Global Scientific JOURNALS

GSJ: Volume 5, Issue 5, May 2017, Online: ISSN 2320-9186
www.globalscientificjournal.com

ENGINEERING PROPERTIES OF MECHANICALLY STABILIZED SUBBASE MATERIAL USING NATURAL GRAVEL AROUND JIMMA QUARRY SITES FOR UNPAVED ROAD CONSTRUCTION

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KeyWords
Engineering Properties of Soil, Natural Gravel, Mechanical Stabilization, Quarry Sites, Soil blending, Subbase Material, Unpaved Road.

ABSTRACT
Unpaved roads are designed with a small input and are constructed from the nearest available materials as possible. It requires routine and periodic maintenance, and their condition can be significantly affected by a period of excessive traffic volumes or inclement weather condition. The accurate estimation of maintenance cost is difficult. Many problems occur in the economic analysis of unpaved roads in comparison with paved roads. Defects which may affect unpaved roads are dusty, potholes, stoneness, corrugations, and rutting. Hence, it needs to apply sufficient stabilization method to strengthen and increase the durability of the unpaved road. Mechanical stabilization is an important application in engineering for different types of construction to improve the performance of road construction materials. The objective of this research was to determine the Engineering properties of natural gravel materials by mechanical stabilization method to be used in subbase material for the unpaved road. The methodology carried out in this research study includes: (a) field visual inspection and sampling of natural gravel materials from three quarry sites around Jimma area; and (b) laboratory tests to identify the physical and mechanical properties of natural gravel. Based on the laboratory test results, natural gravel materials from the Seka quarry site has an excellent Abrasion resistance of 35.26%, Plasticity Index of 13% a little bit above the upper limit, and good gradation (coarser and less subtle or binder materials), right CBR value. While the Jiren quarry site has a little Abrasion resistance of 52.09%, medium plasticity index, poor gradation (moderate fine material), CBR value of 28.90% which was below 30% minimum requirement, but had good MDD. On the other hand, the Merewa quarry site comprised of a very poor Abrasion resistance of 78.34%, Plasticity Index of 23.90% which was beyond the upper limit plasticity index of 12%, and poor gradation (more fine materials), poor CBR value and poor MDD. Therefore, it is concluded that the natural gravel from the Seka quarry site is suitable for subbase course. But since road construction around Jimma is booming, the natural gravel from this quarry site would be soon depleted. About this, mechanical stabilization is recommended by blending the natural gravel from Seka quarry site with 54% by weight with Jiren natural gravel of 46% by weight to meet the minimum requirements for subbase materials.

1 INTRODUCTION

Unpaved roads are the major component of the road network in most developing countries and comprise a significant portion of the network, even in highly developed countries such as the United States [1]. The future development of most third-world countries is fundamentally dependent on the existence of adequate road networks. Unpaved gravel roads often constitute around 70 to 90 percent of the designated road network in developing countries, while earth roads and tracks dominate the undesignated network [3]. The Universal Rural Road Access Program (URRAP) is aimed at connecting all kebeles to the nearby higher-class road using all-weather pavement solutions [2]. Unpaved roads are presently designed with very little scientific input and are constructed from the nearest available material. Unpaved roads demand constant maintenance to arrest damage by both traffic and the environment. Re-gravelling is usually needed after only one or two years' service, putting considerable strain on local financial, manpower and natural resources. There is now an appreciation that more attention needs to be paid to assessing the circumstances appropriate for gravel surfacing and the consideration of other options for low volume roads, particularly for rural communities [3]. Unpaved roads in Ethiopia, require a treatment mechanism by which the sub-base of the road will give sufficient service about bearing capacity and resisting deformability of surface by moving traffic loads. Therefore, it needs to apply stabilization methods to strengthen and increase the durability of unpaved road. The concept of mechanical stabilization was to blend available natural gravel so that, when properly compacted, it will give the desired stability in subject road sections areas. For example, the natural gravel at a selected location material may have low load-bearing strength because of the presence of clay, silt, or fine sand. Soil stabilization aims at improving soil strength and increasing resistance to softening by water through binding the soil particles together, waterproofing the particles or combination of the two. Fine-grained gravel materials are the easiest to stabilize due to their large surface area about their particle diameter while blending fine materials with naturally available natural gravel trial combinations will be followed based on the mechanical analysis of the concerned soil. In other words, the researcher could do the calculations to determine the gradation of the combined materials and the proportion of each component, so that the gradation of the combination could lie within the specified limit.

The source of suitable materials for road construction may become increasingly difficult as conventional high-quality materials are depleted in many areas. The costs of hauling or transporting materials for long distance may also increase. However, to minimize the problem associated with the pavement life, an affordable stabilization method for natural gravel, as sub-base material for the unpaved road had been undertaken for locally available material. So far, from previous related studies, there were different mechanisms by which stabilization of soil had achieved, such as cement, lime, calcium, fly ash both individually and mixing but less attention was given to locally available natural gravel materials. The researcher conducted the study of the three areas of natural gravel materials that constitute a low performance on sub-base layer without blending in several proportions.

The primary objective of the study is to determine the engineering properties of mechanically stabilize subbase material for unpaved road construction using natural gravel around Jimma quarry sites. The tasks carried out: a) To identify sources of materials from the quarry site suitable for sub-base material; b) To investigate the engineering properties of natural gravel material by mechanical stabilization from the sources; and, c) To determine mix proportion of the natural gravel material from quarry sites for use as subbase material on the unpaved road project.

2 MATERIALS AND RESEARCH METHODOLOGY

2.1 Study Area

Jimma is located 353 Km Southwest of Addis Ababa, and it is a specialized zone of the Oromia Region. It has latitude and longitude of 7°40′N 36°50′E and elevation varies from 1,780m-2000m above sea level. The ground water level in the area is variable which ranges from 3- 7m.

The selected materials for this research were taken from quarry sites in Jimma area, namely; Seka site, green site and Merewa site which is located at 10 Km, 12 Km & 14Km away from Jimma Town, respectively.

2.2 Study procedure

Laboratory tests on the blending of materials from quarry sites are conducted based on the standard specifications. Estimation of blending proportions for mechanical stabilization was done by trial and error process. Gradation and plastic properties are the basic parameters in blending [26]. Hereunder is, the equations used;

$$a = 100SB\,(P - PB) / [SB\,(P - PB) - SA\,(P - PA)] \quad (1)$$

$$b = 100 - a \quad (2)$$

Where:

a = amount of soil A in the blended mix (%)

b = amount of soil *B* in the Blended mix (%)

p= desired PI of the blended mix
PA = PI of soil A
PB = PI of soil B
SA = amount of soil A passing the 425micron sieve (%)
SB = amount of soil B passing the 425micron sieve (%).

The amount of blending ratio was estimated based on the above equation. Below are the parameters and values:
P=10; PB=9; PA=13; SA=9.32; SB=33.03

Substituting the values in equations (1) & (2), therefore,

$a = 100*33.03(10-9)/ [33.03(10-9) - 9.32(10-13) = (54\%)$

$b = 100 - a = (46\%)$

2.3 Sampling technique

The sampling technique was used by selecting particular parameters to make it sure that the variables have certain characteristics as applied for this research study. It is projected that these parameters would show normally targeted at particular Geotechnical parameters. Three (3) quarry sites around Jimma Town are considered. However, only two out of three quarry sites are feasible by mixing and blending the natural gravel that is expected to satisfy or fulfill the standard specifications. Using the equations (1) & (2) to compute the percent composition of soil A (Seka site) which composed of 54% by weight, while the amount of soil B (Jiren site) was 46% by weight.

2.4 Study variables

Independent variable: The independent variables for this research study are as follows; CBR, Plasticity Index(PI), Los Angeles Abrasion(LAA), Grain size distribution, Compaction, Water content, Optimum moisture content (OMC).

Dependent variable: Properties of mechanically stabilized subbase by blending natural gravel material.

2.5 Field identification

Identification of soil type in the field is often limited to an estimated of texture, color, and plasticity. Such observation was done in order to get the general understanding of the site and the materials sample by visual examination the soil characteristics which categorized silt or clayey gravel and fine soils.

Figure 2.1: Field identification, Seka (A), Jiren(B) & Merewa(C)

2.6 Data collection process and laboratory test

Three representative samples were collected from each of these sites with a 389m-500m difference.

Table 2.1: The laboratory tests conducted for each parameter

No.	Type of test	Size of sample (Kg)
1	Gradation/sieve analysis	360
2	Abrasion(L.A.A) Test	180
3	CBR Test	360
4	Atterberg's Limit Test	150
5	Compaction Test	360

For each site, there were five different tests carried out. From these tests, the average value was taken as the input parameter for the analysis and to be compared with the ERA standard specifications. The representative samples gathered were brought to Jimma University Laboratory and in Ethiopia Road Authority Jimma district. The tests carried out include Atterberg Limits, Grain-size Analysis, Compaction Tests, Los Angeles Abrasion Test and California Bearing Ratio (CBR) Tests. The researcher collected samples from each quarry site to perform the required laboratory tests. Representative samples were collected and labeled accordingly. It was performed according to AASHTO specification, ASTM, and ERA manual 2002 [4].

3 RESULTS AND DISCUSSION

3.1 Identification of Engineering Properties of Natural gravel

Three gravel sources were selected around Jimma Town. Each of these three quarry sites, three representative samples were taken for laboratory testing. Based on the field observation, all the materials from the three quarry sites, Merewa composed of more weathered rocks. However, the natural gravel materials are easily produced by labor and machine by crushing the weathered rock. To determine the quality of the materials, laboratory tests were carried out. The tests involved were to identify the properties of the natural gravel such as its physical and mechanical properties. Soil test results showed, Merewa site did not satisfy the requirements of ERA standard specification as subbase construction material.

3.2 Laboratory test results

3.2.1 Atterberg's limit test results

The Liquid Limit and Plastic Limits of soil indicate the water contents a certain change in the physical behavior of soil that was being observed.

Table 3.1. Atterberg's Limit test of natural gravel for Jiren (B) quarry site

Quarry site	Representative sample	Soil parameter			ERA specification (PI value)
		LL	PL	PI	
Jiren (B)	Sample -1	35.07	26.06	9.01	6-12
	Sample -2	35.04	26 .02	9.02	6-12
	Sample -3	35.00	26.00	9.00	6-12
	Average	35.04	26.03	9.01	6-12

The PI values of the three representative samples showed no significant difference in each test result. These PI values are within the range of the ERA Standard Specification.

Table 3.2. Atterberg's Limit test of natural gravel from Seka (A) quarry site

Quarry site	Representative sample	Soil parameter			ERA specification (PI value)
		LL	PL	PI	
Seka (A)	Sample 1	44.05	31.07	12.98	6-12
	Sample 2	45.004	32.002	13.00	6-12
	Sample 3	44.08	31.06	13.02	6-12
	Average	44.38	31.38	13.00	6-12

Laboratory test results showed the PI values of the three (3) samples from the Seka quarry site did not meet the required values based on the Standard Specification. It means, all the three (3) samples are slightly above the upper limit PI value of 12%.

Table 3.3. Atterberg's Limit test of natural gravel for Merewa (C) quarry site

Quarry site	Representative sample	Soil parameter			ERA specification (PI value)	
		LL	PL	PI	Lower	Upper
Merewa (C)	Sample 1	46.500	23.00	23.50	6	12

	Sample 2	47.000	23.00	24.00	6	12
	Sample 3	47.017	22.24	22.78	6	12
	Average	47.000	23.08	23.90	6	12

Likewise, the three (3) samples which were collected from the Merewa quarry site, the average Plasticity Index value and the upper limit based on ERA standard specification, the observed PI value is almost two times higher in the upper limits. This indicates that the sample comprised of finer particles, of which did not meet the Standard Specifications.

3.2.2 Sieve analyses

To determine the gradation of natural materials, sieve analyses were undertaken on samples collected from the three quarry sites. The result of the test is used to determine the particle size distribution with applicable specification requirement and to provide necessary data for control of the production of various aggregate mixtures containing aggregate for the proposed pavement material.

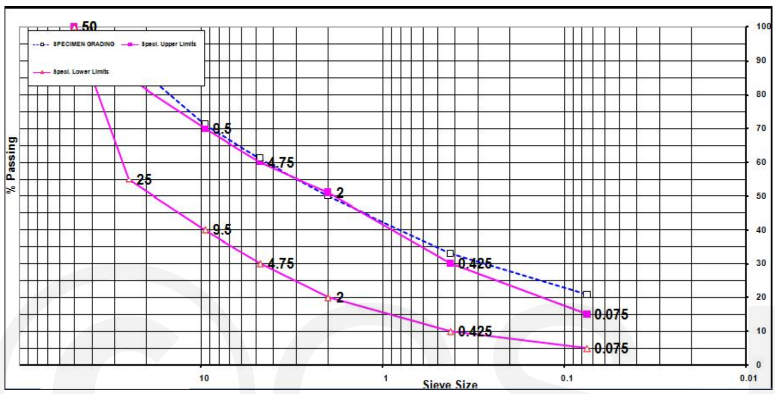

Figure 3.1: Sieve analysis of natural gravel of Jiren quarry site

From Figure 3.1, The test result shows that the average value was above the Upper Limit of the ERA standard specification by different sieve sizes, except the 2mm sieve size which is nearest to the marginal line of the upper limit. This indicates that the gradation of the sampled natural gravel did not pass the requirements for the other aggregate sizes.

On the other hand, the samples from the Seka quarry site are somewhat different. The observed average values of percent passing as compared with the ERA standard specification are below the lower limit of 9.5mm, 4.75mm, and 2mm sieve sizes. At different standard sizes for use as subbase materials. These indicate the materials are coarser and less fine or binder particles.

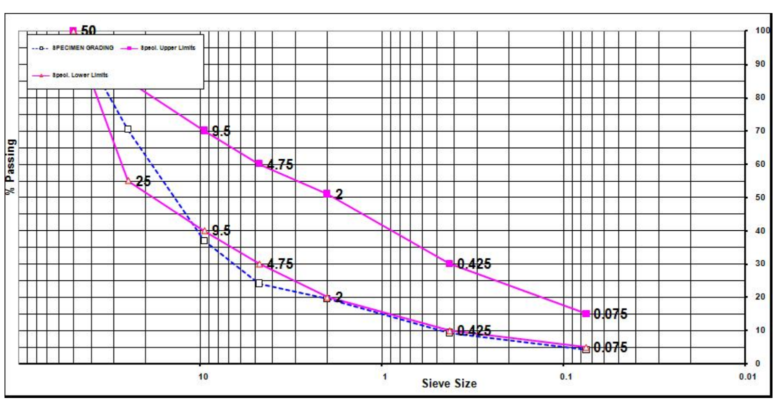

Figure 3.2: Result of Sieve analysis of natural gravel from Seka quarry site

The plot below shows the materials composed of a finer and less courser when comparing with the ERA standard specification based on the lower and upper limits.

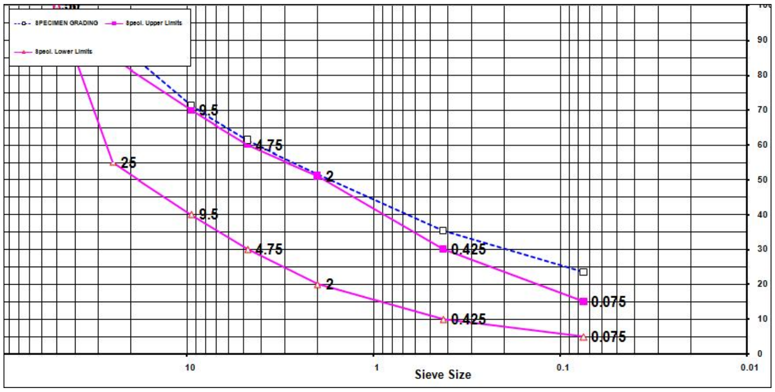

Figure 3.3: Result of Sieve analysis of natural gravel from Merewa quarry site

All sieve sizes are above the upper Limit set by the ERA Standard Specification. It means the material had finer or fewer coarser particles. This result indicates the material was out of the Upper Limit and Lower Limit which is not suitable for subbase materials.

Figure 3.4: Sample aggregates from Seka and Jiren quarry sites

3.2.2 Los Angeles Abrasion test (LAA)

The LAA value which was expressed as the percentage of fine passing the 1.7mm (ASTM) sieve, represent an estimate of the abrasion resistant of the aggregate. The test result is tabulated in Table 3.4.

Table 3.4: Los Angeles Abrasion test result of natural gravel for different quarry site

No.	Quarry site	Average (LAA)	ERA standard specification (LAA)
1	Seka (A)	35.26	51≥
2	Jiren (B)	52.09	51≥
3	Merewa (C)	78.34	51≥

From Table 3.4, it shows the values of Los Angeles Abrasion test (LAA) results of natural gravel from the different quarry sites of the study area. Based on the Laboratory test results the A site indicates of high Abrasion resistance. The B site indicates Low Abrasion resistance, while the C site shows a very low Abrasion resistance.

3.2.3 Moisture-density relationship (compaction test)

The modified compaction test method is used to determine the relationship between the moisture content and density of soil when compacted in a given mold of a given size using 4.5kg rammer and dropped from a height of 457mm. The values of Seka and Jiren sites are tabulated below. Since Merewa found out has a very low for Abrasion resistance, it was no longer considered for the compaction test.

Table 3.5: Result of Compaction test of natural gravel from Seka and Jiren quarry sites

Quarry Site	Parameters	
	MDD (g/cc)	OMC (%)
Seka (A)	2.18	14.5
Jiren (B)	2.11	10

Based on the Compaction test of natural gravel for Jiren and Seka quarry sites as shown in Table 3.5, laboratory test results provide good values. However, these two (2) samples when it was compared each other, Jiren revealed better regarding Optimum Moisture Content (OMC) which is 10% than the natural gravel from Seka quarry site of 14%.

3.2.4 California Bearing Ratio (CBR) test results

The test results obtained from the two different quarry sites are shown in Table 3.6 to Table 3.7. Based on the test results, the CBR value of Jiren quarry site was below the minimum required as stipulated in the Standard Specification of 30%. Therefore, the natural gravel alone from Jiren is not possible to be used for subbase course. While the natural gravel from the Seka quarry site is recommended which is above the minimum. Since road construction projects around the Jimma zone are radiating from North-South and East-West directions. Due to this, it was perceived that the natural gravel from the Seka quarry site would be soon depleted. It is for this reason that blending natural gravel from these two (2) quarry sites using mechanically stabilized to obtain the optimum mix ratio was undertaken.

Table 3.6: California Bearing Ratio (CBR) test results of natural gravel for Seka quarry site

Seka Quarry Site	Representative sample		Test 1	Test 2	Test 3	Test 4	Test 5	Trail average	Site average	Specification
	Sample1	CBR	33	32.98	33	33	33	32.98	33.01	≥30
	Sample2	CBR	32.92	33	33.5	33	33.02	33.1		≥30
	Sample3	CBR	33	33	33	32.9	33	32.98		≥30

Table 3.7: California Bearing Ratio (CBR) test results of natural gravel for Jiren quarry site

Jiren Quarry Site	Representative sample		Test 1	Test 2	Test 3	Test 4	Test 5	Trail average	Site average	Specification
	Sample 1	CBR	29	28.9	29	29	28.9	29	28.9	≥30
	Sample 2	CBR	29	28.9	29	29	29.0	28.98		≥30
	Sample 3	CBR	29.0	28.9	29	29	29	28.98		≥30

3.2.5 Laboratory Test results after blending

After mixing or blending samples from the two quarry sites, it showed weak and strong engineering properties. To improve the weak soil, Laboratory test was undertaken. Laboratory result is tabulated and plotted in the following Figure.

3.2.5.1 Atterberg's limit

Table 3.8: Atterberg's limit test result for the mix proportion

Quarry	Representative	Parameters (Observed)			ERA Standard Specification	
Jiren + Seka	Jiren (46%) + Seka (54%)	LL	PL	PI	Lower limit (PI)	Upper limit (PI)
	Average	36.02	26.00	10.02	6	12

Table 3.9: Effect of mix proportion on the Atterberg's Limit.

Quarry site	Sample was taken by percent (%)		Sample was taken by dry mass(gm)		Parameter (initial and observed)					
					LL		PL		PI	
	Normal	Quarry	Normal (gm)	Quarry (gm)	Natural	Changed	Natural	Changed	Natural	Changed
Seka	100	54	500	270	44	36	31	26	13	10
Jiren	100	46	500	230						

3.2.5.2 Grain size analysis result

The results of grain size analysis are plotted in Figures 3.5 which shows the test results after blending of samples from Seka and Jiren quarry sites on the standard sieve size passing the percentage. The results of the blended natural aggregates are within the lower and upper limits. This means that the materials taken from quarry sites by considering the designed mix ratio satisfied the ERA standard specification. Therefore, the materials fulfilled the requirements of subbase materials for road construction.

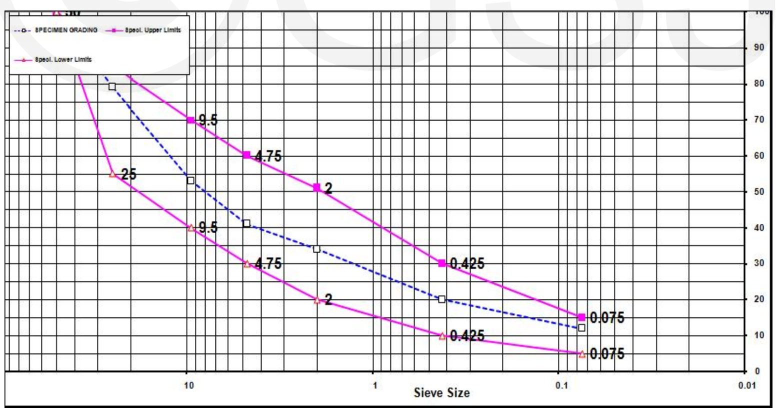

Figure 3.5: Grain size analysis test result after blending

3.2.5.3: Los Angeles Abrasion test result after blending

The average value of Los Angeles abrasion test results after blending had met the requirement set forth under the ERA standard specification for the abrasion resistance impact value.

The test was also conducted on the natural sub-base materials, is used to established baseline data. The average percentage of sub base for the Seka quarry site was 35% and represents good resistance because it is within the limit of the specification. The specification requires the value to be not more than 51%. Hence the compacted abrasion values are good and are within the acceptable limit based on the project specification and ERA Standard Manual. The Jiren quarry site has little Los Angeles resistance because it is more than 51. The samples collected from Merewa showed low values of abrasion resistance which was not considered for blending.

3.2.5.4: Moisture-density test result after blending.

Table 3.10: Comparison on Laboratory test result from moisture-density before and after blending.

Quarry site	Representative sample (after blending)	Observed Values	
		MDD	OMC
Jiren & Seka	Jiren + Seka	2.105 g/cc	13.00 %
Quarry Site	Observed Values (before blending)		
	MDD (g/cc)	OMC (%)	
Seka (A)	2.18	14.5	
Jiren (B)	2.11	10	

The observed values after blending of natural gravel from the two quarry sites indicated a significantly improved condition of 13% Optimum Moisture Content (OMC) and MDD of 2.105 g/cc as compared with the values when it was not blended.
Good compaction produces tightly bound gravel with optimum particle interlock. Minimum Permeability and porosity have significantly increased the soil strength, while a high degree of moist compaction results in a road with a lower roughness than similar materials which are poorly compacted in a dry condition. The roughness deterioration can be much slower, and gravel loss and dust emission can be significantly reduced. The average MDD for the natural sub base material from different quarry sites showed little difference. The OMC of Seka quarry site was higher than the Jiren quarry site. However, after blending considering the mix proportion of two quarry sites Seka (54%) & Jiren (46%), the MDD & OMC have changed.

3.2.5.5: California Bearing Ratio (CBR) test result after blending

Table 3.11: Laboratory test result (CBR)

Quarry	Representative sample	Observed	Standard Specification
Jiren & Seka	Jiren (46%) +Seka (54%)	CBR	
		40.00	≥30

From the result of the laboratory test, the CBR value of mixed samples from the two quarry sites was greater than the minimum required by 30%. The Seka quarry sample composed 33 % of CBR value while Jiren quarry sample revealed below the standard specification 29%. However, after blending the two samples from the quarry sites considering the mix proportion the CBR value had increased due to the improved gradation of the materials while the fine material. Fill the voids between coarser particles.

4 CONCLUSION

The researcher has foreseen that there is a scarcity of suitable natural gravel soils for subbase material in the future. Blending or mix proportion of samples extracted from Seka and Jiren quarry site were performed. Based on analyses, 54% of natural gravel soils form Seka quarry site was considered, while 46% of natural gravel from Jiren quarry site also considered for the study. After mixing/blending of the natural gravel soils, the engineering properties of soils were computed to determine how much improvement of the quality of blended soils. Therefore, the observed values for PI are 10.02 and sizes of all particles are observed to be within the Limit. The Los Angeles Abrasion of 34.01 is below 51 which means high resistance, soil, while the CBR value of 40 is above the minimum. In mixing /blending natural gravel soils from Seka and Jiren, it is concluded that the mixed natural soil improves the strength of sub-base materials of about 33.33%. However, it must be understood that it must satisfy the requirements of the standard specification to perform the mix proportion. This is the most important consideration to obtain a good quality of subbase materials for unpaved road construction around Jimma Town.

Recommendation

Different soil parameters were computed based on laboratory test results. Each observed value was presented according to the requirements of ERA standard specifications. Hereunder are the recommendations which are found to be significant for improving properties of natural gravel soils for subbase course materials to be used in unpaved road construction around Jimma Town:

- Adopt mix proportion of natural gravel soil of 54% by weight from Seka quarry site, and 46% by weight from Jiren quarry site to obtain more or less a CBR value of 40 based on laboratory test results of this study.

- Marawa quarry site is not recommended for use as sub-base material for road construction because it did not satisfy the requirements as per ERA Standard Specifications based on test results.

- Finally, it is recommended that further research study would be undertaken by other researchers to consider similar issues to substantiate significance of mixing different sources of natural gravel soils for road construction within Ethiopia.

Acknowledgment

The authors wish to express their gratitude to the Jimma Institute of Technology (JiT), Jimma University, and the Ethiopian Road Authority (ERA) for the assistance and financial support. This research study could not be completed without this joint sponsorship program.

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