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ADDIS ABABA INSTITUTE OF TECHNOLOGY
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TUNNEL ROAD FOR ETHIOPIA: FROM ITS TOPOGRAPHY POINT OF VIEW
A case study on Entoto Mountain, Addis Ababa

A Thesis in Road and Transportation

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A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Tunnel Road Design and Construction: From Ethiopia Topography Point of View**' presented by **SAMUEL KIFLE TILAHUN**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that research work titled "Tunnel Road for Ethiopia: From its Topography Point of View" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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Samuel Kifle Tilahun

ABSTRACT

Ethiopia, located in the Horn of Africa, is largely mountainous in topography. The Ethiopian landform is characterized by great diversity. There are flat-topped plateaus, high and rugged mountains, deep river gorges and rolling plains. Constructing surface road on such greatly undulating topography is so difficult. To traverse such kinds of terrain, there may be a need of consructing a bridge or increasing the route length by changing the route direction and/or excavation to arequired level of grade according to the design standard of ERA or AACRA. Therefore, it is important to search for an equivalent but best alternative solution to traverse such kind of topography. As the economy of the country shows a considerable progress, the road infrastructure plays a great role. Road infrastructures have noticable impact on socio-economic development of the nation. Road projects, particularly tunnel road projects, savings of time for motorists or commuters, accident reduction, user cost saving and reduction of CO_2 are often the major benefits. These all benefits have a great impact on the GDP of the country directly or indirectly. Specially, the saved time create two areas of contentions. One is predicting what the time savings would be for the road user; the other is estimating what those times savings are worth to the community and even the countries GDP. Converting these benefits which get off by constructing tunnel road to displace the Entoto mountain, the enumerable out put of Benefit-Cost ratio of 3.07:1, an NPV of 15,674.38 METB and an IRR of 36.0 percent, which shows that the project have a greate impact the county GDP. This implies that the Entoto tunnel road is the best alternative transportation system for areas or the country. In general, even if tunnel roads constitute costly infrastructure in terms of construction cost throughout the world, however, from Ethiopian topography point of view, constructing tunnel road is the feasible and sustainable alternative. The costs of construction of tunnel road project in Ethiopia instead of surface road in mountainous and escarpment terrain is offset by economic benefits of travel time saving, user cost saving, urbanization development in the surrounding areas of the cities and towns of Ethiopia like Addis Ababa, enhancing traffic fluidity along the route, increasing diverted and induced traffic to developed area due to the tunnel project, comfort, safety, reliable routes (mountain crossings) as well as the overall reduction of the environmental impact on the surrounding areas. Therefore, constructing tunnel road in Ethiopia is an effective and efficient alternative transportation infrastructure from its topography point of views.

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TABLE OF CONTENTS

ABBREVIATIONS

AACRA ---------------Addis Ababa City Road Authority

AADT ------------------Annual Average Daily Traffic

AASHTO ------------- American Association of State Highway and Transportation Office

ADT ------------------- Average Daily Trafic

Avg. -------------------Average

BC ----------------------Before Christ

CBA ----------------------Cost Benefit Analysis

CBR ----------------------Cost Benefit Ratio

cm ----------------------cent meter

DC ---------------------Design Class

E ------------------------East

EBCS --------------------Ethiopia Building Code Standard

E.C. ----------------------Ethiopia Calendar

EEPCO ----------------Ethiopia Electric Power Corporation Office

e.g. ---------------------example

EIA ---------------------Environmental Impact Assessment

EIS --------------------Environmental Impact Statement

EPB ---------------------Earth Pressure Balance

ERA ---------------------Ethiopia Road Authority

ESIA -------------------European Standard of Impact Assessment

ESL ---------------------Equivalent Static Load

etc. ---------------------extra

FHWA -----------------Federal Highway Administration

ft------------------------Feet

FTA -------------------Federal Transport Authority

g ------------------------gravity

GPS --------------------Global Positioning System

GSE ----------------------Geological Survey of Ethiopia

HGV -------------------Heavy Good Vehicles

In. -----------------------Inch

IRR --------------------Internal Rate of Return

km ----------------------kilo meter

km/h -------------------kilo meter per hour

m-----------------------Meter

m.a.s.l ------------------meter above sea level

MER -------------------Main Ethiopian Rift

M_L. ----------------------L*ocal (Richter) magnitude*

M_w----------------------M*oment magnitude*

N -----------------------North

NATM -----------------New Austrian Tunneling Method

NB ---------------------Note be

NE ----------------------North East

NEHRP ----------------National Earthquake Hazard Reduction Program

NE-SW ----------------North East to South West

NFPA ------------------National Fire Protection Association

NNE – SSW ----------North North East to South South West

NPV -------------------Net Present Value

N-S ---------------------North to South

NW ---------------------North West

pc ----------------------particle

PGA --------------------Peak Ground Acceleration

PGV --------------------Peak Ground Velocity

PPP ---------------------Private Public Partnership

SEM -------------------Sequential Excavation Method

SE – NW --------------South East to North West

v/h/l --------------------vehicles per hour per lane

USD --------------------United State Dollar

USGS --------------------United State Geological Survey

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 TUNNEL ROAD FOR ETHIOPIA: FROM ITS TOPOGRAPHY POINT OF VIEW

1.1 Background

Ethiopia, located in the Horn of Africa, is largely mountainous country. The central highlands with altitudes between 1,500 and 4,000 m are dissected by numerous rivers, including the Blue Nile. The highlands are split by the Rift Valley, which runs from the Danakil depression close to the Red Sea to the southern part of the country in a south-southwest direction.

Since most of the cities and towns are founded on the base of mountain range like Addis Ababa, Gonder, Dessie, Harer and so on, the roads which are built across these cities cross escarpment and/or mountainous terrains. In addition most of the trunk roads of the country cross these difficult topography. The surface roads which are built across the escarpment and/or mountainous terrain require high investiment cost, long travel time and incure high discomfort to the road user.

The economic development of the country is now on progress. To endure this fast economic development of the country, constructing a better infrastructures which fasilitate the transportation system and communication rate between cities and towns with considerable travel time, travel user cost and desirable comfort facility should be essential.The travel time and comfort of road which is constructed on mountainous terrain is not such satisfactory. To reduce this there must be tunnel road which solves the problems on surface road due to terrain of the area, like Tarma Ber, along the route of Addis Ababa to Dessie-Mekele.

There is tunnelling practice in the country for train truck and access road to the hydro-power station and dam like Tekeze and Gibie. The hydro-power production of the country is accelerating. By its nature, the hydro-power production needs a selection of highly gorgeous areas like Tekeze, Gibie III and the like. Access facility to the selected dam place using surface road is too difficult. So the use of tunnel road facility is a must. The Ethiopia Electric power corporation built a considerable number tunnel roads in different hydro-power production sites. For-instant, Beles, Tekeza, Gibie I, Gibie II and Gibie III. This current practice of tunneling should transfer to road infrastructure.

According to FHWA, a road tunnel [13] is an alternative vehicular transportation system to a surface road, a bridge or a viaduct. Road tunnels are considered to shorten the travel time and distance or to add extra travel capacity through barriers such as mountains or open waters. They are also considered to avoid surface congestion, improve air quality, reduce noise, or minimize surface disturbance. Often, a tunnel is proposed as a sustainable alternative to a bridge or a surface road.

Road tunnels [6] are feasible alternatives to traverse through physical barriers such as mountains, existing roadways, railroads, or facilities; or to satisfy environmental or ecological requirements or to cross a water body. In addition, road tunnels are viable means to minimize potential environmental impact, traffic congestion, pedestrian movement, air quality, noise pollution, or visual intrusion; to protect areas of special cultural or historical value such as monasteries like Abune Petrous (which is protected by constructing cut and cover tunnel for light rail), conservation of districts, buildings or private properties; or for other sustainability reasons such as to avoid the impact on natural habit or reduce disturbance to surface land.

A tunnel can be designed to accommodate any class of roads and any size of vehicles. Alignments, dimensions, and vehicle sizes are often determined by the responsible authority based on the classifications of the road (i.e. Ethiopia Road Authority or Addis Ababa City Road Authority Manual) [9, 10, and 6]. However, most regulations have been formulated on the basis of open roads. Ramifications of applying these regulations to road tunnels should be considered. For example, the use of full width shoulders in the tunnel might result in high cost. Modifications to these regulations through engineering solutions and economic evaluation should be considered in order to meet the intention of the requirements.

In general, the use of tunnel road on mountainous country like Ethiopia is advisable to facilitate fast transportation system development through out the country. As the current development of the country looks sustainable, there must be an advance of the current surface road infrastructure in to underground road structure. Therefore, tunnel road, like Tarmaber which connect the central city Addis to the Northern country like Dessie and Mekele by crossing a Tarmaber mountainous geological formation, must be constructed to reduce the travel time and traffic accident which occur due to terrian conditions and increase the comfort and safety condition of the road users. For the city of Addis Ababa, it is advisable to build tunnel road to reduce the congestion, travel time from one sub city to other and to expand the city in the simple way to the neighboring town of the Oromia Region or Finfinae.

1.2 Statement of the problem

Since Ethiopia is a mountainous country, most of the surface roads constructed subjected to traverse through mountains and/or escarpment terrain. To fulfil the geometric standard criteria Ethiopian Road Authority (ERA) and/or Addis Ababa City Road Authority (AACRA), either there must be high amount of earth work (cut to fill) or route change. These way of constructing the surface road to cross such topograpy or terrain resulted in high investment cost, long travel time, high working discomfort and also reduce the performance of the vehicle during operation. The environmental impact of surface road constructed on such terrain is so high. The current practice to reduce the high cost of construction in related to earth work of surface road across escarpment and/or mountainous area is route changing or constructing it with zig zag fasion. There is also a problem of sustainability on surface road constructed on mountainous or escarpment terrain. The life time of surface road is short, with the attainment of its design life. Since the stress developed on the pavement structure on mountainous and escarpment terrain is relatively higher than on level or on moderate grade, the deterioration of the pavement is sever. To mitigate such kinds of problem, there should be best and approprete infrastructure.

1.3 Objectives of the study

1.3.1 General Objective

Since Ethiopia is a mountainous country, most of the surface roads constructed in the country cross or traverse mountains, escarpment and/or rugged terrains. Construction of surface road on such area costs a lot in-terms of money, time and user comfort. So construction of tunnels in such areas are beneficial from different point of views. The objective of this paper is to investigate the feasibility, socio-economic benefit, constructability, applicability and environmental impact of tunnel road for Ethiopia from its topography point of view, with case study on Entoto mountain.

1.3.2 Specific Objectives

- To compare surface road which is constructed on escarpment and/or mountainous terrain with tunnel road from different aspects.
- To investigate the feasibility of constructing tunnel road in Ethiopia, case study on Entoto mountain along Addis Ababa Comando trunk road.
- To investigate the socio-economic benefit of tunnel road.
- To show tunnel road is the effective and efficient transport infrastructure for Ethiopia.

1.4 Hypotheses

Are road tunnels feasible alternatives to traverse through physical barriers such as mountains or to satisfy environmental or ecological requirements in Ethiopia?

Is tunnel road a sustainable transport solution for Ethiopia from its topography point of views?

Is the geology, hydro-geology and sub-surface condition of Ethiopia favourable for tunnel road?

Do tunnel road constructions in Ethiopia have contribution to the national growth of the country?

1.5 Research methods

- ❖ Study area: Different parts of Ethiopia, especially, along the trunk road from Addis Ababa to Commando on Entoto mount and Addis Ababa to Dessie on Tarmaber tunnel road (existing).

- ❖ Study design: observational study
  Observational approach
  Observation is a key attribute of the study to effective geotechnical, geological and tunnel engineering. Observation implies the ability to use the senses, mostly but not exclusively by sight, to identify features of significance, or potential significance, to engineering decisions. Many circumstances of the ground or of the construction process are too

complicated to describe with exactitude. Observation of characteristics and comparison with similar examples elsewhere explicitly or by personal judgment, leads to an understanding of the potential risks and opportunities.

Photographic or video records for zoning of specific characteristics is essential. This method strengthen the observational study and make the observer recognase some day later about the specific site.

Some of the investigation techniques for design and construction of road tunnel need detail experimental studies i.e. they require experimental approach. But the scope of this paper is to assess the suitability of Ethiopia topography for tunnel road using observational approach and with simple techniques like geological map evaluation and some other related approach.

- ❖ Sampling methods: simple random sampling; mostly on EEPCO and train site, Tarmaber tunnel road (existing) and some of the road constructed on mountainous and escarpment terrain.
- ❖ Method of data collection:
  - Data is collected from EEPCO and/or tunnel construction site using observation. This is supported using photograph and video.
  - Detail study on Tarmaber existing tunnel road and on Entoto mount. Collect data using GPS, like tracking. By using GPS tracking compare the tunnel road with the existing surface road. At this time rent car must be necssary for detail observation study.
  - Geological map of Ethiopia and information or any related data from geological surveying agency of Ethiopia.
  - Digital map of Ethiopia and any other map related to the work from mapping agency of Ethiopia.
  - Data from traffic police, transportation Minister of Ethiopia and road agencies like ERA and AACRA.
- ❖ Description of variables:
  - Geometrical and structural design of tunnel road
  - Geological and seismic conditions
  - Geotecnical
  - Feasibility
  - Sustainability

1.6 Scope of the Study

This study attempts to provide rationalized information on the necessity of tunnel road for Ethiopia, especially for Addis Ababa, on the bases of topography, current transportation condition according to travel time, traffic accident, road user cost and urban land use. The basic initiative point of the research is the tunnel road of Tarmaber, tunnels which are built by Ethiopia Electric Power Corporation Office (EEPCO) for access to the hydro-power dam like Tekeze and Gibie hydro-power plants, the tunnel which built for train along Awash-Kombolcha-Woldia railway project to the northern of Ethiopia and the congestion of Addis Ababa city due to shortage of living area and traffic condition. Since Addis Ababa is surrounded by chain of mountains like Entoto in the four direction, land-use for urbanization becomes so hard after a time. But there is a huge flat area behind each mount for the expantion of the city. Therefore, constructing an automated tunnel road through Entoto mount benefits the city and the people living around there as to become one of the subcity of Addis Ababa. The study is made based on observation. It is not dependent on experimental. So the study is limited to observation with random sampling.

CHAPTER 2 LITERATURE REVIEW

2.1 Overview

The American Association of State Highway and Transportation Officials (AASHTO) define road tunnel as [8], “enclosed roadways with vehicle access that is restricted to portals regardless of type of the structure or method of construction.” The FHWA Technical manuals also define as sustainable features which have longer life expectancy than a surface facility (125 versus 75 years) [6]. The American society of civil engineers expresses tunnels as a key element of the nation’s infrastructure. They play a key role in urban transportation, mining, and water and sewerage transportation. Tunnels also provide opportunities for land development for residential, commercial, or recreational facilities. They enhance the area and potentially increase property values. Tunnels also enhance communities’ connections and adhesion and protect residents and sensitive receptors from traffic pollutants and noise [6, 8 and 69].

In general road tunnels [1, 6 & 8] are, therefore, feasible alternatives to cross or traverse through physical barriers such as mountains, existing roadways, railroads, or facilities and even water bodies; or to satisfy environmental or ecological requirements. In addition, road tunnels are viable means to minimize potential social and environmental impact such as traffic congestion, pedestrian movement, air quality, noise pollution, or visual intrusion; to protect areas of special cultural or historical value such as conservation of districts, buildings or private properties; or for other sustainability reasons such as to avoid the impact on natural habit or reduce disturbance to surface land.

2.2 Background to Modern Tunneling

It is necessary to understand how circumstances have changed with time and with the increased complexity of the tunneling operation [1]. The many contributory factors include the increasingly specific technical requirements to satisfy the objectives of an underground project, developments in the techniques and the means of tunneling, also in the associated improved capability to explore the ground, to measure and model its characteristics [1].

Tunneling in antiquity: We need to respect the intelligence of these early tunnels of 3000 years ago and more for the magnitude of their achievements, whose art depended entirely on trial-and error (heuristics) to learn what could be done and how best to achieve results, with neither the benefit of underlying technology nor with access to specialized tools [32]. This kind of tunneling also performed in Ethiopia also, in the monastery of Lalibela. All ancient civilizations have left behind examples of tunneling at varying scales. It is remarkable that the first known subaqueous tunnel was built in about 2000 BC to connect the royal palace of Queen Semiramis to the Temple of Jove (or his equivalent) beneath the River Euphrates [1].

Needham (1971) found evidence of similar tunnels in China as early as 280 BC and conjectures as to whether the art might have passed from China to Middle East or *vice versa*. The Greek water supply

tunnel on the island of Samos (Plichon 1974) highly regarded by Herodotas, merits a brief description. The tunnel conceived by Eupalinos and constructed in 525 BC, provided water from a spring to the town of Samos.
The first sizeable tunnel in soft ground is recorded by Sandström (1963) as the Tronquoy tunnel on the St Quentin canal in France in 1803, where the method of construction, based on the use of successive headings to construct sections of the arch starting from the footing, was a for runner to the German system described above [1 & 32].

Towards the present day: Until the 1950s tunneling continued to be seen as largely a traditional craft-based operation, undertaken by skilled miners and timber men largely educated from experience [1]. Design methods, developed in the nineteenth century, were being extended but not essentially modified by Kommerell, Terzaghi and others. Since 1970, miniaturization, mostly undertaken in Japan, has developed a family of devices for cutting and reaming the ground, largely superseding the earlier systems which depended on jacking a blind pipe.

"Ground freezing by the use of brine in circulation pipes was first used for shaft-sinking for mining through water-bearing zones of the ground in South Wales in 1862 (Glossop 1968). More recently, the technique has been adapted for tunneling, using a pattern of freezing around a cylinder ahead of the tunnel together with a plug of frozen ground at its extremity" [32].

2.3 Tunnel Planning

Almost every tunnel is a solution to a specific challenge or problem. In many cases, that challenge is an obstacle that a roadway or railway must bypass without altering its route. They might be bodies of water, mountains or other transportation routes which is forced to be built on escarpment terrain. Even cities like Addis Ababa in the context of Ethiopia, with little open space available for new construction, can be an obstacle that engineers must tunnel beneath Entoto and the like mountains to avoid the land use shortage of the city and the future traffic congestion. Sometimes, tunnels offer a safer solution than other structures. The Seikan Railway Tunnel in Japan was built rather than bridge because ferries crossing the Tsugaru Strait often encountered dangerous waters and weather conditions [32].

Successful tunneling required a good planning with a sound understanding of the topography and geology and the selection of the best rock strata through which to tunnel [3]. How a tunnel is built depends heavily on the material through which it must pass. Tunneling through soft ground, for instance, requires very different techniques than tunneling through hard rock or soft rock, such as shale, chalk or sandstone. Tunneling underwater, the most challenging of all environments, demands a unique approach that would be impossible or impractical to implement above ground [1].

That's why planning is so important to a successful tunnel project. Engineers conduct a thorough geotechnical and geological investigation like soil and rock types, weak beds and zones including faults and shear zones, ground water condition and special hazards as heat and gas like methane. This investigation used to determine the type of material they will be tunneling through and assess the relative risks of different locations. Often, a single tunnel will pass through more than one type of material or encounter multiple hazards. Good planning allows engineers to plan for these variations right from the beginning, decreasing the likelihood of an unexpected delay in the middle of the project [29].

2.4 Tunnel Site Investigation

Tunnel construction is governed by the ground condition and hence site investigation is vital to obtain ground characteristics and geotechnical parameters. Knowledge of the ground conditions plays a key role in the choice of construction technique, and hence the success of a tunnel project. Investigations should be conducted to obtain data for planning, design, construction and maintenance. To design and construct tunnel road the following site investigation should be done in stage wise. These are route selection, geotechnical investigation, geological investigation and investigation for environmental protection [61].

2.4.1 Route Selection

The tunnel route selection needs a good understanding of the topography condition and the socio-economic benefit of the area.

2.4.2 Geological Investigation for Tunneling

Each tunnel project is unique! The importance of geology in the planning of tunnels is stressed, as is the significance of the vast uncertainty and risk that exist in underground projects [2]. The effect of the geological features on the tunnel alignment is the presence of active or inactive faults. The geology along a tunnel alignment plays a dominant role in many of the major decisions that must be made in planning, designing, and constructing a tunnel [4]. Geological survey, data collection, and evaluation should begin very early in the conceptual planning of any project and should continue through construction and even after construction to document the as-built conditions and the behavior of the tunnel in service [61].

2.4.3 Geotechnical Investigation for Tunneling

There is a fundamental difference between the way geotechnical investigations are conducted for underground construction and for any other project. This is related to the fact that, in order to predict costs, the geotechnical engineer must estimate the behavior of the tunnel under several anticipated excavation and lining scenarios. Thus, the investigative program must be directed towards the goal of predicting behavior and estimating costs [4].

Geotechnical investigations [4, 6] should be carefully planned to take into account the significance of geology as well as the vast uncertainty associated with underground design and construction. There is wide latitude for determining what should be done during an investigation. Each project is unique; there is no fixed standard or check-off list that can be used to determine the scope and how to do geotechnical investigations.

Geotechnical investigations are critical for proper planning of a tunnel. Fortunately, in spite of the inherent uncertainty and risk, geotechnical investigations for tunnels are largely successful. Geotechnical information can be invaluable in both the decision of the general corridor and the specific alignment of a tunnel project. Selection of the alignment, cross section, and construction methods is influenced by the geological and geotechnical conditions, as well as the site constraints. Good knowledge of the expected geological conditions is essential. The type of the ground encountered along the alignment would affect the selection of the tunnel type and its method of construction. The selection of the tunnel profile must therefore take into account potential ground movements and avoid locations where such movements or settlements could cause surface problems to existing utilities or surface facilities and mitigation measures should be provided [37].

2.4.4 Investigation for Environmental Protection

Road tunnels are more environmentally friendly than other surface facilities. Traffic congestion would be reduced from the local street [6]. The environment must be protected from the impact caused during the construction and operation of tunnel road.

2.5 Geometrical Configuration

Road tunnels for this paper cover all roadways including freeways, arterials, collectors, and local roads and streets in urban and rural locations following the functional classifications from AASHTO, ERA and/or AACRA publication “Highway Functional Classification: Concepts, Criteria, and Procedures”. Although the geometrical requirements for roadway alignment, profile and for vertical and horizontal clearances in the above design standards generally apply to road tunnels, amid the high costs of tunneling and restricted right-of-way, minimum requirements are typically applied to planning and design of road tunnels to minimize the overall size of the tunnel yet maintain a safe operation through the tunnel. To ensure roadway safety, the geometrical design must evaluate design speed, lane and shoulder width, tunnel width, horizontal and vertical alignments, grade, stopping sight distance, cross slope, The design standards used for a road tunnel project should equal or exceed the minimum given below to the maximum extent feasible, taking into account costs, traffic volumes, safety requirements, right of way, socioeconomic and environmental impacts, without compromising safety considerations. Super elevation, and horizontal and vertical clearances, on a case by case basis.

2.5.1 Design Standards

Planning and design of road tunnel options for new route corridor should initially be to the same highway standards as for open road options, except for differences including: capital, operating and whole life costs; ventilation; lighting and maintenance requirements and also the security condition. The nature and mix of vehicles in the traffic flow will also affect the physical design of tunnels [1 & 4].

To design the tunnel road there should be different standards to guide the designer. The American use the Green Book (AASHTO 2004 design guide) for the geometric design of road tunnels. In addition to the Green Book (AASHTO, 2004), standards to be used for the design of geometrical configurations of

road tunnels should generally comply with the manual developed by the Federal Highway Administration.
Geometric design for road tunnels must consider tunnel systems such as fire life safety elements, ventilation, lighting, traffic control, fire detection and protection, communication, etc. Therefore, planning and design of the alignment and cross section of a road tunnel must also comply with National Fire Protection Association (NFPA) 502 – Standard for Road Tunnels, Bridges, and Other Limited Access Highways [20].

Geometrical design standards are influenced by the special features of tunnel which distinguish them from open road conditions. Departures from Standards that would normally be adopted for comparable sections of open road could be considered by the Technical Approval Authority of the Overseeing Organization, bearing in mind that tunnels are special sections of road requiring high investment for their construction, operation and maintenance [6].
The nature and extent of any modifications to the criteria that are used for open roads will vary according to the circumstances at each tunnel and a detailed consideration of the following:

- Traffic composition and design flows
- Design speed
- Sight distances and the relations between alternative tunnel cross-sections and minimum horizontal radii
- Scope for tunnel widening at curves
- Basis of tunnel operation (one way, two way, contra flow)

The requirements provide the adjustments that are to be made to the Standards used for the design of carriageways on open roads. These adjustments make allowances for the special demands and conditions of approaching and driving through tunnels.

Traffic Capacities and Vehicle Classification

Traffic Capacity: The procedure for estimating the capacity of a tunnel involves individual and separate determinations of the partial capacities for each of the directions of travel. The capacity is determined in two steps; the first step is to calculate the theoretical capacity on the basis of the free flow speed. The second step is to adjust this theoretical capacity depending on the presence of heavy vehicles and the type of drivers to obtain the practical capacity [6, 37].

Vehicle Classification: A tunnel can be designed to accommodate any class of roads and any size of vehicles. The class of the road should be determined from the geometric standard manuals like the AASHTO Green Book, ERA and AACRA. The size and type of vehicles to be considered depend upon the class of road [6, 59].

Alignment

Planning and design of road tunnel alignments must consider the geological, geotechnical and groundwater conditions at the site as well as environmental constraints [6]. The tunnel alignment was a critical stage in the design process [32]. The design of the alignment must aim to achieve the correct balance between four principal factors. The factors were firstly, the desire to provide the required ridership, secondly optimum tunnel road geometry for operational purposes, thirdly, the constraints on tunneling imposed by the existing ground conditions, impacts on existing infrastructure and the desire to avoid expensive construction methods and high risk underpinning wherever feasible. The fourth factor was that the alignment design sought to provide least impact on the public in terms of nuisance, safety and private land acquisition. The optimizations of these factors have a significant impact on the successful design of the tunnel project [37]. The alignment design process involved the assessment of alignment options by using ground characterization through geological and geotechnical investigation, analysis of tunneling effects on structures, design of mitigation works and railway and motor vehicle considerations. Each option was tested in terms of impact on the general public, build ability and cost.

Horizontal alignment: The horizontal curve should satisfy the open road geometric standards of the country i.e. ERA or AACRA geometric standards. Straight alignments should not necessarily be avoided, but they should not be more than 1500 m in length because the effect of excessive concentration on one point could distract the driver, or even induce an unconscious increase in the speed [59, 30].
When horizontal curves are needed, it should satisfy the following minimum requirement, according to FHWA [6];

- Minimum acceptable horizontal radii should consider traffic speed, sight distances, and the super-elevation provided. In general, for planning purpose, the curve radii should be as large as possible and no less than 255 to 300-m radius.
- Super elevation rate, which is the rise in the roadway surface elevation from the inside to the outside edge of the road, should preferably lie in the range 1% to 6%.
- When chorded construction is used for walls where alignments are curved, chord lengths should not exceed 25 feet (7.6 m) for radii below 2,500 feet (762 m), and 50 feet (15 m) elsewhere.

Vertical alignment: The design of vertical alignment should satisfy the geometric standard of open road of the country i.e. ERA or AACRA geometric standards. Steep inclination of the pavement alignment (more than 3.5%) makes ventilation more difficult as the chimney effect becomes powerful, and considerable resistance must be overcome to establish an air flow against this effect. This becomes even more important in the event of fire, as hot gases have even more tendency to rise [6, 32, and 60].

Sight and Braking Distance Requirements: Sight and braking distance requirements cannot be relaxed in tunnels [6].

Cross-section

The cross section is determined by the space required for traffic, space required for other facilities, by construction methods and socio-economic value of the tunnel. The traffic space determines the lane width and the maximum load height of the vehicle. By considering the economic condition some country provides walkway for the purpose of inspection, maintenance, and emergency use for access to the site of an accident and for escape. The following are commonly considered in the design of tunnel road cross-section [6, 32, and 59]:

- Lane width

- Hard clearance width
- Central median strip
- Off carriageway width and visibility or sight distance

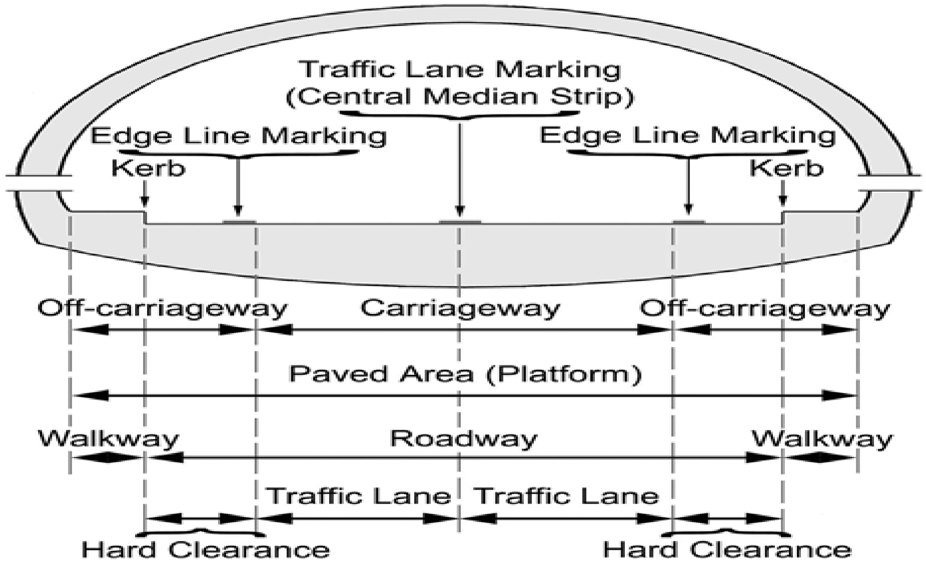


Figure 2. 1 cross-section of paved bi-directional tunnel road (Source: B.P. Rigter)

Uni-directional Tunnel Road: Due to the costs of tunnel there is a need to minimize their cross section. On the other hand minimum cross sections might cause a decrease of the Free Flow Speed and the Road Capacity, as well as an increase of the chances on congestion, in- and accidents, whereas the possibilities for Incident Management and Rescue get less [6, 32 & 57].

Bi-directional Road Tunnels: The forcible criterion in the bi-directional road tunnel is the safety considerations. The safety criteria tend to increase the section (wide hard clearance, comfortably wide walkways, facilities for disabled people, long visibility distances, possibility of overtaking a stopped vehicle at any point, etc.). The economic criteria lead to cross sections that are more restrictive than those used for open roadways with similar traffic density and geometric conditions. But the following basic principles must be fulfilled in bi-directional tunnels design [6, 32 & 57]:

- ❖ The design of tunnels should incorporate the geometric conditions, illumination, signaling and road markings that best improve and increase traffic safety conditions.
- ❖ It should be possible for one heavy goods vehicle to overtake a stopped heavy goods vehicle without completely interrupting traffic in the opposite direction.
- ❖ If there is only one lane of traffic for either or both directions, overtaking a moving vehicle in this direction must be absolutely forbidden.
- ❖ The cross section point of a tunnel where there is the minimum capacity for passage of vehicle traffic should be located before the tunnel itself or in the entry section of the tunnel in each direction, it should never be located at any intermediate point or at the exit.
- ❖ For planning and design purposes, each lane width within a road tunnel should be no less than 12 feet (3.6 m) as recommended in the 5th Edition of Green Book (AASHTO, 2004).

Travel Clearance

The clearance of the tunnel should take into consideration potential future vehicle heights, vehicle mounting on curbs, construction tolerances, and any potential ground and structure settlement. Ventilation equipment, lighting, guide signs, and other equipment should not encroach within the clearance diagram. Vertical clearance should be selected as economical as possible consistent with the vehicle size. The AASHTO Green Book (2004) recommends that the minimum vertical clearance to be 4.9 m for highways and 4.3 m for other roads and streets. Note that the minimum clear height should not be less than the maximum height of load that is legal in a particular country [6 & 8].

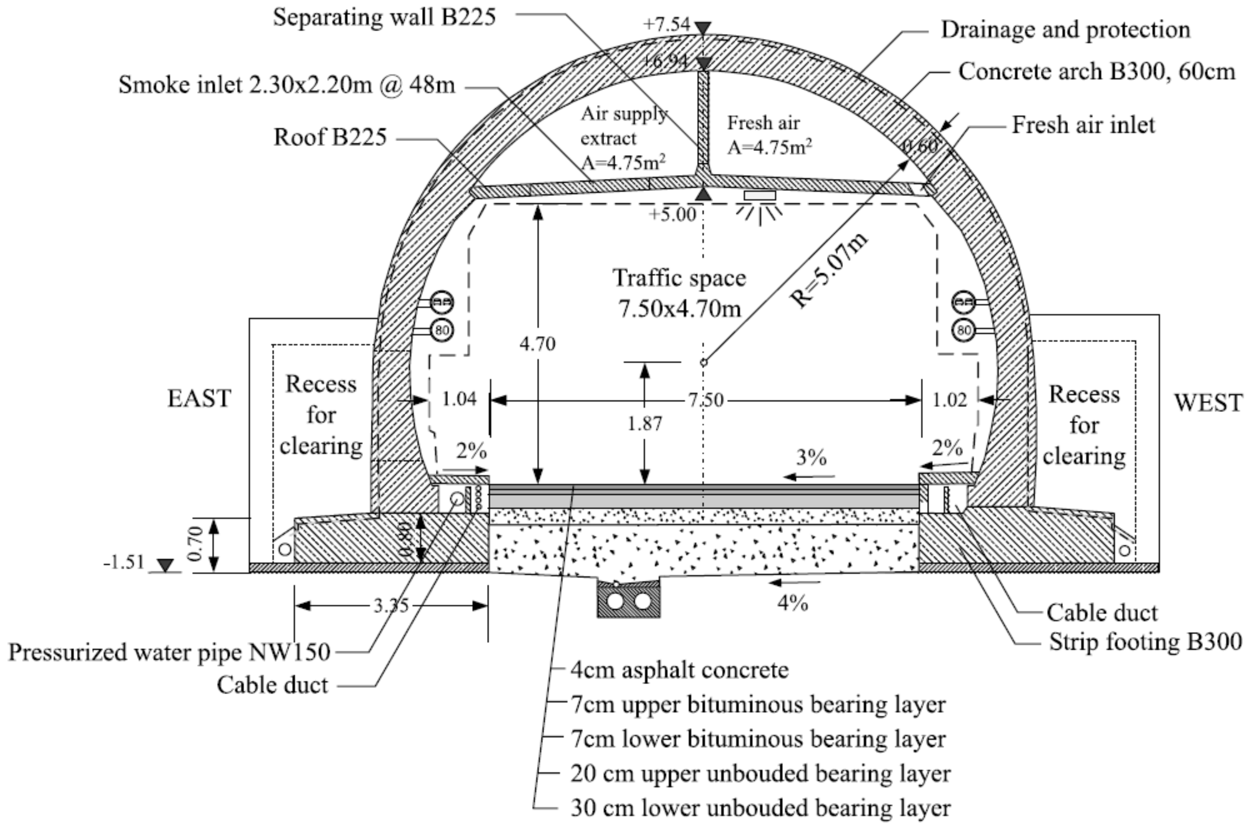


Figure 2. 2 Typical Two-Lane Tunnel Cross section elements and Clearance Requirements [Source: Dimitrios Kolymbas; Tunneling and Tunnel Mechanics]

Portals and Approach

Tunnel portals may require special design considerations. Portal sites need to be located in stable ground with sufficient space. Orientation of the portals should avoid if possible direct East and West to avoid blinding sunlight.

2.6 Seismic Considerations

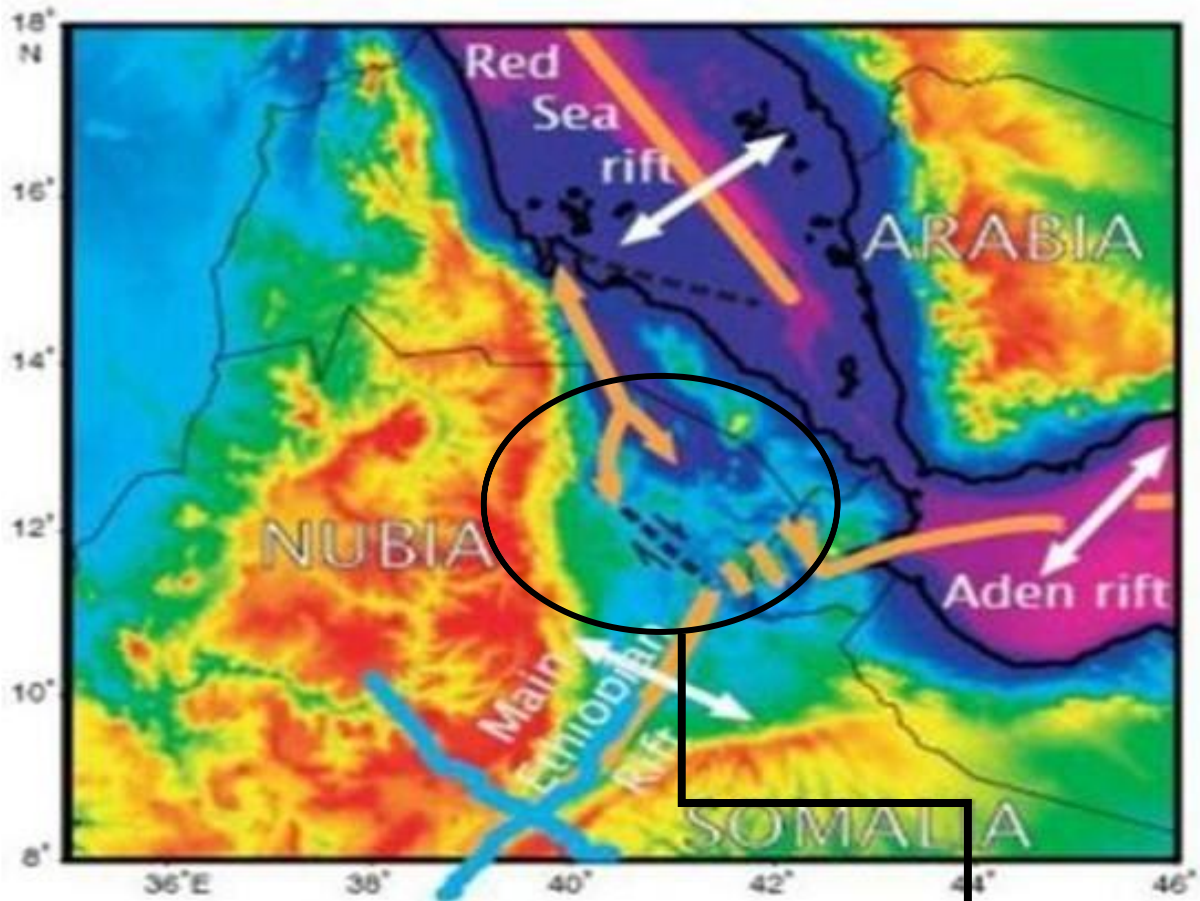
Underground structures, in general, have performed better during earthquakes than have above ground structures such as bridges and buildings. Since they are constrained by the surrounding soil or rock and cannot move independently so are not generally subjected to significant dynamic amplification effects. They are affected by the deformation of the surrounding ground and not by the inertia forces acting on the structure. In contrast, above-ground structures often have natural frequencies that are within the range of the predominant frequencies of earthquake ground motions, resulting in resonant effects with the accelerations acting on the structure amplified with respect to the ground surface [6, 32].

The main loading of tunnel structures have been associated with large ground displacements (deformation) due to ground failure, i.e., fault rupture through a tunnel, land-sliding (especially at tunnel portals), and soil liquefaction, which may be assumed to be identical with the deformation of the surrounding ground. Ground shaking in the absence of ground failure has produced a lower incidence and degree of damage in general, but has resulted in moderate to major damage to some tunnels in recent earthquakes [32, 34].

2.6.1 Seismic Activity

Earthquake Fundamental

Major tectonic features in Africa, mainly in the eastern and southern African region, are mainly controlled by the well-known geological structure, the East African rift system. This feature extends as a continuous structure for approximately 4000 km from the triple junction in the Afar region joining the full spreading ridges in the Red-Sea and the Gulf of Aden in the north, to the less mature continental rifting that basically follows the mobile belts in the south (Fig. 4.9) [39].



The Trip Junction in Afar Region

Spreading vectors:

Nubia – Somalia	6 mm/yr	Chu & Gordon 1999
Somalia – Arabia	18 mm/yr	Joffe & Gorfunkel 1997
Arabia – Nubia	20 mm/yr	Joffe & Gorfunkel 1997

Proposed refraction profile

Actively spreading rift segment

Figure 2. 3 The Trip Junction of Plates in Afar Region, Ethiopia [Source EAGLE]

2.6.2 Fault Movements

A fault is a crack in rock or soil along which earthquake movement has taken place. When the fault slips, the elastic energy stored in the rock is released as seismic energy in the form of seismic waves, or earthquake waves. These waves spread outward from the fault. But, most faults that exist today are the result of tectonic activity that occurred in earlier geological times.

Earthquakes with focal depths from the surface to about 70 kilometers are classified as shallow. Earthquakes with focal depths from 70 to 300 kilometers are classified as intermediate. The focus of deep earthquakes may reach depths of more than 700 kilometers [39]. The maximum depth of hypocenter in Ethiopia from 1990 to 2006 is 70 km in the north eastern part but the most frequant depth in the main Ethiopia Rift is 33km [27]. Therefore, the earthquakes in Ethiopia are classified as shallow.

Type of Faults: Faults may be broadly classified according to their mode, or style of relative movement. But the major type of fualt in Ethiopia is Dip Slip.

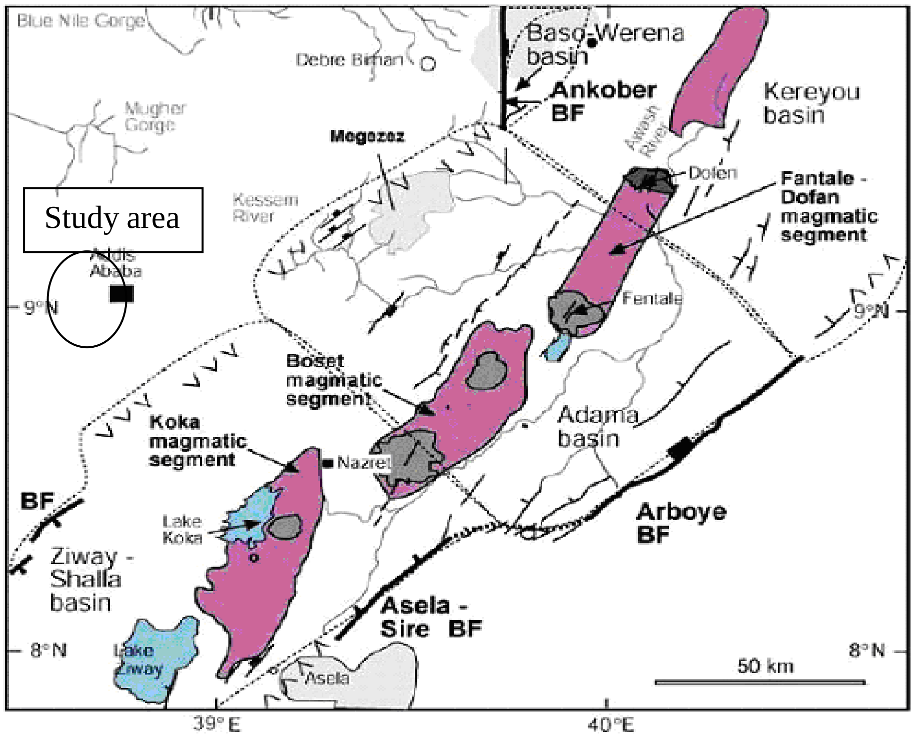


Figure 2. 4 Major faults and magmatic segments of the northern Main Ethiopian rift (Wolfenden et al, 2004).

2.6.3 Major cities/ towns vulnerable to earth quake

The Ethiopian Building Code 8, EBCS 8, divides Ethiopia in to four seismic zones to satisfy the standard requirment for buildings. The zonation depends on the local hazard. According to the code, seismic zones with a design ground acceleration not greater than 0.05g (zone 1 and zone 2) are low seismicity zones. Therefore, the most vulnerable is zone 4. Addis Ababa city be allocated in zone 2/3 according to the code. The table below shows major cities/towns which is vulnerable to seismicity, according to EBCS 8 zonation.

Table 2. 1 Cities along Zone four of EBCS

City/Town	Zones	Remark
Addis Ababa	2/3	on the boarder of MER
Maichew	4	Along the MER
Woldia	4	Along the MER
Asaita	4	Along the MER
Dessie	4	NW
Kara Kore	4	Along the MER
Ankober	4	Along the MER
Arbaminch	4	Along the MER
Awash station	4	Along the MER
Nazrit	4	Along the MER
Hawasa	4	Along the MER
Debre Birihan	4	Along the MER
Jinka	3	On the doarder
Bati	4	Along the MER
Debre Sina	4	Along the MER
Hosaina	4	Along the MER
Metehara	4	Along the MER
Abomsa	3	On the board
Sodo	4	Along the MER

NB. Not all cities / towns are listed.

2.6.4 Seismic Zones

The seismic zone of an area determines the level of equivalent static forces that will be applied in a building frame in seismic design using the ESL (Equivalent Static Load) procedure. Likewise, the seismic zone also determines the level of dynamic loads to be considered for design based on response spectra analysis. Ethiopian Building Code of Earthquake subdivided the country in accordance to the figure 4.15 below in to four seismic zones, depending on the local hazard. By definition, the hazard within each zone can be assumed to be constant [31].

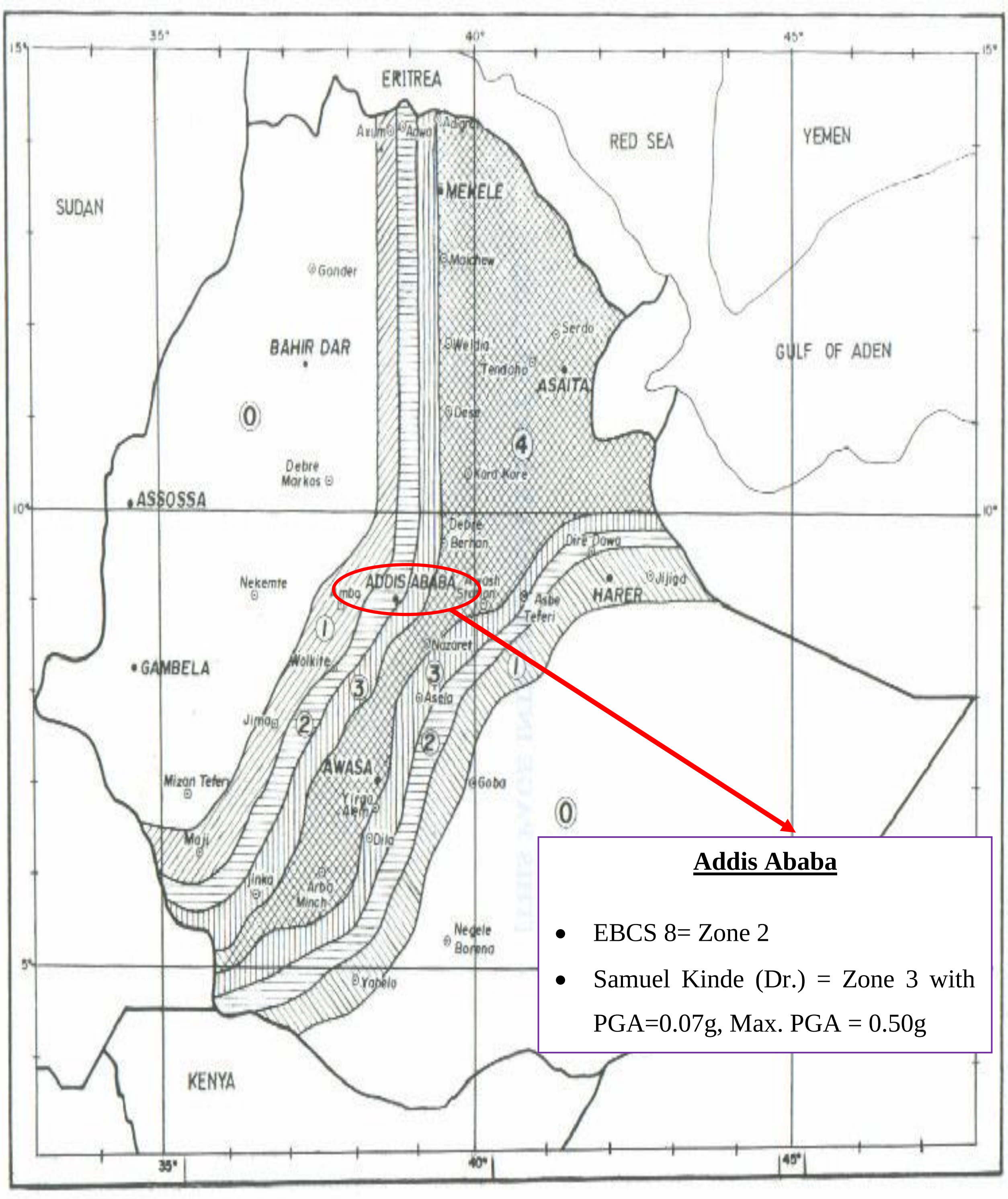


Figure 2. 5 Seismic zoning of Ethiopia as per EBCS-8:1995.

CHAPTER 3 OVERVIEW OF TOPOGRAPHY AND GEOLOGY OF ETHIOPIA

3.1 Topography of Ethiopia

3.1.1 Overview of General Topography of Ethiopia

The topography of Ethiopian is best expressed as abstractive blend of massive highlands, highly rugged terrain, and remarkable valleys divided by the Ethiopian Great Rift Valley which runs from southwest to northeast surrounded by lowlands, steppes, and semi-desert [24 & 50]. As Ethiopia is the horn of Africa much of its landmass is part of the East African Rift Plateau. The general elevation of the landmass ranging from 1,500 to 3,000 meters above sea level [51].

The Ethiopian landform is characterized by great diversity. There are flat-topped plateaus, high and rugged mountains, deep river gorges and rolling plains. Altitude ranges from more than 100 m. below sea level to mountain peaks greater than 4,000 m. Although the highest mountain in Ethiopia, Ras Dashen (4,620m) is only the fourth highest in Africa, Ethiopia has the largest proportion of elevated landmass in Africa [50]. It is sometimes appropriately described as the Roof of East Africa. More than 50 percent of the Ethiopian landmass is above 1000 of elevation and above 1,500 meters makes 44 percent of the country. Half of this, in turn, is at more than 2,000 meter [52].

The topography of Ethiopia is largely determined by the late-date geologic activity of the Cenozoic era. The uplifting of the Arabo-Ethiopian swell and the subsequent outpouring, spreading and thick accumulation of Trapean lava have given rise to an outward sloping highland plateau and mountains [51]. The major faulting resulted in the division of the plateau into two broad units and the formation of a great structural valley. Faulting elsewhere and on the floor guided part of the course of some rivers. They also formed depressions on which lakes were subsequently created. Geomorphic processes brought some modification to the structural landform by river dissection and roughening on the highlands, and deposition on the lower areas [51].

The physical aspect of the highlands is impressive. For example, the northern portion, lying mainly between 10° and 15° N, consists of a huge mass of Archaean rocks with a mean height of 2,000 to 2,200 m (6,562 to 7,218 ft.) above sea level, and is flooded in a deep central depression by the waters of Lake Tana. Above the plateau rise several irregular and generally ill-defined mountain ranges which attain altitudes of from 3,700 m (12,139 ft.) to just under 4,600 m (15,092 ft.). Many of the mountains are of unusual shape [23]. However, most of the cities and towns of Ethiopia were founded on the base of these mountains range. For example Addis Ababa which is the capital city of Ethiopia is surrounded by continuous ranging mountains like Entoto and three other such mountains. North of Addis Ababa, the surface of the plateau is interspersed with towering mountains. The plateau also contains mountain ranges such as the Chercher and Aranna. Few of these peaks' surfaces are flat except for a scattering of level-topped mountains known to Ethiopians as Ambas (local name which means flat-topped hills or small plateaus). Southwest of Addis Ababa, the plateau also is rugged, but its elevation is slightly lower than in its northern section. To the southeast of Addis Ababa, beyond the Ahmar and Mendebo mountain ranges and the higher elevations of the southeastern highlands, the plateau slopes gently toward the southeast. The land here is rocky desert and, consequently, is sparsely populated [23 & 26].

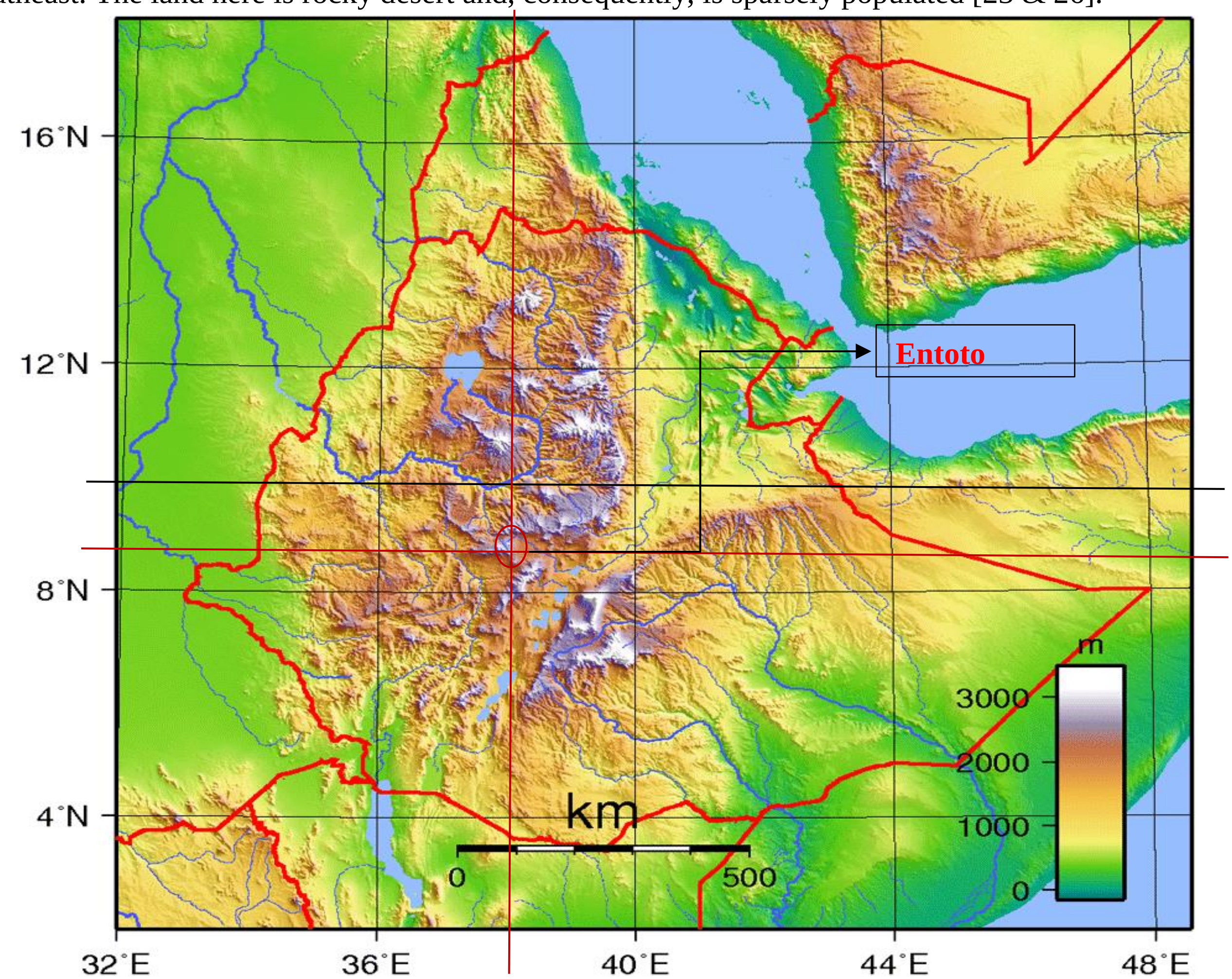


Figure 3. 1 Topography of Ethiopia [23]

At the present condition, Addis Ababa shows a continuous development in road infrastructures and high rise buildings. Since Addis Ababa is surrounded by chain of mountain range, the living environment on the city becomes so much congested due to shortage of residential land use area and urbanization will become difficult i.e. there is a shortage of land-use for the development of residential area and the like at the current level of the city. Due to the incremental of car ownership the highway of the city serviced beyond their design capacity. To alleviate this traffic congestion of the city, expansion of the existing surface is not as such best alternative due to right of way problems. But at the back of the mountains range, there is a huge flat landmass [23].

According to the topography of Ethiopia, tunnel road should be considered as one alternative means for the development of road infrastructure to facilitate transportation system and urbanization development for the cities and towns of Ethiopia. At the present time, the number of road tunnels continues to grow worldwide as important components of modern highway design. In the urban environment, tunnels are replacing surface roads as a more socially acceptable alternative. For the rural situation tunnels are used to reduce the grades of highways in more hilly or mountainous countryside, thus ensuring better traffic flows and reducing journey times, other road user costs and vehicle emissions [19].

3.1.2 The Physiographic Divisions

Following the structural divisions brought about by the geologic processes of the Cenozoic era, three major physiographic units can be recognized in Ethiopia [51, 50]. These are:

a) Western Highlands and Lowlands
b) South Eastern (Eastern) Highlands and Lowlands
c) Rift Valley

3.1.3 The Western Highlands and Lowlands

This physiographic unit includes all the area west of the Rift Valley. It extends all the way from north to south encompassing nearly the whole western half of Ethiopia. It makes up about 44 percent of the area. In the east, the Western escarpments of the rift valley bound it whereas westward, the land gradually descends in altitude until it merges into the western foothills and lowlands, along the Sudan border. This region is further subdivided into four groups of highlands (76.3 percent) and four groups of lowlands (23.7 percent) [50].

3.1.4 The Highland Units

a) The Tigray Plateau

As the name indicates, this plateau is made up of the highlands of Eritrea and Tigray. It extends from the Tekeze gorge in the south to Ethio-Eritrea border. It constitutes about 13 percent of the area of the region. It is an elongated highland with most of the land being in between 1,000 and 2,000 meters. The right bank tributaries of Tekeze drain this plateau. Long period of denudation has created residual features of granite hills, rugged topography, and Ambas. Mention can be made of Mount Sedie in Tigray (3,988m) and the famous monastery at Debre Damo, a tableland that can only be climbed by a rope pulley [50, 51].

b) **North Central Massifs**

This Physiographic division is the largest in the Western highlands. Much of its northern and southern limit follows the Abay and Tekeze gorges. The Abay, Tekeze and their tributaries have cut into this region a maze of gorges, steep sided river valleys, dividing the land into many isolated plateau blocks, precipitous tablelands and other rugged surface forms. But much of these plateau and tablelands are still capped by the trappean lava. In its central part the physiographic unit also accommodates the Lake Tana basin surrounded by plains of Foggera and Dembia in the north and an upland-plain in its South.
Fifty-eight percent of the region is at an altitude of more than 2,000 meters, making it, next to the Shewan Plateau, the second highest physiographic division. The region consists of the Gonder, Wollo and Gojjam Massifs. Nineteen mountain peaks are with an altitude of more than 4,000m.a.s.l. There are 26 such mountain peaks in Ethiopia. Among these, the well-known ones include Ras Dashen (4,620m) in the Simen Mountain System, the highest in Ethiopia, Mt. Guna (4,231m) in the Debre Tabour Mountain System, Abune Yoseph (4,190m) in the Lasta highlands of Wollo and Mt. Birhan (4,154m) in the Choke Mountain System.

The Mountain systems in Gonder and Gojjam are separated from the eastern group of mountains in Wollo by impassable and deep gorges. At one point though, they are attached by Yeju-Wadla Delanta land bridge (ridge). This land bridge has been significant in history. It served as a route of penetration by the Turks, Portuguese, and Italians etc. Recently, the Woreta-Debre Tabor - Woldya road, constructed by the Chinese to link the northwestern region with Aseb through Weldya and Dessie, took advantage of this land bridge [39, 50, and 51].

c) **The Shewa Plateau**

The Rift Valley in the east and Southeast bound this plateau. Part of its northern and Western limit is made by the Abay and Omo gorges, respectively. With most of its area coextending with the Shewa Administrative region, the plateau occupies a central geographical position in Ethiopia. Accounting only for 11 percent of the area of the whole physiographic region, the Shewa Plateau is the smallest of the Western highlands. Nearly three-fourth of its area is at an altitude of more than 2,000m. It has, therefore, the largest proportion of elevated ground.

The Shewa plateau is drained, outward in all directions by the tributaries of Abay, Omo, and Awash. It, therefore, forms a water divide for these three river basins. The tributaries of Abay - Guder, Muger, and Jema etc. have cut deep gorges and steep sided river valleys. They have created several tablelands and isolated plateau units in the north. Similarly, the tributaries of Omo and Awash have dissected the other sides of the plateau. Otherwise, this plateau has relatively extensive flat-topped uplands, giving it the appearance of a true plateau. The highest mountain here, is Mt. Abuye Meda (4,000m) in Northern Shewa, Mt. Guraghe in the south is 3,721 m. high [39, 50, and 51].

d) **The South Western Highlands**

This Physiographic subdivision consists of the highlands of Wellega, Illubabour, Kefa, and Gamo Gofa. Separated from the adjacent highlands by the Abay and Omo river valleys, the highlands extends from the Abay gorge in the north to the Kenya border and Chew Bahir in the south. With an area of 124,200 km^2 (or 22.7 percent of the area of the region), the region is the second largest in the Western highlands. About 70 percent of the area is within 1,000-2,000 meters altitude.

With a height of 4,200 meters, Guge Mountain (Gamo Highlands) is the highest peak. In these detached and rugged terrain, and separated from one another by a maze of river valleys, are accommodated the most numerous and diverse ethnic linguistic groups in Ethiopia [39, 50, and 51].

3.1.5 The Western Lowlands

These are the western foothills and border plains that extend from Western Tigray in the north to southern Gamo Gofa in the South. In certain places, ridges or part of the highlands protrude into the lowlands, interrupting their continuity. They make 11 percent of the area of the physiographic region. The general elevation is 500-1000m.

This physiographic sub-region is further subdivided into four. The protruding ridges separate these units from each other. These are from north to south.

- **a)** Tekeze Lowland ,
- **b)** Abay - Dinder Lowland,
- **c)** Baro Lowland,
- **d)** Ghibe Lowland

The Ghibe/Omo lowland, which includes the lower Ghibe/Omo Valley and the northern section of the Turkana basin, is classified in the western lowlands from its geographical location. But structurally it also belongs to the Rift Valley. It is an area, which is both faulted and tectonically depressed.

In the Western lowlands, there are small but important towns. Their importance could be related to agriculture, history, or are simply border towns and frontier ports. These are Humera, Metema, Omedla, Kurmuk, and Assosa, Gambella etc [39, 50, and 51].

3.1.6 The South Eastern Highlands and Lowlands

This physiographic region is the second largest in terms of area. It accounts for 37 percent of the area of Ethiopia. The highlands make up 46 percent of the physiographic division while the rest is lowland. In the west and north, the eastern escarpment of the Rift Valley makes the western and northern limit. In many places the land raises so abruptly that from the edge of the plateau one literally looks down the Rift Valley. From here, the land gradually descends southeastward into the southeastern lowlands and then to the plains of Somali-land. These are further subdivided into two units of highlands and two units of extensive lowlands. These are briefly discussed as follows [50, 51].

The Highlands

i) **The Arsi - Bale-Sidamo Highlands**

These highlands are found to the east of the Lakes Region. They are located in the south western section of the physiographic region. They make up 28.5 percent of the area of the region and 62 percent of the south - Eastern Highlands. As the name indicates, they include the highlands of Arsi-Bale and Sidamo Regions.

The Arsi Highlands are generally made up of flat rolling uplands and dissected mountain. Among the last group the dominant ones are Mt. Chilalo (4,036m), Mt. Bada (4,139m) and Mt Kaka (4,180m). Separated from these highlands by the head and main stream of Wabishebelle and to their south, are located the towering highlands of Bale. These consist of a platform looking basaltic plateau in the north-central part and high mountain massif to the south. The Afro-Alpine summit of Senetti plateau is found on the latter group. The highest mountain peaks in this region, Tulu Demtu (4,377m and Mt. Batu (4,307m), top it. Erosion features belonging to Pleistocene glaciation but later modified by fluvial processes are seen in the trough-like gorges, hanging valley, and depressions. Detached from the Bale Highlands by the Ghenale river valley, the Sidamo Highlands dominate the southwestern corner of this region. The prominent feature here is the Jemjem plateau, an important coffee growing area [50, 51].

ii) **The Hararghe Plateau**

This plateau is a north-easterly extension of the south-eastern highlands. It extends from the Chercher highlands in the south-west to Jijiga in the east. With an area of 79,600km^2 it makes up 38% of the South

Eastern Highlands and 17.4 percent of the whole physiographic region. In Ethiopia it is the plateau with the smallest proportion of upper highland (>2,000m). It is a low lying and elongated region.
Rising sharply from the Rift Valley floor, it immediately but gently descends east and south-east ward. The left-bank tributaries of Wabi- Shebelle drain it. Much of the trappean lava is removed and the Mesozoic rocks are extensively exposed. The highest mountain here is Gara Muleta. It is 3,381 meters high [50, 51].

The South Eastern Lowlands

Located in the southeast and these are the most extensive Lowlands in Ethiopia. With an area of 247,000 km^2, they make up 54 percent of the area of the physiographic region and around one fifth of that of Ethiopia and Eritrea. They coextend with the plains of Ogaden, Elkere, & Borena. Southeastward sloping plains characterize these lowlands. These extensive plains are interrupted here and there, by low hills, low ridges, and inselbergs and by shallow and broad river valleys and depressions. Because of the harsher climatic conditions, these lowlands are little used and support very small population. Mainly pastoral nomads sparsely inhabit them. The economic potential for this region includes animal husbandry, irrigation, agriculture and probably the exploitation of petroleum [37].
This region is divided into Wabishebelle plain (60 percent) and the Ghenale Plain (40 percent). Even in the lowlands, these rivers have cut into the Mesozoic Sedimentary rocks to produce topography of low ridges and depressions [50, 51].

3.1.7 The Rift Valley

The Rift Valley is a tectonically formed structural depression. Two major and more or less parallel escarpments bound it. The formation of the Rift Valley has separated the Ethiopian Highlands and Lowlands in to two.
The Rift Valley extends from the Afar triangle in the north to Chew Bahir in the south of Ethiopia for about 1,700 km^2. It covers 18 percent of the area of Ethiopia. It is elongated and funnel shaped, with a NE-SW orientation. It opens out in the Afar Triangle, where it is the widest. Further south, it narrows down to an average width of 50-80 kms [33].
The floor of the Rift Valley is made up of interconnected troughs, grabens and depressions. Volcanic rocks, fluvial and lacustrine deposits cover the floor. In many places, numerous volcanic domes, hills and cinder cones rise from the floor. Altitude in the floor ranges from below sea level, 120 m below sea level at Dallol Depression, to as high as 2000 m.a.s.l. in the Lakes region. The bounding escarpments are also of varying heights. From the floor to the edge of the escarpment, the heights vary from 200 to 1,500m.
The Rift Valley is further subdivided into three physiographic sub-regions. These are the Afar Triangle, the Main Ethiopian Rift and the Chew Bahir Rift. A brief description of each the sub-divisions follow below [50, 51].

i) The Afar Triangle

The Afar Triangle is the largest and widest part of the Rift Valley. It makes up 54 percent of the Rift Valley area. It is bounded by the high western and eastern escarpments in the west and east respectively, and by the Afar and Aisha Horst in the northeast. The area is generally of low altitude (300-700 m). The escarpment, both sides, rises to great heights.

The area is characterized by faulted depressions (grabens), volcanic hills, active volcanoes, volcanic ridges, lava fields and low lava platforms. Lakes (Abe, Asale, and Afrera) occupy some of these basins. A prominent feature in this region is the Denakil Depression (Kobar Sink). Separated from the Red Sea by a 200 m. high land barrier, much of it lies below sea level. A larger part of this is covered by thick and extensive salt plain. Lake Asale (-116m) and Lake Afrera (-80m) occupy the lowest parts of this sunken depression [50, 51].

ii) The Main Ethiopian Rift

The name, here, is used in a restricted sense. It refers to the narrow belt of the Rift Valley that extends from Awash station in the north to Lake Chamo in the south. The western and eastern escarpments bound the region. With the exception of the Arbaminch area, the bounding escarpments are generally low. This part of the Rift Valley is the narrowest and the highest. It has an average width of 50-80 km and general elevation of 1,000-2,000m [50, 50].

The floor in many places is dotted by cinder cones and volcanic mountains. The big ones include Mt. Fentale, Boseti Guda (near Nazereth), Aletu (north of Lake Ziway) and Chebi (north of Lake Awasa). The northern section has more of these cinder cones and lava fields. The prominent features, however, are the numerous lakes. These are formed on tectonic sags and fault depressions.

iii) The Chew Bahir Rift

This is the smallest and the southern most part of the Rift Valley. Gneissic highlands of Konso and the surrounding highlands separate it from the Main Ethiopian Rift to the north. The characteristic feature of this region is the broad and shallow depression, which is a marshy area covered by tall grass, into which the Segan and Woito streams empty.

CHAPTER 4 DISCUSSION AND ANALYSIS: A CASE STUDY ON ADDIS ABABA COMANDO TRUNK ROAD, ON ENTOTO MOUNTAINE

4.1 Introduction

Addis Ababa (the name means 'new flower') is of fairly recent origin - Menelik II founded the city in 1887. Situated in the foothills of the Entoto Mountains and standing 2,400 meters above sea level and it is the third highest capital in the world. The city has a population of about five million. Before moving to the present site of Addis Ababa, Menelik had established temporary capitals at six different locations caused by exhausting the fuel wood at each of these sites. Addis itself was in danger of being abandoned until the introduction of fast-growing eucalyptus trees from Australia provided the city with a regular source of fuel. Addis Ababa is an important administrative center not only for Ethiopia but also for the whole of Africa. The headquarters of the UN Economic Commission for Africa was established here in 1958 and it is the site of the OAU's secretariat [23].

Addis Ababa is surrounded by a continuous ranging mountain like Entoto, Wechecha, Yerer, Mendebo, Debrezeit and chercher. North of Addis Ababa, the surface of the plateau is interspersed with towering mountains [33]. The plateau also contains mountain ranges such as the Chercher and Aranna. Few of these peaks' surfaces are flat except for a scattering of level-topped mountains known to Ethiopians as Ambas. Southwest of Addis Ababa, the plateau also is rugged, but its elevation is slightly lower than in its northern section. To the southeast of Addis Ababa, beyond the Ahmar and Mendebo mountain ranges and the higher elevations of the southeastern highlands, the plateau slopes gently toward the southeast. The land here is rocky desert and, consequently, is sparsely populated [26].

Due to its dependent on topography, road tunnels have been deemed to be increasingly cost-effective infrastructures which provide underground vehicular passageways for motorists and commuters, especially in densely populated cities of Ethiopia like Addis Ababa. With the increasing traffic volume and urban development as well as land use needs for residential and industrial growing, especially in urban areas like Addis, constructing road tunnels are becoming more essential and challenging. For some urban road tunnels, due to the complexity of traffic conditions, tunnel characteristics such as tunnel configurations, geometries, provisions of tunnel Electrical & Mechanical systems (e.g. tunnel ventilation system), traffic volumes, accident frequencies, etc. may vary from one section to another. From the point of topographic conditions of the cities of Ethiopia, tunnel road should be constructed to alleviate the shortage of landuse for the expansion of the existing road to overcome the coming generated traffic of the city and urbanization development of the cities. It is noticable that most of the cities of Ethiopia is founded on the base of mountains or along the chain of mountain, which is an obstraction for the expantions of the cities and the development of surface road network. This will be clear when we see the conditions of Addis Ababa which is now very congested in traffic and uncomfortable living environment. If there is a tunnel road accross the mount which surround the cities and across the city from one end to the other, the tunnel will create a likely expantions of the cities, motivate though vehicles to relife the conjustion of traffic thoughout the citis surface road and also presserve the environmental condition of the area (the biodiversity seen on Entoto Mountain).

4.2 Case Study: Tunnel Road Along Entoto Mountain

The terrain of Ethiopia includes massive highland, complex of mountains and dissected plateaus divided by Great Ethiopia Rift Valley running generally southwest to northeast and surrounded by lowlands, steppes or semidesert; northeastern coastline of about 960 kilometers along the Red Sea [36]. Great terrain diversity determines wide variations in climate, soils, natural vegetation and settlement patterns. Addis Ababa is the capital city of Ethiopia in which its foundation is on the base of such massive highlands to the west of the MER. Lets say that, the Addis Ababa City Administration shoud have aspiration to make Addis Ababa's transport system the rival of any in Africa. For many times and for a quarter century above, plans are being developed across Addis Ababa to tackle the transport problems. Planners and policy makers need to be aware how other countries are applying modern tunneling methods to solve the problem of transportation.

No-one should contemplate a tunnel option lightly or think any environment can justify the cost. The cost of building tunnels can be sky high but it can be compensated by its benefit to the people. Unexpected ground conditions can lead to runaway costs. Nevertheless, even if the topography or the geology isn't obviously favorable, tunneling is an option that should be seriously considered for this historic city, for areas of truly outstanding natural beauty, for major urban areas problem, and for pressure points where a short length of tunnel can release benefits from a whole network.

There are geologies like Entoto where tunneling can be an attractive economic option. In towns and cities too, where property acquisition, car owner ship, movement of people using motor vehicle and the costs of moving utilities can be sky high, tunneling can make real economic sense. But it is usually the environment that changes the balance sheet. And a more prosperous Addis Ababa aspiring to match Ethiopian standards should be willing to pay to protect precious urban space and countryside. As tunneling costs continue to fall, there are new options to "re-conquer" degraded surface streets in our towns and cities. Entoto tunnel can take through roads away from people and animals. Local roads can be freed up reducing the risk of emergency services being stuck in heavy traffic, improving the reliability of bus services, and making walking and cycling safer and less threatening. Tunnels can create real value, not just for travelers going underground but by allowing networks of streets to be reborn and increasing the live ability of whole urban areas.

The necessity for tunnels and the benefits they bring to Addis Ababa and other cities of Ethiopia cannot be overestimated. The tunnels which built across Entoto mount improve connections between the surrounding areas of Oromia region and shorten lifelines of the area. Moving traffic underground, they improve the quality of life above ground and may have enormous economic impact. Of course, the construction of tunnels is risky and expensive and requires a high level of technical skill.

4.2.1 Need for the Project of Entoto Tunnel

Addis Ababa requires a substantial investment and improvement in its transportation infrastructure [98]. Together with rapid population growth and economic development in recent years, there has been a significant increase in car ownership, placing considerable pressure on the existing transport system. Growth in car travel, together with the difficult topography and dense urban structure of the city, result in severe commuting and parking problems for the residential and working populations and businesses in Addis Ababa. There are more than 700,000 vehicles circulating in the city on a daily basis. Car based transport (including taxis and other service vehicles) accounts for over 76.25% of all journeys in the city and uses over 94% of the road space. As a result the connection between two different routes or traffic movements has become a major issue with the current surface road operating well above the design capacity and experiencing severe congestion over long periods every day. The number of vehicles is predicted to increase by a rate of 1.14 each year.

The Entoto Tunnel is designed to contribute towards alleviating current pressure. Initial predictions indicate that journey times from Addisu Gebeya of Addis Ababa to the start of Sululta will reduce from up to 45 minutes today to as little as 15 minutes with the Project. This should provide substantial economic benefits in improved accessibility, reduced journey times and improved reliability, and lead to an overall reduction in fuel consumption, greenhouse gas and other emissions, and noise.

4.2.2 Proposal for Tunnel Road along Entoto Mountain

The Proposed tunnel roads would have significant benefits in terms of improve travel time, accessibility, and reduced traffic levels on this heavily congested road next to Addis Adama route of the country. The tunnel would provide facilities to the people of Addis Ababa and the surrounding Oromia region. The tunnel also improves the use of public transportation and very benefitial for Addis Ababa interms of urbanization development in the NW and NE of the city, development of road infrastructure of the city, increase a one level step in the road transportation of the country as wel as the city, increase diverted traffic and car owner ship.

The stated benefits of the Proposal would be realized in the form of road user benefits (travel time savings, improved safety, reduced operating costs, better public transport), local community improvements (improved air and noise environment, improved access to facilities, safer and more amenable environment) and give relief to Addis Ababa City Administration interms of landuse especially in residential area. In particular, it would provide significant road-based public transport improvements along the length of the Proposal and key connecting roads.

Proposal Need: The need for the Entoto Road Tunnel is said to be demonstrated in its current performance of Addis Ababa city road and land use of the city, where demand is greater than its present capacity of the surface road of the city. The provision of tunnel road provides transport efficiencies including free flowing traffic and more efficient working time and fuel usage and for development of urbanization on a wide platform landuse around the city like Sululta and the like of Finfinae zone of Oromia region. The benefits of the tunnel would also be realized in the greater opportunities for the provision of public transport and improved amenity for residents and businesses on Sululta Area, the same as to the vicinity of Addis. The objectives of the proposed tunnel road are to:

- improve the efficiency of Addis-Commando route (NW of Addis Ababa) along the corridor for road-based transport modes through a reduction in traffic congestion and improved travel times;
- improve air quality and reduce traffic noise, particularly along this trunk road network through a reduction in surface traffic volumes and congestion; Addisu Gebeya.
- improve the amenity of the local community and businesses through: improving safety, connectivity and access for pedestrians and cyclists on the road improving air quality and reducing traffic noise along the trunk road network a reduction in traffic congestion on Adisu Gebeya and other roads improving local access by reducing restriction on traffic turning movements on the Road enhancing the urban fabric of the lower North Shore of Addis;
- improve the operation of road-based public transport for people in north-western Addis Ababa and along the corridor through an improvement in bus priority through the corridor;
- minimize impacts on the natural environment during both the construction and operation phases of the Proposed road
- improve the shortage of landuse in the city and create an opportunity for Addis to wide towards Sululta area
- provide for cyclists along the corridor; and
- provide the benefits of the Proposal to the community at least cost to the Government.
- increase car owner ship of the people
- increase traffic mobility, induced and diverted traffic too.

4.3 Entoto Tunnel Road Portal Site Selection

The selection of the portal is based on how to displace the way of the existing surface road, which cross the Entoto Mountain. The selection is also based on the comparison of the existing surface road which is constructed on Entoto mountain and the escarpment terrain of this area which is covered by a diversified bio-diversity with development of tunnel road to traverse such kind of terrain by using map output of Google earth, geological map which have the road network of the area and handheld GPS map coordinate source. The other way of selecting the tunnel site was on the development of urbanization, landuse of the area and the availability of wide flat area for the development and expantions of the city. For Addis Ababa, the area was found in the north west (NW) i.e. Sululta and surrounding of Oromia regional state which is currently becoming a high industrial area. A hand-held GPS is used to collect data which is the easy and simple way to fined the displacement of the selected route of Addis Commando. The center lineof the existing surface road has been marked with handheld GPS, and then the tunnel portal point is selected based on accessibility, easy of construction, geological and geotechnical of the area, their crosseponding coordinates were recorded as shown on table below. By making a straight line, we can got a displace point which is almost half less the current route. Note that, the final route is set if the geological and geotechnical value of the area is sane in any inspection check point during the construction phase. Otherwise there should be a slight cure according to the specification set of the client. At the time of data collection, the place where the proposed entry and exit points of the tunnel is as shown in picture below is selected based on elevation, accessibility and portal condition if I consider it to be constructed through a point. In addition, the comparable selected urbanization area around Sululta also another case for the selection. The last picture of figure 4.2D indicates the new best entry point which is in b/n Shiro Meda and Addisu Gebeya area; which is the displace on to the route rather than the one selected before. But the area needs high development of approach road, access to the portal point. Figure 4.2 A, B, C & D shows Entoto tunnel road sites of Entoto area.

Table 4. 1 Coordinate of Entoto tunnel road portal

Point	Northing	Easting	Elevation	Remark
1	0471244	1003172	2694	Point at Dil Ber, Addis Ababa
2	0472627	1007833	2668	Point at Sululta, at the back of Entoto`

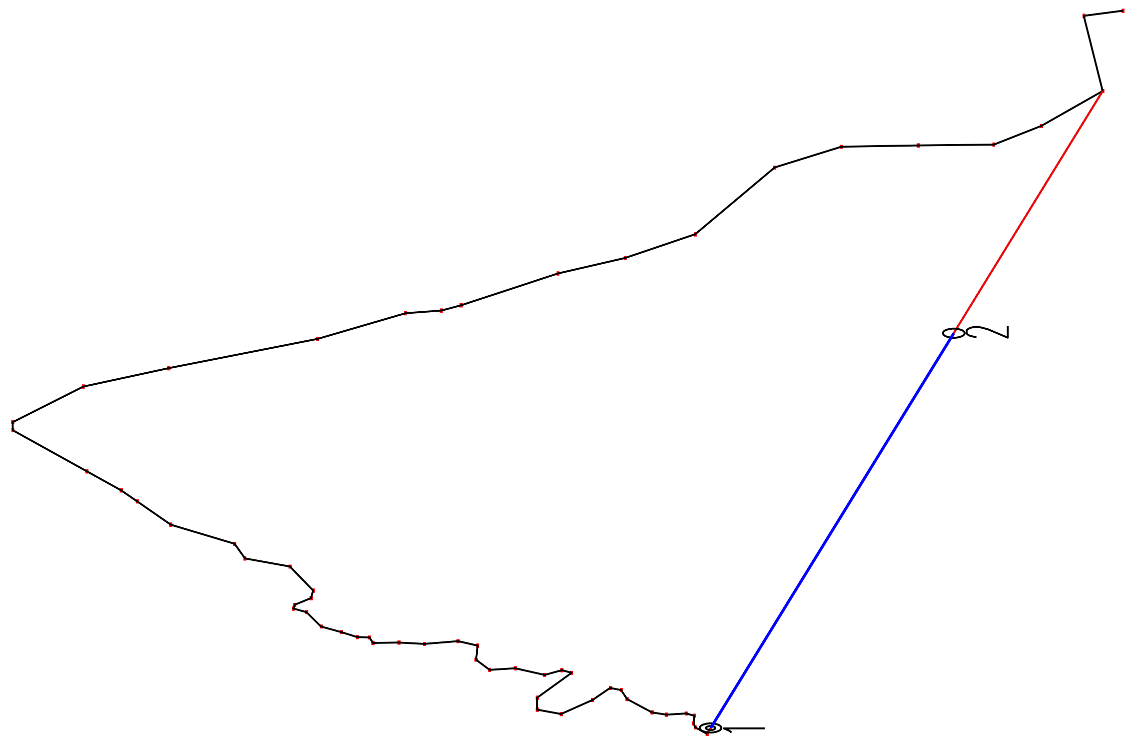


Figure 4. 1 Horizontal layout and Entoto Tunnel Road Portal from hand GPS data of existing surface road

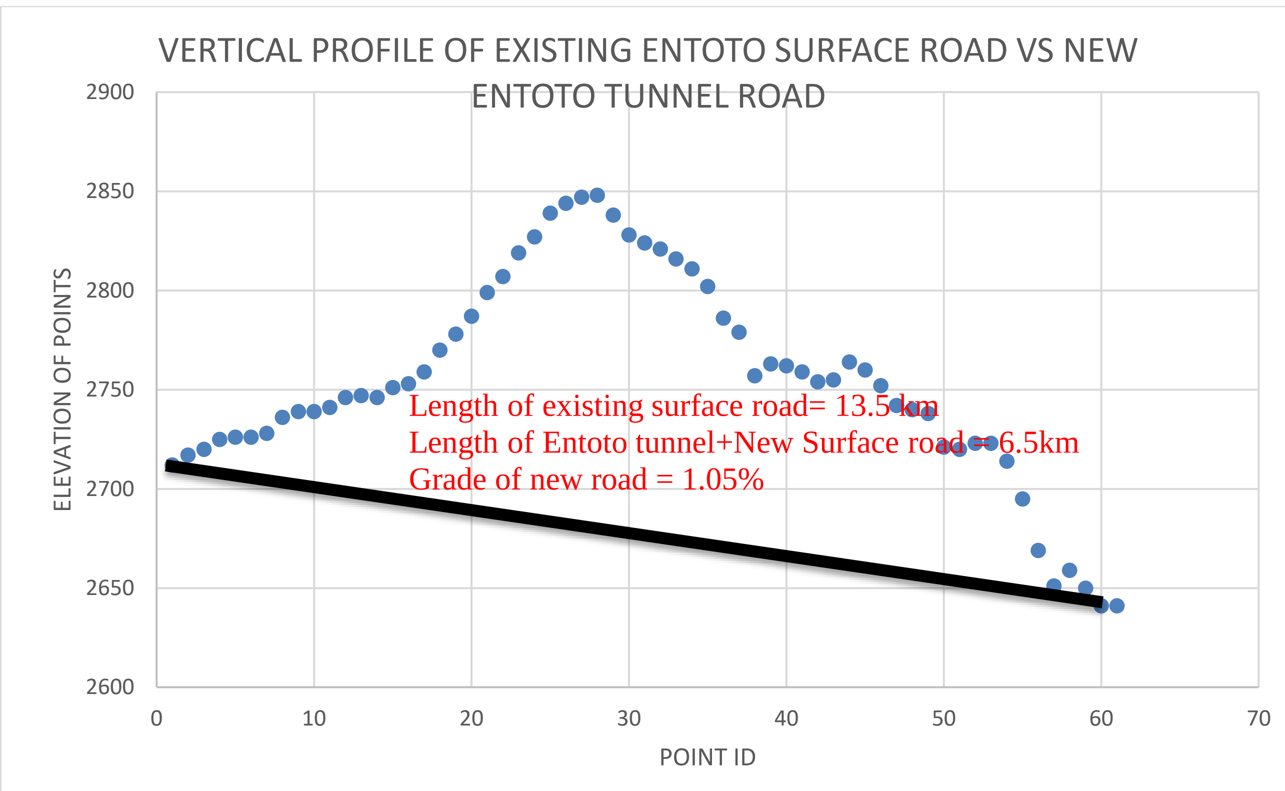


Figure 4. 2 Vertical profile and grades of Entoto Tunnel Road

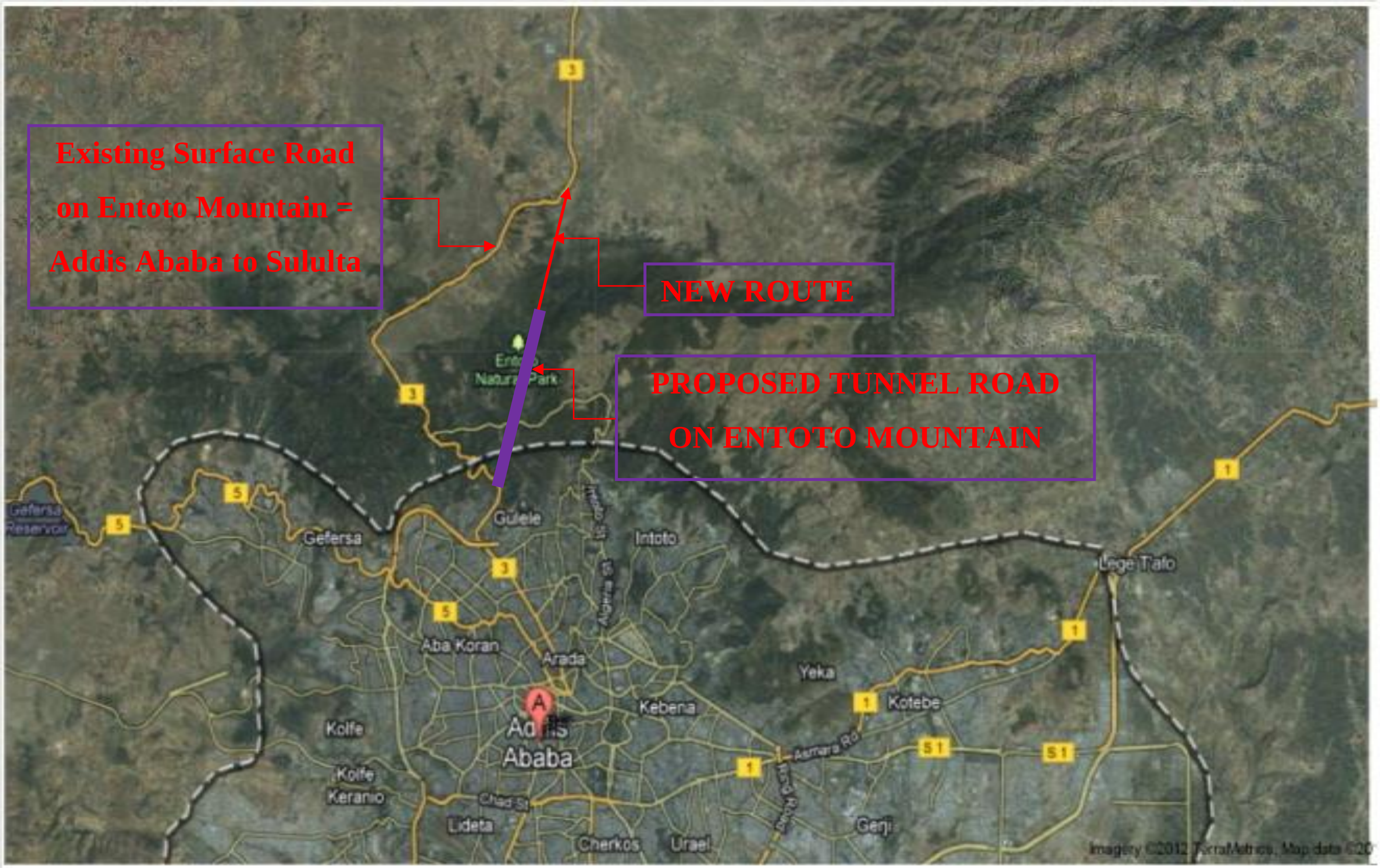
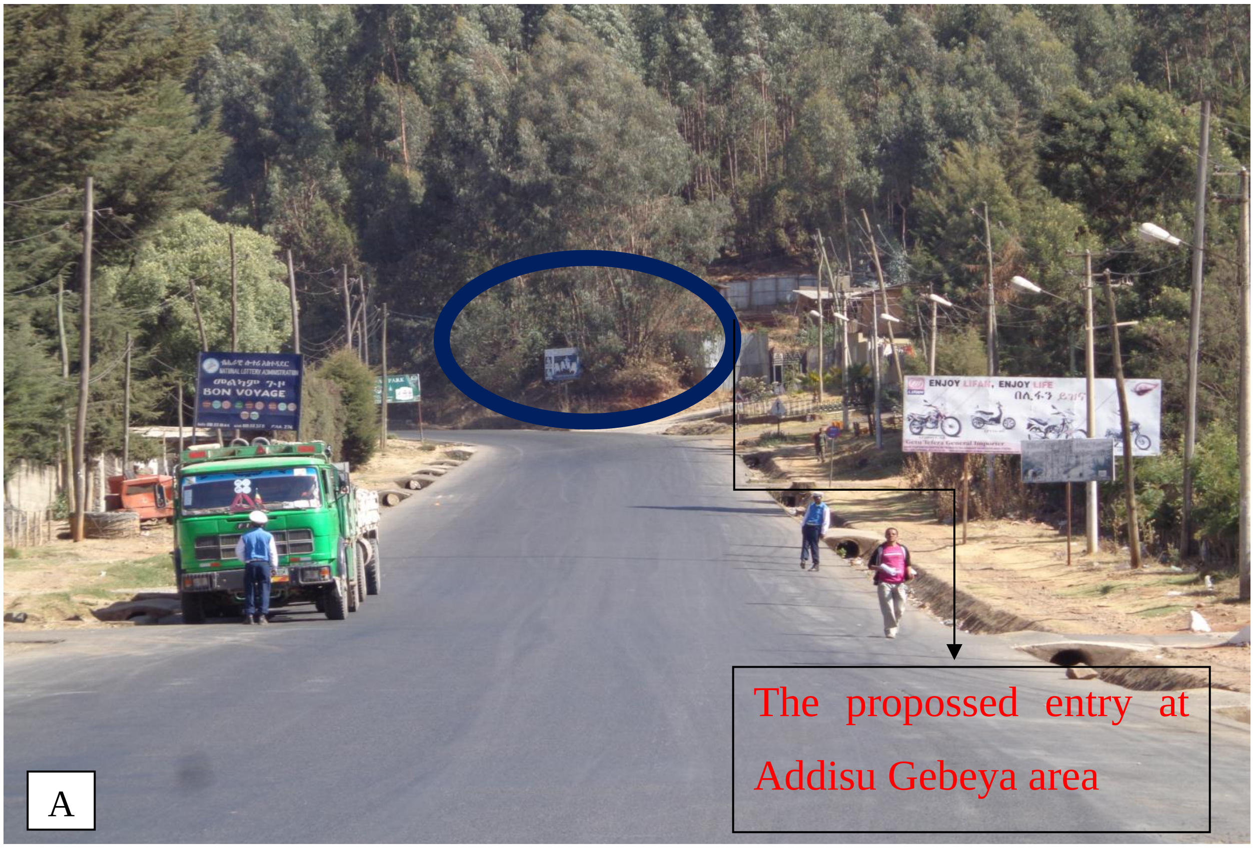
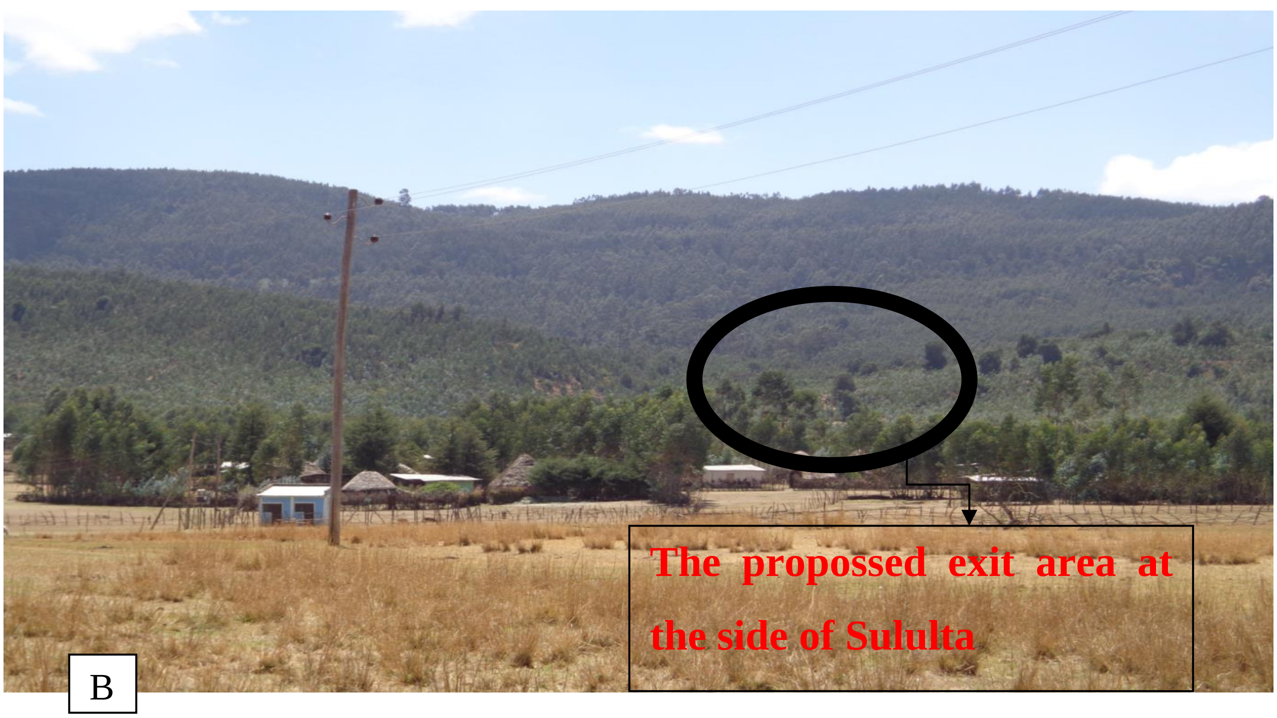
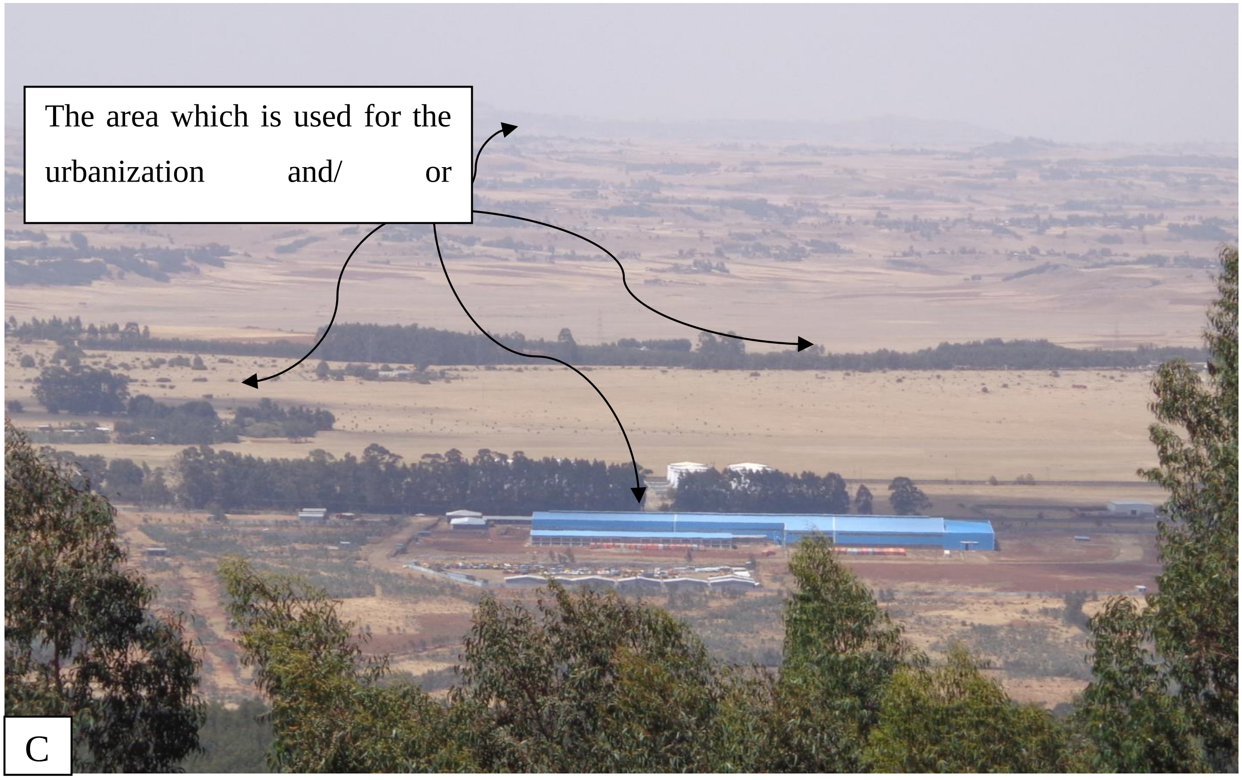


Figure 4. 3 Proposed Tunnel Road Alonge Entoto Mountain horizontal layout [not in scale, source google map]



A propossed tunnel entry site at Addisu Gebeya, which is the toe of Entoto mountain





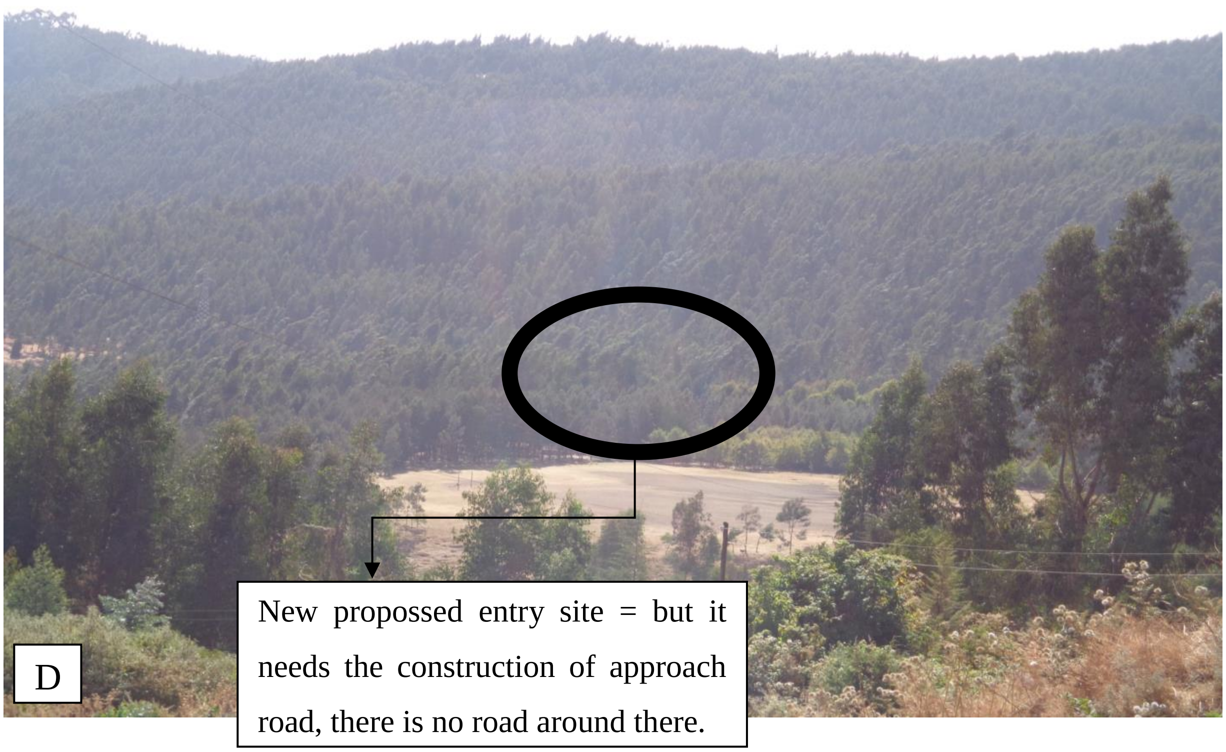


Figure 4. 4 Proposed Entoto tunnel road entry and exit site and area indication for the development of urbanization of Addis

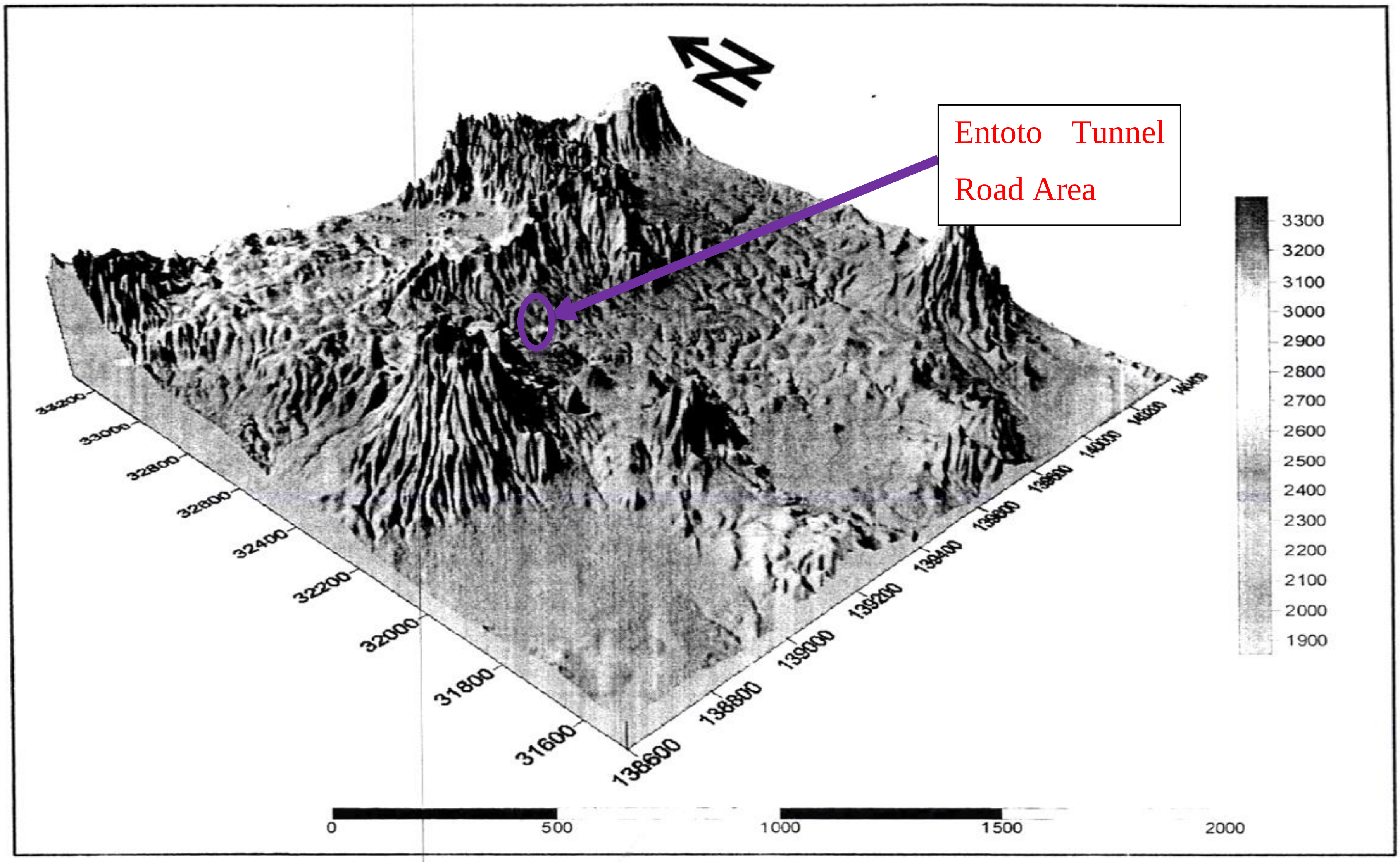


Figure 4. 5 3D view of topography of Addis Ababa

4.4 Geometric Configration and Trafic Capacity of Entoto Tunnel Road

Geometric configertion

The Entoto tunnel road be constructed as DC7 of ERA geometric design standard with the following facilities [10]:

- Design Traffic Flow (AADTs) = 3000 - 10000
- Side walkway = 1.2m
- Carriageway = 8.5m
- Median = 1.2 m
- Clearance = 6.8m, above the finished surface to the mechanical and electrical part

Traffic Capacity of Entoto Tunnel Road

Road tunnels have at least the same traffic capacity as that of surface roads. Studies suggest that in tunnels where traffic is controlled, through its output is more than that in uncontrolled surface road suggesting that a reduction in the number of lanes inside the tunnel may be warranted.

General characteristics of traffic: The behavior of traffic in a one-way tunnel with two lanes is generally similar to that on the roadways of a motorway. Prior studies by the Tunnels Committee [59] and others observe that tunnels have greater capacities (10 - 20% and even much more) than similar sections in the open. It was reasoned that this is due to the higher level of attention paid in a tunnel, as well as the greater smoothness and regularity in the flow of vehicles due to the absence of sudden man oeuvres.

Theoretical and practical Entoto tunnel raod traffic capacity: According to FHWA, the theoretical capacity of a road section is defined as the maximum through-flow of vehicles per hour. It is determined by measuring the maximum number of passenger cars in a fifteen-minute period and multiplying this by a peak hour factor. This is not an absolute maximum, but rather refers to reasonable repeatability. Expressed in this way, the capacity only depends on the number and width of lanes and off-carriageways, and the slope of the section. It does not depend on the percentage of heavy vehicles, since it is clear that this intensity will be a maximum when traffic is formed exclusively by light vehicles and regular drivers. If there is no element that limits it, this theoretical capacity is approximately 2,200 vehicles per hour per lane (v/h/l).

The practical capacity of a section is calculated based on the theoretical capacity without the previously mentioned restrictions (2,200 v/h/l). Limiting factors are applied based on the actual characteristics of the roadway. These main factors are:

- **Fw:** Lane width factor, which reduces the capacity depending on the width of the lanes and the off-carriageways. It is considered that a lane does not limit the practical capacity if the width is equal to or greater than 3.60 m.
- **Fhv:** Heavy vehicle factor, which adjusts the theoretical capacity depending on the percentage of heavy vehicles and the inclination and length of the ramp or slope of the roadway.
- **Fc**: Correction factor due to the predominant type of driver. This factor adjusts the capacity based on whether the drivers are regular drivers along the route and if the type of traffic is that of a working day.

The practical capacity of a carriageway in one direction, $\mathbf{C_p}$, is calculated then by:

$\mathbf{C_p}$**= 2200* N*Fw*Fhv*Fc** in which **N** is the number of lanes in one direction and the different factors are those indicated previously (N=1 in one direction for the tunnels considered in this report).

Capacity of Entoto Tunnel Road: Based on the above formulation**,** the capacity of the tunnel road depends on the percentage of heavy vehices using the route. The percentage of heavy vehicles for 2017 AADTs of ERA for the route along Addis to Comando is almost 82.99% [89]. The AADT of the surface road on this route is 3827 which is almost the design capacity of trunk road, 1000 AADTs and above. If the tunnel road is built instead of surface road at this level, the practical capacity of the tunnel road be by taking Fc of 0.8 i.e. 95% of the drivers are regular:

C_p = 2200*N*Fw*Fhv*Fc, NB= the tunnel road have the same carriageway which is 3.6m as the surface road

C_p = 2200*1*1*0.8299*0.8

C_p = 1461 v/h/l which is the maximum input for the route at the current condition if we use tunnel road instead of surface road along the route.

Saturation level and traffic speed: The Saturation Level of the traffic is determined by dividing the Intensity by the Practical Capacity (SL = I / C_p), at low saturation levels the average speed in a tunnel, just as on a road in the open, will depend on the geometric characteristics of the tunnel. The wider the curves and the gentler the slopes, the greater the speed. Japanese experiments indicate that measures to improve visual guidance (kind and color of the cladding or illuminating line markings) can increase average speed and capacity as well. For a certain road section or tunnel this free flow speed can only be determined by measuring speed in practice. The free flow speed, however, can be estimated as approximately 90% of the design speed [8]. When the road is saturated (SL = 1), traffic speed is approximately 86 to 91% of the free speed. The lower the saturation, the more closely the traffic speed equals the free speed. At high saturation levels traffic conditions will be congested with consequent low speed and low total traffic flow.

Queues inside a tunnel should be avoided normally so as to limit the total number of people affected by an emergency situation. According to FHWA, in continuous flow condition, the maximum traffic density (expressed in vehicles per km and per lane v/km/l) is 30, corresponding to a separation of 33 m, while in congestion the density increases to 130 v/km/l, corresponding to a separation of about 7.5 m.

4.5 Seismic Considerations

4.5.1 Earthquake Risks in Addis Ababa

The city of Addis Ababa which is located at about N9.02 and E38.45 is near the western escarpment of the rift valley. Addis Ababa itself is only 75-100 kilometers away from the western edge of the Main Ethiopian Rift Valley, which is a hotbed of tremors and active volcanoes. Some of Ethiopia's major cities like Addis Ababa, Nazret, Dire Dawa and Hawassa are very near to the main fault lines such as the Wonji fault, the Nazret fault, the **Addis-Ambo-Ghedo** fault, and the **Fil Woha** fault lines along which numerous earthquakes of varying magnitude have occurred over the years. The presence of the Fil Woha hot springs in the middle of Addis Ababa itself, for example, is nature's reminder that the city lies on fault plane that have been slowly building strains. It is the release of these strains accumulated over the years that cause the phenomenon of earthquake [38].

The soil conditions in certain areas of Addis Ababa, particularly areas like Fil Woha, Mesqel Square, Bole, Beqlo Bet, Nifas Silk, Lideta, Mekanisa etc., actually may aggravate the effect of earthquakes. These areas consist of layers of soft soil deposits (as much as 15 meters deep in the case of the Fil Woha area) that further amplify the earthquake-induced ground motion. These amplifications of earthquake forces will, inevitably, lead to foundation and structural failures. Buildings and structures in these areas are, therefore highly susceptible to more damage than their counter parts in areas like Entoto, Kolfe and Shola which have a thick layer of basalt rock nearer to the surface [38].

Table 4. 2 Some of the recent significant earthquakes that have rocked the Rift Valley, the Afar Plains and the Western Edge of the Rift Valley. (Source Samuel Kinde, March 2002)

Location	Year	Magnitude	Distance of Epicenter from Addis (kms)	Damage
Langano	1906	6.8	110	Felt as far as Addis
Kara Kore	1961	6.7	150	Town of Majete destroyed, Kara Kore seriously damaged
Central Afar Area	1969	6.3	200	Town of Serdo destroid
Wendo Genet	1983		300	
Langano	1985	6.2	110	
Rift Valley Area	1987	6.2	200	Widely felt and widely spread damage
Dobi [Central Afar]	1989	6.3	200	Several bridge damage
Nazret	1993	6.0	60	Injuries and damage in Nazret. Also felt in D/Zeit and Addis.
Southwest of Addis	1997	4.0	22	
Lake Shala-Adamitulu	1999		250	

4.5.2 Ground Motion Hazard Analysis

For the seismic design of underground tunnel facilities, one of the main tasks is to determine the seismic hazard, which define the design earthquake(s) and the corresponding ground motion levels and other associated seismic hazards. Seismic hazard analyses generally involve the following steps [6]:

- Identification of the seismic sources capable of strong ground motions at the project site
- Evaluation of the seismic potential for each capable source
- Evaluation of the intensity of the design ground motions at the project site

Seismic source characterization: Identification of seismic sources: As indicated above the main source of seismicity in Ethiopian is the Main Ethiopian Rift (MER).

- Types of fault = Dip slip which is normal fualts
- Geographic location = 38^0E7^0N to 42^0E12^0N
- Depth = 70 to 33 kms
- Size Δ 0.25g – 0.75g extrapolated) ------ Afar Depression (source – RADIUS-1999)

- ❖ Orientation = parallel to the fast-polarization direction→ Repulsion of ≈ 5mm per year (MER)
- ❖ Evaluation of the seismic potential: the earthquake magnitude (or range of magnitudes) that the source, the main Ethiopian Rift, can generate be 4 to 7 M_L.

Once the seismic sources are characterized, the intensity of ground motions at the project site from these sources must be characterized. There are three general ways by which the intensity of ground motions at a project site is assessed in practice [6]. They are, in order of complexity:

(1) use of existing hazard analysis results published by credible agencies such as Ethiopia Geological Survey (EGS), United State Geological Survey (USGS) and the like;
(2) project-specific and site-specific deterministic seismic hazard evaluation; and
(3) project-specific and site-specific probabilistic seismic hazard evaluation.

For our purpose we use the first and second method.

Use of Existing Hazard Analysis Results: Information used for seismic source characterization for this paper can often be obtained from publications of the United States Geological Survey (USGS). Seismic hazard maps that include spectral acceleration values at various spectral periods have been developed by USGS under the National Earthquake Hazard Reduction Program (NEHRP).

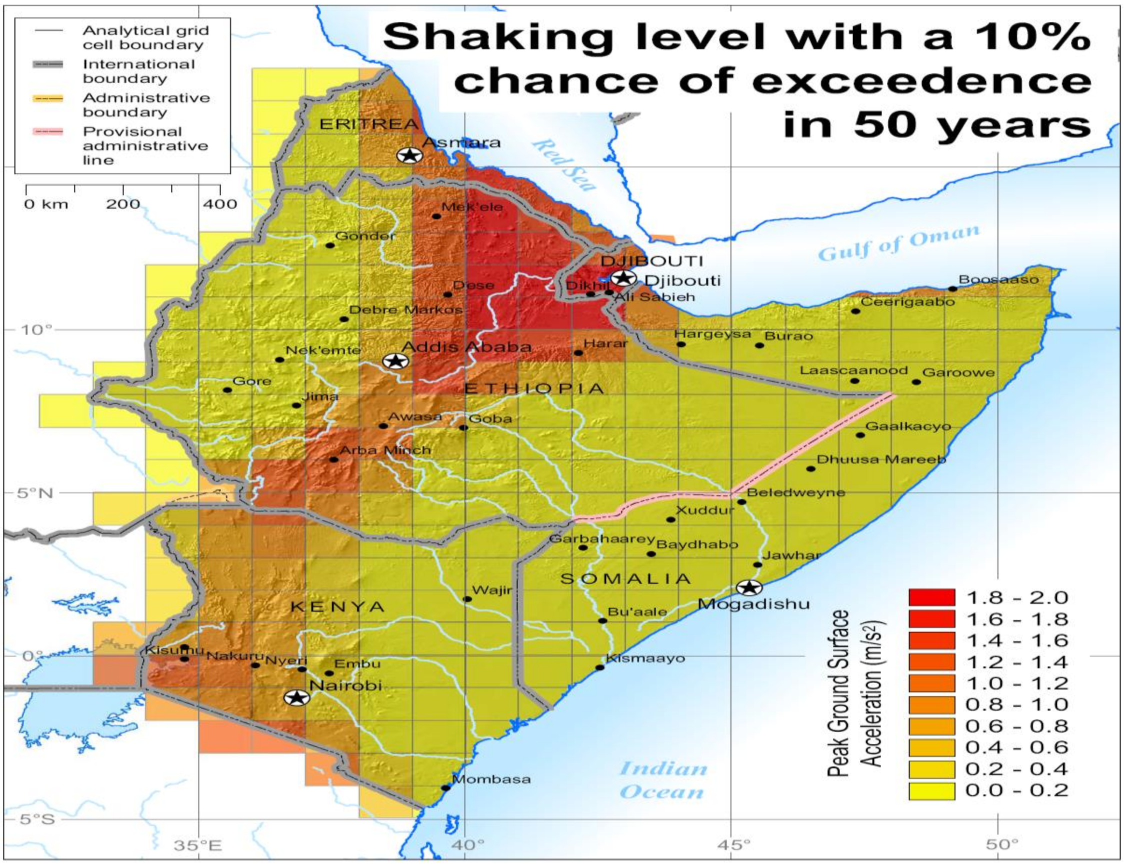


Figure 4. 6 Seismic Hazard map of Ethiopia (source USGS)

4.5.3 The Deterministic Hazard Analysis Approach

In this method, the intensity of shaking at the site from each capable source is calculated and the design earthquake is identified based on the source capable of causing the greatest damage. The steps in a deterministic seismic hazard analysis are as follows [6]:

1. Establish the location and characteristics (e.g., style of faulting) of all potential earthquake sources that might affect the site. For each source, assign a representative earthquake magnitude.
2. Select an appropriate attenuation relationship and estimate the ground motion parameters at the site from each capable fault as a function of earthquake magnitude, fault mechanism, site-to-source distance, and site conditions. Attenuation relationships discriminate between different styles of faulting and between rock and soil sites.
3. Screen the capable (active) faults on the basis of magnitude and the intensity of the ground motions at the site to determine the governing source.

4.5.3.1 Analysis

Step one: Establish the location and characteristics (e.g., Style of faulting) of all potential earthquake sources that might affect the site (Entoto Tunnel Road).

Table 4. 3 The location and characteristics of all potential earthquake sources that might affect Addis Ababa [38].

Location	Types of Fualt	Magnitude $M_L \rightarrow M_W$	Epidistance	Remark
Langano	Dip Slip – Normal Fault	6.8→7.1	110 km	Zone 4 – Along the Main Ethiopian Rift
Nazret	Dip Slip – Normal Fault	6.0→6.0	60 km	Zone 4 – Along the Main Ethiopian Rift

Step two: Selection of an appropriate attenuation relationship and estimate the ground motion parameters at the site from each capable fault.

Empirical Relations of Jonathan and Twesigomwe

Attenuation relations for the Eastern Africa region based on the strong motion data are virtually not-existent. However, attempts have been made recently by Jonathan (1996) and Twesigomwe (1997) to establish average attenuation relation for the region. The two relations are:

$$lna = 3.024 + 1.030M_w - 1.351\ lnR - 0.0008R ------Jonathan, 1996$$

$$lna = 2.832 + 0.866M_s - lnR - 0.0025R + \varepsilon -------Twesigomwe, 1997$$

Where a = the ground acceleration (cm/s^2), R = the hypocentral distance (km) and ε = the error term

Fot this paper we use the Jonathan relation, because the magnitudes are in Moment Magnitude (M_w). Figure 4.16 below shows the comparison.

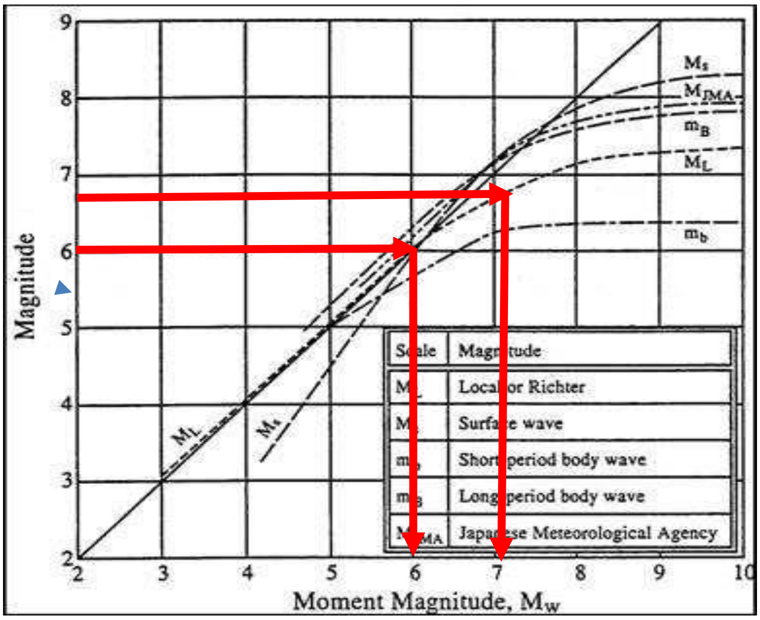


Figure 4. 7 Comparisons of Earthquake Magnitude Scales (Heaton, *et al.*, 1986)

According to Jonathan relation the ground acceleration at the selected site due to seismicity at the source shown in the above tables;

Addis Ababa

Due to seismic at Langano

$$lna = 3.024 + 1.030M_w - 1.351\ lnR - 0.0008R ------Jonathan, 1996$$

$$lna = 3.024 + 1.030 * 7.1 - 1.351\ ln110 - 0.0008 * 110$$

$$a = 49.34\ cm/s2$$

Due to seismic at Langano, ground acceleration at Addis will be: a = 49.34 cm/s^2

Due to seismic at Nazret

$$lna = 3.024 + 1.030M_w - 1.351\ lnR - 0.0008R ------Jonathan, 1996$$

$$lna = 3.024 + 1.030 * 6 - 1.351\ ln60 - 0.0008 * 60$$

$$a = 51.19\ \text{cm}/s2$$

Due to seismic at Nazret, ground acceleration at Addis will be: a = 51.19 cm/s^2

FHWA Method

Ground Motion Parameters: Once the design earthquake events are defined, design ground motion parameters are required to characterize the design earthquake events. Various types of ground motion parameters may be required depending on the type of analysis method used in the design. In general, ground motions can be characterized by three translational components (e.g., longitudinal, transverse, and vertical with respect to the tunnel axis). The various types of common ground motion parameters are described in the following paragraphs [6].

Peak Ground Motion Parameters: Peak ground acceleration (PGA), particularly in the horizontal direction, is the most common index of the intensity of strong ground motion at a site. Peak ground velocity (PGV) and peak ground displacement (PGD) are also used in some engineering analyses to characterize the damage potential of ground motions. For seismic design and analysis of underground structures including tunnels, the PGV is as important as the PGA because ground strains (or the differential displacement between two points in the ground) can be estimated using the PGV [6].

Recent study (NCHRP-12-70, 2008) has found that PGV is strongly correlated with the spectral acceleration at 1.0 second (S1). Using published strong motion data, regression analysis was conducted and the following correlation has been recommended for design purposes.

$$PGV = 0.394 * 10^{0.434C}$$

Where: PGV is in in/sec

$$C = 4.82 + 2.16log_{10}S_1 + 0.013[2.30log_{10}S_1 + 2.93]^2$$

Classification of Subsoil condition: The influence of local ground conditions on the seismic action shall generally be accounted by considering the soil classes of the specified code. The AASHTO LRFD and EBCS 8 soil classification is shown in the table below [31, 60].

AASHTO LRFD classify in to four but EBCS 8 in to three. Both codes consider by developing the effect as a site coefficient term, S in the response spectral.

Table 4. 4 Soil classifications according to AASHTO LRFD and EBCS 8

Soil Type		AASHTO LRFD	EBCS 8	Site coefficient, S	
AASHTO LRFD	EBCS 8			AASHTO LRFD	EBCS 8
I	A	• Rock of any type • Stiff soils with thickness less than 60m and stable deposite of sand, gravel or stiff clay over rock	• Rock or other geological formation characterized by shear wave velocity of at least ---- • Stiff deposits of sand, gravel or over consolidated clay with shear wave velocity of atleast 400 m/s at a depth of 10m.	1.0	1.0
II	B	• Stiff cohesive or deep cohesionless soil with soil deposit greater of 60m.	• Deep deposits of medium dense sand, gravel or medium stiff clays with shear wave velocity of 200 m/s at 10 m and increase to 350 m/s at 50m.	1.2	1.2
III	C	• Soft to medium-stiff clays and sands, 9m thick or more of soft to medium-stiff clays with or without intervening layers of sand or other.	• Deposits with predominant soft to medium stiff cohesive soil or loose cohesionless soil deposits with or without some soft cohesive layers with shear wave velocity below 200m/s in the uppermost 20m	1.5	1.5
IV		✓ Soft clays or silts greater than 12 m.		2.0	

Since it is difficult to identify the site with EBCS method, AASHTO LRFD is used instead. In any case the value is the same because both have almost related geological discriptions. According to AASHTO LRFD the selected site catagorised to I (Addis Ababa – Entoto). So the equivalent with EBCS be A.

Design Response Spectra: According to Ethiopian Building Code, EBCS 8, the design response spectra for the three class of soils is shown in the figure 4.17 below.

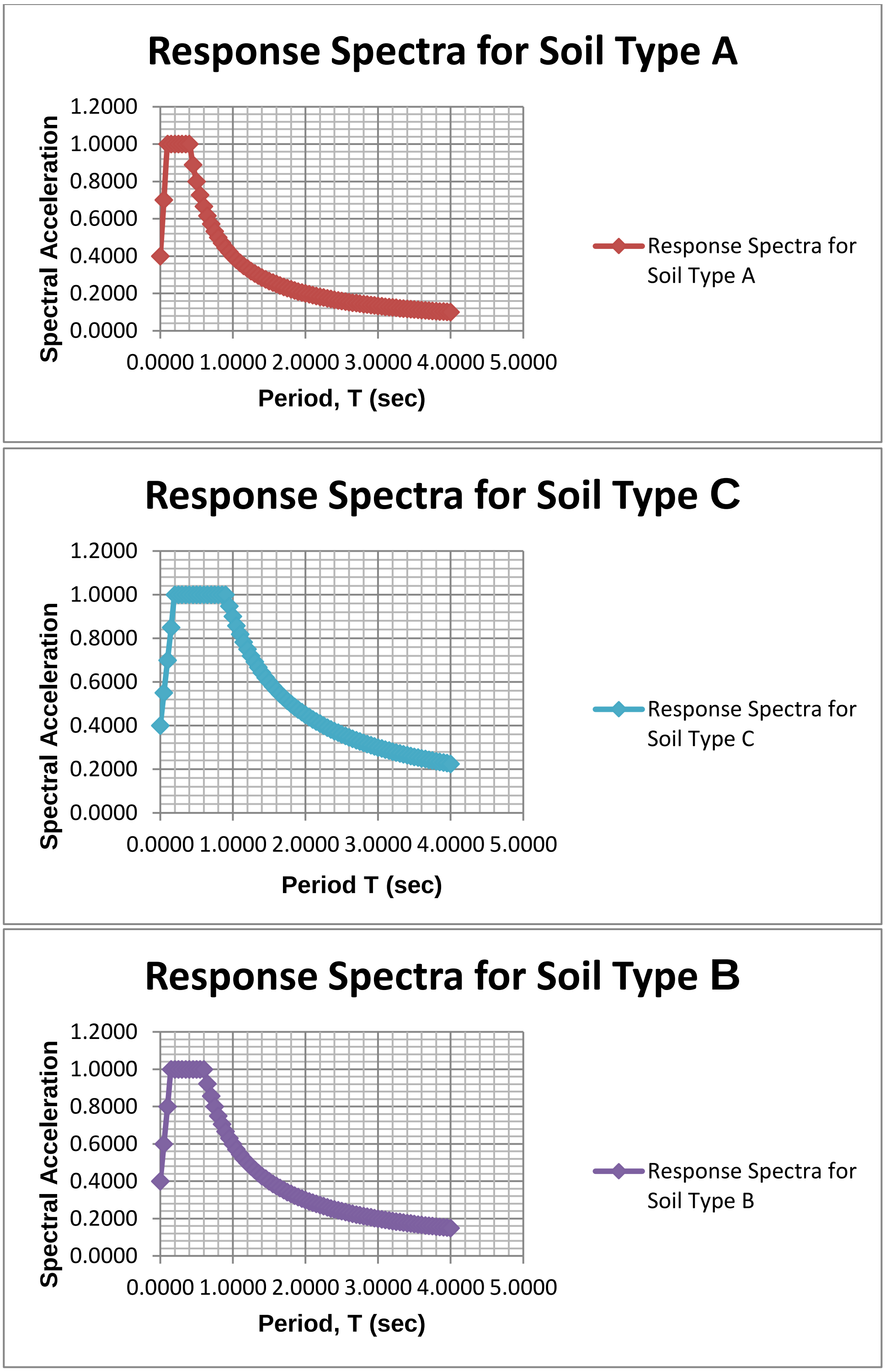


Figure 4. 8 Response Spectra of different soil type according to EBCS 8 [31]

On the base of the above soil classification assumption the ground motion parameter for the selected site be:

- ✓ Addis Ababa (class A)

$$PGV = 0.394 * 10^{0.434C}$$

Where: PGV is in in/sec

$$C = 4.82 + 2.16log_{10}S_1 + 0.013[2.30log_{10}S_1 + 2.93]^2$$

From the response sectra of soil type A, S_1 = 0.400

$C = 4.82 + 2.16log_{10}S_1 + 0.013[2.30log_{10}S_1 + 2.93]^2$

$C = 4.82 + 2.16log_{10}0.4 + 0.013[2.30log_{10}0.4 + 2.93]^2$

C = 4.013

So, $PGV = 0.394 * 10^{0.434C}$

$PGV = 0.394 * 10^{0.434*4.013}$

PGV = 21.734 in/sec

This condition may be changed if we do detail soil classification according to EBCS 8.

Step three: The capable (active) faults on the basis of magnitude and the intensity of the ground motions at the site to determine the governing source.

According to Jonathan, active fualt for

Addis Ababa = Nazret Fault

NB, If the epicenter for the site is short the seismic source will have greate effect.

4.5.4 Ground Motion Parameters Attenuation with Depth

The ground motions parameters discussed above are typically established at ground surface. Tunnels, however, are generally constructed at some depth below the ground surface. For seismic evaluation of the Entoto tunnel structure, the ground motion parameters at Entoto should be derived at the invert elevation of the Entoto tunnel Road [34]. According to the result from handheld GPS during the site visit, the elevation at ground level of Entoto tunnel portal is 2694, 2668m in and out from Addis Ababa to Sululta respectively. By reducing 0.7m for pavement structure, the invert of the tunnel should be 2693.3 and 2667.3m respective. Because ground motions generally decrease with depth below the ground surface, these parameters generally have lower values than estimated for ground surface motions (e.g., Chang et al., 1986). The ratios of ground motion values at tunnel depths to those at the ground surface may be taken as the ratios summarized in Table 4.5 unless lower values are justified based on site-specific assessments.

Table 4. 5 Ground Motion Attenuation with Depth

Tunnel Depth (m)	**Ratio Of Ground Motion At Tunnel Depth To Motion At Ground Surface**
Ω6	1.0
6 – 15	0.9
15 – 30	0.8
Δ30	0.7

The invert of Entoto tunnel road from the pick point of Entoto mount is 135m. According to table 4.5, the Entoto tunnel depth is greater than the data indicated, at an inverted elevation of 135m the tunnel depth falls to the criteria of Δ30 m deep form ground surface elevation. Therefor, the ground motion at the tunnel invert will be

$$0.7 = \frac{Ground\ Motion\ at\ Tunnel\ Depth}{Ground\ Motion\ at\ Surface}$$

From Jonathan result,
Ground Motion at Addis Ababa due to seismic at Nazret = 51.19 cm/s^2

$$0.7 = \frac{Ground\ Motion\ at\ Tunnel\ Depth}{51.19}$$

Addis Ababa (Entoto tunnel road), the ground motion at Entoto tunnel depth of Δ30m be 35.83 cm/s^2 which is 0.03583g. According to FHWA and EBSC 8 the seismic generated from Nazarez hypocenter resulted in small damage to the Entoto tunnel road structure.

4.5.5 Ground Deformation

Underground structures are constrained by the surrounding soil or rock and cannot move independently so are not generally subject to significant dynamic amplification effects [30]. They are affected by the deformation of the surrounding ground and not by the inertia forces acting on the structure. The larger anticipated permanent ground deformations is due to:

- liquefaction: Settlements, lateral spreading
- Slope failure
- Fault movements

Wells and Coppersmith, 1994, develops an empirical relations for the determination of the mean anticipated ground displacement due to fault rupture. The maximum anticipated displacement is about twice the mean value. According to Wells and Coppersmith, ground displacement due to capable (active) faults on the basis of magnitude and the intensity of the ground motions at the selected site is as follows.

Displacement of ground at the selected site

At Addis Ababa; Entoto Mountain Area

- Fault type: Normal fault

- Active fault: Nazarez fault line
- Moment magnitude: $6M_w$

Therefore, the ground displacement of Entoto tunnel road due to seismicity at Nazarez:

$$M = 6.93 + 0.82 * \log(AD)$$

$$6 = 6.93 + 0.82 * \log(AD)$$

$$AD = 0.0734m$$

Therefore, the average displacement at Entoto tunnel due to seismicity at Nazret, (AD) = 0.0734m, which is very low and maintainable. The maximum anticipated displacement is about twice the mean value. So, the maximum anticipated displacement at Entoto tunnel road be 0.1468m which will be maintainable.

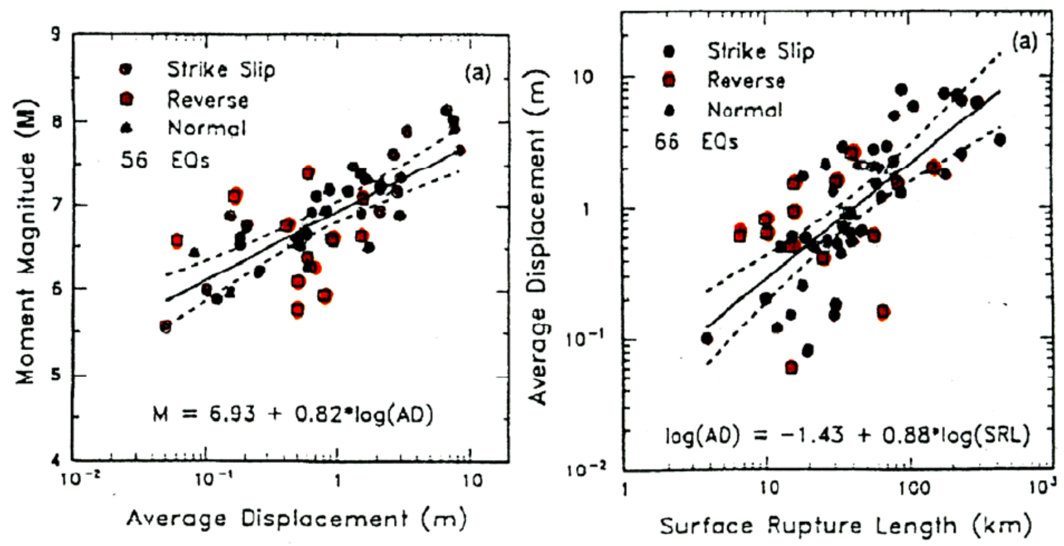


Figure 4. 9 Relations for the determination of the mean anticipated ground displacement due to fault rupture (Source Gantes and Bouckovalas- analysis of buried pipelines at crossin)

4.5.6 Performance of Entoto Tunnel Road

FHWA recommends the following Screening guidelines [6]

- An active fault intersecting the tunnel; **there is no such dangerous active fault along the route**
- A landslide intersecting the tunnel, whether or not the landslide is active; **No land slide section along the route**
- Liquefiable soils adjacent to the tunnel; **no soil liquefaction**

- History of static distress to the tunnel (e.g., local collapses, large deformations, cracking or spilling of the liner due to earth movements), unless retrofit measures were taken to stabilize the tunnel. **As indicated in the above analysis, the average displacement of the area is not such exaggerated one for repair.**

Additional Screening Guidelines for Bored Tunnels: If the above conditions do not exist, then the risk to a bored tunnel is a function of the tunnel design and construction, the characteristics of the geologic media, and the level of ground shaking. Power et al. (1998), develop empirical observations of the effects of seismic ground shaking on the performance of bored/mined tunnels. He developed this emperical observation from damage due only to shaking; damage that was definitely or probably attributed to fault rupture, land sliding, and liquefaction was not included [6]. From the result shown above, the damage due to ground shaking in the selected site at the invert fails to:

Addis (35.83 cm/s^2 = 0.3583 m/s^2 = 0.03583g) = **None Damage State for all types of tunnel Lining**

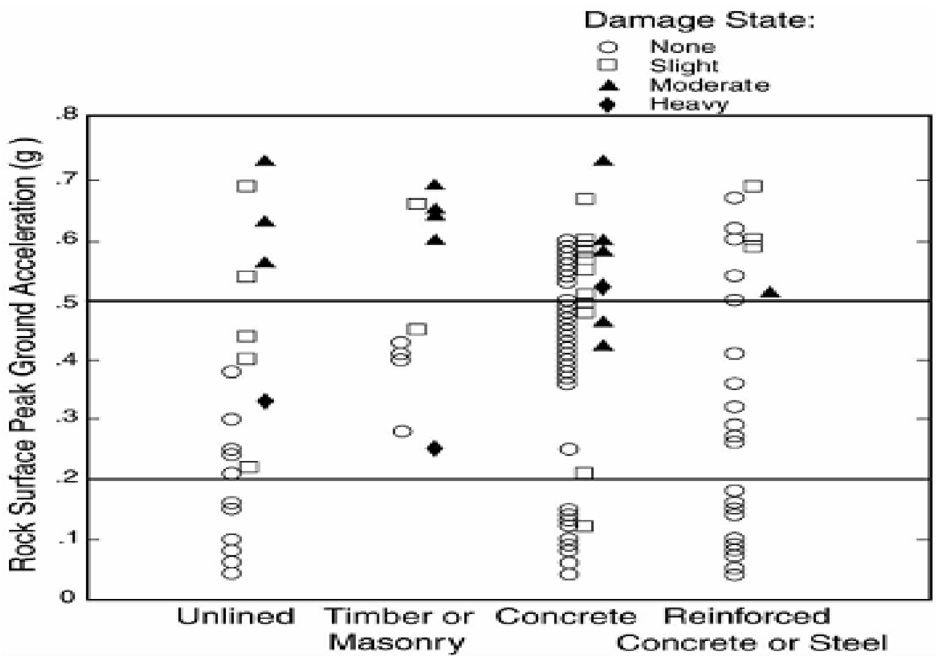


Figure 4. 10 Summary of Observed Bored/Mined Tunnel Damage under Ground Shaking Effects (Power et al., 1998)

4.5.7 Vulnerability of Entoto Tunnel Structures

Entoto tunnel structures have fared more favorably than surface structures in past earthquakes. Some severe damages - including collapse - have been reported for tunnel structures, however, during earthquakes. Most of the heavier damages occurred when:

- The peak ground acceleration was greater than 0.5g but at Entoto it be 0.05119g
- The earthquake magnitude was greater than 7.0 but at Nazarez seismic it be 6.0

- The epicentral distance was within 25 km. but the epicentral distance for Entoto be 60km
- The tunnel was embedded in weak soil but Entoto tunnel be embedded in rock
- The tunnel lining was lacking in moment resisting capacity but the lining should designed to resist moment
- The tunnel was embedded in or across an unstable ground including a ruptured fault plane but there is no such rapture fault along the route

According to these, the tunnel road if it is built along the Entoto Mountain, it may not be vulnerable to seismic effects.

4.6 Proposed Geometry of Entoto Tunnel Road

I will recommend that Entoto tunnel road with the following geometry and construction method are preferable:

Construction method: The construction methodogy usually determines the shape of the tunnel cross-section. There are three main shapes of highway tunnels: – circular, rectangular, and horseshoe or curvilinear. The shape of the tunnel is largely dependent on the method used to construct the tunnel and on the ground conditions. For example, rectangular tunnels are often constructed by either the cut and cover method which is now implemented in light rail of Addis Ababa around St. George route, by the immersed method or by jacked box tunneling. Circular tunnels are generally constructed by using either tunnel boring machine (TBM) or by drill and blast in rock which is also practically implemented in hydro power projects. Horseshoe configuration tunnels are generally constructed using drill and blast in rock or by following the Sequential Excavation Method (SEM), also as known as New Austrian Tunneling Method (NATM) which is implemented in rail track construction in the northern part of Ethiopia at Awash Combolcha Woldia route. The SEM offers flexibility in geometry such that it can accommodate almost any size of opening. The regular cross section involves generally an oval shape to promote smooth stress redistribution in the ground around the newly created opening. Lastly, because SEM tunneling allows for an adjustment to ground conditions as encountered in the field it benefits from a unit-price contract form. Therefore, from the geologcal condition, the shape of the tunnel which is approprate recommend by most countries to road tunnel from economic point and the easy of construction is the SEM method of construction. Therefore SEM is the best construction method for Entoto tunnel road. This method is also applicable due to easy for construction and it is not costly like other method of construction, for example TBM method, which is too costy even in assembling the machine.

Cross-section: In addition to tunneling method to determine the tunnel cross-section, the tunnel cross section should take into account the expected traffic capacity, safety measures (emergency exits, evacuation tunnels, lay-by’s, vehicle turn around point), provisions for breakdowns, horizontal and vertical alignment, width of the elements indicated above and vertical clearances, in accordance to the regulations prevailing for a considered tunnel. According to PIARC recommendations Entoto tunnel road should have the following details:

Widths:

- For traffic lanes, the recommended width = 3.60m
- The width of traffic lane markings should be >= 15cm
- For safety reasons, the width of the roadway should be >= 8.50m, by considering passing sight distance for heavy goods vehicle.
- Width of hard clearance should be 2.50-3.0m. The width can be reduced to a minimum of 0.5m if their functions as emergency and breakdown lane are taken over by a central median strip having a width between 1.0 to 2.5m.

Walkway:

- The recommended width is 0.75m. Regular pedestrian and bicycle traffic should, in general, not be allowed in tunnels.
- The walkway should be raised 7 to 15 cm above the carriageway with a vertical kerbs.

Vertical clearances:

- Minimum headroom = design height of heavy goods vehicles plus necessary allowance for dynamic vehicle movements. The recommended value be 4.20m
- Maintained headroom: additional allowances for signs, luminaries, fans etc. Vary betweens 0.20 and 0.40m.

Climbing lane: if the speed of heavy vehicles drops below 50 km/h, a climbing lane of 3.0m width should be planned.

Lay-by’s: planned to acommedate breakdowns.

Therefore, horseshoe or curvilinear tunnels are the best for Entoto tunnel road.

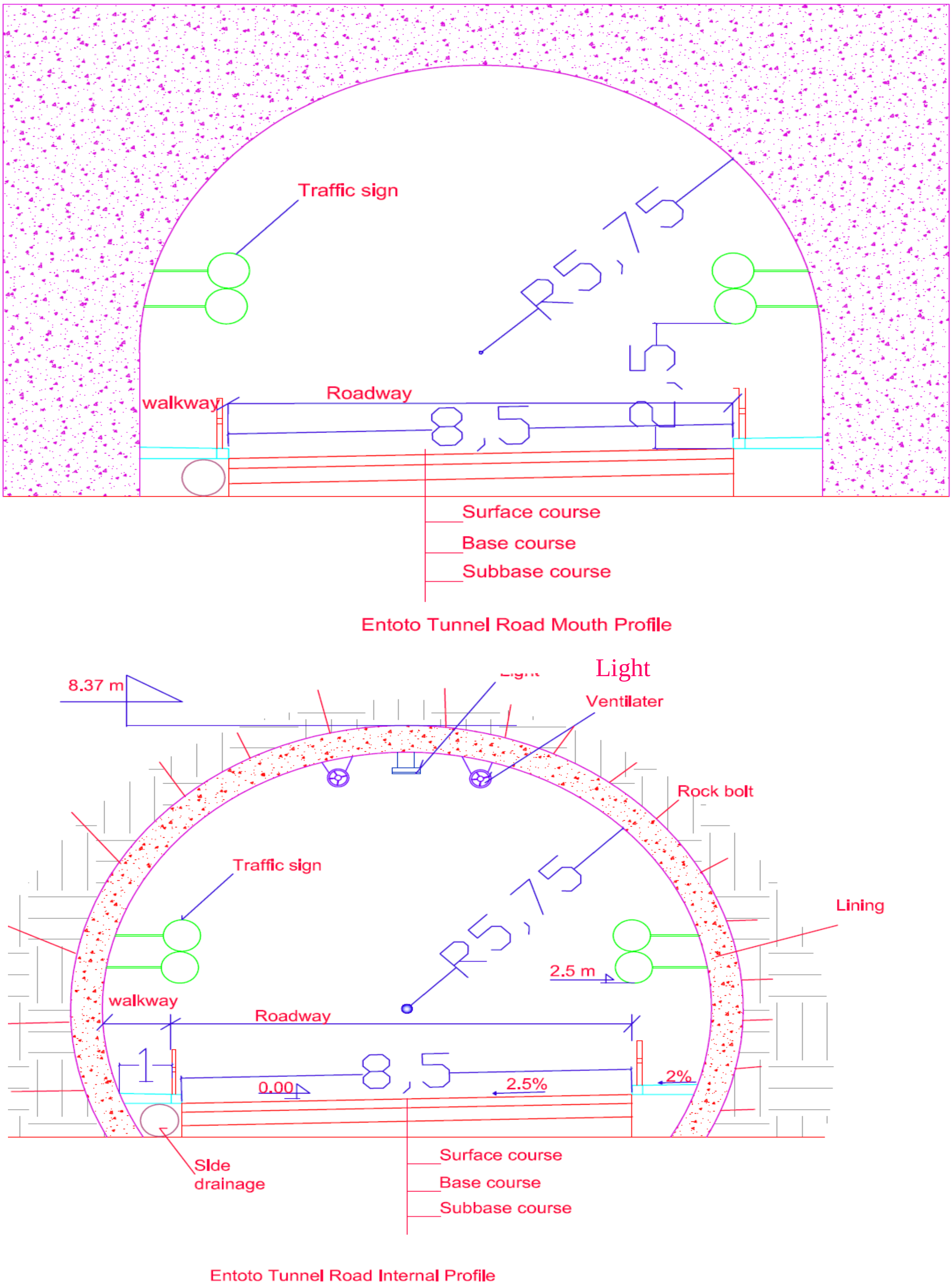


Figure 4. 11 Typical Cross-section of Entoto Tunnel Road at portal and internal section

4.7 Comparison of Entoto Surface Road Vs Entoto Tunnel Road

The basic benefit of Entoto tunnel road is in user cost and travel time saving, reduction of accident, increament of comfort for the road user and protection of the environment (bio diversity of the area=Gulele Bio Diversity), especially in travel time saving and development of urbanization in the NW of Addis Ababa i.e. Sululta area. From this point of view definetly Entoto tunnel road is better than the existing surface road. Lets compare the two roads interms of construction cost in the case of constructing surface road on harsh terrain condition of Entoto area. In the current condition of Ethiopia, to travers mountainous terrain, like Entoto area, in the case where there is a considerable amount of earth work with out some extraordinary bridge and retaining wall costs 10 to 20 million birr per kilometer, lets take the average 15 million birr per km [source: from ERA projects]. Note that there is common activities like subbase, base and surfacing works in common to both for surface and tunnel road in addition to earth work exception to the method of excavation and the way of removal from the site. The basic difference be on the type of drainage structure, quantity and type and amount of excavated material and methods of excavations. Therefore, the basic cost variation raise from the work methodology and machine used, the type and amount of excavation work and the way of waste disposal or cart away. The methodology, the geology and geotechnics of the area makes tunnel road so expencive. But if we consider the road length to traverse some harsh terrain, there should be a big difference. Tunnel road could displace the area by reducing the route with considerable amount, for example, in the case like Entoto tunnel road more than a half in reduction of the route length. In the like of this surface road costs more than the tunnel road.The basic and the main difference of surface and tunnel road is operational cost. During the period of operation the surface road incure lot to the road user due to its grade but in Entoto road tunnel this is the reverse one.

Table 4. 6 Comparison of surface and tunnel road along Entoto Mountain

Name	Length km	Max. Grade	Max. Speed (Avg.)	Travel Time (Avg.)	Remark
Entoto Surface Road (Existing)	13.50	>10%	30km/hr	45min	Non comfortable for road user
Entoto Tunnel Road (New)	6.5	2%	>80km/hr	15min	Comfortable
NB: This data is collected randomly from representative vehicles according to ERA vehicles classification and taking their average or maximum.					

The surface road which is built on Entoto mountains perform in better way now but there is some defect on it on operation for road users.

- It takes long time to travers the mountain. It is total of 13.22 km to reach a level or flat or rolling terrain.
- Almost all the route along the mount is constructed to the maximum grade of 10% with sharp curves. With this grade HGV face a problem of climbing the mount with expected time and speed.
- To travers the mountain, the maximum driving speed in the area is 30 km/hr for up and down grade of the road.
- There is sharp curve along the route which is dangerouse for the road user, especially for heavy good truck in which they needs a relative flat curve to turn on a speedy condition.
- There is a considerable road accident in the route due to grade and curves. The curves along the routes have insuficient sight distance, no guiding information or traffic signs ahead of each accident expectance areas and others.
- The route passes through reserved forest area. There may be wild life which might be exposed for traffic accident.

If Entoto tunnel road be constructed to travers the mount

- The road users can save a considerable amount of time
- There may be more induced and diverted traffic due to the improvement of the road infrastructure facility of the area.
- Urbanazation to the north west of Addis increases
- Since there is a development of industrial area around Sululta, heavy good vehicles travel can be generated
- The road user costs will be reduced to significant amount
- Trip generation and attraction increases in the area
- Reduce environmental impact on mount Entoto and the surrounding area
- Protect the Gulele Bio-Diversity
- Save historical heritage of the mount
- Cost of construction is less than that of surface road which is built to travers the mount, because it shorten the surface road by 6.5 km, which means reduce the cost to that proportion upto its survice life.
- It reduce the operation cost

In general, short tunnels like Entoto Tunnel road are preferable than surface road in mountainous or escarpment terrains of Ethiopia.

4.8 Financial Studies and Recommendations for Entoto Road Tunnel Constructions

4.8.1 Financial

The financial viability of Entoto tunnel road depends on its life cycle cost analysis. Traditionally, tunnels are designed for a life of 100 to 125 years. However, existing old tunnels (over 120 years old, Tarmaber Road Tunnel) still operate successfully in our country and throughout the world [6, 33]. Recent trends have been to design tunnels for

150 years life. To facilitate comparison with a surface facility or a bridge, all costs should be expressed in terms of life-cycle costs. In evaluating the life cycle cost of an Entoto tunnel road, costs should include construction, operation and maintenance, and financing (if any) using Net Present Value. In addition, a cost-benefit analysis should be performed with considerations given to intangibles such as environmental benefits, aesthetics, noise and vibration, air quality, right of way, real estate, potential air right developments, etc. The financial evaluation should also take into account construction and operation risks.

4.8.2 Cost Drivers of Entoto Tunnel Road Construction

There are numerous cost drivers associated with Entoto tunnel road construction. These can be grouped into physical, economic and political.

Physical Costs

The single most important driver of Entoto tunnel road project cost is the geology, geotechnic and hydrogeology of the Entoto area through which the tunnel will be driven. The ground conditions controls the methods and equipment used to drive the tunnel, the support elements that will be needed to ensure that the excavated cross section remains stable and safe for the personnel constructing the tunnel and the final lining needed for long term stability of the structure. In addition the ground through which the tunnel is driven will contain varying amounts of ground water that will dictate the pumping requirements, waterproofing needs and lining quality that will ensure a dry tunnel environment.

Road tunnels are also grade restrictive and curvature restricted which also impact project cost. Tunnels that will service as road infrastructure must be able to deliver large quantities of fresh air throughout the length of the tunnel and be able to remove smoke and heat developed during a fire incident anywhere in the tunnel. Large ventilation structures or in line fan systems are needed to supply this air and remove the smoke.

N.B. In road tunnels refuge areas or rest areas are often needed along with on and off ramps or connections to outside road systems.

Economic Costs

Entoto road tunnels require personnel, equipment, materials incorporated into the physical structure, materials that are consumed during the construction of the tunnel along with insurances, bonds, offices, shops and other indirect elements. These all impact the total cost of the road tunnel project. The largest portion of these costs is the actual cost of labor.

Material is another major cost component of the Entoto road tunnel projects, Materials like cement, steel, copper wiring are all very price volatile now due to strong worldwide demand and the shortage of foreign currency of the country. Currently the price escalation of key materials is a significant cost driver and one that is often not addressed in the contract specifications as a separate cost. Entoto road tunnel projects require large quantities of both permanent and consumable materials in a constant stream.

There is also a continual cost of disposing of the muck or excavated material that is produced during the tunnel operations. Muck can sometimes be sold off (especially rock) by the contractor or owner to help reduce the cost of tunnel construction. However the market for this material is not guaranteed and often the contractor must be paid to haul this muck away and also paid to dispose of it at approved dump locations. More and more regulations governing the disposition of materials are driving up the cost of Entoto tunnel road construction. In addition, there is a probable cost on the muck due to EIA.

Bonds and Insurance are smaller components of tunnel costs that are becoming cost drivers due to the increased scrutiny being imposed by the insurance and surety industry. Since most owners require both bonds and insurance on their projects by law and as risk management tools any contractor that cannot qualify for bonds and insurance cannot bid the project.

Political Costs

Significant costs are placed on Entoto tunnel road projects by either the communities through which the tunnels will be mined or by the owner agencies or by the requirements and restrictions incorporated into the specifications. Tunnels are expensive undertakings even without these restrictions but when concessions to various groups are added to the requirements the costs can skyrocket. Typical restrictions are, mandating certain types of construction to minimize community disruptions. Restrictions on the hours worked is commonly employed when the tunnel is in an urban location like Entoto tunnel road. Tunnels are a cyclical series of operations where one cannot start till the predecessor is complete. With restrictions on the hours of operation fewer steps can be completed in the reduced time so the job takes longer. In one case an owner agency allowed 24 hour tunneling (recognizing that this is a typical mode of operation) but limited the hours that could be worked at the surface where the muck is brought out to be trucked away. In order to compensate for this reduced time the tunneling work had to be made larger, so that the muck that was produced during the time where no surface work could be done, could be stored underground awaiting that time of day when it could be brought to the surface and trucked away.

4.8.3 Costs of construction, operation, maintenance/upgrading - financial aspects

Tunnels are relatively expensive civil engineering structures with respect to their construction and operation. Particular attention must be paid from the beginning of the project of Entoto road tunnel in order to spot any possible technical and financial optimizations.

It is recommended from the first stages of the design to implement a process of Entoto tunnel roads includes:

- The detailed definition of the "function" of the tunnel,
- An iterative process of “value engineering analysis" achieved at all strategic stages of the project, to which must be integrated into the various stages of the risk analysis,

- ❖ Detailed analysis and monitoring of the potential risks in the design and construction stages. These potential risks are related to: technical uncertainties relating in particular to the complexity of the ground (geological and geotechnical uncertainties), uncertainties of traffic volume forecasts, that constitute an important risk concerning earnings in the case of construction and financing by “concession", uncertainties and risks concerning the financial environment, in particular changes in interest rates and conditions of financing and refinancing. This aspect constitutes an important risk in the case of construction and financing by "concession" or by PPP (Private Public Partnership) with a financial contribution. This process will enable the optimization of the project (construction and operation costs) and an improved management of the technical and financial risks, as well as the schedule.

Construction costs

Cost ratios per kilometer: The construction costs of tunnels are very variable and it is impossible to give representative ratios of costs per kilometer, because these ratios may vary in important proportions (average of 1 to 5) according in particular to:

- the geological, geotechnical and hydro-geological conditions,
- difficulties concerning the access roads and the tunnel portals,
- the geographical location of the tunnel: urban or non-urban,
- the length of the tunnel: in particular the "weight of the ventilation facilities and safety arrangements is more significant for a long tunnel; on the other hand all the works concerning the access roads and portals have a more important impact for a short tunnel,
- the traffic volume which is a determining factor for the dimensioning of the number of lanes, as well as for the ventilation facilities,
- the nature of the traffic: in particular a tunnel used by vehicles carrying dangerous goods will require expensive arrangements for ventilation, safety and possibly the resistance of the structure to fire; conversely, a tunnel dedicated to the passage of only light vehicles may enable very important savings because of the possible reduction of the width of the lanes, headroom and reduced requirements for the ventilation facilities,
- the tunnel environment that may lead to expensive protection arrangements for the mitigation of its impact,
- arrangements taken for the management or the sharing of construction risks,
- the socioeconomic environment of the country in which the tunnel is to be constructed. The impact can reach about 20% of the costs.

According to the experience of different country, it is possible to indicate that the average cost of a usual tunnel, built under average geotechnical conditions is about ten times the cost of the equivalent infrastructure built in open air (outside of urban areas). So the Average constraction cost of DC8 to DC5 trunck road (surface road) on mountainous and/or escarpment terrain be X birr per km implay that the tunnel cost to this road classiffication be 10X.

Breakdown of the construction costs of Entoto tunnel road: The construction cost of Entoto tunnel road may be broken down into three types of cost:

- the cost of the civil engineering structures,
- the cost of the operation facilities, including the supervision center and the energy supply from public networks,
- various costs including in particular: owner's costs for the development of the project – project management – design and site supervision – survey and ground investigations - environmental studies and mitigation measures – land acquisitions - various procedures - etc.

4.8.4 The Recommended Aspects relating to financing for the Construction of Entoto Tunnel Roads

Entoto tunnel roads constitute costly infrastructure in terms of construction and operation for Ethiopia at the current level of the country, but this is offset by economic benefits including regional and urban development, traffic fluidity, comfort, safety, reliable routes (mountain crossings) as well as protection of the environment of Entoto bio-diversity.
The recomended financing for the construction of Entoto tunnel road is ensured either by:

- the "traditional mode": financing and maintenance by a public authority, the financial resources coming from public taxation or fuel taxes,
- a "concession" to a private or semi-public body, which is charged with the construction and operation of the tunnel during a contractual period of time. This body is in charge of the financing (often partly by loan), which is offset by a toll paid by the users, that reimburses the costs of the construction and the operation, as well as the risks and the financial expenses. This type of "concession" can be granted by the financial involvement of the grantor or by particular guarantees (example: guarantee of a minimal traffic volume with the payment of a financial compensation if this minimal traffic volume is not reached),
- "mixed mode" of PPP (Public Private Partnership) or similar, that may concern: only the construction or the construction and the operation, construction under a "turnkey" scheme in the case of a "design and build" process, partial or whole financing.

This paper does not intend detailing these various modes of financing, or presenting their mechanisms, their advantages or disadvantages.

4.8.5 Cost Benefit Analysis, CBA, for Entoto Tunnel Road Construction

Cost-Benefit Analysis: In order to weigh costs against benefits of Entoto tunnel road projects, cost-benefit analysis usually attempts to put a monetary value on both costs and benefits so that they are expressed in the same units. This is an extremely important tool for project appraisal of Entoto tunnel road, especially for 'sectors that do not have a marketable output'. The costs of Entoto tunnel road project would include the cost of labor, materials and equipment used in construction, as well as other costs such as the loss of parkland and homes, pollution, disruption to neighborhoods' or the loss of peace and quiet.

The benefits of such a projects might include time saved to motorists, increased predictability of journey times and increased accessibility to a particular location.

Obviously, some costs and benefits are not easy to put into monetary terms. These include environmental values such as the value of clean air and water, unspoiled wilderness areas, ecological balance and diversity. In addition Entoto Tunnel Road project has certain benefits were not quantified but were listed. These included reduction of traffic in the city, improved access between the city center and exterior corredor of the city and ficilitate urbanization if the tunnel built to cross the barrier boundary to get plat form.

In transport, and particularly Entoto tunnel road projects savings of time and user cost for motorists or commuters are often the major benefit of such projects and these are quantified. This creates two areas of contention. One is predicting what the time savings would be; the other is estimating what those times savings are worth to the community. The assessment of how much a person's time is worth, another value decision, can determine whether benefits will exceed costs in the CBA. This was indeed the case for the Road Tunnel CBA in Entoto mount tunnel road project for this paper.

CBA is an application of welfare economics and, as such, consumer surplus is used to measure the benefits of road investment. This is due to the fact that ‘transport is not usually an end product in itself… it permits other activities to be undertaken’ and therefore CBA substitutes ‘social benefit for the revenue of the firm’. Clearly then, it is important that overall gains to society are evaluated in the CBA and a project must satisfy the Pareto optimality condition: ‘if we can find a way to make some people better off without making anybody else worse off, we have a Pareto improvement’ (Varian, 2006: 15). Barrett and Mooney (1984: 22) state that ‘highway investments have quantified three main benefits: time savings, accident reduction and vehicle cost savings’ and similarly, this paper finds these benefits with regard to the tunnel roads on Entoto mount. The valuation of costs is relatively straightforward because they reflect market prices, and in this paper it is assumed that they are competitive. While these are ‘the quantified benefits from road investment’ (Barrett and Mooney, 1984: 33), other environmental effects such as air quality, noise levels and the impact on the physical environment could be observed. Money values will be attached to the benefits (where applicable), and they will be listed alongside the costs while comparing the time streams of both (Barrett, 1982: 33). For the purpose of this paper, sensitivity tests will be omitted in preparing the CBA.

Normally, future costs and benefits are discounted (reduced) because it is assumed that they are not worth as much to people today, because people would rather have money and benefits now than later. In order to put everything into today's values a discount rate is applied to future values. The choice of a discount rate makes a big difference to the outcome of a CBA. It can be very much influenced by value judgments’, including the judgments about entitlements of future generations. For our case 5% discount rate is used.

Entoto Road Tunnel: the project is a 3km underground dual carriageway on Entoto Mountains, and the entrance to the tunnel is at Addisu Gebeya area of the Gulele subcity of Addis Ababa, creating a direct link between Sululta town of Oromia region and the outer ring road which newly constructed across Gulele subcity at Addisu Gebeya. If properly planned the construction will take about 3 years.

The objective of these projects were to create a ‘vital strategic corridor for the urbanazation development of Addis Ababa in the northern and northwestern direction and to use the industrial area of Sululta as one subcity of Addis so as ultimately for the benefit of the national economy of the country and to facilitate the transportation system in both areas. The beneficial effects would therefore stem from a dramatic increase in the number of public transport and light vehicles in the direction and develop residential areas behind the Entoto Mountains and around Sululta town. As a result, there would be time savings on journeys for cars in the city, accident cost savings due to safer conditions, and vehicle cost savings due to lower journey times.

Accident costs

In the absence of more detailed research targeted at societies and economies in low income countries, it is suggested to add 38%, 100% and 8% of the total resource cost of fatal, serious and slight casualties, respectively as costs of pain, grief and suffering for fatal, serious and slight casualties (BTRL, 1995).

The information obtained from Awash Insurance company shows that about 4990 individuals have got life insurance with an amount of 436,133,671 Birr and when the average is taken each individual have put 87,401 Birr as their life insurance cost. By applying TRL research, fatality cost for this study, depending on the insurance cost as initail value, become = 1.38*87401 = 120613.40 Birr.

On the other hand from the same insurance company information was obtained on 5052 individuals who have obtained health insurance with an amount of 197,704,784 Birr which results on average amount of 39,133 Birr per individual as health insurance cost for serious injury. By applying TRL research, serious injury cost for this study, depending on the insurance cost as initail value, become = 2*39133 = 78266 Birr per individual.

In this study for slight injury casualties the cost of pain, grief, and suffering is estimated from emergency medical treatment cost set by government for third party insurance which is 500 Birr per accident victim.

The cost of property damage on the current condition of the country depends on the severity of the damage. According to information from car owners and some insurance company indicates that the value of property damage depends on the severity. Lets say if the vehicle damage some part, the insurance maintence the vehicle with the current maintenance cost on garage. So the cost of property damage depends on the condition of damage.

According to a report by federal police in the year 2017/18, for instance, there were 3725 traffic accident fatalities, 4589 serious injuries, 2854 slight injuries and 27,909 property damage through out the country. With the expected considerable underreporting, the road traffic hazard is believed to be much higher than indicated by such statistics. Compared with international figures, the country is one of the worst examples in terms of fatality rate per vehicle which was 94.4 fatalities per 10,000 vehicles in 2017/18.

Murad Mohamed study of costing traffic accident in Ethiopia (2011) showed that the national economic losses resulting from road accidents in Ethiopia are considerably high, even if the conservative human capital method is employed in estimating. Based on data and economic figure of 2009/10, road accident costs of Ethiopia were calculated. The cost of damage only, slight, serious and fatal road traffic crashes were 327.12, 204.65, 619.38, and 716.02 million Birr respectively in the year 2009/10. This represents the total national economic loss resulting from road accidents to be estimated as 1.87 Billion Birr which is equivalent to 145.07 Million USD considering the exchange rate of the same year, or approximately 0.49% of the gross domestic product of the country in the same year.

For the purpose of this paper, lets distribute the above cost with daily traffic accommodation and traffic accident. The traffic accommodations of the Addis Comando route at 2017/18 is 3827 vehicles per day. The accident proportion (factor) of Addis Comando route in referred fisical year from the estimated data be 0.24. Therefore the accident costs in 2017/18 in the Addis Comando route were 78.51, 49.12, 148.65 and 171.85 million birr for damage only, slight, serious and fatal acident respectively.

Time savings

This is the 'largest benefits of most transportation projects' especially in Entoto tunnel road projects. The 'key assumption is that the value of a person's output is at least equal to the cost of employing him or her and that a saving in time will allow the per capital production to increase by a corresponding amount' (Mulreany, 2002: 10). Following from this, work and non-work travel times are valued differently. Examined below are the time savings that materialize for motorists in the city area as a result of the removal of slow speed of haulage vehicles, heavy good vehicles and very old vehicles due to grade and sight distance problems when traversing the mount Entoto. The volume of traffic flows has been recorded (ERA, 2017) in various areas throughout the city exites and these figures indicate that the route become the conjusted one next to Addis Ababa Nazret route. On average daily base, 3827 vehicles travel though this Addis Comando main route daily and out of this 2031 (53.07%) of this was accounted by HGVs (ERA, 2017). Using expansion growth factor methods of traffic forecast with growth factor of 1.14 (value obtain from the traffic count value comparison of each year for the referred route only). Therefore, the AADT of Addis Ababa to Comando will be become to these volumes of increament to 4363 vehicles daily in 2018. There is no current or historic data available for journey times within the city and more specifically, no data relating to time savings as a result of the removal of HGVs in these areas and shortening the travel time of road user by built such infrastructure in Addis or through out Ethiopia, therefore the following analysis is be based on certain assumptions.

Table 4. 7 Time Saved due to the Construction of Entoto Road Tunnel (at project opening date 2023)

Category	AADT	People per day	Time Saved (hours/day)	Value of Time (Birr/day)	Annual Savings (Birr)
Work = office	1597	20413	8165	450	143,300,982.73
Non-work= other than office	3100	91776	21414	200	167,032,675.54
Total	4696	112189			310,333,658.27

According to ERA, one HGV is equivalent to 3.5 'passenger car units' in level terrain (ERA, 2013); each HGV removed will therefore be worth 3.5 passenger cars. In the same way medium good truck and large bus be 2.5 and 2.0 equivalent pcu. Accordingly, with the removal of 53.07% of HGVs and 9.93% of large buses delay time from Addis Ababa Comando route due to construction of Entoto tunnel road to reduce the grade of the Addis –Comando surface road, travel times within the route will be reduced by 60% (40 min. max. to 16 min. max. for HGV). Therefore 4696 vehicles should have lower journey times due to Entoto road tunnel. Taking ERA vehicle proportions by categorization and vehicle occupancy rates, it is estimated that over 112189 people per day will save time on journeys. It is difficult to calculate actual journey time savings for these motorists because of the vast variety in their routes and journey lengths (surveys would be useful in this regard); therefore based on anecdotal evidence, the assumption is made that the average journey time in the route between 6:00 and 21:00 is 0.75 hour. It is also assumed that 80% of the daily traffic is accounted from between 6:00 and 21:00 and that journey time outside this period is two-thirds of these within it (30 minutes). Therefore, 3757 vehicles (80% of traffic in the route) save 24 minutes and 939 (20%) save 14 minutes daily. In total, 20413 people will save 8165 hours for office work and 91776 people will save 21414 hours daily and using values of time savings, the estimate annual value of savings is 310.33m ETB. By considering a 75% of reduction for correction of count and overlap, Entoto road tunnel will save 232.75m EBR.

Vehicle Cost Savings

Entoto Tunnel Road: These savings are made through differences in levels of fuel consumption that arise from a tunnel road project. Below is an analysis of additional costs to HGVs using Entoto road tunnel and savings to those remaining motorists in the city. It is estimated from the Transportation Minister (2010 fiscal year vehicle status) that there are approximately 935888 cars in Ethiopia. Out of which 553938 vehicles, almost 59.2% percents are in the central city, Addis Ababa, and 129339 vehicles (13.82%) are in the Oromia regional state. The three registration types, i.e the AA, OR and AM plate number, are use Addis Ababa Comando route. 2.1% of which travel through Entoto route daily. A source of overstatement would arise if, for simplicity, fuel savings are directly equated to travel length, grade or terrain of the road and traffic volume. Therefore, (somewhat arbitrarily) the resulting benefits will be increased by a greater of 100%, since distances travelled are assumed to be shortend by over of half irrespective of the volume of traffic. Therefore, with an increase of passenger car units of 133% the improvement of the route by constructing Entoto tunnel road, just over 3827 vehicles will save 25717.44 kilometers per day. According to Federal Transport Authority (FTA, 2018) transportation data, vehicle operating costs saved with the construction of Entoto tunnel road will be 1.096b EBR annually. By considering a 75% of reduction for correction of count and overlap, Entoto road tunnel will save 821.7m EBR.

Table 4. 8 Fuel cost of traffic used of tunnel road

Catagory	AADT	Fuel consuption litre per km	Saved Km	Avg. Fuel Cost per Km	Annual Cost
Truck Trailer	1280	1.5	13.22 – 6.5 = 6.72	25.95	81,472,204.80
Truck	3178	2		34.6	269,734,132.55
Bus	2513	3		51.9	319,936,721.44
Car	1429	7		121.1	424,440,069.76
Total	8400				1,095,583,128.55

Costs

The costs of an individual road investment are those that are required ‘to establish, maintain and operate a project’ and the ERA split these project costs into two categories: investment costs and operating costs. The former includes construction, land acquisition and labor while the latter relates to the cost of maintenance. According to the country current condition of economic status, the toll system to revenue the construction of the Entoto tunnel road from all vehicles using the road is minimal but ‘roughly offsets maintenance costs’. Therefore, for simplicity it will be assumed that this will always be the case and both their toll revenues and maintenance costs will be removed from the streams of discounted costs and benefits throughout the appraisal period (30 years). Assume the cost of construction of tunnel road in Ethiopia from the current construction cost of surface road in harsh terrain is 100 times of the cost of surface road, by consideration technological effects on the country in the case of tunneling, tunnel mechanics, tunneling machines and methods. From some project cost constructed by ERA, the average cost of asphalt surface road on harsh terrain reaches to almost 25 million birr per km. Therefore, the 3km tunnel road construction in Entoto mountain plus a 3.5km surface road be equal to 7587.5 million = 7500 million plus 87.5 million = [25*3*100 + 3.5*25 = 7500 + 87.5 = 7587.5 million]. Note that, there is a cost varation in earth work and muck desposal only in addition to the tunnel linning in tunnel rather than surface.

Table 4. 9 Stream of costs and benefits (at the 5% discount rate)

Year	Time Cost (m-birr)	Accident Cost (m-birr)	Vehicle Cost (m-birr)	Total Benefit (m-birr)	Cost (m birr)
2023					7587.5
2024	232.75	448.13	821.70	1502.58	
2025	221.11	425.72	780.62	1427.45	
2026	210.06	404.44	741.58	1356.08	
2027	199.55	384.22	704.51	1288.27	
2028	189.58	365.00	669.28	1223.86	
2029	180.10	346.75	635.82	1162.67	
2030	171.09	329.42	604.03	1104.53	
2031	162.54	312.95	573.82	1049.31	
2032	154.41	297.30	545.13	996.84	
2033	146.69	282.43	517.88	947.00	
2034	139.36	268.31	491.98	899.65	
2035	132.39	254.90	467.38	854.67	
2036	125.77	242.15	444.01	811.93	
2037	119.48	230.04	421.81	771.34	
2038	113.51	218.54	400.72	732.77	
2039	107.83	207.61	380.69	696.13	
2040	102.44	197.23	361.65	661.33	
2041	97.32	187.37	343.57	628.26	
2042	92.45	178.00	326.39	596.85	
2043	87.83	169.10	310.07	567.00	
2044	83.44	160.65	294.57	538.65	
2045	79.27	152.62	279.84	511.72	
2046	75.30	144.99	265.85	486.14	
2047	71.54	137.74	252.56	461.83	
2048	67.96	130.85	239.93	438.74	
2049	64.56	124.31	227.93	416.80	
2050	61.33	118.09	216.53	395.96	
2051	58.27	112.19	205.71	376.16	
2052	55.35	106.58	195.42	357.35	
Total				23261.88	7587.5
BCR					3.07

Summary of CBA Cash Flows

Using a 5% discount rate the values of benefits (cash inflows) can be seen over time; this analysis shows that these only marginally cover the costs. The internal rate of return (IRR) is therefore determined to be 36%, higher than the 'hurdle rate' on public sector projects of 4.5%. It is important to note however, that the above calculations are based on zero growth rates in traffic and income levels (it can be viewed as a pessimistic scenario), and since this may be unrealistic over a 30 year period, sensitivity tests showing growth in these areas would result in higher IRRs. Time savings and accident reduction along the route account for 45.31% of the benefits of the ENTOTO road tunnel, so the IRR would be most sensitive to changes in the monetary values attached to these, which also vary according to sensitivity tests. Nevertheless, the above analysis shows an observed Benefit/ Cost ratio of merely 3.07:1.

The observed benefits will be weighed against the costs and discounted to establish a Benefit/Cost ratio and the Net Present Value (NPV) over the 'appraisal period'. Benefit-Cost ratio of 3.07:1, an NPV of 15,674.38 METB and an IRR of 36.0 percent for Entoto Tunnel Road. Individual project: NPV > 0; Benefit-Cost ratio > 1:1; and the IRR > the ERA 'hurdle' discount rate. However, the discounted benefits shown by these methods as part of the CBA only marginally exceed the costs, delivering only a small gain to the welfare of society. While there may be drawbacks in terms of the breadth of this type of analysis, it is apparent why it is considered 'the most important technique for project appraisal in the public sector'. Perhaps the most disappointing result in this types of study is the apparent lack of accountability for public investment projects and this highlights the fear that 'the failure to publish *ex post* cost benefit analyses of these and the likes projects increases the taxpayer risk in further tunnel transport projects'.

4.8.6 Unquantifiable Benefits

These take the form of 'amenity and environmental aspects of road investment', but despite difficulty in valuation, these items are 'none the less important. A significant result of the tunnel project is the resulting HGV ban, and this has had a tangible impact due to the removal of environmentally deficient vehicles from the route. This gives rise to an automatic increase in the quality of the environment that is immediately noticeable since there is a reduction in noise and pollution levels around the route.

4.9 Environmental Impact and Socio-Economic Benefits of Entoto Tunnel Roads

4.9.1 Environmental Impact Assessment of Entoto Tunnel Road

The environment of Entoto area is complex. It includes the human population, fauna, flora, soil, water, air, climatic factors, material assets (including the architectural and archaeological heritage), landscape, calture, protected park and the way these interact with each other. Consequently evaluating the impact of a project on the environment is often an elaborate technical exercise, requiring the collection, presentation and analysis of a large amount of information, the identification of involved issues and a consequential specification of mitigation measures [96].

The transportation condition of Ethiopia shows some improvement with time [97]. This is due to the development of road infrastructure, the increment of car owner-ship and the increment of individual income, which implies there is econmomic growth in the country. In Addis Ababa the vehicle growth rate increases rapidly and the same as thoughout the county i.e. There is a high incremental rate of car owner ship especially in Addis Ababa. From Ethiopian cities and regions, Addis Ababa has a large concentration of motorized vehicles. About 80 percent of the total vehicles in the country operate in the city. In 2017, registered vehicles in the capital city have reached 935,888. It has 1.32 [(935,888-708,416)/708,416*100=32.11%)] growth when compared with 2016 data that was 708416. This number is expected to be growing at a rapid pace with the development of the socio-economic activity of the city and grow the purchasing power of the people. This challenge demands proactive planning to accommodate the growth. As the number of road trasnportation usage increases the fuel consumption of the country increases. Fuel consumption by road transport grows exponentially, since vehicle number growth exponentially as shown below. National Green House Gas Inventory (1994 E.C) showed that 50% of the countries CO_2 emission is from Road Transport. During the inventory the following amount of pollutant should be recorded; 1000 gG of co_2 and other a relatively small other gases, No_x: 10 gG, CO: 50 gG, So_2: 4.3 gG

The vehicle status which is currently used in Ethiopian are almost aged and have a highest fuel consuptions. A greate number of vehicle imported from Dubai, which is in a second hand level, i.e used vehicles. So they emit a lot CO_2 than a new one. But there is a good begging in the use of new vehicle which has less emission of CO and CO_2, becuase there are some car assembly campony in Ethiopia, who can deliver with affordable cost. When one car imported to Ethiopia, the vehicle should satisfay either the standard of Ethiopia (if any) or the standard of the country which is made or imported.

Nowadays the Ministry of Transportation sets the following standard for vehicle inspection for 2005 fiscal year [97]. The Carbon dioxide (CO_2) emission from vehicles operating on gasoil and do not have catalytic converters has to be less or equal to 4.5per cent by volume while those which do cannot go beyond 0.75pc. On the other hand, the limit for diesel operated vehicles emissions without a turbo charger is at 0.06pc, while 0.04pc is set for those with a turbocharger.

The environmental impact of transport in Ethiopia is significant because it is a major user of fuel energy, and burns most of the petroleum imported than any one industry in the country. This creates air pollution, including nitrous oxides and particulates, and is a significant contributor to global warming through emission of carbon dioxide, for which transport is the fastest-growing emission sector on the current condition of the country. By subsector, road transport is the largest contributor to global warming.

Environmental regulations in the countries have reduced the individual vehicles emission is on practice; however, this has been offset by an increase in the number of vehicles, and more use of each vehicle. Some pathways to reduce the carbon emissions of road vehicles considerably should be studied and even implemented like express way from Addis Ababa to Adama and the likes, which increase travel speed. Energy use and emissions vary largely between modes, causing environmentalists to call for a transition from air and road to rail and human-powered transport, and increase transport electrification and energy efficiency. In some cases they depend to reduce the transportation travel time, traffic conjustion by facilitating the development of efficient transportation infrastructure like Addis Adama express road and reducing the grade of newly constructed roads. To do so tunnel road should be the best alternatives for congested and topographically difficult city like Addis Ababa.

Other environmental impacts of transport systems include traffic congestion and automobile-oriented urban sprawl, which can consume natural habitat and agricultural lands. By reducing transportation emissions globally, it is predicted that there will be significant positive effects on Earth's air quality, acid rain, smog and climate change.

4.9.2 Environmental Impact of Entoto Tunnel Roads

The environmental impact of Entoto Tunnel Roads (both positive and negative) include the local effect of the tunnel such as on noise, water pollution, habitat destruction/disturbance and local air quality; and the wider effects which may include climate change from vehicle emissions [96]. The design, construction and management of roads, parking and other related facilities as well as the design and regulation of vehicles can change the impacts to varying degrees.

Environmental and Community Issues

Entoto road tunnel is more environmentally friendly than the surface facilities. Traffic congestion would be reduced from the local streets. Air quality would be improved because traffic generated pollutants are captured and disposed of away from the public. Similarly, noise would be reduced and visual aesthetic and land use would be improved. By placing traffic underground, property values would be improved and communities would be less impacted in the long term. Furthermore, the tunnel will provide opportunities for land development along and over the tunnel alignment adding real estate properties and potential economic development. Especially, the Entoto Park (bio-diversity) should be protected.

4.9.3 Sustainability and Socio-Economic Benefit of Entoto Tunnel Road

Sustainability of the Entoto tunnel road

Tunnels by definition are sustainable features. They typically have longer life expectancy than a surface facility (125 versus 75 years). Entoto tunnel provide opportunities for land development of residential, commercial, or recreational facilities for Addis Ababa and the neighboring Oromia region and also enhance the area and potentially increase property values. The tunnel also enhance community's connections, adhesion, protect residents, sensitive receptors from traffic pollutants and noise. The main socio-economic impacts of this project will be positive and consist of employment creation (direct and indirect), and economic benefits through reduced journey time savings across the route.

In addition to the direct employment benefits during construction of the project, indirect and induced employment benefits will also arise. Available data from various sources suggests that indirect and induced employment could amount to of the order of 150%; that is every person year of direct employment will generate an additional 0.9 person years of indirect and induced employment in the economy. The wider economic impact will have a minor and positive impact on levels of unemployment in the city through providing approximately 3,585 temporary jobs or the equivalent of 1,250 full time jobs. Once operational, the Project will employ approximately 110 people.

Socio-Economic Benefit of Entoto Tunnel Road

Tunnel road development of the area increases the transportation network and facilitates the socio-economic benefit of Addis Ababa and the surrounding cities of Oromia region. A reliable transportation network represents a net benefit to society, and conversely, a vulnerable network represents a net cost to society [5]. The Project may change the community's exposure to risks and impacts arising from accidents, structural failures, releases of hazardous materials, and the activities of personnel. The change of the social and economic conditions as a result of implementation of the activities under review will come about through the increase in of demand for manpower resources, the creation of additional jobs which will be a stabilizing factor for these territories facing the reduction of production volume and an increasing exodus of population. The new road will improve the social conditions and stimulate the development of local industry. The road will make a great contribution into the region's development and improve the social and economic conditions of both the region's population and all the adjoining areas. In addition the proposed tunnel will have a great impact in money value of time and the high development of urbanization in the surrounding areas.

CHAPTER 5 CONCLUSIONS AND RECCOMENDATIONS

5.1 Conclusions

The Ethiopian landform is characterized by great diversity. There are flat-topped plateaus, high and rugged mountains, deep river gorges and rolling plains. Constructing surface road on such greatly undulating topography is so difficult. Therefore, it is kind to search best equivalent alternative solution to traverse such kinds of topography. A number of cities, towns and villages in Ethiopia like Addis Ababa, which is found along the western plateau margin of Ethiopia, have an altitude ranging 1750m to 3250m above sea level. Major of the cities of Ethiopia are on the west of MER. The physiographic of this area cover the highest portion of Ethiopia. It makes up about 44 percent of the area. From this 76.3% of this physiographic area covered with highlands. So the road cover on this area of 76.3% bypass through this highland. Accordingly, it is better to consider tunnel road for the area west of the MER.

Addis Ababa which is found on the Shewa plateau is surrounded by continuous ranging mountains like Entoto and three other such mountains. The south eastern and the north western part of Addis Ababa are >2000m above sea level and surrounded by a continuous ranging mountain like Entoto. Since the city is surrounded by such kinds of chain of mountains it is defficult to expand laterally and develop with the required coverage of surface road. Surface road construction on such types of topography is not economical. So to traverse such kinds of high difficulty topography as well as expand the city laterally tunnel Road is the feasible alternative.

All in all, the constructed tunnel like Entoto tunnel road through Entoto mountain should have a great benefit to the surrounding area of Addis and/or country: indicating that the projects' feasibility should be checked before constructing them from the context of the surrounding benefit as well as the geological and geotechnical point of the project. The feasiblity of the project should be evaluated with costs of construction against benefits of project incured for the road user in accordance with user cost and time saving on its life time. The costs of construction of Entoto tunnel road project would include the cost of labor and materials used in construction, which is now a number one job opportunity for the youngster. The benefits of such project include time saved to motorists, increased predictability of journey times and increased accessibility to a particular location. Therefore, as shown above in the CBA part of Entoto tunnel road project, definitely tunnel road construction in Ethiopia, across Entoto Mountain, is feasible and best road infrastructure alternative from its topography point of view as well as for the western physiographic of Ethiopia tunnel road is the best alternative and incure a threefourth addition of benefit to the surface road constructed on this physiographic region.

5.2 Recommendations

This study attempts to provide rationalized information on the development of tunnel road infrastructure in Ethiopia. The paper main idea comes from current condition of Ethiopia surface road according to travel time, traffice accident, road user cost and urban land use effect due to the topography of the country. The basic initiative point of the research is the tunnel road of Tarmaber, tunnels which have been built by EEPCO for access to the hydro-power dam like Tekeze and Gibe, the tunnel road for train in the northern part of Ethiopia, especially along the route of Awash Combalcha Woldia train and the congestion of Addis Ababa according to living environment and traffic condition. Therefore, the following shall be studied.

- Tunnel road for Ethiopia, their travel time in comparison to surface road.
- Development of urban tunnel road for the city of Addis Ababa, as a solution for the transportation facility for the city.
- The benefit of tunnel road infrastructure for the development of the country.
- The role of tunnel road in the reduction of traffic accident in Ethiopia.
- The use of tunnel road to alleviate the conjuction in the central of addis Ababa
- Risk assessment on Entoto Tunnel Road
- Analysis of Entoto Tunnel Road Lining
- The benefit of Entoto tunnel road for Gulele Bio-diversity or Entoto forestry
- The interaction of road user with tunnel road
- The benefit of tunnel road to reduce carbon due to vehicle

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APPENDIX A

Tables and Figures

Table A: Road Traffic Accident Trend in Ethiopia (2001 – 2005)

Year	2001/02	2002/03	2003/04	2004/05	2001-05 increase (%)	Annual Avg. increase (%)
Fatal	1327	1510	1630	1801	36	12
Serious	1712	1790	2072	2368	38	13
Slight	2196	2365	2705	2731	24.4	8
Damage only	7188	8563	10569	10822	51	17

Source: Federal Police Commission

Table B: Summary of costs of road traffic accidents (2009/10) [90]

	Fatal	Serious	Slight	Damage only	Total
Damage to Vehicle	148,353,727	151,269,252	85,215,105	110,142,759	494,980,842
Lost Output	224,230,640	4,052,417	292,400		228,575,457
Medical	7,255,941	37,512,050	2,649,875		47,417,866
Police and Admin.	7,596,806	7,713,349	12,342,033	11,014,276	38,666,464
Pain, grief & Suffering	185,377,521	109,141,937	1,827,500		296,346,958
Adjustment for Under-reporting	(1.25X)	(2X)	(2X)	(2.7X)	
Total	**716,018,294**	**619,378,010**	**204,653,826**	**327,123,995**	**1,867,174,125**

Table C: Annual Average Daily Trafic of Addis Ababa Comando Route [10]

Year	Route Name	Length	Car	Land rovers	Small Buses	Large Buses	Small Truck	Medium Truck	Heavy Truck	Truck Trailer	Total
2007	Addis Ababa to Comando	113	113	173	428	142	219	245	170	149	1639
2008			83	155	472	120	219	196	143	146	1534
2009			106	254	575	118	364	423	335	222	2397
2010			116	284	633	131	225	338	268	134	2129

Table D: Average Daily Trafic of Addis Ababa Comando Route for 2010 [10]

Year	Route Name	Length	Cars	Land drovers	Small Buses	Large Buses	Small Truck	Medium Truck	Heavy Truck	Truck Trailer	Total
2010 cycle 1	Addis Ababa to Comando	113	114	335	598	123	104	341	285	91	1991
2010 cycle 2			119	248	616	125	265	290	204	155	2022
2010 cycle 3			115	269	685	146	307	383	314	157	2376

Table E: Comparison On 2009 And 2010 Average Vehicle kilometer By Road Sections

Road Section	Length (km)	2009	2010	%
Addis Ababa – Comando	113	270,861	240,577	-11
Combolcha – Dessie	25	27,825	35,375	27

Table F: Travel Time and Fuel Cost by Vehicle Type Along Addis Comando Route to Travers the Entoto Mount Only (13.22 km only)

Addis Ababa – Comando Route					
Vehicle Type	Time Taken (min)	Fuel Consume per km	Running Speed (km/hr)	Avg. Fuel Consumption per km	Fuel Cost (ETB)
Truck 1	39.66	3	20	2.0	16.35
Truck 2	31.728	3	25		
Truck 3	52.88	2	15		
Truck 4	26.44	1	30		
Truck 5	26.44	1.5	30		
Track Trailer 1	79.32	1	10	1.5	
Track Trailer 2	52.88	2	15		
Track Trailer 3	39.66	1	20		
Track Trailer 4	31.728	2	25		
Track Trailer 5	39.66	3	20		
Bus 1	26.44	4	30	3.0	
Bus 2	19.83	3	40		
Bus 3	39.66	3	20		
Bus 4	31.728	4	25		
Bus 5	22.66286	3	35		
Car 1	19.83	5	40	7.0	
Car 2	39.66	4	20		
Car 3	26.44	5	30		
Car 4	26.44	6	30		
Car 5	15.864	10	50		

Table G: Traffic Growth Rate of Addis Ababa Commando Route

Route	Fiscal Year	AADT	Rate of growth	Average Growth Rate
Addis Ababa-Commando	2017	3827	1.04	1.14
	2016	3682	1.03	
	2015	3578	0.96	
	2014	3739	1.53	
	2013	2445	1.28	
	2012	1917	0.78	
	2011	2447	1.15	
	2010	2129	0.89	
	2009	2397	1.56	
	2008	1534	0.94	

2007	1639	1.15
2006	1428	1.53
2005	935	0.99
2004	943	1.11
2003	849	1.15
2002	736	

Table H: Types of vehicles and numbers in the country

Type of Vehicles and Number in the Regions (up to Sene 30.2010) Registration											
Description	**AA**	**AM**	**AF**	**BN**	**DD**	**SO**	**TG**	**GM**	**HA**	**SN**	**OR**	**Total**
Ambulance	198	0	37	35	9	2	91	0	4	25	238	639
Automobile	184227	1485	59	49	2057	558	1421	228	1275	16162	4796	212317
Bajaj	0	2132	2644	0	289	0	0	0	536	8721	34339	48661
Tri Cyle	0	40	0	0	0	0	0	0	0	27	0	67
Bus(< 12 Seats)	26408	7146	448	324	1468	755	4768	0	0	709	14174	56200
Bus(> 11 Seats)	15242	9747	449	325	514	537	3335	1375	357	1144	22772	55797
Combiner	20	17	0	0	1	2	5	0	357	0	75	477
Dozer	16	0	3	3	0	1	5	0	20	0	0	48
Dry Cargo(<=10 Quinta	37384	1602	289	101	890	953	1069	0	176	3070	7063	52597
Dry Cargo(>10 Quintals	109952	4099	229	98	4089	2152	4886	0	2	1195	1810	128512
Dual Purpose Vehicle	44954	3443	348	301	1157	515	2063	0	36	1435	372	54624
Field Vehicle	45081	1590	303	148	447	912	1185	0	445	117	5421	55649
Grader	7	2	0	0	1	1	4	0	3	0	1	19
Forklift	188	0	4	1	6	0	13	0	317	0	2	531
Not Specified	18154	8121	32	25	222	263	602	0	0	1534	6020	34973
Gotach	5598	0	0	0	59	0	572	0	1699	0	0	7928
Liquid Cargo	6341	272	35	2	206	114	645	0	7	65	189	7876
Liquid Trailer	0	11	0	0	0	0	0	0	336	0	117	464
Motor Bicycle	22931	26442	1152	4129	5891	1157	10744	2166	0	49409	29378	153399
Other	9912	442	36	1	88	33	494	1353	72	36	1763	14230
Three wheel dry load	12	0	0	24	2	166	888	0	1	0	4	1097
Three wheel public loa	375	0	0	1909	0	5145	9962	0	0	0	0	17391
Tractor	1059	281	46	134	21	0	265	0	0	7	503	2316
Trailer	25336	292	8	1	394	1	2793	0	0	0	302	29127
Vehicle with Machiner	543	135	15	1	113	27	115	0	0	0	0	949
Total	**6E+05**	**67299**	**6137**	**7611**	**17924**	**13294**	**45925**	**5122**	**5643**	**83656**	**1E+05**	**935888**

Table I: Forecast of AADT for Entoto Tunnel Road

AADT for Addis Ababa Comando										
Fisical Year	Growth Rate	Cars	Land Rover	Small Bus	large Bus	Small Track	Medium Truck	Heavy Truck	Truck & Trailer	Total
Basic Year 2017	1.14	273	378	765	380	497	535	416	583	3827
2018		311	431	872	433	567	610	474	665	4363
2019		355	491	994	494	646	695	541	758	4974
2020		404	560	1133	563	736	793	616	864	5670
2021		461	638	1292	642	839	904	703	985	6464
2022		526	728	1473	732	957	1030	801	1123	7369
Project open year 2023		599	830	1679	834	1091	1174	913	1280	8400
PCU 2023		599	830	1679	834	1091	1174	913	1280	
passengers		4	12	24	50	4	4	4	4	
total Traveler		2397	9956	40300	41704	4364	4697	3652	5119	112189
people to work		20413	By considering 20% of small bus passengers be office worker							
people to non work		91776								

Table J: GPS Point of the existing surface road center point

Point ID	North	East	Elevation
I1	471236	1003081	2712
I2	471182	1003152	2717
I3	471174	1003194	2720
I4	471178	1003278	2725
I5	471140	1003301	2726
I6	471050	1003289	2726
I7	470984	1003313	2728
I8	470870	1003457	2736
I9	470843	1003555	2739
I10	470793	1003577	2739
I11	470713	1003449	2741
I12	470568	1003296	2746
I13	470459	1003343	2747
I14	470459	1003471	2746
I15	470616	1003741	2751
I16	470572	1003769	2753
I17	470493	1003719	2759
I18	470358	1003790	2770
I19	470242	1003773	2778
I20	470179	1003883	2787
I21	470187	1004035	2799
I22	470097	1004083	2807
I23	469943	1004054	2819
I24	469827	1004068	2827
I25	469708	1004065	2839
I26	469692	1004122	2844
I27	469636	1004127	2847
I28	469563	1004181	2808

I29	469471	1004241	2838
I30	469404	1004397	2828
I31	469344	1004436	2824
I32	469350	1004475	2821
I33	469425	1004548	2816
I34	469435	1004630	2811
I35	469329	1004889	2802
I36	469122	1004977	2786
I37	469075	1005135	2779
I38	468783	1005342	2757
I39	468630	1005594	2763
I40	468557	1005713	2762
I41	468400	1005918	2759
I42	468061	1006363	2754
I43	468060	1006449	2755
I44	468383	1006835	2764
I45	468774	1007033	2760
I46	469455	1007350	2752
I47	469856	1007627	2742
I48	470020	1007656	2740
I49	470111	1007713	2738
I50	470554	1008057	2721
I51	470861	1008224	2720
I52	471182	1008480	2723
I53	471545	1009202	2723
I54	471850	1009426	2714
I55	472202	1009440	2695
I56	472547	1009450	2669
I57	472765	1009651	2651
I58	473045	1010028	2659
I60	472959	1010841	2650
LOW POINT1	473138	1010896	2641
LOW POINT	473138	1010896	2641

Table L: Traffic Accident Report of Transport Authority

ክልል መስተዳድር	የደረሰው ትራፊክ አደጋ ብዛት					በትራፊክአደጋተጎጂየሆኑግለሰቦችብዛት										በትራፊክአደጋ በንብረትላይ የደረሰጉዳት በገንዘብሲተመን
						ሞት		ከባድ የአካል ጉዳት		ቀላል የአካል ጉዳት		ድምር		ጠቅላላ ድምር	
	ሞት	ከባድ የአካል ጉዳት	ቀላል የአካል ጉዳት	የንብረት ጉዳት	ድምር	ወንድ	ሴት	ወንድ	ሴት	ወንድ	ሴት	ወንድ	ሴት		
ትግራይ	303	339	55	489	1,186	254	117	471	193	254	102	979	412	1,391	59,191,154.70
አፋር	90	50	14	201	355	112	19	124	40	58	21	294	80	374	80,558,700.00
አማራ	796	502	565	1167	3,030	807	228	860	330	1,355	635	3,022	1,193	4,215	366,798,848.10
ኦሮምያ	1188	568	518	1626	3,900	1,157	384	1,068	391	1,056	429	3,281	1,204	4,485	153,004,478.00
ሶማሌ	125	171	10	15	321	128	29	327	81	257	139	712	249	961	35,276,000.00
ቤን/ጉሙዝ	31	98	114	44	287	26	7	180	44	254	141	460	192	652	9,711,900.00
ደቡብ	642	693	261	211	1,807	582	119	871	317	791	303	2,244	739	2,983	30,704,447.00
ጋምቤላ	13	23	49	68	153	12	4	30	8	56	45	98	57	155	6,983,860.00
ሀረሪ	42	55	206	248	551	43	10	82	41	165	119	290	170	460	3,047,644.08
አ.አ	466	1996	973	23,510	26,945	367	110	1,619	466	885	347	2,871	923	3,794	417,922,804.00
ድሬዳዋ	29	94	89	330	542	26	5	98	43	112	68	236	116	352	6,247,405.00
ድምር	3,725	4589	2,854	27,909	39,077	3,514	1,032	5,730	1,954	5,243	2,349	14,487	5,335	19,822	1,189,447,240.88
						4,546		7,684		7,592		19,822			

Figure A. GPS map of Entoto existing surface road