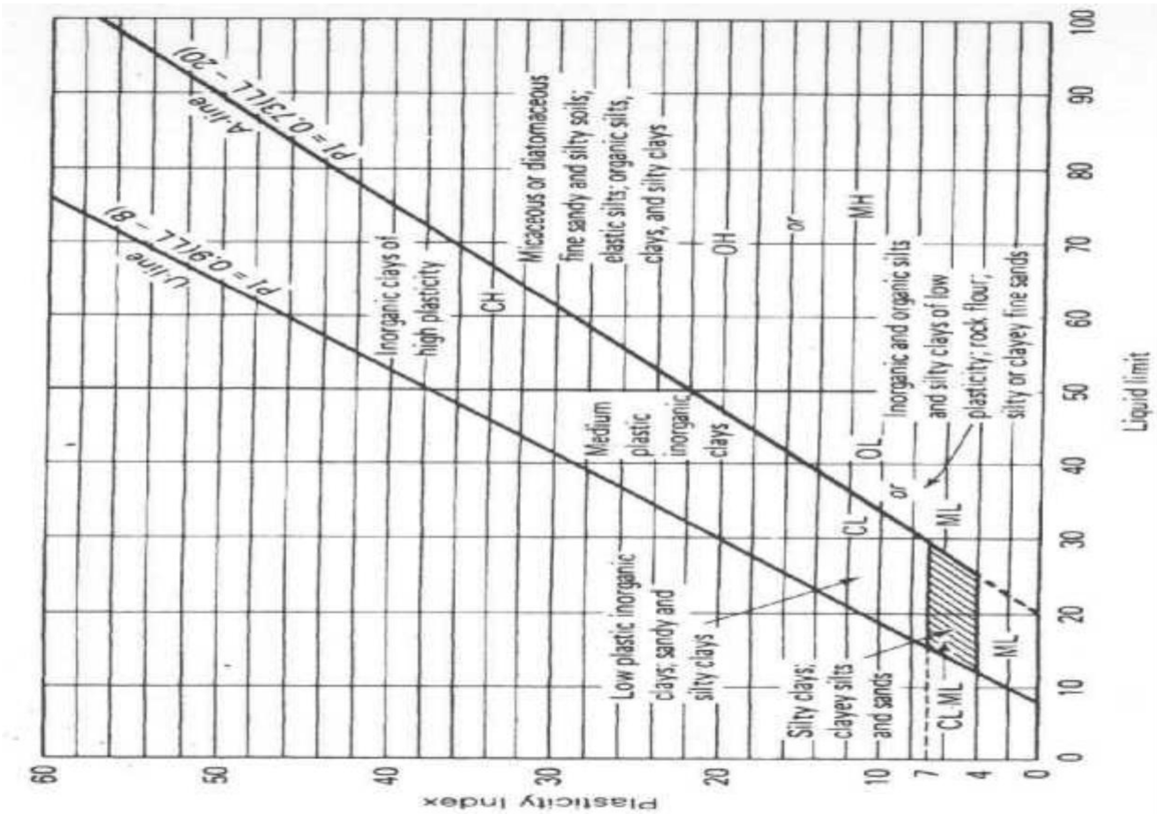


Figure 3.2 Figure 3.2 Soil behavior determination chart for USCS method of soil classification

3.11. Methods and procedures for obtaining gradient of the roads

The data regarding the absolute gradient of the road was obtained by the help of total station. The elevation difference between 5m (for example between A2 and B2 of figure 3.3) was recorded as the height difference (a). The length of the road which was recorded as horizontal difference between the two points was calculated by Pythagorean formula.

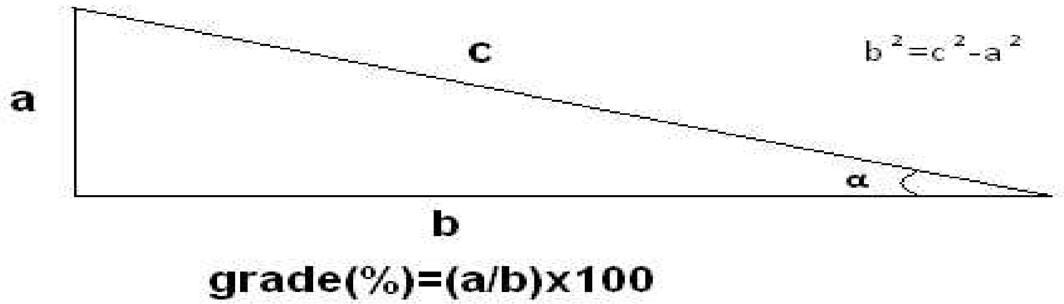


Figure 3.3 Calculation of gradient of the road

The absolute value of the observed gradient was used to eliminate the problem that will be encountered in using the model for different signs.

3.12. Methods and procedures for obtaining interview and observation roads

The data concerning to obtaining by asking the localy people to use the gravel road merit, demerit and impact of environmental and social to produced local gravel material from quarry and also ask the deriver the importance of the road and effect for passengers. An observed the gravel surfacing material road performance and effect of environmental and social impact by pollution of the environment.

CHAPTER FOUR
RESULTS AND DISCUSSION

After the data was collected as specified in the methodology section, it was analyzed using different mechanism and methods. The results of the analysis were explained in the consecutive sub sections.

4.1. Locally Produced Gravel Material Tests Results

One of the first things to be considered is the quality of the gravel in the locality, to determine whether it is, or can be made suitable for the purpose. As the quality of the gravel generally varies in the different deposits in the same locality and often in the same deposit, it is necessary that the person in charge of the selection, have a knowledge of the relation of the physical characteristics of the pebbles to the wearing qualities. Probably the best evidence is obtained by observation of the surface of a road on which similar material has been used.

The ideal gravel should consist largely of pebbles which are hard and tough and will offer great resistance to abrasion. They should be well graded from the coarse to fine particles. There should be intermingled with the particles some material which will bond them into a compact mass. A careful examination of the gravel, with regard to these characteristics, will give this information.

The hardness and durability of a gravel is determined by the composition of its pebbles. With a knowledge of these ingredients, the relative hardness can be and usually is determined by visual inspection. It can also be determined to a fair degree by sorting out the pebbles from representative samples and testing them with a hammer. By means of weighing, the relative proportion in which the more durable materials are present, can be determined. The durability or resistance to abrasion may also be determined by use of the Deval machine. Pebbles of a certain size are weighed, placed in the steel cylinder, which is set at an angle of thirty degrees, together with a number of steel spheres, and the cylinder given about ten thousand revolutions at the rate of thirty-three revolutions per minute. The sample is then removed and passed over a No. 16 sieve. The material passing through is weighed and the per cent of loss determined.

Table 4.1 Results of MDD of proctor test

WT material to each trial (g)			5000				
Density		Trial number	1	2	3	4	5
	1	Weight of soil + mold g	9733	9885	9987	9903	
	2	Weight of mold g	5551	5551	5551	5551	
	3	Weight Of Soil, (1-2) g	4182	4334	4436	4352	
	4	Volume of mold cc	2194	2194	2194	2194	
	5	Wet density of soil, (3/4), g/cc	1.906	1.975	2.022	1.984	NMC
Moisture	6	Container number	P	K	e	I	L
	7	Wet soil + container g	202	173	192	184.	210.0
	8	Dry soil + container g	171	146.4	161	152	193
	9	Weight of water, (7-8) g	31.0	26.6	31.0	32.0	17.0
	10	Weight of container g	27	30	31	30	34.0
	11	Weight of dry soil, (8-10) g	144	116.4	130	122	159
	12	Moisture content, (9/11)*100, %	21.5	22.9	23.8	26.2	10.7
	Dry density of soil, (5/(100+12))*100, G/Cc		1.568	1.608	1.633	1.571	

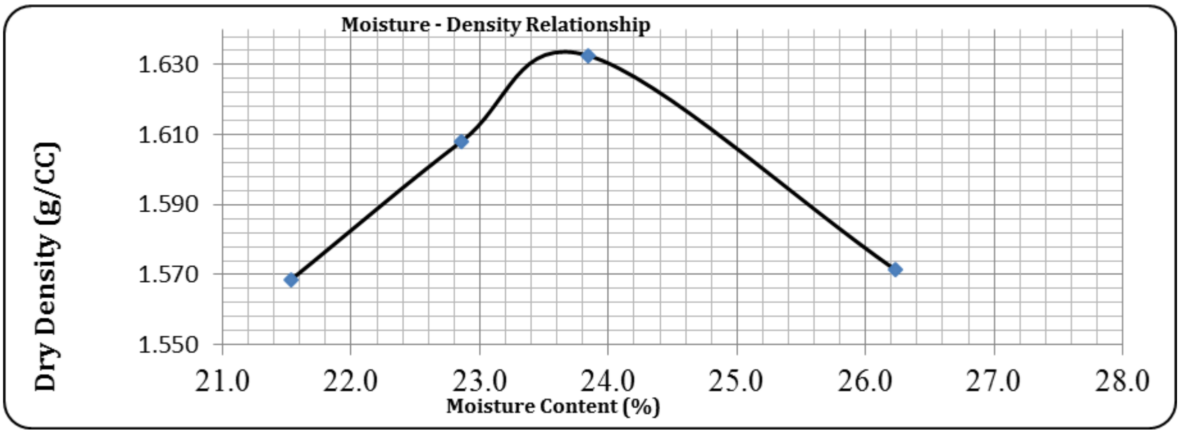


Figure 4.1 Moisture density relationship

The material density result was shown in figure 4.1 has obtained that the maximum dry density of the sample was 1.635 g/cc and the maximum moisture content by percent was 23 .6% .this moisture density relation curve from proctor test result shows up to optimum moisture content density of the material was increasing after that the density of the gravel was decreased increasing of the moisture content this is because the surfacing material was not needs more water in site during construction to compact the layer of gravel road .

Table 4.2 Results of CBR test

Density Determination						
Soaking Condition	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
Mold number	c	c	m2	m2	i	i
Weight of soil + mold g	10313	10475	10465	10574	10542	10613
Weight of mold g	6500	6500	6472	6472	6413	6413
Weight of soil g	3813	3975	3993	4102	4129	4200
Volume of mold cc	2036	2036	2036	2036	2036	2036
Wet density of soil g/cc	1.873	1.952	1.961	2.015	2.028	2.063
Dry density of soil g/cc	1.516	1.545	1.575	1.618	1.647	1.681

Moisture Determination									
Soaking Condition	10 Blows			30 Blows			65 Blows		
	Before	After		Before	After		Before	After	
		Top 1 In.			Top 1 In.			Top 1 In.	
Container Number	m	t		q	h		a3	0	
Wet soil + container g	202.0	188.0		219.0	224.0		214.0	167.0	
Dry soil + container g	169.0	155.0		182.0	186.0		180.0	142.0	
Weight of water g	33.0	33.0		37.0	38.0		34.0	25.0	
Weight of container g	29.0	30.0		31.0	31.0		33.0	32.0	
Weight of dry soil g	140.0	125.0		151.0	155.0		147.0	110.0	
Moisture Content %	23.6	26.4		24.5	24.5		23.1	22.7	
Avg. Moisture Content %									

Penetration Test Data												
Penetration	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		0.00			0	0.00			0	0.00		
0.64	21	0.91			17	0.73			24	1.03		
1.27	42	1.81			55	2.37			63	2.72		
1.96	63	2.72			107	4.61			122	5.26		
2.54	86	3.71	3.7	27.7	149	6.42	6.4	47.9	172	7.42	7.4	55.4
3.18	96	4.14			194	8.36			219	9.44		
3.81	109	4.70			264	11.38			258	11.12		
4.45	121	5.22			274	11.81			291	12.55		
5.08	132	5.69	5.7	28.6	308	13.28	13.3	66.7	321	13.84	13.8	69.2
7.62	210	9.05			514	22.16			570	24.58		
10.2												
12.7												

Table 4.3 Swell test result

Swell % [Height of Specimen (mm) = 116.43]			
No.of Blows	10	30	65
Read (Before Soaking)	0	0	0
Read (After Soaking)	0.22	0.42	0.1
Percent Swell	0.19	0.36	0.09
Average Percent Swell :	0.21		

Table 4.3 results shows the swelling of the gravel surfacing material in water soaking condition the testes done in different number of blows that is 10, 30 and 65 blows this different blows shows different swelling values i.e. 0.22, 0.42 and 0.36 respectively this was because the same material in different compaction differ water absorption content in depending on compaction of material this results shows the material water absorption behaviors and void space of the material was low due to this reason the results shows to satisfying ERA or AASHTO specification i.e. the average value of swelling was 0.21 % less than 2 % .therefore the surfacing material was satisfying quality tests and material it was possible to surfacing for URRAP road and others.

Table 4.4 Density moisture in soaking curve result

Blows	Before Soaking		After Soaking	
	DD (g/cc)	Moisture (%)	DD (g/cc)	Moisture (%)
10	1.516	23.6	1.54	26.4
30	1.575	24.5	1.62	24.5
65	1.647	23.1	1.68	22.7

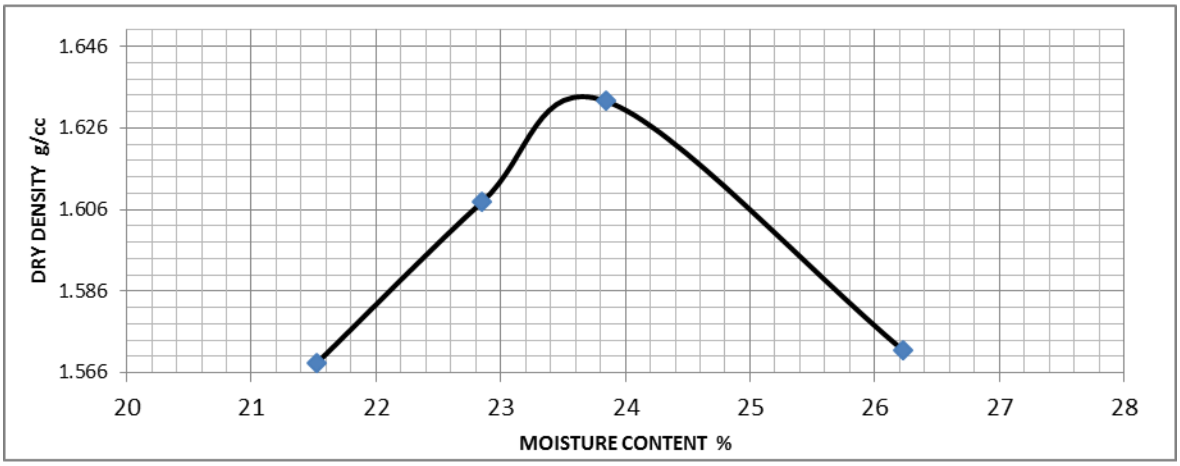


Figure 4.2 Moisture density relationship

The minimum in- situ dry density of sub-base material shall be as specified here in after for the layers in terms of a percentage of modified AASHTO density was 95% or 97% as required for material from this specification limit the tested gravel surfacing material density was 97% therefore the material was located in limitation this show the surfacing material was the maximum compaction requirement in constructed site to gate this density. The material density for CBR Procter test result was shown in figure 4.2 has obtained that the maximum dry density of the sample was 1.635 g/cc and the maximum moisture content by percent was 23 .6%.

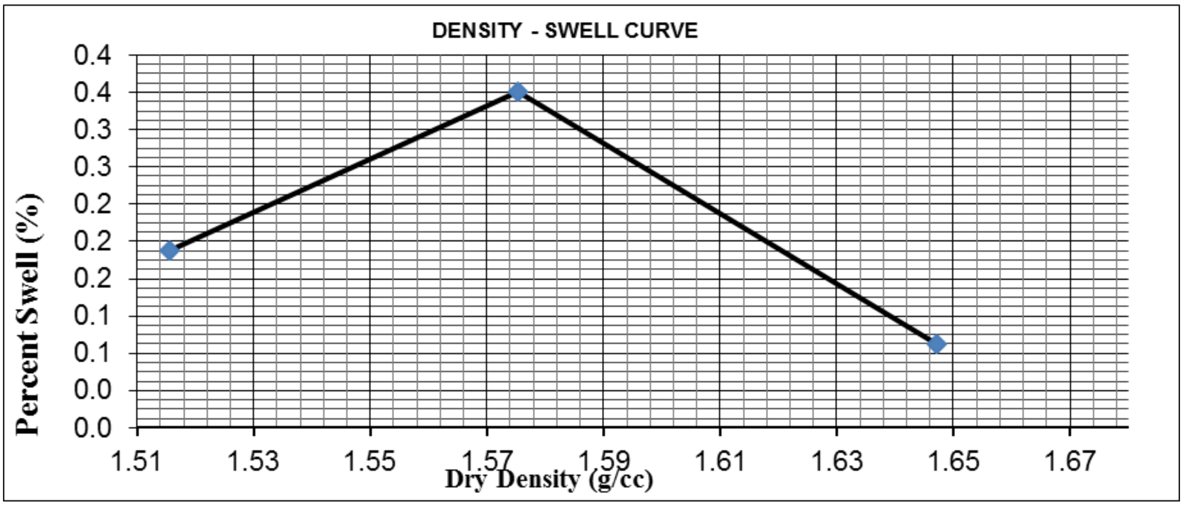


Figure 4.3 Density swell curve

The material density and swell for CBR soaked @97% MDD Procter test result was shown in figure 4.3 has obtained that the maximum dry density of the sample was 49.0% and the maximum swelling was 0.2%.

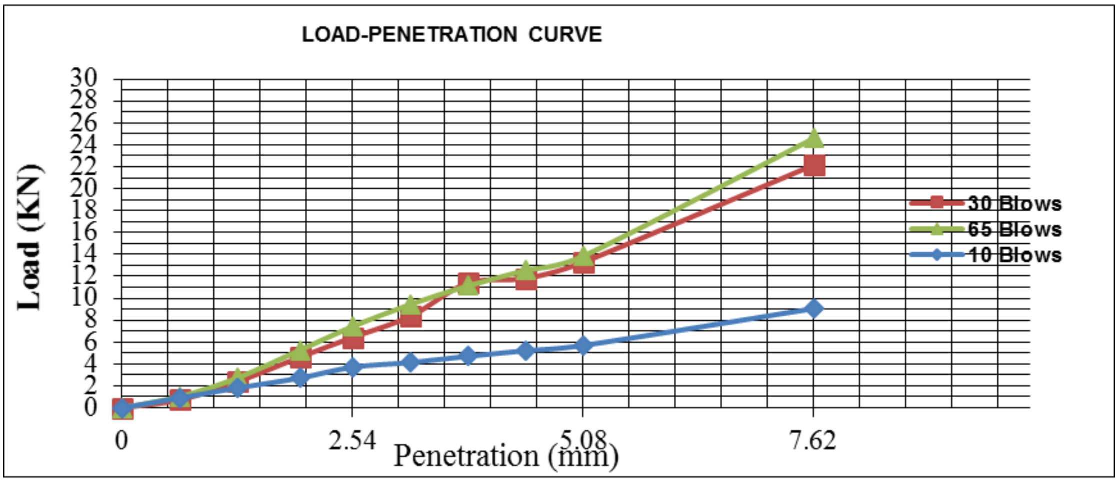


Figure 4.4 Load penetration curve

The material CBR soaked @97% MDD load penetration in 30 blows, in 65 blows and in 10 blows test result was respectively shown in figure 4.4 has obtained that to see the standard penetration point's i.e. 2.54 , 5.08 and 7.62 with respective load by this process to read load vs. CBR values at the same time and at standard penetration point from this the above fig was done this fig shows the penetration was directly preoperational to load and

CBR if load is increasing penetration and CBR also increases this also depending on compaction because number of blows increasing needs high load and CBR value also increasing at standard penetration point .Therefor the result shows in fig 4.4 surfacing material needs high compaction to resists high load bearing capacity and the material was safe for getting high compaction to support any load this tell as the material is best material for surfacing of URRAP road construction.

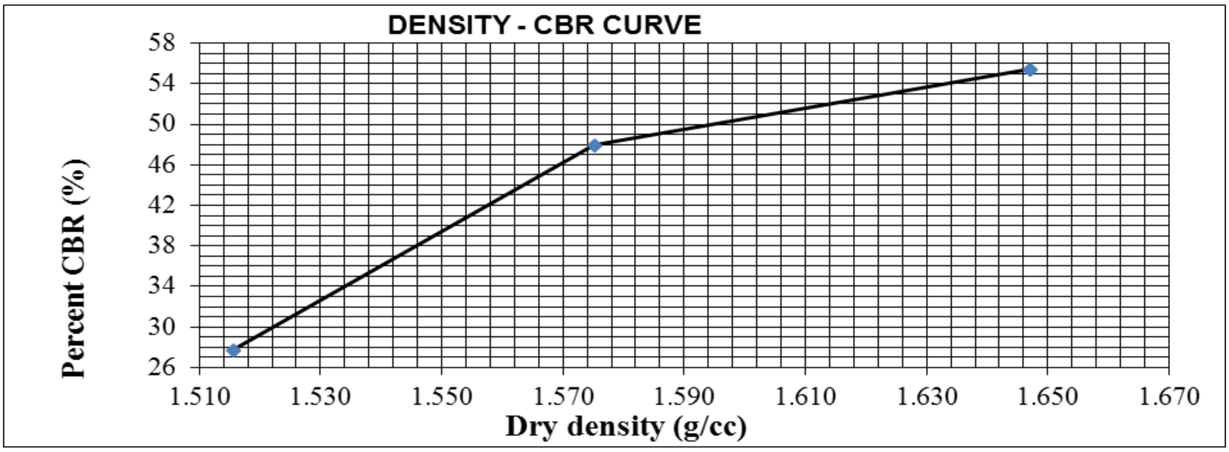


Figure 4.5 Density CBR curve

The minimum soaked Californian Bearing Ratio (CBR) shall be 30% when determined in accordance with the requirement of AASHTO T-193. The Californian Bearing Ratio (CBR) shall be determined at a density of 97% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method D from this specification the material test result of CBR was from above fig 4.5 for this study was 49% this result shows the CBR value was satisfied the AASHTO T-193 requirement ,therefore the gravel material was fulfill quality test standard and the material was best material of gravel road surfacing for URRAP road construction in case of Kambatta Tambaro zone URRAP road surfacing .

Table 4.5 Result of PI test

		Liquid Limit			Plastic Limit	
Test No.		1	2	3	1	2
Number of blows		31	25	19		
Container No.		8	30	19	2	8
Wet Soil+Cont (g)		30.00	45	45	21	21
Dry Soil+Cont (g)		27	38.00	37.50	20.50	20.30
Mass Container (g)		18	18	18	18.40	18
Mass Moisture (g)		3	7	7.5	0.50	0.70
Mass Dry Soil (g)		9	20	19.5	2.10	2.30
Moisture Content (%)		33.33	35.00	38.46	23.81	30.43
Average		35.60			27.12	

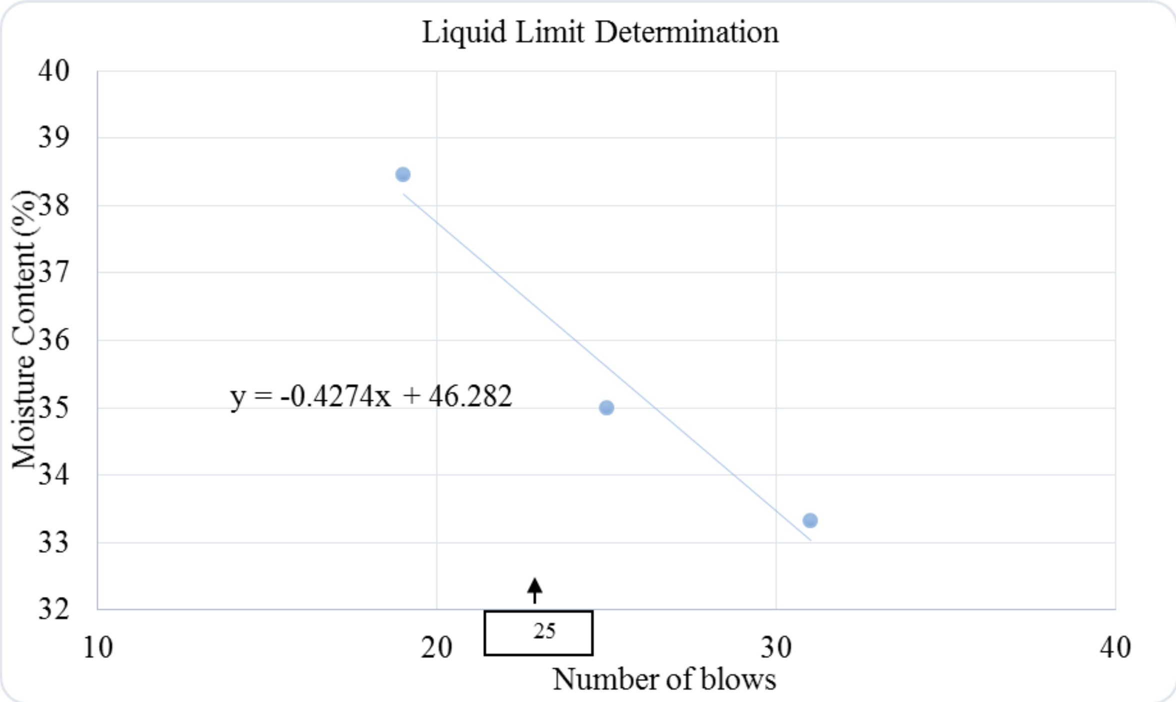


Figure 4.6 Liquid limit determination

All gravel materials shall have a maximum Plasticity Index of 6 or 12, as described in the Contract, and when determined in accordance with AASHTO T-90. The plasticity product (PP = PI x percentage passing the 0.075mm sieve) shall not be greater than 75. From this specification the tested gravel material of the Plasticity Index of the material was equal to 8.5 this show PI was interval of 6 to 12 therefore the tested result was satisfied AASHITO T-90 specification. But, the plasticity product of the material was equal to 153 this result is not satisfied AASHTOT T-90 standard so, the gravel material was not suitable for gravel road construction in case of plasticity product AASHTO T-90 specification but I recommended that the material was it is possible for gravel road construction in URRAP road project in case of Kambatta Tambaro zone URRAP road construction because studied road traffic was 67veh/day up to 10 years and the rain fall of the area was low than low volume road standard i.e. 177mm/month for result the material is recommended for surfacing material for URRAP program.

Table 4.6 Gradation test

		Trial-1			Trial-2				
		Total weight before washing (gm) =		10536	Total weight before washing (gm.) =		10553		
		Total weight after washing (gm) =			Total weight after washing (gm) =				
Sieve Sizes (mm)	Weight Retained (g)	Cumulative Pass		Weight Retained (g)	Cumulative Pass		Average of % passing	Spec-Limit	
		%retain	%pass		%retain	%pass		lower	upper
			100			100			
63	374	3.55	96.45	335	3.17	96.83	97	100	100
50	1105	10.49	85.96	329	3.12	93.71	90	90	100
25	3132	29.73	56.24	3591	34.03	59.68	58	51	80
4.75	1528	14.50	41.73	1742	16.51	43.17	42	34	70
0.075	2863	27.17	14.56	2373	22.49	20.69	18	5	15

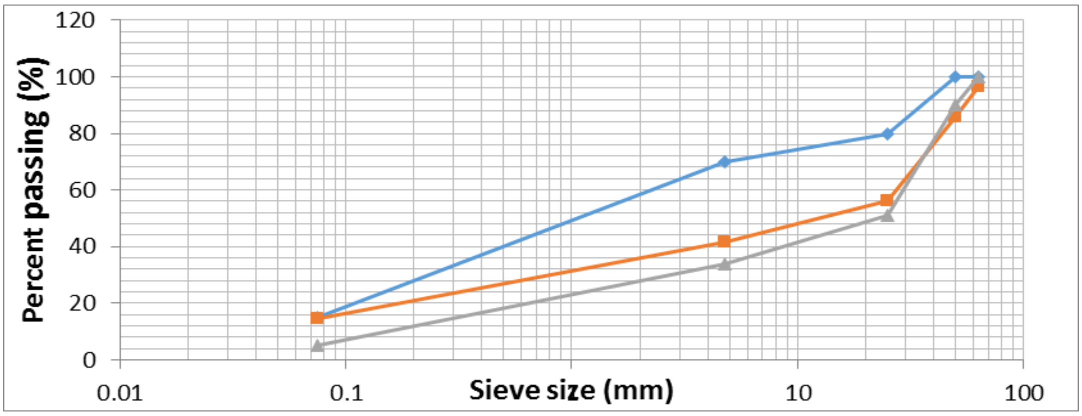


Figure 4.7 Gradation test

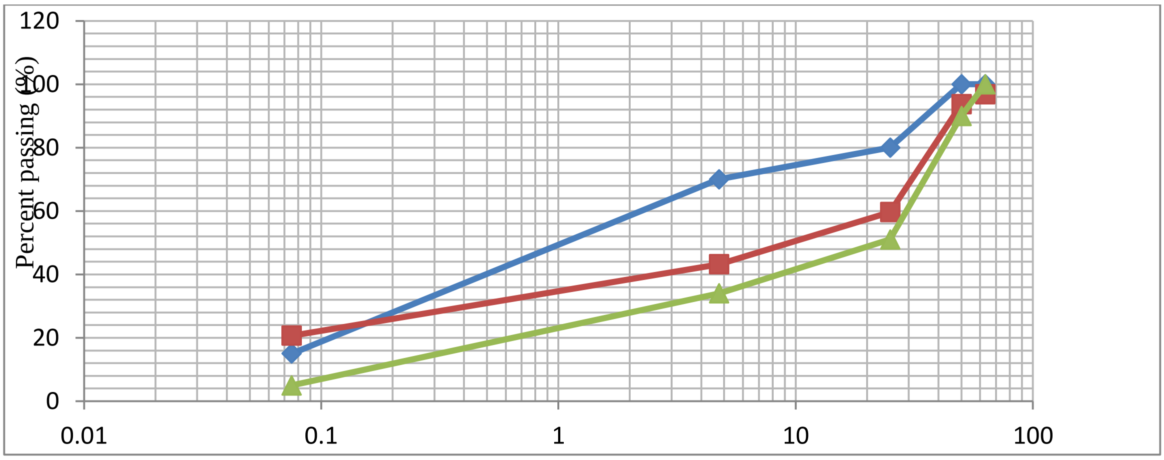


Figure 4.8 Gradation test trial 2

The gravel material shall comply with one of the grading shown in Table 5104/1 as described in the Contract. The material shall have a smooth continuous grading within the limits for grading A, B or C from this limit the tested material was in grade A standard according to AASHTO specification And the tested result of the gravel material was shown in fig not out of the upper and lower limitation this decided that the material suitable for surfacing material for UURAP gravel road construction. The complete gravel contain no material having a maximum dimension exceeding two-thirds of the compacted layer thickness. Gravel material shall unless otherwise authorize conform following requirements when finally placed.

Table 4.7 Grading of test samples and oppression test results.

Grading of Test Samples										
Sieve Size (mm)		Mass Of Indicated Sizes,gm								
		Grading								
Passing	Retained on	A		B			C		D	
37.5mm (11/2in.)	25mm (1in.)	1250±25		------			------		------	
25mm (1in.)	19mm (3/4in.)	1250±25		------			------		------	
19mm (3/4in.)	12.5mm (1/2in.)	1250±10		2500±10			------		------	
12.5mm (1/2in.)	9.5mm (3/8in.)	1250±10		2500±10			------		------	
9.5mm (3/8in.)	6.35mm (1/4in.)	------		------					------	
6.35mm (1/4in.)	4.75mm(No.4)	------		------			2500±10		------	
4.75mm(No.4)	2.36mm (No.8)	------		------			------		5000±10	
Total ,gm		5000±10		5000±10			5000±10		5000±10	
Abrasion Test Results										
Grading of Test Samples		Grade A		Grade B			Grade C		Grade D	
Mass of Charge, gm		5000±25		4584±25			3330±20		2500±15	
Number of Spheres		12		11			8		6	
Test No.		1	2	3	1	2	1	2	1	2
A.Original Mass of Test Sample,gm		5000	5000							
B. Final Mass of Test Sample after 500 Revolution (Retained on NO. 12 Sieve(1.70mm)),gm		974	970							
C. mass of sample pass sieve no.12 (1.70mm) (A-B) gm		4026	4030							
Percentage of Wear/Loss ,C/A*100 %		80.52	80.60		-	-	-	-	-	-
Average of LAA (T1+T2+T3…TN)/N %		80.6		-			-		-	

The Los Angeles abrasion value shall not exceed 51% when determined in accordance with the requirements of AASHTO T-96 depending on this specification the tested gravel surfacing material was not satisfied requirements of AASHTO T-96 standard i.e. the gravel material test result was 80% but the standard value of AASHTO T-96 was not exceed 51% in this case the material was not test quality satisfied but I recommended the material was it is possible for URRAP road construction because the testes result was depended on the vehicle load but on that road the vehicle load was minimum than the recommended in low volume road standard value and the subgrade of the road was to support any load from this information the surfacing material it is possible in Kambatt Tambaro zone gravel road surfacing specially.

Table 4.8 Summary of material testing results

No	Test Performed	Applicable Standard	Acceptance Criteria	Test Results
1	Sieve Analysis	AASHTO T 27	Tec.Specification, 5100(b)	ERAMANUAL 2002 TABLE 5104/1
2	Plasticity Index %	AASHTO T 89	<12	8.5
3	Plastic product %	AASHTO T 90	<75	153.0
4	MDD (g/cm^3)	AASHTO T 180	N/A	1.632
5	OMC (%)			23.7
6	CBR Soaked @ 97% MDD	AASHTO T193	>30%	49.0
7	Swell		<2%	0.2
10	LAA	AASHTO T96/ASTM C131	<51 %	80.60%

The material test result summary was shown in table 4.6 i.e. Plasticity Index %, Plastic product %,, MDD (g/cm3) and OMC (%),CBR Soaked @ 97% MDD and Swell, and LAA has all value putted above table.

The sample material of the wearing surface of the particular roads was taken from the respective quarry sites. The samples were appropriately stored and prepared for the laboratory test. The aim of the laboratory test was to have Sieve Analysis, the plasticity index, MDD, CBR, Swell and LAA are fulfills the specification of AASHTO manual each sample roads wearing surface material. Laboratory test result was summarized in table 4.8.The engineering property of locally produced gravel materials used for the wearing course of gravel road are determined by their components or ingredients of the material, generally the locally produced gravel materials consists of granular material ,gravel, , reclaimed(blended) material or a combination of these materials but the material used for gravel road is the natural selected material which fulfills the specification listed under 2002 Pavement design manual of ERA volume I and 2011 ERA LVR manuals in our country since this materials are used as pavement and gravel road is the portion of the highway which is most obvious to the motorist .

There should be improved and adequate testing and quality control arrangements and funding in place to approve gravel material sources, and confirm availability of the necessary quantities for both construction and maintenance needs. Furthermore sufficient material testing must be arranged to ensure that the material placed on site conforms to the specifications and contract requirements, and will not deteriorate under traffic.

The Decision Management System is based on the research carried out in Kambat Tambaro under the Universal Rural Roads Program (URRAP) of Gravel surfacing and Rural Road Surfacing Trials (RRST).

Natural gravel is often the cheapest method of upgrading an earth road to a better quality surface. However, a number of factors mean that in many circumstances in Kambat Tambaro gravel surfacing rural road, it is not the most appropriate rural road surface.

The Decision Management System guides the user through the objective process of assessing the various factors that influence the suitability of gravel for a specific rural road, or section of the road. Often the varying physical conditions and traffic along a route, including problem sections, will justify a composite approach. This may determine that some sections should be designed with different surfaces, pavement types or standards to achieve the most cost-effective and sustainable use of the limited resources available. When gravel is assessed not to be the most suitable option, the separate Matrix of Surfacing Options will further guide the user to identify the most appropriate surface options.

4.2. Traffic Count Results

A subjective and preliminary assessment of traffic on each road length was obtained by a combination of observation and discussion with PDoTs and local people. Table 4. 2presents a general summary of this data Traffic count was done to obtain average daily traffic of the selected roads. The highest traffic volume was encountered in Shinshicho –Shona Mazore and lowest traffic was observed on Shinshicho – Ladda –Sarara Roads. The average value of the traffic observed on the roads was 49veh/day.

Table 4.9 Traffic Volume of the Selected Roads

No.	Road name	Total km	ADT
1	Shinshicho –Shona Mazore	23	88
2	Shinshicho – Ladda –Sarara	6	10

4.3. Climatic Data Results

In general terms Kambata Tembaro zone is a low rainfall environment, and hence no erosion potential. This undoubtedly has no impact on the deterioration of the unsealed rural roads in Kambata Tembaro zone. However, the relative no effects of differential rainfall patterns within Kambata Tembaro zone are ease to assess from the URRAP gravel surfacing material data for a number of reasons:

- The apparently overriding influences of other factors such as material type and quality.
- Unsealed road condition information was available from the lowest rainfall provinces because the local authorities had already overlaid their gravel roads with more durable surfacing.
- The very localized and variable patterns of rainfall.

It may be possible, however, to undertake a more detailed assessment of road location and rainfall data to produce some correlation. An indication of this is the fact that, with a low annual rainfall figure of is one the best provinces as regards current road condition. The gathered data was analyzed to obtain the mean monthly precipitation of the two towns. Mean monthly precipitation of Kamebatta- Tmebaro zone it was 177.9mm/month. Since the two towns are neighbors, the historical precipitation data was not highly varied.shawon in Appendix B

Average of three month rainfall data= (Sum of Mean Monthly Precipitation)/(no of month)

= (Junuary+March+April)/3= (31.8+156+345.9)/3=177.9 (4.1)

4.4 Environmental and Social Aspect of Using Localy Produced Gravel

Today's gravel roads are a product of influences showing the effects in their location produced and of, course, the some influences affect todays gravel roads and will continue to affect them in the future .

The social factors such as history, political, and economics can affect the physical characteristics of gravel roads compare to road development in the early

Typical, this road followed the boundaries between farms or occupied the lands least suited for agriculture, and thus were often winding and poorly located.

Political events and decisions affecting gravel road including turnover of local elected or appointed officials changes in fixing jurisdiction and levying property and other taxes earmarked for roads.

More purely economic issues influencing gravel road including economic upswings and downturns that alter road budget allocation , fluctuation in the costs of materials used to surface or treat gravel road equipment change , and developments in local economics that affect how road are used . This was study focused in two aspect. i.e. Environmental Aspect and social Aspect

4.5 Construction Costs of Locally Produced Gravel Surfacing Material for 1 Km

Costs will vary considerably depending on a wide range of factors such as scale of works, cross section, management quality, material haul distances, technology used, finance costs, fuel costs, equipment utilization and support, labor costs, market conditions, payment arrangements, etc., and these should be carefully assessed for local circumstances.

Gravelling by heavy equipment usually requires considerable (and high risk) investment in expensive imported equipment. Labor and intermediate equipment approaches can be more attractive and cheaper for small local enterprises and communities, and small scale work. The principal factor influencing costs is the haulage distance as indicated in the example figure below. These costs include quarry development, loading and royalties for placed compacted material. Compacted gravel volume unit costs will be approximately 30% higher than for material volume measured loose in the vehicles.

Labor-based methods are significantly cheaper than equipment-based methods for similar types of road works (i.e. the same quality and standard) in both financial and economic terms in Ethiopia. The Regional Road Authorities using force account units, report that the average cost per kilometer for road construction using labor-based methods compared to equipment-based methods was 54% cheaper in financial terms and 60% cheaper in economic terms .Based on the average financial costs for every 1 Kilometer built using equipment- based methods 2.5 Kilometers could be built using labor-based methods.

Table 4.10 Example bill of quantities for 1km of 6 meter wide, 15cm gravel surface for a URRAP gravel road in Tambata Tambaro zone

Item	Description	Unit	Quantity	Birr per unit	Total Cost Birr
1	Setting up site operation, signs, safety, diversions etc.	Lump Sum		20000	20000
2	Clear worksite and repair drainage system	m	2000	5	30000
3	Setting out alignment and thickness controls	m	2000	7	14000
4	Preparation of formation or existing gravel surface	m^2	6*1000=6000	3	18000
5	Quarry clearing, preparation & haul road	Lump Sum		10000	10000
6	Excavate, load, haul and deposit gravel at road site, maximum ha	m^3	1000*6*0.3=1800	80	144,000
7	Earthworks	m^2	6*1000=6000	6	36000
8	Spread, water and compact gravel to 15cm final thickness	Lump Sum	1000*6=6000	6000	6000
9	Dismantling worksite and make good site and quarries			5000	5000
Total (birr)					236,000

Source; URRAP Road construction

Each activity to construct a gravel surface may be carried out using various technology options; from labor, through intermediate equipment to heavy equipment, depending on local circumstances. Therefore the construction costs of gravel road is lower initial cost than most other surfacing options for this case this locally produced gravel material is recommended as surfacing material for URRAP gravel road in case of Kambata Tambaro zone.

Table 4.11 Example bill of quantities for 300 m surface treatment asphalt cost

Description	Unit	unit rate	Design Quantity	Total amount
Earth Work				
Soft Excavation to Spoil	m3	80.00	2,540.00	203,200.00
Intermediate Excavation to spoil	m3	110.00	205.00	22,550.00
Hard Excavation to spoil	m3	410.00	180.00	73,800.00
Borrow to fill/embankment	m3	190.00	190.00	36,100.00
Capping Layer under the sub base layer	m3	210.00	1,517.69	318,714.90
			Sub Total	654,364.90
PAVEMENTS				
Subbase Compaction to 96% of AACRA Test S-11	m3	490.00	561.00	274,890.00
b. Side Walk			Sub Total	274,890.00
Capping Layer under the sub base layer	m3	210.00	401.00	84,210.00
15cm thick Gravel Subbase	m3	490.00	143.00	70,070.00
			Sub Total	154,280.00
MINOR STRUCTURES				
Excavating soft material				
0.0m up to 1.5m	m3	95.00	264.00	25,080.00
1.5m upto 3.0m	m3	105.00	74.00	7,770.00
Backfill using imported selected material	m3	250.00	155.50	38,875.00
Foundation fill consisting of compacted material	m3	250.00	110.00	27,500.00
Lean concrete	m3	2,000.00	10.85	21,700.00
Grade 420 steel reinforcement	kg	37.00	8,839.20	327,050.40
RC concrete cover (C-25) to be constructed on the manhole	m3	2,500.00	300.00	750,000.00
C-25 concrete	m3	4,500.00	84.84	381,780.00
1060mm RC pipe culverts	lm	3,500.00	15.00	52,500.00
Concrete lining for open drain (paved water way) on inlets and outlets of crossing culverts a	m2	350.00	18.00	6,300.00
Type B concrete curbing (450*180*1000mm)	lm	300.00	290.00	87,000.00
Type B concrete curbing (80*250*1000mm)	lm	250.00	580.00	145,000.00
Cement mortared stone walls	m3	1,500.00	-	-
retaining wall	lm	600.00	80	48,000.00
			Sub Total	1,918,555.40
TOTAL				2,727,200.2

Source; ERA

Therefor for 1 km of this asphalt road where 9,090,667 birr to comparing with gravel surfacing big difference depending on this cost gravel surfacing where recommended surfacing material for rural road construction in Ethiopia .

4.6. Evaluation of Gravel Road Wearing Course Material Performance

To a greater or lesser extent, all gravel roads will give off dust under traffic. After all, they are unpaved roads that typically serve very low volumes of traffic, and some dust will be generated from that traffic.

The amount of dust that a gravel road produces varies greatly depending primarily on the type of gravel, volume and type of traffic and annual precipitation. In areas of the country that receive a high amount of moisture, the problem is greatly reduced.

Dust can bring complaints in these areas especially if there are residences located directly adjacent to or near the road. The quality and type of gravel has a great effect on the amount of dust. For example, some limestone gravels will produce significant dust in a dry condition. But, some natural deposits of gravel that have some clay in the mix of material can take on a strong binding characteristic that will produce much less dust. Still, in prolonged dry weather the environmental pollution and dust emulation was be produced by virtually any gravel constructed by localy material surfacing UURAP road.

If traffic is high enough, road dust can impact the health of people and animals. There will be pressure to control the dust. On the other hand, the cost can be prohibitive and hard to justify.

The cost-benefit of doing this needs to be carefully considered. Most methods of dust control require annual treatment and it must be factored into annual maintenance costs.

For this problem gravel surfacing material performance was lost and this problem also effect of the environmental and social aspect problem is happened.

Based on the data collected from the study site, the performance or the serviceability of the wearing course of gravel road Kambat zone URRP gravel can be evaluated.

Table 4.11Observable distresses in the gravel road with their structural functional and load associated and non-load associated characteristics.

Table 4.12 Observation of the gravel road performance

Type of distress	structural	Functional	load associated	non-load associated	Comment
Loss of		×		×	Observed
Potholes	×	×	×		Observed
Rutting		×	×		Observed and
Erosion		×		×	not observed
Corrugations		×		×	Not observed
Loose	×		×		Not
Stoniness		×	×		Observed
Dust		×		×	Observed
Cracking	×		×	×	Not observed

During observation the gravel road performance in field the following distresses are shown Loss of gravel, Potholes, Erosion, Corrugations, Loose material, Stoniness, Dust and Cracking all this distresses are observed located in URRAP road in Kambatta Tambaro zone this because the material used for that road is not standard material and not proper compaction.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Gravel is the common material for URRAP gravel road construction. There was localy produced gravel at each region of Ethiopia. The need to check the applicability of this material performance and engineering property of the road position is crucial.

This research conceded that the use of the localy produced gravel surfacing material was satisfied from the ERA and AASHTO specification .The laboratory results summarized below.

- The laboratory results for the plasticity index is 8.5% which passes the requirement from EAR and AASHTO T 89 which should be less than 12%. This shows that the material pass the requirement.
- Plastic product for gravel surfacing material should be less than 75% from AASHTO T 90 and ERA Specification. In this research, laboratory test result shows 153% which concluded that the material did not satisfy the standard specification. The standard says that less than 75 percent plastic product is applied to areas where moisture content and humidity is high with annual rainfall intensity of 300mm/year. Since in the study area the annual rainfall is 177.9mm/year the plasticity product can be accepted. Reduction of smaller particles in the gravel will improve the plastic product of the tested gravel
- The Maximum Dry Density and Optimum Moisture Content for locally produced gravel surfacing material were taken as 1.632g/cm^3 and 23.7% respectively. This values was taken at 97% compaction which satisfy the standard of AASHT T 180.
- The soaked California Bearing Ratio at 97 % MDD for locally produced gravel surfacing material should be greater than 30% for AASHTO T193 and ERA Specification. In this research, laboratory test result for soaked CBR is 49.0%. Therefore the material satisfy the standard specification for locally produced gravel. The Swell factor of material was 0.2 from the laboratory results and from AASHTO T 193 and ERA, it should be less than 2% which shows that it satisfy the standard.
- The Los Angeles Abrasion Value shall not exceed 51% when in accordance with the requirements of AASHTO T-96. Depending from this specification, the tested gravel surfacing material did not satisfy the requirements of AASHTO T-96 standard because the gravel material test result was 80%. The vehicle characteristic

in the study area is ranging from light vehicle to medium vehicle so the gravel can fit the requirement for used. Additional the baring capacity of subgrade soil where satisfying quality test standard of ASHTO and ERA shown in Appendix.

Therefore the surfacing material from locally produced gravel located Kambbat-Tambaro zone fulfill 75 % of AASHTO and ERA specification by laboratory testing of material. It was concluded that the surfacing material can be use for URRAP road construction.

- Gravel surfacing materials should not be used for roads with traffic volume higher than 200 vehicles per day. For expected motor traffic levels of more than or equivalent to 100 vehicle per day, a whole life cost evaluation of gravel and other technically feasible surface options should be carried out. From this restriction, traffic count were observed to be 67veh/day which shows that the road should be gravel surfaced.
- Total cost of gravel surfacing material for 1km is 236,000 birr. Comparatively, the cost of macadam road is 9,090,667 Birr. The construction costs of gravel road has lower initial cost than other surfacing materials like macadam and asphalt. For this case, this locally produced gravel material is recommended as surfacing material for URRAP gravel road in case of Kambata Tambaro zone.
- The amount of dust that a gravel road produces varies greatly depending primarily on the type of gravel, volume and type of traffic and annual precipitation. In areas of the zone that receive a low amount of moisture, for this case the quality and type of gravel has a great effect on the amount of dust for this impact the health of people and animals can affected and the performance or the serviceability of the wearing course of gravel road was lost.

5.2 RECOMMENDATIONS

- From the laboratory results, it was recommended that the locally produced gravel can be used for gravel surfacing material in construction of URRAP gravel road.
- It is also recommended to further improve the plasticity product by decreasing the smaller material in the gravel materials.
- Stabilization can be applied to further increase the usability of the material in case of LAA value
- The use of these localy produced gravel should be maximized to help the local community increasing their income and lessening the unemployment in the area.
- Further study is recommended for other application of the material is any areas of construction.
- Good surface performance can be achieved by maintaining drainage system, selecting quality materials, grading/reshaping, ripping and reworking existing layers, re-graveling ad controlling vegetation. So these factors should be followed in dealing with gravel surfaced road

  .

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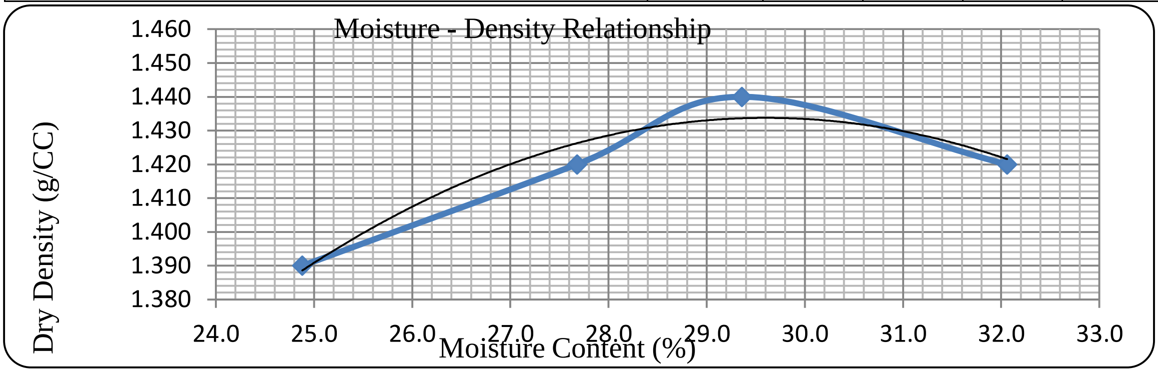
APPENDIXES

Appendix-1 Moisture - Density Relations of sub grade Soils Test Methods: AASHTO T - 180 , Method D

		Amount Of Water Ml Or **%**	400	500	600	700	
Density		Trial Number	1	2	3	4	5
	1	Weight of Soil + Mold (g)	9349	9521	9638	9687	
	2	Weight of Mold (g)	5560	5560	5560	5560	
	3	Weight of Soil, (1-2) (g)	3789	3961	4078	4127	
	4	Volume of Mold (cc)	2194	2194	2194	2194	
	5	Wet Density of Soil, (3/4), g/cc	1.73	1.81	1.86	1.88	NMC
Moisture	6	Container Number	h	D	Q	N	A1
	7	Wet Soil + Container (g)	184.4	188.3	188	181.8	175.4
	8	Dry Soil + Container (g)	153.90	154	152	144.9	155.3
	9	Weight of Water, (7-8) (g)	30.5	34.3	35.7	36.8	20.1
	10	Weight of Container	31.3	30.1	30.7	30.1	27.4
	11	Weight of Dry Soil, (8-10) (g)	122.6	123.9	121.6	114.8	127.9
	12	Moisture Content, (9/11)*100, %	24.9	27.7	29.4	32.1	15.7
Dry Density of Soil, (5/(100+12))*100, g/cc			1.39	1.42	1.44	1.42	



MDD Test Result

MDD g/cc	1.44
OMC %	29.3

Appendix-2. CBR Test Table of Subgrade Soil; AASHTO T 193

Soaking Condition	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
Mold number	j1	j1	p2	p2	i3	i3
Weight of soil + mold g	9805	10180	10040	10336	10205	10330
Weight of mold g	6446	6446	6395	6395	6443	6443
Weight of soil g	3359	3734	3645	3941	3762	3887
Volume of mold cc	2036	2036	2036	2036	2036	2036
Wet density of soil g/cc	1.650	1.834	1.790	1.936	1.848	1.909
Dry density of soil g/cc	1.137	1.468	1.203	1.577	1.233	1.564
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	k	l		o	m5		a	q	
Wet soil + container g	181.4	150.0		194.7	159.0		185.0	153.7	
Dry soil + container g	135.5	126.0		141.2	135.0		134.6	131.5	
Weight of water g	45.9	24.0		53.5	24.0		50.4	22.2	
Weight of container	33.6	29.8		31.7	29.6		33.4	31.0	
Weight of dry soil g	101.9	96.2		109.5	105.4		101.2	100.5	
Moisture content%	45.0	24.9		48.9	22.8		49.8	22.1	
Avg. moisture content %									

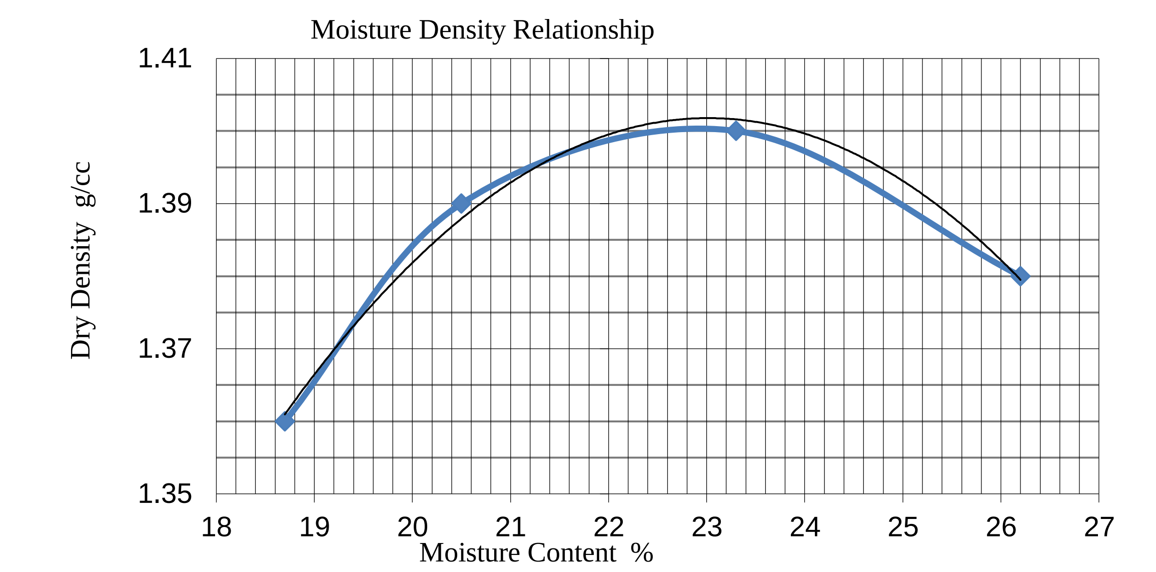
Penetration Test Data

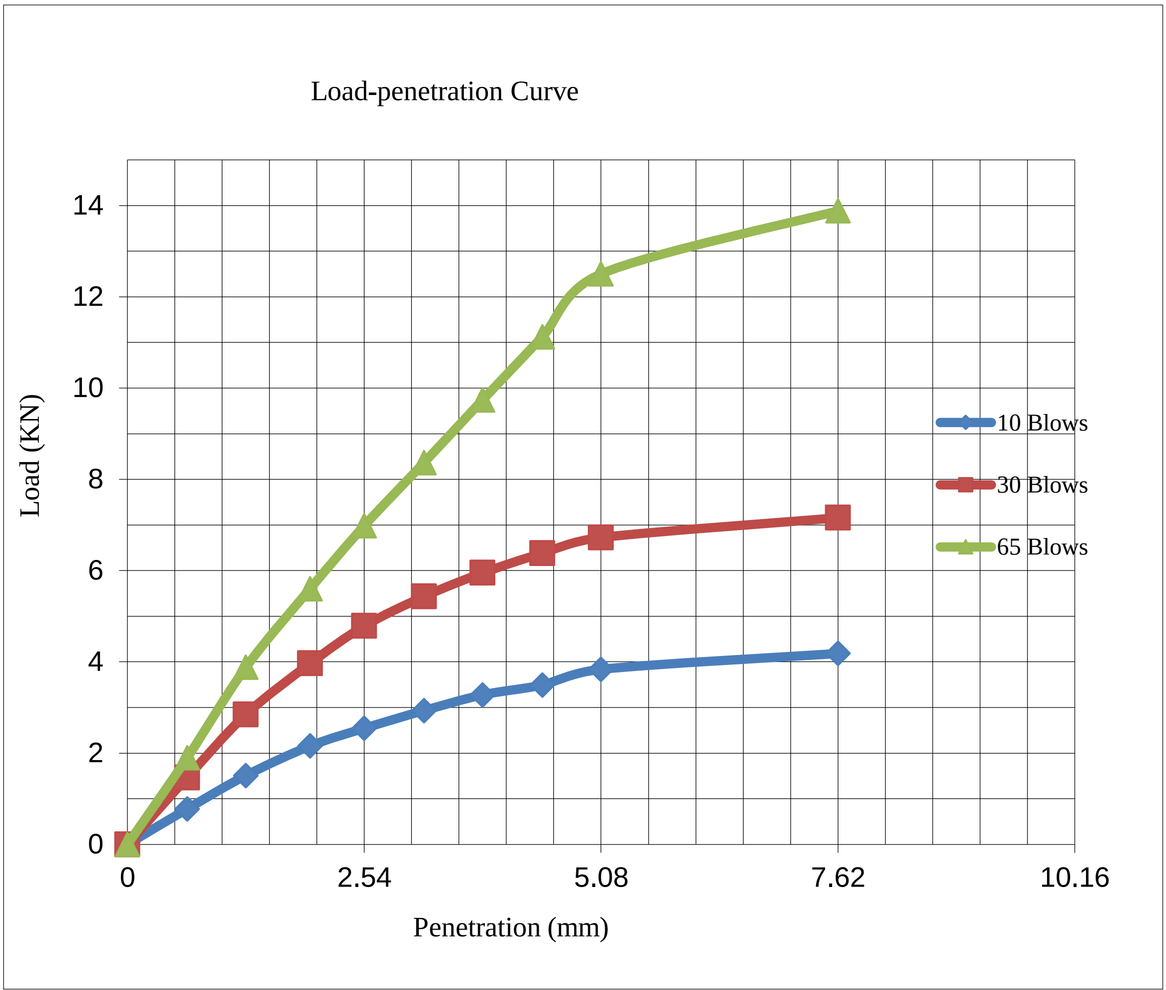
0	10 Blows				30 Blows				65 Blows			
(mm)	DIAL RDG	LOAD (kN)	COR.LOAD (kN)	CBR %	DIAL RDG	LOAD (kN)	COR.LOD (kN)	CBR %	DIAL RDG	LOAD (kN)	COR.LOAD (kN)	CBR %
0	0	0.00			0	0.00			0	0.00		
0.64	18	0.78			34	1.47			44	1.90		
1.27	35	1.51			66	2.85			90	3.88		
1.96	50	2.16			92	3.97			130	5.60		
2.54	59	2.54	2.5	19.3	111	4.79	4.8	36.0	162	6.98	7.0	52.4
3.18	68	2.93			126	5.43			194	8.36		
3.81	76	3.28			138	5.95			226	9.74		
4.45	81	3.49			148	6.38			258	11.12		
5.08	89	3.84	3.8	19.2	156	6.73	6.7	33.6	290	12.50	12.5	62.7
7.62	97	4.18			166	7.16			322	13.88		
10.16												
12.7												

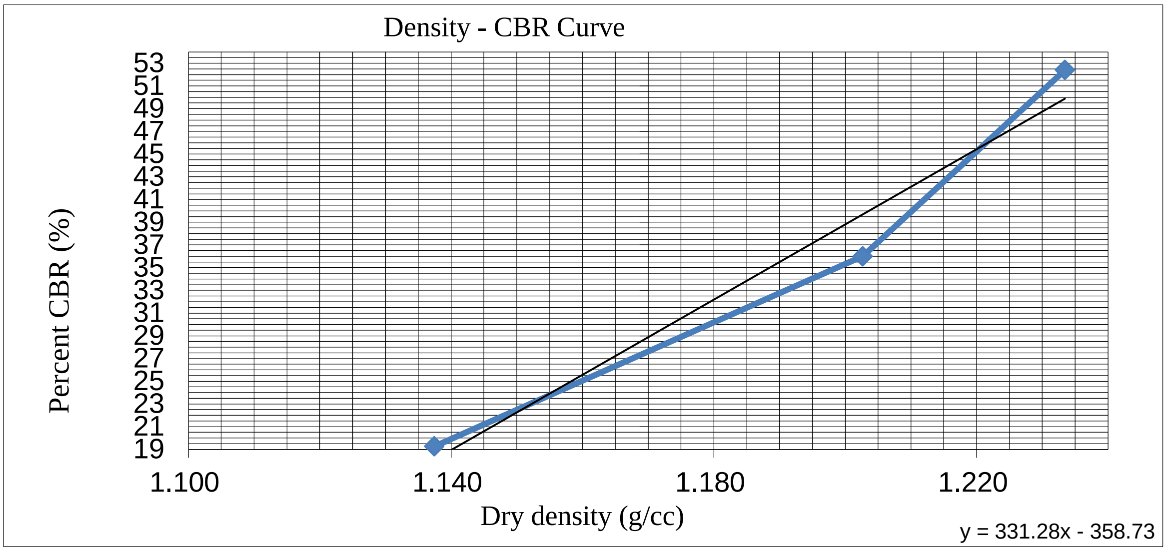
Swell Test Result

Swell % [Height of Specimen (mm) = 116.43]			
No.of blows	10	30	65
RDG (before soaking)	0	0	0
RDG (after soaking)	0.92	0.75	0.5
Percent swell	0.79	0.64	0.43
Average percent swell	0.62		

Moisture - Density Relationship of Soils: AASHTO T - 180, Method D







Blow	Dry Density (g/CC)	CBR (%)	Swell (%)
10	1.14	19.27	0.79
30	1.20	36.00	0.64
65	1.23	52.40	0.43
CBR at 95 % of MDD (%):			32%
Percent Swell (%):			0.62%

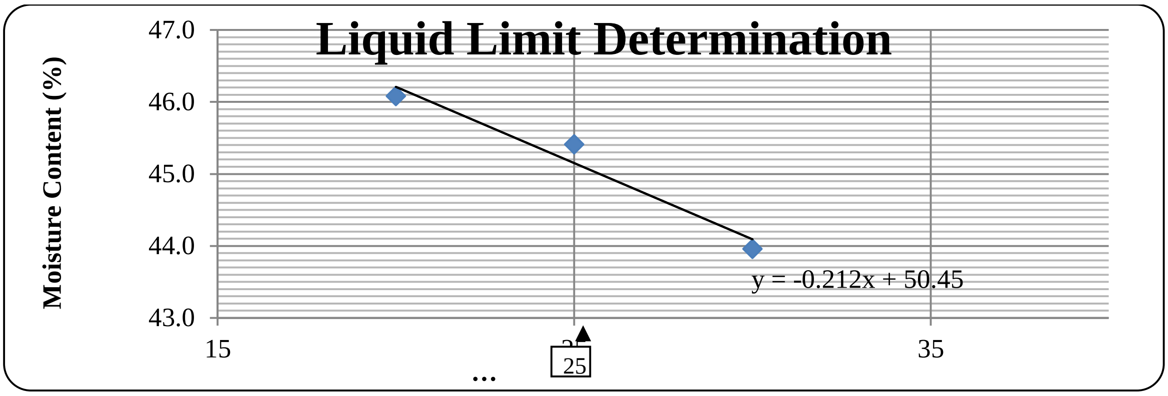
Appendix-3 PI TEST

Test No.	Liquid limit				Plastic limit	
Number of blows	1	2	3	4	1	2
Container No.	30	25	20			
Wet Soil+Cont (g)	16	25	8		b1	6
Dry Soil+Cont (g)	47.3	49.2	49.4		20.50	20.5
Mass Container (g)	38.20	39.30	39.4		19.8	19.7
Mass Moisture (g)	17.5	17.5	17.7		17.7	17.6
Mass Dry Soil (g)	9.1	9.9	10		0.7	0.8
Mass Dry Soil (g)	20.70	21.8	21.7		2.1	2.1
Moisture Content (%)	44.0	45.4	46.1		33.33	38.10
Average	45.2				35.7	

Test result

Liquid Limit (LL)	45.15
Plastic Limit (PL)	35.7
Plasticity Index (PI)	9

Sieve Sizes	Wt. Retained	% Retained	Cum. % Pass
4.75	583	58.30	41.7
2.00	173	17.30	24.4
0.425	79	7.90	16.5
0.075	64	6.40	10.1
Total	1000		



Appendix-4 Rainfall Data

Summary of RF data of January

Diary Weather Condition (Rain Fall) Record Data					
Item No.	Date Record	Rain Fall(Mm)	Climate Condition	Remark	
1	23/12/2015	-	Sunny		jointly
2	24/12/2015	-	Sunny		jointly
3	25/12/2015	-	Sunny		jointly
4	26/12/2015	-	Sunny		jointly
5	27/12/2015	-	Sunny		jointly
6	28/12/2015	-	Sunny		jointly
7	29/12/2015	-	Sunny		jointly
8	30/12/2015	-	Sunny		jointly
9	31/12/2015	-	Sunny		jointly
10	1/1/201	-	Sunny		jointly
11	2/1/2016	-	Sunny		jointly
12	3/1/2016	-	Sunny		jointly
13	4/1/2016	-	Sunny		jointly
14	5/1/2016	1.9	Rainy		jointly
15	6/1/2016	-	Rainy		jointly
16	7/1/2016	-	Sunny		jointly
17	8/1/2016	19.3	Rainy		jointly
18	9/1/2016	9.4	Rainy		jointly
19	10/1/2016	-	Sunny		jointly
20	11/1/2016	-	Sunny		jointly
21	12/1/2016	-	Sunny		jointly
22	13/1/2016	1.2	Rainy		jointly
23	14/1/2016	-	Sunny		jointly
24	15/1/2016	-	Sunny		jointly
25	16/1/2016	-	Sunny		jointly
		31.8			
Diary Weather Condition (Rain Fall) Record Data					
Item No.	Date Record	Rain Fall(Mm)	Climate Condition	Remark	

1	23/2/2016	-	Sunny		Jointly
2	24/2/2016	-	Sunny		Jointly
3	25/2/2016	-	Sunny		Jointly
4	26/2/2016	-	Sunny		Jointly
5	27/2/2016	-	Sunny		Jointly
6	28/2/2016	-	Sunny		Jointly
7	29/2/2016	-	Sunny		Jointly
8	1/3/2016	-	Sunny		Jointly
9	2/3/2016	-	Sunny		Jointly
10	3/3/2016	8.2	Rainy		Jointly
11	4/3/2016	-	Sunny		Jointly
12	5/3/2016	66.2	Rainy		Jointly
13	6/3/2016	-	Sunny		Jointly
14	7/3/2016	3.5	Rainy		Jointly
15	8/3/2016	7.4	Rainy		Jointly
16	9/3/2016	36.5	Rainy		Jointly
17	10/3/2016	6	Rainy		Jointly
18	11/3/2016	-	Sunny		Jointly
19	12/3/2016	-	Sunny		Jointly
20	13/3/2016	-	Rainy		Jointly
21	14/3/2016	-	sunny		Jointly
22	15/3/2016	-	sunny		Jointly
23	16/3/2016	-	Sunny		Jointly
24	17/3/2016	-	Sunny		Jointly
25	18/3/2016	-	Sunny		Jointly
26	19/3/2016	15.1	Rainy		Jointly
27	20/3/2016	12.3	Rainy		Jointly
28	21/3/2016		sunny		Jointly
29	22/3/2016	0.8	Rainy		Jointly
	Total	156			

Summary of RF data of April

Diary Weather Condition (Rain Fall) Record Data					
Item No.	Date Record	Rain Fall(Mm)	Climate Condition	Remark	
1	23/3/2016	_	Sunny		Jointly
2	24/3/2016	16.2	Rainy		Jointly
3	25/3/2016	1.5	Rainy		Jointly
4	26/3/2016	8..5	Rainy		Jointly
5	27/3/2016	0.4	Rainy		Jointly
6	28/3/2016	2.8	Rainy		Jointly
7	29/3/2016	_	Sunny		Jointly
8	30/3/2016		Sunny		Jointly
9	31/3/2016	19	Rainy		Jointly
10	1/4/2016	0.4	Rainy		Jointly
11	2/4/2016	7.9	Sunny		Jointly
12	3/4/2016		Sunny		Jointly
13	4/4/2016	7.9	Rainy		jointly

14	5/4/2016		Sunny		jointly
15	6/4/2016		Sunny		jointly
16	7/4/2016		Sunny		jointly
17	8/4/2016	61.4	Rainy		jointly
18	9/4/2016		Sunny		jointly
19	10/4/2016	11.5	Rainy		Jointly
20	11/4/2016	4	Rainy		Jointly
21	12/4/2016		Sunny		Jointly
22	13/4/2016	18	Rainy		Jointly
23	14/4/2016	15.7	Sunny		Jointly
24	15/4/2016	11.1	Sunny		Jointly
25	16/4/2016	40.4	Sunny		Jointly
26	17/4/2016	6.7	Sunny		Jointly
27	18/4/2016	50.4	Sunny		Jointly
28	19/4/2016	1.1	Rainy		Jointly
29	20/4/2016	31.8	Rainy		
30	21/4/2016	31	Sunny		
31	22/4/2016	6.7	Rainy		
TOTAL		345.9	TOTAL		

Appendix-5 Photos of Material Testes

CBR machine and soaking the surface material

Oven and sieve size ordered

LLA machine 500 revolution balls

PI measurement tools

Gravel road performance observation

A coating of dust on roadside vegetation caused by high traffic on the adjacent road.

Gravel road performance lost and impact of social and environmental