Hawassa University Journals

Volume I
Pages: 76-84
Article Number: 560-Article Text-3159-1-4-20220516
Copyright©2021
Author(s) retain the copyright of this article
www.journals.hu.edu.et/hu-journals/index.php/ejet/index

Ethiopian Journal of Engineering and Technology

Wearing Course Material Quality Evaluation for Unsealed Roads in Southern Ethiopia: a Case Study

Bereket Bezabih*, Henok Reffisa, Thomas Bezabih, Belete Tsegaye, Temesegen Ayenabeba

Department of Civil Engineering, Hawassa University, Institute of Technology, Hawassa, Ethiopia
** bereket.bezabih@hu.edu.et Phone +251994783890*

The sustainable performance of unsealed roads is a function of the regular maintenance, which improves the ride quality. Good quality wearing course has significant contribution to mitigate various distresses which develop in the use of the roads. In this paper the results of material quality test for 43 quarry sites used in maintenance of roads in southern Ethiopia are presented as per the existing guidelines of quality specification of wearing course material for unsealed roads. After a field geologic review of quarry sites, 125 kg of samples passing 50 mm sieve size were collected and particle size analysis, Atterberg’s limits, soaked California bearing ration (CBR) and Treton Impact tests were conducted. Grading coefficient and shrinkage product values were computed to determine the position of samples on material quality plot. The most prevalent problems observed in these materials are low shrinkage product and wide spread use of a nonstandard material i.e. cinder gravel as wearing course material. Based on these findings appropriate recommendation were put forward to improve the low shrinkage product value. Cinder gravel can be used in the subbase of roads blended with local soils but its use as wearing course material shall be avoided unless verified via a full scale field tests.

Key Words: Wearing Course, Grading Coefficient, Shrinkage Product, Cinder Gravel

1. Introduction

1.1. Background

Unsealed roads make up a large proportion of the road network in a developing country like Ethiopia and play an irreplaceable role in the delivery of social services and overall economic development. These roads require regular maintenance to perform under the variable tropical climate and traffic conditions. In Ethiopia, the national road authority (ERA) looks after the major arterial roads and provides technical support for the regional roads authorities (RRAs), which oversee the construction and maintenance of unsealed roads in their respective districts.

“Good Quality” wearing course material is one of the major inputs of the construction and maintenance operations. There exists an early recognition for the need for specification since the early 1920 (Strahan, 1922). According to Andrews (2009), the pavement material for gravel wearing course shall have properties which result in “an even, tight, relatively impermeable (erosion resistant) and wear resistance surface”. Adrew (2009) further specifies the material shall have enough fines with plasticity and sufficient course materials to provide bonding of the course materials to provide resistance to wear, adequate dry strength through mechanical interlock, fine particle bonding and low permeability to mitigate against loss of strength when the surface becomes wet. In addition, the soil fractions are required to have sufficient dry strength to hold aggregate fractions in place. This is to prevent raveling and the development of loose material on the surface.

Beaven, et al., (1987) presented a study on the use of weathered basalt gravels in Ethiopia. The study was conducted on roads with traffic volume 50 - 175 vehicles per day. The performance of the wearing course materials measured in terms of resistance to deformation, rate of gravel loss and deterioration of ride quality. They recommended the use of weathered basalt gravels. Crushing and screening is cost effective for roads with traffic more than 50 vehicles per day.

Cinder gravel (Scoria) is one the widely available gravel material in Ethiopian Rift Valley. Newil et al., (1987) assessed the potential use of cinder gravel for both paved and unpaved roads. They put forward recommendations of particle sizes which would be resistant to corrugation and mechanical stabilizations of cinder gravel for better performance. Hearn et al., (2018) observed the engineering use of cinder gravel is limited to hallow concrete blocks as opposed to pavement material. The main reason being scoria fails to satisfy the robust specifications required for use in the road sector and lack of guidelines for use of such a nonstandard material in roads. The authors developed guidelines which recommends among others; pretests selection criteria for base course shall be Aggregate Impact Value, AIV < 45 and water absorption <12% and for sub base and capping aggregate impact value AIV <55 reduce the 4 days soaked CBR specified in ERA low volume manual for low volume roads from 65 to 55 and maximum allowable particle size 75 mm and the sub layer thickness a minimum of 150 mm etc., (ERA, 2018).

Irrespective of the mineral type, the choice of wearing course materials is a function of the mechanical behavior of its constituents. The choice of the gravel surfacing material is most often a compromise between a material which possesses sufficiently high plasticity to minimize gravel loss in the dry season and sufficiently low plasticity to prevent serious rutting and deformation in the wet (Toole et al., 2018).

Paige-Green (1989) presented a comprehensive study providing specification for wearing course materials. This work used a factorial design approach with geologic materials, climate, traffic volume, and road geometry as factors affecting performance.

Ideally, the selection of wearing course materials for unsealed road shall be based on full-scale performance evaluation on ride quality. Such a study is time consuming and uneconomical. Hence, it is preferable to evaluate a set of parameters, which are indicators of good performance. In the absence of such testing, the roads will need frequent maintenance or reconstruction.

1.2. Wearing Course Material Specification

The Ethiopian Roads Authority (ERA) adopted the work of (Paige-Green 1989) as a standard for low volume roads in its manual for low volume roads (ERA, 2011). It provides the following specifications for the selection of wearing course materials for unsealed roads. The key parameters include oversize index, Shrinkage Product, Grading Coefficient, soaked CBR and Treton Impact Value (TIV).

The specification identifies the most suitable material based on two basic soil parameters i.e., grading coefficient and shrinkage product. Figure 1 shows the five classes of materials for use as a wearing course material on unsealed roads.

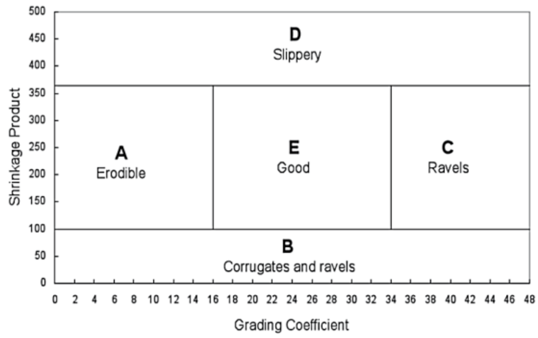

Figure 1 Material Quality Zones (ERA, 2011)

The single most important factors affecting the performance of unsealed roads is gravel loss. Natural weathering (wind, rain), friction, and whip-off can cause gravel loss from vehicles (Paige-Green, 1989). In addition to that, many gravel loss model enumerate traffic volume, road geometry, material property and maintenance practice, (Pardeshi, et al., 2020).

Gravel loss can be determined from direct measurement or predictive models. For the first three years (disregarding other deformations as causes of gravel loss). ERA (2011) puts forward the rate of gravel loss for soils classified as per Figure 1 as shown in Table 1.

Table 1 Typical Standard Gravel Loss(ERA 2011)

Material Quality Zone	Material Quality Description	Typical Gravel Loss (mm/year/100vpd1)
Zone A	Satisfactory	20
Zone B	Poor	45
Zone C	Poor	45
Zone D	Marginal	30
Zone E	Good	10

ERA (2011) provides the specification for wearing course material in urban and rural areas as given in Tables 2 & 3. In urban an area, where a large number of dwellers are expected, an improved criterion to eliminate stones and dust is deployed as shown Table 3.

[1] *Vehicles per day*

Table 2 Recommended Material Specification for Rural Areas (ERA 2011)

Description	**Value**
Maximum Size (mm)	37.5
Oversize Index (I_o)	$\leq 5\%$
Shrinkage Product (S_p)	$100 - 365$
Grading Coefficient (G_c)	$16 - 34$
Soaked CBR (at 95% Mod AASHTO)	$\geq 15\%$
Treton Impact Value (%)	$20 - 65$

Table 3 Recommended Material Specification for Urban Areas (ERA 2011)

Description	**Value**
Maximum Size (mm)	37.5
Oversize Index (I_o)	0
Shrinkage Product (S_p)	$100 - 240$
Grading Coefficient (G_c)	$16 - 34$
Soaked CBR (at 95% Mod AASHTO)	$\geq 15\%$
Treton Impact Value (%)	$20 - 65$

In the present work, the quality of wearing course material used in parts of southern Ethiopia is assessed as per the guidelines set forth by Ethiopian Roads Authority’s Low Volume Manual (ERA, 2011). The work presents sampling from 43 quarry sites used for the maintenance of 83 road stretches with a total length of approximately 1560 km.

2. Material and Methods

2.1. Location

The project areas are located in seven administrative zones (Alaba, Gedio, Gurage, Hadiya, Kembata - Tembaro, Segen Peoples’ and Selti) of South Nations Nationalities and Peoples’ Regional (SNNPR) state. The quarry sites provide wearing course material for five maintenance districts namely Hossana, Durame, Gubre, Dilla and Werabe under the regional roads authority. Figure 2 shows administrative districts and the 43 quarry site locations.

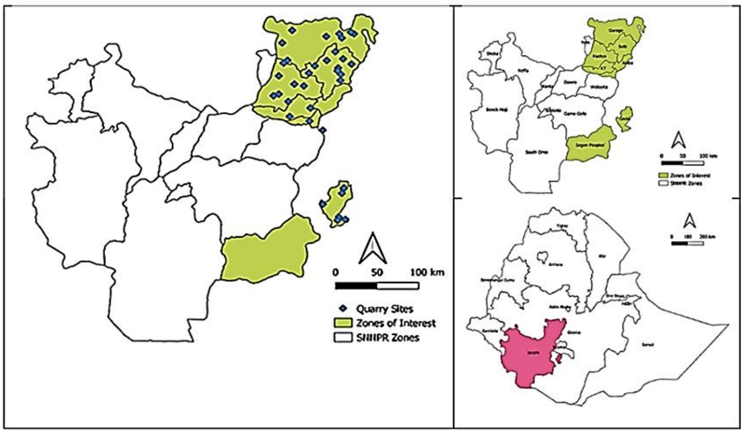

Figure 2 Location of the quarry sites

2.2. Geology

The quarry sites are located within the Main Ethiopian Rift Valley (MER) and are dominated by volcanic rocks. In Hossana and Durame area the rift is covered with Cenozoic volcanic and, Tertiary/quaternary sediments with few patchy occurrences of Precambrian rocks.

The volcanic rocks are dominantly fissured basaltic lava flows, rhyolites and ignimbrites associated with volcanoclastic tuff and ash deposits. Some of the stones extracted are rhyolites, basalts, tuff, ignimbrites and scoria.

Werabe and Gubre area sites are dominated by scoria, pyroclastic rocks, weathered ignimbrite, weathered basalts, and highly weathered welded tuff. The prevalent rock materials in the quarry site in Dilla area include basalts, ignimbrites, and scoria. Figure 4 shows typical scenes at some of quarry sites during sampling.

(a) Jukara - Hossana (b) Forqessa - Hossana

(c) Datwezir - Werabe (d) Endeneba - Werabe

(e) Welayadiber - Werabe (f) Gumer - Gubre

Figure 4 Geological materials of basalts, scoria, and ignimbrites at various quarry sites

2.3. General Approach

Desk Study

The project team collected location references of the quarry sites and undertook a review of secondary data sources such as geologic maps and access roads planned efficient logistic routes. A review of the quarry site geology based on secondary data sources was compiled.

Field Work

The fieldwork included a survey by an engineering geologist to determine mineral composition of the wearing course material with a brief description with emphasis on its mechanical properties and degree of weathering. Samples for laboratory test have been prescreened with 50 mm sieve and collected from 43 sites.

Laboratory Tests

Approximately 125 kg of soil is collected for laboratory testing from each quarry site. The samples were used to undertake index property tests and strength tests as specified in (ERA, 2011). The Laboratory tests conducted include Particle Size Distribution (PSD), Shrinkage Limit, Soaked CBR (Three Point), Compaction Test and Treton Impact Test. Procedural details for sampling and laboratory tests are available on (ERA, 2011) Part D. Three trials were done for each test and average values are reported.

Data Analysis

A. Grading Coefficient, G_c

Grading coefficient is a parameter developed to indicate the proportion of fine and medium size gravel in a wearing course material along with the relationship between this proportion and the slope of he particle size distribution curve. It is computed from particle size distribution of sample with maximum size 37.5 mm as shown in equation (1), and has a range of values between 0 - 100. A comparative analysis of grading coefficient with other particle size parameters is presented by Paige-Green P., (1999).

$$G_c = (P26 - P2) \times P475/100 \quad (1)$$

where

$P26$	*Per cent passing sieve size 26 mm*
$P2$	*Per cent passing sieve size 2 mm*
$P475$	*Per cent passing Sieve size 4.75 mm*

B. Shrinkage Product, S_p

Shrinkage product is a measure of the plasticity of the wearing course material that is required to avoid loosening and corrugation. It is computed from bar linear shrinkage (BLS). The linear shrinkage value computed by various standards vary. The procedure suggested in (ERA, 2011) is used to compute shrinkage product of sampled wearing course materials, see equation (2).

$$S_p = BLS \times P425 \quad (2)$$

where

$P425$	*Per cent passing sieve size 0.425 mm*
BLS	$LS \times 0.67$
LS	*Linear Shrinkage*

C. Treton Impact Value

Treton Impact value (TIV) is a parameter used to measure the aggregate particle strength of borrowed materials. Materials with low particle strength are likely to break down under rolling traffic load. Particles with very high strength will contribute to the undesired attribute of 'stoniness' of unsealed roads. TIV is computed as shown in equation (3).

$$TIV = \frac{A-B}{A} \times 100 \quad (3)$$

where

A	*Total mass of Stone Particles Before Stamping, gms*
B	*Total mass of Stone particles remained on Sieve size 2 mm after stamping, gms*

D. Strength Test

Soaked CBR test at 95% of maximum dry density using the three point method i.e., a series of three test specimens 10, 30 & 65 blow count is adopted to measure strength of the pavement material, AASHTO T193-93. The results are then compared with the acceptable range of values set forth in (ERA, 2011).

3. Results and Discussion

3.1. Results

This section presents a summary the results of the laboratory tests and analysis of quarry sites. The findings are reviewed as per (ERA, 2011) specification for wearing course material for unsealed roads. Gravel wearing course material quality is essentially determined through the grading in the form of grading coefficient, G_c and plasticity measured in terms of shrinkage product, S_p (ERA, 2011). Based on combined values of grading coefficient and shrinkage product, the materials under consideration are categorized into one of the five letter groups. Figure 5 presents the material quality plot for all quarry sites. Quarry sites with little or no fines are plotted with S_p= 0 on Figure 5.

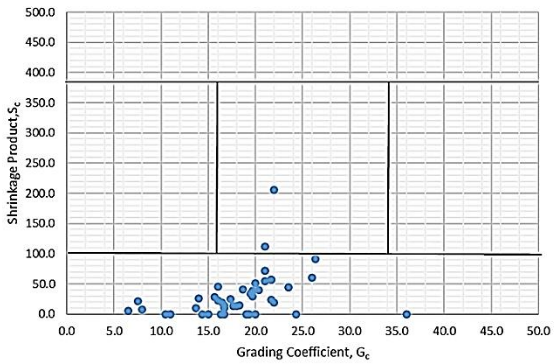

Figure 5 Material Quality Plot

The results of the strength tests using soaked CBR tested at 95% of maximum dry density are shown in figure 6. The specification requires the values to be greater than 15%.

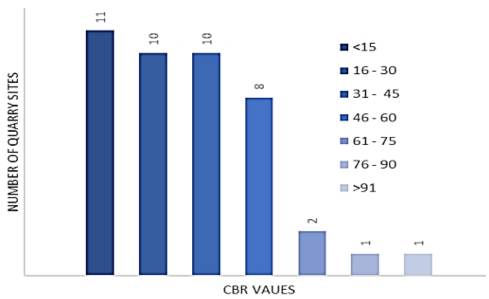

Figure 6 Soaked CBR Tests Results

Figure 7 presents the results of Treton Impact tests. The specification requires the materials to have values ranging between 20 and 65.

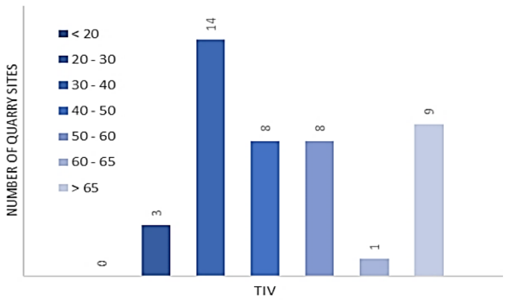

Figure 7 Treton Impact Values

All samples from the quarry sites have over size ratio at least 5% with a maximum value of 16%. ERA (2011) recommends screening for samples with oversize ratio above 5% percent. These results are found from pre-tests screening using 50 mm size sieve. Hence, it may not be a true representation of the particular quarry site.

The grading coefficient, G_c is within the acceptable range for 70% of samples collected in this project. However, some rock types such as scoria may not have the same grading after application on the roads as they quickly lose their grading characteristics during compaction.

The shrinkage product of the soil samples collected in this project shows 95% of the samples lay below the acceptable level. This result is attributed to the lack of fine-grained soil, more specifically plastic fines. It is not an unexpected result, as these are quarry sites for gravel material. However, the direct use (without mechanical improvement) of these materials for wearing course on unsealed is bound to lead to corrugation and raveling type distresses on unsealed roads under wheel load.

As shown in Table 1, wearing course materials categorized as Class B are highly susceptible to gravel loss, in addition to the loss in ride quality. Table 1 is only a guideline and actual amount of gravel loss need to be assessed through direct measurement or relevant empirical models.

From the 43 samples tested using three point CBR, 74.4 % of the samples satisfy the requirement for use as a gravel wearing course material as per (ERA, 2011). There is no clear pattern as to which rock material type is prone to low CBR values.

The Treton Impact test result shows 79% of the samples have acceptable Treton Impact values. Samples from Scoria and some pyroclastic deposits dominate those, which fall short of the requirement.

3.2. Discussion

Cinder gravel (scoria) suffers from two major deficiencies as a wearing course material. First its vesicular textures causes it to break down under wheel load altering its grading under use, second it lacks adequate fine-grained materials more specifically plasticity. As a result, it is not considered a 'standard material' but rather a 'marginal material'. Hence, its application as a pavement material cannot and should not be under the same framework as other materials such as basalts, rhyolite, ignimbrites etc.

Despite its poor engineering characteristics, the wide availability of scoria has tempted its use for pavement construction for all levels of roads. The conventional methods of testing prove scoria is not a 'standard material' materials for pavement design.

The CBR values of neat scoria samples exhibit a wide range of values. It is pertinent to recognize the fact that often scoria samples are used blended with plastic fines, the CBR value from neat tests shall be used as selection for blending rather than design. A distinction shall be made urban section of road where there is lateral confinement between curbstones.

Material quality plot of neat scoria categorizes it as Class B, materials that will corrugates and ravels. These materials 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 (ERA, 2011). They also have expected gravel loss 45 mm/yr/100vpd.

If scoria materials is blended with plastic material it can be improved to be a Class A material (ERA, 2018) showed in their samples, which is characterized as finely graded and particularly prone to erosion. Roads constructed from Class A materials require frequent periodic labor intensive maintenance over short lengths and have high gravel losses due to erosion (20mm/yr/100vpd). They should be avoided if possible, especially on steep grades and sections with steep cross-falls and super-elevations.

4. Conclusion and Recommendations

4.1. Conclusion

The rock materials identified on the field visit and testing are suitable for use in different section of a pavement including wearing course. The degree of suitability depends on the degree of weathering, volumetric availability, accessibility etc. Scoria, however, needs special attention.

The lack of fine-grained plastic soils in materials from these samples is the most prominent problem. Mechanical stabilization can be used to improve the fine content. However, given the large volume of soil required adequate Atterberg's limits tests shall be conducted to determine the plasticity of the selected material.

Existing manuals such as (ERA, 2011) put forward a guideline of proportioning binding (plastic fines) with the quarry materials to satisfy the shrinkage product and grading coefficient criteria. However, the plasticity of the fines must be tested before the guideline is used, as not all fines are plastic.

4.2. Recommendations

Most of the gravel quarry sites do not have adequate plastic fine content. It is recommended that quarry sites shall be explored and developed for plastic fine-grained soils within reasonable haul distance from the existing gravel quarry sites. There exist a guideline for mechanical stabilization of gravel quarries with plastic fine on (ERA, 2011), which can be used for designing mix proportions.

Grading coefficient of samples can be improved with mechanical stabilization. However, for the majority of the samples it is not necessary. The grading of soil samples from scoria samples shall be conducted after the compaction tests.

Mechanical stabilization of materials can improve the CBR values of quarry materials. However, low CBR is not a major problem for the tested samples.

Treton Impact values are directly related to either the rock material type i.e. scoria or the degree of weathering.

A study conducted by (ERA, 2018) on use of cinder gravel for road pavements has found the following facts and put forward some recommendation.

Scoria samples are coarse grained, lack fine-grained particles (less than 4.75 mm).However, compaction breaks down the coarse grains to increase the fine content. In general, the fine-grained content is non-plastic, except in rare cases of very old deposits. Hence, the particle size distribution shall be tests from the sample, which has undergone compaction and careful review of the plasticity of the material shall be conducted.

The standard method of determining the maximum dry density and optimum moisture content is known to yield unreliable results. Hence, it is recommended the same sample shall be used to determine the maximum dry density (MDD) and optimum moisture content (OMC) in successive compaction trials.

If economic reason make its use unavoidable, a full scale test of the particular material shall be conducted and a separate standard, such as (ERA, 2018) shall be adopted.

Acknowledgment

We are grateful for the financial support provided by SNNPR Roads authority, Hawassa University Institute of Technology for letting us allowing time in geotechnical/highway laboratories, civil engineering department staff & laboratory technicians; Zelalem Mekonen and Abdulhafiz Aragaw for comprehensive & unreserved support in our endeavor.

References

Andrews, B. (2009). Guide to Pavement Technology Part 6 Unsealed Roads. Sydney, Australia: Austroads Ltd.

Beaven, P., Robinson, R., & Aklilu, K. (1987). Experimental Use of Weathered Basalt Gravels in Ethiopia. Transport Research Record 1106, 103-115.

ERA. (Ethiopian Roads Authority) (2011). Design Manual for Low Volume Roads, Part B Design Standards for Low Volume Roads. Addis Ababa, Ethiopia

ERA. (Ethiopian Roads Authority) (2011). Design Manual for Low Volume Roads, Part D. Addis Ababa, Ethiopia:.

ERA. (Ethiopian Roads Authority). A Guideline for the Use of Cinder Gravels in Pavement Layers in Low Volume Roads. Addis Ababa, Ethiopia: ERA, Final Draft Report.

Hearn, G. J., Otto, A., Green, P. A., Endale, A. A., & Etefa, D. M. (2018). Engineering Geology of Cinder Gravel in Ethiopia: Prospecting, Testing and Application to Low Volume Roads. Bulletin of Engineering Geology and the Environment, 3095-2110.

Newil, D., Robinson, R., & Aklilu, K. (1987). Experimental Use of Cinder Gravels on Roads in Ethiopia. 9th Regional Conference for Africa on Soil Mechanics and Foundation Engineering (pp. 467-488). Lagos, Nigeria: Overseas Canter Transport Research Laboratory.

Paige-Green, P. (1989). The Influence of Geotechnical Properties on the Performance of Gravel Wearing Course Materials. Pretoria, South Africa.

Paige-Green, P. (1999). A Comparative Study of the Grading Coefficient, A New Particle Size Distribution Parameter. Bull. Eng. Geo. Env.(57), 215- 223.

Paige-Green, P. (2007). Improved Material Specification for Unsealed Roads. Quarterly Journal of Engineering Geology and Hydrogeology, 175-179.

Pardeshi, V., Nimbalkar, S., & Khabbaz, H. (2020). Field Assessment of Gravel Loss in Unsealed Roads in Australia. Fronties in Building Environment, 1-11.

Strahan, C. M. (1922). Research Work on Semi gravel, top soil, Sandy Clay and Other materials in Georgia. Bulletin 5a, University of Georgia, 35.

Toole, T., Rice, Z., Latter, L., & Sharp, K. (2018). Appropriate Use of Marginal and Non-standard Material in Road Construction and Maintenance. Sydney, Australia: Austroads Ltd.

MSc Bereket Bezabih – Hawassa University, Institute of Technology Lecture Civil Engineering Department
Main research area(s): Geotechnical Engineering
Address: Hawassa, Ethiopia
E-mail : bereket.bezabih@hu.edu.et
Tel.:+251994783890

MSc Henok Reffisa – Hawassa University, Institute of Technology Lecture Civil Engineering Department
Main research area(s): Geotechnical Engineering
Address: Hawassa, Ethiopia
E-mail : yehenok64@gmail.com
Tel.: +251941163232

MSc Thomas Bezabih – Hawassa University, Institute of Technology Lecture Civil Engineering Department

Main research area(s): Highway &Transport Engineering
Address: Hawassa, Ethiopia
E-mail : thomasbezabih@gmail.com
Tel.: +251912048833

MSc Belete Tsegaye – Hawassa University, Institute of Technology Lecture Civil Engineering Department
Main research area(s): Highway & Transport Engineering
Address: Hawassa, Ethiopia
E-mail : belettetsegaye@gmail.com
Tel.: +251937900118

MSc Temesgen Ayenabeba – Hawassa University, Institute of Technology, Lecture Civil Engineering Department
Main research area(s): Geotechnical Engineering
Address: Hawassa, Ethiopia
E-mail : temesgenemu@gmail.com
Tel.: +251919743536