ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL and ENVIRONMENTAL ENGINEERING

EVALUATION OFALTERNATIVE TRACK ALIGNMENTS ON WHOLE LIFE COST OF LOT 11 SECTION OF THE AWASH-WELDIYA RAILWAY LINE

By

Muna Abebe

A thesis submitted to the school of Graduate Studies of Addis Ababa University in Partial fulfillment of the degree of Master Science in Civil Engineering

Advisors

Professor Elias Kassa

Ato Matias Kabtamu

March, 2015

Abstract

Geometric design is an essential and major component in the design development of railway projects. Geometric alignments (horizontal and vertical) affect project cost and safety significantly keeping other factors constant.

The effect of track alignment on cost of awash-weldiya railway project in particular to Lot-11 stretch is evaluated in this thesis. Three different horizontal and vertical alignments are designed and their respective costs computed and compared. In the design process, topographic data is generated from 30m Resolution Digital Elevation Model using Global Mapper software. Horizontal and vertical alignments are designed using widely applicable Bentley Rail Track (BRT) software. In this thesis, Ethiopian Railways Corporation manual is used as governing rail standard.

Basic techniques are applied for economical and safe design of the project. Generally, a minimum curve radius of 2000m and a maximum gradient of 2% is applied but a deviation from the standard is made in some parts due to topographic and other constraints. Accordingly, horizontal curves as low as 500m and gradient as high as 2.5% have been used in some places where there is topography constraint.

The main parameters that are considered to evaluate the impact of track alignment on cost of the project are: earth work quantity, length of project, tunnel length, length of swampy section, total number of structures and total span of structures. Critical sections are identified along potential corridor routes and then different sensitivity analysis has been applied on these critical sections before final decision is made.

Prioritization of alternative routes has been made based on construction cost, operational cost and safety comparisons to identify the most economical and low risk alternative alignment.

According to the analysis, from the three alternatives alignments compared, alternative II is economical but alternative III has low risk of construction while alternative I fulfills the required design criteria of the standard better than the other two alignments.

Key Words: Horizontal alignment, Curve, Vertical alignment, Cost, and Safety.

Table of Contents

List of Tables

List of Figures

List of Akronyms

AREMA = American Railway Engineering and Maintenance-of-Way Association

BR = British Railway

CDE = Chemin de fer Djibouto-Ethiopien (Ethio-Djibouti Railway)

CEN=Comité Européen de Normalisation(Committee for European Standardization)

CWR = Continuous Welded Rail

ERA = Ethiopia Road Authority

TSI = Technical Specification of Interoperability

ORE = Office of Research Experiments (now UIC)

RGS = railway Group Standard

SNCF = Société Nationale des Chemins de Fer Français (France Railway)

TGV = Train Grande Vitesse (High Speed Train)

UIC = Union Internationale des Chemins de Fer (International Union of Railways)

UK = United Kingdom

US = United States

USCS = Unified Soil Classification System

PRC standard = People's Republic of China standard

ERC standard = Ethiopian Railway Corporation standard

EN = European standard

LRT= Light Rail Track

PI= Point of Intersection

PVI= point of vertical intersection

Acknowledgements

Firstly, I would like to express deepest gratitude to Professor Elias Kassa (my adviser) for his voluntary consultation, constant supervision, guidance and comments to keep the research on track.

I also want to thank MSc. Matias Kabtamu (my co-adviser) for constant supervision, guidance and comments for this research work.

I gratefully acknowledge the Ethiopian Railway Corporation (ERC) for being my sponsor.

I want to thank MSc. Yared Amdie, Lecturer at AASTU, for his support, guidance constructive suggestion for this thesis work.

I also want to thank Abdulkerim and Zelalem from the Ethiopian Railway Corporation for providing me the necessary information as input data for the thesis work.

Muna Abebe

March 2015, Addis Ababa.

1. Introduction

1.1 Background

Railway transportation facilities design includes the design of geometric cross sections, horizontal alignment, vertical alignment, intersections, and various design details. These basic elements are common to all linear facilities, such as roadways, railways, and airport runways and taxiways. Although the details of design standards vary with the mode and the class of facility, most of the issues involved in geometric design are similar for all modes. In all cases, the goals of geometric design are to maximize the comfort, safety, and economy of facilities, while minimizing their environmental impacts.

The track geometry determines the standards to be applied on the track alignment. Minimum horizontal curves as well as minimum and maximum ruling gradient must be specified for the alignment. These standards directly affect the amount of earthworks, tunnels and viaducts on the line and therefore directly impact the capital cost of the line. Horizontal and vertical design standards for railways are more stringent compared to, for example, a road, and the challenges to optimize the cost of a railway alignment is therefore greater compared to a road. For example, in mountainous terrain, a road can simply follow the terrain contours with sharp bends and steep grades in order to minimize earthworks quantities. This is not possible with a railway.

The use of geometric design standards fulfils three following important aspects:

1. Standards are intended to provide maximum levels of safety and comfort
2. Provide framework for economic design
3. Ensure a consistency of alignment standards

Apart from the above listed, the endorsed design standards take into account the environmental and social conditions and operational characteristics.

The output of the detailed design would also help for the categorization of the routes in terms of construction cost . The basic criteria include cut and fill height, type and span of structure and tunnel and viaduct construction.

1.2 Problem Statement

Cost is one of the major factors to select final alignment before construction because the alignment selected should be safe and economical. Varying routes and gradients affect the construction and operational costs of the project differently keeping other factors constant. It is also important that passenger comfort is being ensured. In this thesis an attempt is made to evaluate how different railway alignments and gradients affect the construction and operational costs of selected section of the project (in particular called as Lot-11).

1.3 Research Objective

The general objective of the research is to compare (construction & operational) costs for three alternative routes of the project and to give recommendations on railway route selection.

Specific objectives:

1. To evaluate gradient variation on earth work quantities and overall cost of the railway line without exceeding the maximum gradient.
2. To realize how significantly gradient variation affect tunnel length and overburden height.
3. To examine all possible engineering options to avoid or reduce swampy section stretches.
4. To evaluate geometric parameters effect on number and span of cross-drainages.

1.4 Research Methodology

The research methodology for this study involves literature review, data collection from relevant stake holders like Ethiopian Railways Corporation (ERC), Ethiopian Roads Authority (ERA), Ethiopian Mapping Agency (EMA), Ethiopian Metro logical Agency.ERC standard track design manual is used as reference manual for designing the horizontal and vertical alignments.

Topographic data is generated from 30m resolution digital elevation Model using Global Mapper software, Bentley rail track software is used for the design of horizontal and vertical alignments and MS-excel used for some mathematical analysis.

The design process includes following key activities

1. The DEM is imported to the Bentley Rail Track (BRT) railway design software.

2. Horizontal Alignment is designed based on the criteria on ERC standard

3. Existing ground (profile) is extracted from DTM.

4. Vertical Alignment (Grade line) is designed based on the criteria on ERC standard

5. Selected typical single track cross section is run through the defined horizontal and vertical alignments.

6. Earthwork area and volume is processed.

After going through the design process, construction cost is estimated. Operational cost of running train is calculated using following formula as discussed in detail in analysis and discussion part of the thesis (chapter 5).

$$\boxed{OP = C \cdot L + A\left(\Delta H + 0{,}012 \cdot \sum \alpha\right) + Б\left(H_C - 0{,}012 \cdot \sum \alpha_c\right) - B \cdot L_C}$$

Where

OP = Operational cost

L= Total length of the alignment, km

ΔH= Algebraic difference marks the final and initial points of the alignment, m

∑α= The sum of all deflection angles of horizontal curve, degree

Lc= Length of alignment with gradient greater than 0.4%, km

H_{C}=The sum of the heights of all brake slopes for section with slope greater than 0.4%, m

α_c =The sum of deflection angles of horizontal curves where g is greater than 0.4%, degree

A = Normative rate for each meter rising

B = Normative rate for traveling 1km in section with gradient greater than 0.4%

Б = Additional normative rate for rising gradient greater than 0.4%

C = Normative rate for traveling 1km at normal terrain conditions.

1.5 Scope of the research

The scope of the research presented in this thesis include

- Literature review about track geometric design and track geometric components.
- The geometric design of three alternative alignments (both horizontal and vertical alignments).
- Whole life cost analysis and comparison.
- The rates A, B, Б, C used in calculation of operational costs are derived from world's experience on train operation and to be verified to apply to Ethiopia when train operation starts but these cost relation factor values can be applied as a general indicative operational cost factors.
- The three alternative alignments compared mostly sharing common axis and in sections where they depart, the offset distance is very short and doesn't bring variation in construction unit rate.
- Cost comparison of the railway line is particularly to Armenia- kemise (lot-11).

1.6 Structure of the Thesis

This Thesis presents its work in six chapters

- Chapter one establishes the introduction and background of the thesis. Problem statement, objective, methodology and scope/limitations are also included.
- Chapter two covers the theoretical foundation part focusing mainly on the review of railway history, track components, track geometric design and discussing standards and practices of different countries.
- Chapter three of the thesis aims at description of the project. It also includes location, climate of project area and applied design standards.
- Chapter four presents the design process or steps used in this thesis.
- Chapter five includes the analysis and discussion part based on different findings like quantity, construction cost, operation cost and safety.
- Chapter Six concludes the research results and recommends based on the findings either for further research or for considerations for making the results more acceptable and understandable.

2. Literature Review

2.1 General

2.1.1 Introduction

Geometric design is the design of the visible dimensions of a railway with the objective of forming or shaping the facility to the characteristics and behavior of drivers, trains and traffic. Therefore, geometric design deals with features of location, alignment, and profile.

The objectives of Geometric design are as follows:

- Provide the most simple geometry attainable, consistent with the physical constraints
- Provide a design that has a reasonable and consistent margin of safety at the expected operating speeds, and
- Provide a facility that is adequate for the expected traffic conditions.

Railway design is the process whereby the layout of the rail in specific terrain is designed to meet the needs of the rail users, keeping in view the rail function, type and volume of traffic, potential traffic hazards and safety, capital cost, maintenance costs, train operating costs, environment impacts, aesthetics as well as convenience of the railway users.

Most railways have rolling stock with hard steel flanged wheels running on two rails set at or about 1435 mm standard gauge, supported in some way to spread loads to the ground below. ‘Sub-grade’ is the term used for the natural soil stratum, or embankment soil, after trimming off organic topsoil and made ground, upon which the track bed is constructed.

The ‘Trackbed’ comprises the ballast and any sub-ballast layers and is there to support the track, to drain water from the bottom of the sleepers and to distribute the imposed track load to such a degree that the sub-grade can resist the imposed bearing pressure adequately. [1]

2.1.2 Perspectives on movement by road and rail (w.r.t freight movement)

In order to reveal that the railway would have advantages over the highway system (with a major drawback of lacking a door-to-door service unlike the road system), the summary of evaluation criteria and its benefits in long term outcomes are presented in the following table depicting the relationship between the two modes.

Table 2.1 Summary matrix of identified benefits of railway mode and description of evaluation criteria. [2]

Criteria	Benefit(s)	Description
Mobility and time Saving	Freight and passenger mobility and time saving enhanced	Due to the relatively high speed associated with the railway, it has the advantage in movement of cargo and passengers especially for relatively long distances along the corridors.
Economic advantages and competitiveness	Shipper cost savings	Rail transport generally costs less (relative to weight) than air and road freight transport, especially over long hauls.
Shipment level	High shipment volume/weight over long distance	Large volumes of bulk loads can be carried in single trains over long distances, which can reduce air pollution and ease the traffic burden on roads.
Environmental sustainability	Emissions reductions	Reductions in pollutants and green house gases due to auto and truck use reductions because freight is diverted off highways and on to rail.
Traffic congestion	Congestion reduction	Rail transport is not as vulnerable to traffic congestion as road transport. Theoretically, trains can be scheduled more reliably than road and transport.
Traffic safety	Accident reduction	Reductions in property losses and injuries and especially fatalities due to diversion of truck traffic off roads.
State of good repair	Pavement maintenance savings	The accident safety record of rail transport, especially with the transport of hazardous goods, is good.

2.1.3 Historic development of railway

The rail as supporting and guiding element was first utilized in the sixteenth century to transport coal from mines. During crises as a result of over production in the iron industry in England in 1760, the wooden rails were covered with cast iron plates which caused the running resistance to diminish to such an extent that the application of such plates soon proliferated. About 1800 the first free bearing rails were applied and flanged iron wheels took care of the guiding as we still practice. [3]

Demand for railway infrastructure is driven by [3]

- higher speeds and higher axle loads
- higher availability and fewer disturbances
- lower Life Cycle Cost (LCC)
- satisfy environmental demands
- higher reliability and safety

(a)

(b)

(c)

(d)

Figure 2.1 Railway transportation in the early 19th century

2.1.4 Railway Transport sector in Ethiopia

2.1.4 .1 The old railway line

Ethiopia has one narrow gauge railway connecting Addis Ababa to Djibouti port. This line is jointly owned by the Ethiopian and Djibouti Governments and is operated by Chemin de Far Djibouti-Ethiopian (CDE). It is a historical line build at the initiative and the authority of Emperor Menelik II. Construction began in 1889 E.C at the port city of Djibouti, and the final link reached Addis Ababa in 1910 E.C. The rail line passes through 32 cities between Addis Ababa and Djibouti. It has 34 stations out of which Addis Ababa, Dire Dawa and Djibouti are the main stations and they provide both passenger and freight services the rest provide passenger service only. [4]

Figure 2.2 Railway transportation in Ethiopia

<u>The Chemin de Fur Djibouti – Ethiopien (CDE)</u> [4]

The 781 KM CDE railway line jointly owned by Ethiopian and Djibouti government connects Addis Ababa and Djibouti port. This line is of great importance both to a landlocked country like Ethiopia as well as Djibouti. More than 82% of the railway line traverses through Ethiopian land linking major Ethiopian trade and production centers and is also a strategic link for Ethiopia to access international maritime route and has the potential to carry up to 80% of the Ethiopia's international in-bound cargo.

On the other hand, 90% of cargo in and out of Djibouti port requires an access route to disperse the cargo quickly to reduce port congestion and railroad.

Basic features of this line are as follows:

- 781 KM line of which approx 100 KM is in Djibouti and the rest on Ethiopian land.
- Meter gauge line designed for 12 T axle load.
- The line traverses through some of the most difficult terrain.
- 187 steel bridges with large number of slab and pipe culverts across the line.
- Diesel traction and low capacity locomotives.
- HF/AM radio transceivers for communication.
- Maintenance activities not favorably located to cater the railroad needs.
- Operations based on old antiquated technology

Fig 2.3 Alfred IIg and his family at the train Ethiopia station in Dire Dawa

Fig 2.4 Present station of the Djibouti-Railway in Dire Dawa

2.1.4.2 The new national railway routes

Table 2.2 ERC has studied and proposed national railway network and prioritized the lines as follows: [4]

Route No.	Route name	Route Length (Km)
1	Addis Ababa-Modjo-awash-Dire Dawa-Dewanle	656
2	Modjo- Shashemene/Hawasa-Konso-Weyto(Including konso-moyale)	905
3	Addis Ababa- Ijaji-Kombolcha-Guraferda-Dima including kombolcha -Hara Gebeya	637
4	Ejaji_Nekemt_Asossa_Kurmuk	460
5	Awash_Kombolcha_Mekele_Shire	757
6	Fenoteselam_Bahirdar_Wereta_Weldia_semera_Elidar	796
7	Wereta_Azezo_Metema	244
8	Adama_Indeto_Gasera	248

`

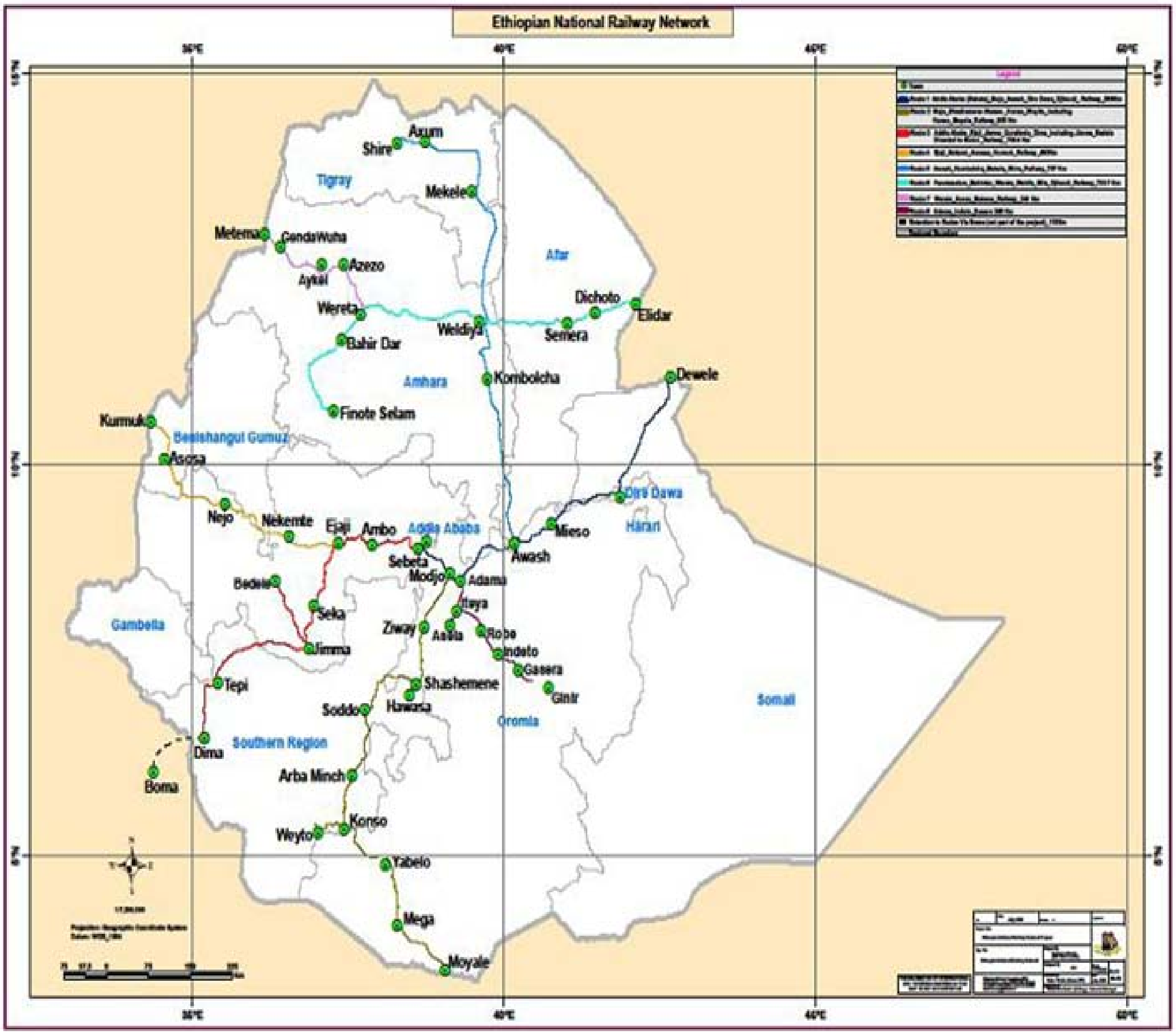

Fig 2.5: Ethiopia national railway network map [4]

2.2 The track and its components

A railway track structure consists of rails, sleepers, railpads, fastenings, ballast, sub ballast and sub grade (see fig 2.6). Sometimes for example, in tunnels, the ballast bed is omitted and the rails are fastened to concrete slabs resting on the track foundation. Two subsystems of a ballasted track structure can be distinguished: the superstructure, composed of rails, sleepers, ballast, and subballast and the substructure (subgrade, subground) composed of a formation layer and the ground. [5]

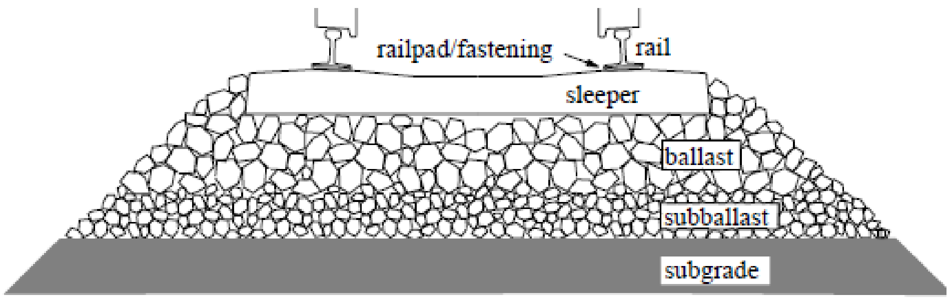

Fig 2.6 typical track cross section

2.2.1 Rails

A modern steel rail has a flat bottom and its cross section is derived from an I-profile. The rails should provide smooth running surfaces for the train wheels and they should guide the wheel sets in the direction of the track. The rails also carry the vertical load of the train and distribute the load over the sleepers. Lateral forces from the wheelsets, and longitudinal forces due to traction and braking of the train should also be transmitted to sleepers and further down into the track bed. the rails also act as electrical conductors for the signaling system. [5]

2.2.2 Sleeper (Crosstie)

The choices of concrete sleepers, more widely used in the world, are because of different reasons; basically it is according to economical advantages. In addition, in Ethiopia steel is relatively highly costy; and the concrete sleepers are not affected very much by either climate or weather, made concrete sleeper preferable than others. [1]

2.2.2.1 Sleeper functions

Sleepers and bearers or timbers (for points and crossings) need to fulfill the following basic functions: [1]

1. Spread wheel loads to ballast

2. Hold rails to gauge and inclination

3. Transmit lateral and longitudinal forces

4. Insulate rails electrically

5. Provide a base for rail seats and fastenings

2.2.3 Rail fastenings, base plates and pads

Early railways adopted various forms of cast iron chair which were fixed to the sleepers and in which rails sat, being held in position by hardwood wedges or 'keys'. All railways which used bullhead section rail used fixings which were basically of this type. It was soon found that too rigid fixings became loose under vibration and that some degree of elasticity was necessary to resist both creep and buckling. [1]

2.2.4 Ballast

The ballast layer supports the track (the rails and the sleepers) against vertical and lateral forces from the trains. The standard depth of ballast is 0.3m.traditionaly, angular crushed, uniformly graded hard stones and rocks (granite, limestone, slag or other crushed stone) have been considered good ballast materials. However, availability and economic motives have often been prime factors considered in the selection of ballast materials. [5]

2.2.5 Subballast

Subballast is material chosen as a transition layer between the upper layer of large particle, good quality ballast and the lower layer of fine-graded subgrade. The subballast used in most new constructions is intended to prevent the mutual penetration of the subgrade and the ballast and to reduce frost penetration. any sand or gravel materials may serve as subballast material as long as they meet necessary filtering requirements. [5]

2.3 Track Geometry Design

The route upon which a train travels and the track is constructed is defined as an alignment. An alignment is defined in two fashions. First, the horizontal alignment defines physically where the route or track is laid (mathematically the xy plane). The second component is a vertical alignment, which defines the elevation, rise and fall (the z component). [11]

For balance in railway design, all geometric elements should, as far as economically feasible determined to provide safe and continuous operation at a speed likely under the general conditions for the railway. For the most part, this is done using design speed as the overall control.

Track geometry components

The most common quantities of track geometry are: [6]

- Track gauge
- Track cant
- Transition curve
- Horizontal curve radius
- Vertical curve radius & Gradient

2.3.1 Track gauge

Distance between the inner sides of the rails, measured 14 mm below rolling surface.

Most countries in the world have 1435mm designed track gauge called standard gauge.

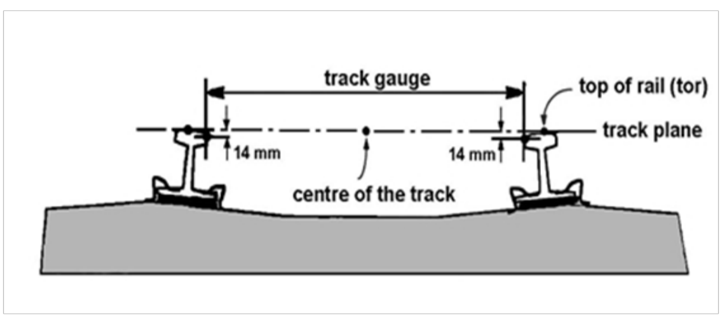

Figure 2.7 Track gauge

2.3.2 Track cant

Cant or super elevation is the amount by which one rail is raised above the other in a curve. In a very highly canted curved track, it is possible that the vehicle standing or traveling over the curve at a very low speed may overturn about the lower rail. (See figure 2.8) [1]

Such overturning can occur on account of the combination of the following adverse factors:

a) Absence of centrifugal force due to very slow speed causing substantial off- loading of the high rail

b) Wind pressure blowing on the vehicle towards the inside of the curve

c) Lateral vibration of car body and other disturbing forces

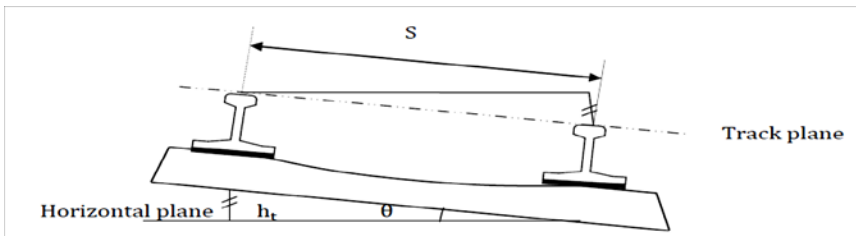

Figure 2.8 Track cant

Where: S = centre to center length of track gauge, ht =cant height and θ=cant angle

$$\sin \theta = ht / S$$

2.3.3 Horizontal Alignment

The horizontal alignment is the projections of the track centerline on horizontal plane. The elements for horizontal alignment are straight tracks, circular curves and transition curves. Intersecting curves with conflicting super elevations present maintenance difficulties. In such cases, other design elements need to be considered that would compensate for the reduced visibility and maintenance difficulties (e.g., signing, pavement marking, other warning devices, appropriate types of crossing surfaces).

2.3.4 Tangent Sections

The minimum length of tangent track between curved sections is based on passenger comfort and vehicle wheel /truck forces. According to AREMA Manual the minimum length is equal to the longest car that will traverse the system. Due to the forces between the bogies/wheels on curved track, it is recommended that all bogies be on tangent track before negotiating a curve, at a minimum two sets of bogies are on tangent track.

2.3.5 Circular curve

In the design of railway curves, it is necessary to establish the proper relation between design speed and curvature and also their joint relations with super elevation and side friction. Although these relations stem from the laws of mechanics, the actual values for use in design depend on practical limits and factors determined more or less empirically over the range of variables involved.

Curve effects

It is a known fact that a vehicle running at a speed v in a curve with a radius R experiences a centrifugal lateral acceleration a = v2/R which results in a number of undesirable effects: [6]

- Possible passenger discomfort
- Possible displacement of wagon loads
- Risk of vehicle overturning
- Risk of derailment
- High lateral force on track

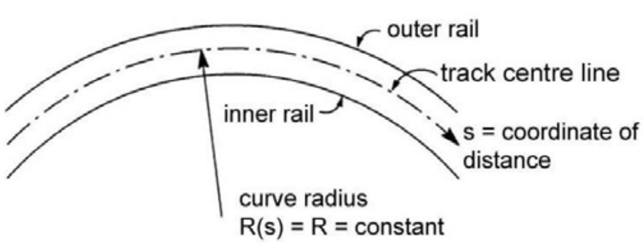

Figure 2.9 Horizontal circular curve radius R [6]

2.3.6 Transition curves

Basically, transition curves are used between straight track and curves or between two adjacent curves to allow gradual change in lateral acceleration .the centre line of the transition curve has the same tangent at the connection points as the adjacent part, whereas the curvature changes gradually from the value of one connection point to the value of the other. Transition curves also introduce cant by means of transition gradients and if necessary, gauge widening. [7]

Transition curves are not used if

- The curve radius is > 3000 m

- A calculation shows that no cant is necessary

2.3.7 Vertical Alignment

The topographical conditions for constructing a railway may require some kind of vertical alignment along the way. Building bridges and tunnels are some options to manage the topography constraints. However, such large civil structures are very expensive to construct compared to earth works. In particular, these are very challenging for heavy railway traffic to overcome the large gradients. Hence, limiting the gradient is one option in the design process. [6]

The following requirements need to be considered because they have an effect on railway traffic.

- The power supply and energy consumption will increase with large gradients
- Heavy freight with an ordinary locomotive may have problems to climb up the gradient.

2.3.7.1 Gradient

The topography of the land has an influence on the alignment of the railway. Any departure of the track from the level is known as grade or gradient, an up or rising gradient is one when the track rises in the direction of movement, and a down or falling gradient is one when the track falls in the direction of movement.

Gradients are provided on the tracks due to the following reasons:

1. To provide a uniform rate of rise or fall as far as possible

2. To reach the various stations located at different elevations, and

3. To reduce the cost of earthwork

Ruling gradient

It is the maximum gradient allowed on the track section.

The ruling gradient for the line will be 2% including gradient compensation.

Ruling gradient lengths are to be kept as short as possible. [9]

Effects of grade on train speed

Sections of ruling grade, and grades approaching the ruling grade, affect train speeds. Even quite gentle grades can slow trains down if they apply over long section. Building to the absolute steepest grade can significantly affect train speeds and therefore journey times.

2.3.7.2 Vertical curve

A vertical curve provides a smooth transition between successive tangent gradients in the railway profile. In changes of gradients a suitable radius must be used. If the vertical acceleration on a crest is too great, the loads on the vehicle wheels can cause the wheels to climb the rail and thus cause a derailment furthermore, the resistance against vehicle overturning at side –winds will be lower. [6]

2.4 Standards and Practices of Different Countries

European standard (EN)

CEN(EUROPEAN COMMITTEE FOR STANDARDIZATION) members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom. [8]

ERC standard

ERC standard (ETHIOPIAN RAILWAY CORPORATION standard). This specification gives requirements for the design of track centre line alignments to allow International and Local Consultants, Contractors and others to proceed with the ERC design works. It has been issued as draft before the final version applied currently is printed. [9]

PRC standard

PRC standard (NATIONAL STANDARD OF THE PEOPLE'S REPUBLIC OF CHINA). The compilation of this code has absorbed experiences and special scientific research achievements obtained concerning railway design, construction and operation, and the railway speed-increasing. [10]

AREMA standard

AREMA standard (American Railway Engineering and Maintenance of way Association) [11]

2.4.1 Track Guage

Table 2.3 Various rail gauges on world railways [12]

Type of Gauge	Gauge (mm)	Countries
Standard gauge	1435	English,USA,Canada,Turkey,persia, and China
Broad gauge	1676	India, Pakistan, Ceylon, Brazil, Argentina
Broad gauge	1524	Russia, Finland
Cape gauge	1067	Africa, Japan, Java, Australia, and New Zealand
Meter Gauge	1000	India, France, Switzerland, and Argentina
23 various guages	Different guages	Various countries

2.4.2 Horizontal curve standards

AREMA Manual gives Degree of curve D as [11]

$$D = E_e / 0.0007\, V^2 \qquad (2\text{-}1)$$

Where: D = Degree of curvature (Decimal degrees 100 foot chord basis).

Ee = Equilibrium elevation in inches.

V = Velocity in miles per hour.

Likewise, Indian practice shows [13]

$$V = 4.35\, SQRT(R-67) \qquad (2\text{-}2)$$

Where V= SPEED, R= radius of curvature

The relationship between radius of curvature and degree of curve for length of chord 30m is

D/30 = 360/2ΠR, D= 1750/R, where length of chord is 30m (2-3)

D = Degree of curve

R = Radius of a curve in meter

In Indian practice curves on through tracks, are limited to the following maximum degree of curvature. [13]

(i) Maximum degree of curvature for Broad Gauge (1.67m) = 10° (min. R = 175 m)

(ii) Maximum degree of curvature for Meter Gauge (1.0m) = 16° (min. R= 109 m)

(iii)Maximum degree of curvature for Narrow Gauge (0.67m) = 40° (min. R = 44 m)

Table 2.4 Minimum Radius of Curve

Speed(Km/hr)	Indian Practice(m)	Network rail(UK)(m)	AREMA(m)
120	1085	1135	1116
160	1928	2017	1984
200	3013	3152	3099
225	3813	3989	3923

According to ERC standard, minimum desirable horizontal curve radius is 2000 meters and lower radii will be permitted to eliminate the need for major infrastructure construction such as tunnels or long viaducts.

All curve radii less than 2000 meters radii to be identified during the design development process and submitted to the ERC Alignment Design Manager for approval prior to submission of the detailed design. [9]

According to EN standard, the parameters that shall be considered in the determination of the minimum curve radius are: [8]

- the maximum and minimum speeds;
- the applied cant;

The limits for cant deficiency and cant excess

For every combination of maximum speed V_{max} and maximum cant deficiency I_{lim}, the minimum permissible curve radius shall be calculated using the following equation:

$$R_{min} = \frac{C}{D + I_{\text{lim}}} \cdot V^2_{\text{max}} \qquad \text{Where } C = 11.8\ \text{mm}\cdot\text{m}\cdot\text{h}^2/\text{km}^2 \qquad (2\text{-}4)$$

According to Chinese standard

Table 2.5 The minimum curve radius **[10]**

Design running speed of passenger train in section(km/h)			160	140	120	100	80
minimum curve radius(m)	project condition	general area	2000	1 600	1 200	800	600
		Difficult area	1 600	1 200	800	600	500

2.4.3 Cant

According to EN standard

Cant D (cant is represented as D in EN standard) [8]

- Cant shall be determined in relation to the following considerations:
- High cant on small-radius curves increases the risk of low-speed freight wagons derailing. Under these conditions, vertical wheel loading applied to the outer rail is much reduced, especially when track twist (defined in EN 13848-1) causes additional reductions;
- Cant exceeding 160 mm may cause freight load displacement and the deterioration of passenger comfort when a train makes a stop or runs with low speed (high value of cant excess).Works vehicles and special loads with a high centre of gravity may become unstable

High cant increases cant excess values on curves where there are large differences between the speeds of fast trains and slow trains.

Normal limit for cant is 160 mm.

It is recommended that cant should be restricted to 110 mm for tracks adjacent to passenger platforms. Some other track features, such as level crossings, bridges and tunnels may also, in certain local circumstances, impose cant restrictions.

Exceptional limit for cant is 180 mm.

To avoid the risk of derailment of torsionally-stiff freight wagons on small radius curve (R < 320 m), cant should be restricted to the following limit:

$$D\ lim = \frac{R - 50m}{1{,}5m/mm} \qquad (2\text{-}5)$$

The application of this limit assumes a high maintenance standard of the track

2.4.4 Vertical curve standards

According to ERC standard [9]

Vertical curves should be at least 20 m long and may be designed without vertical transition curves. These are normally designed as parabolas (2nd degree polynomials) or as circular curves.

A vertical curve shall be provided where the difference in slope between adjacent gradients is more than:

- 2 mm/m for permissible speeds up to 230 km/h
- 1 mm/m for permissible speeds over 230 km/h

Radius of vertical curve R_v [9]

The normal limit for radius of vertical curve is calculated according to following formula without going under 2000m vertical curve radius.

$R_{v,lim}=q_{R,lim}.V^2$[m], where $q_{R,lim}=0{,}35 m \cdot h^2/km$, V=speed in km/h (2-6)

On lines where most of the passengers may be standing, it is recommended that q_R should be greater than 0.77 m·h2/km2. On exceptional limits, $q_{R,lim}$ = 0,13 m·h2/km2 for hollow sections and qR,lim = 0,16 $m \cdot h^2/km^2$ for crest sections.

1. Minimum radius

   Normal limiting design and all new construction is 1000 m

   Exceptional design for a hump 600 m

   Exceptional design value for a hollow 900 m

2.4.5 Gradient

According to AREMA [11]

The length of the vertical curve for both sags and summits is determined by the following formula

$L= (D \times V^2 \times K) / A$ (2-7)

Where: A = vertical acceleration in feet/sec/sec (ft/sec^2)

D = Absolute value of the difference in rates of grades expressed as a decimal

K = 2.15 conversion factor to give L in feet

L = Length of vertical curve in feet

V = Speed of the train in miles per hour

The recommended vertical acceleration (A) should be selected based on the type of operations and is the same for both sags and summits.

Freight Operations: A = 0.10 feet/ sec^2, Passenger and Transit Operations: A = 0.60 feet/ sec^2

According to ERC standard [9]

Ruling gradient is defined as the maximum gradient allowed on track section.

The ruling gradient for the line will be 2% including gradient compensation.

According to Chinese standard [10]

The maximum ruling grade varies according to terrain type and traction type as
Shown in table below

Table 2.6 Maximum ruling grade (%)

Type of terrain		plain	hilly	Mount
Type of traction	Electric	0.6	1.2	1.5

A largest permissible gradient of 1 % on track with heavy freight trains and 1.25 % can be permitted if the mean value does not exceed 1 % over each kilometer. On tracks with only passenger trains and light freight trains higher values may be allowed. **[6]**

3. General description of the project area

3.1 Location of the project area

The project starts at Awash Station diverting from the new Addis Ababa -Djibouti Railway Project traversing through the lowlands of Shewa towards Kombolcha and Weldia side.
Most of the alignment passes through Amhara regional state and some part of it through Afar regional state of Ethiopia. [4]

3.2 Climate

The area through which the project traverses can be classified as dominantly “semi-desert or kefil bereha” and “Warm or kola” near the end of the project route with mild effective temperature between 14^{o}c and 20^{o}c which is most of the time comfortable.

3.3 Rainfall

The mean monthly and annual rainfall of the project area is obtained from the Meteorological Maps of Ethiopia, 1979.

Accordingly, the mean monthly rainfall of the project area is presented in the table below.

Table 3.1 Mean Monthly Rainfall (mm)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	50	50	100	50	50	50	150	150	50	50	25	10

3.4 Temperature

The mean monthly minimum and maximum temperature of the project area is obtained from the Meteorological Maps of Ethiopia, 1979. Accordingly, the mean monthly maximum and minimum temperatures for the project area are presented in the table below.

Table 3.2 Mean Monthly Maximum and Minimum Temperature (^{0}C)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. Min.	30 15	30 15	30 15	35 15	35 15	30 20	25 15	30 20	30 15	30 15	30 10	30 10

3.5 Terrain

The Project is characterized by a Rolling, Mountainous and Flat terrains both longitudinally and in the transverse directions.

The terrain has been classified taking in to account the criteria indicated in the Ethiopian Roads Authority Geometric Design Manual - 2002 which is used in the country to classify terrain of any project. The terrain has been classified after collecting and analyzing the topography data. [14]

Table 3.3 Summary of terrain classification

Terrain Type	Coverage (%)
Flat	48.7
Rolling	38.2
Mountainous	31.33
Escarpment	8.2
Total	126.43

3.6 Alignment soil

According to geologic map of Ethiopia (1996), the alignment soil varies along the alignment with the major portion of the alignment is covered with Black cotton soil, Light brown and dark brown silty/clayey sandy gravel material, basaltic and trachyte rock. There are frequent incursions of rock out crop of short stretches in the black cotton soil which shows that the thickness of the soil has no depth.

3.7 Design speed

Design speed of a railway purely depends on the topography and the resultant design of the railway. The top sheets of the proposed corridor indicate that the area is a mixture of flat and hilly terrains. The alignment of Railway system will therefore have to traverse two distinct types of topography:

- Flat terrain.
- Hilly terrain

In the flat terrain, curvatures will be flat and even if gradients are there higher speeds should be possible. A system design of 160 kmph speed for passenger trains and 120 kmph speed for goods trains are proposed according to ERC manual.

In hilly terrain curvatures will be sharp and gradients will be steeper; therefore design of the system for higher speeds may not serve any purpose as sharper curves will in any case restrict the speed. In hilly terrain therefore a design speeds of 100 kmph is proposed.

Capital cost versus the earning capacity of the line is important. also important is the usage of the line. Considering that mixed traffic i.e. both passenger and goods trains have to run suggested speeds should suffice to achieve economy in construction and also in train operations.

3.9 Applied Design Standards

In the process of geometric design the layout of the railway alignment within the selected corridor in question is designed to a required standard to meet the needs of the customers. The principal geometric features are the Track cross-section, horizontal and vertical profile of the railway alignment. In this thesis ERC standard is used as the governing rail standard.

Table 3.4 Requirements to be applied in the design of the project. [9]

Technical Item	Requirement
Track Length	Km (different alignment lengths)
Gauge	1,435mm.
Alignment	Where possible, construct as open route (i.e. in Cutting/embankment, on bridges/viaducts as much as possible). Where tunnels are required, these to be as short as possible
Formation Width	Single Track
Horizontal Curvature	> 2000 meters minimum (in urban areas, large river crossings and difficult terrain locations, lower radii can be adopted at a Selected and limited number of locations).
Ruling Gradient	<2.0% (in exceptional conditions 3.5% maximum gradient will be permitted to minimize extent of cut/fill + Tunneling Works), includes gradient compensation.
Maximum Passenger Trains Speeds	160Kph (with future provision for 225kph operation)
Earthworks	Maximum cut height of 30m and the maximum embankment height of 22m has been adopted.

4. Geometric Design of three alternative routes

4.1 The design process or design steps

The design process includes the following key activities

1. Digital Terrain Model (DTM) is prepared from the topographical survey study.
   The DTM is prepared from 30m resolution Digital Elevation Model manipulated using global mapper software for further processing in BRT software.
2. The DTM is imported to the Bentley Rail Track (BRT) railway design software.
   The DTM is then imported to Bentley Rail Track software. Data is then triangulated contours (points of same elevation) generated to indicate economical design of project.
3. Horizontal Alignment is designed based on the pre-defined criteria
4. Existing ground (profile) is extracted.
   After designing the horizontal alignment, the vertical longitudinal section of the railroad is generated along the centerline on original ground levels to get profiles.
5. Vertical Alignment (Grade line) is designed based on the pre-defined criteria comprising gradients and vertical curves
6. Selected single Typical Cross section is run through the defined horizontal and vertical alignments within the BRT software to create cross-sections order to generate earthworks.
7. Earthwork area and volume is processed after going through all the above steps.

4.2 Data Collection

Prior to the commencement of the field investigation, all existing reports, topographical maps, Geological and soil maps, and any relevant data concerning the project railway need to be collected, reviewed and compiled. The documents/data collected were from the relevant authorities, i.e. Ethiopian Railways Corporation (ERC), Ethiopian Roads Authority (ERA), Ethiopian Mapping Agency (EMA), Ethiopian Metrological Agency, regional offices and other relevant authorities/organizations.

The data collected includes

Surveying data

- Contour (surveying data) for the design of the project is generated from global mapper by using 30m resolution dem data.

  While generating data the following steps need to be considered

- Projection = U.T.M.
- Datum Parameters = Adindan
- Origin of latitude = 0
- Central Meridian = 39000’00’’
- False Easting & Northing = 500,000 & 0
- Ellipsoid Parameters origin = WGS84

Maps

- Topographical maps at scale of 1:50,000 ;
- Recent climatic and rainfall data;
- Geological maps for the area: Geological Map of Ethiopia 1:2,000,000 (1996);

Standard manuals

- ERC Design manual

  ERC manual is used as reference manual for designing the horizontal and vertical alignments.

Softwares (Engineering design software’s)

Bentley Rail Track, Micro station/AutoCAD, Global mapper,Ms excel, and other relevant software.

- Bentley rail track is used for designing horizontal and vertical alignments and to generate earth works using end area volume method.
- Microstation/Autocad is used to display the outputs of the software graphically i.e. plan, profile, cross sections.
- Ms excel is used for mathematical analysis and to show some of outputs of software numerically. Outputs can be earthworks, horizontal curve data, vertical curve data, centerline coordinates etc.

4.3 Design of horizontal alignment

Geometric design has been carried out with Bentley Rail Track design Software. The survey data in the form of X, Y, Z were loaded onto software to prepare a DTM model. Once the horizontal and vertical alignment is finalized, track cross-section is designed.

Minimum radius of horizontal curves is considered as 2000 m. However, curve radius as low as 500m has been used in few locations. The reason for the deviation is that the existing terrain has hilly sections. The high elevation fall in short distances resulted in small curves in order to avoid long tunnels with large overburden height.

4.4 Design of vertical alignment

4.4.1 Gradient

Wherever possible the design will use the flattest gradient possible. In adverse terrain this will have a considerable impact on construction costs due to the increased amount of earthworks and length of tunnels or viaducts. The cost of building easy gradients versus the increased journey time and reduced carrying capacity of building steeper gradients should be optimized in detail design work. For example, short steep gradients may be acceptable where they can be shown to have no effect on operations, such as a bridge over an existing road.

4.5 Track cross-sections

Having set the design speed, the track cross section becomes the key to determination of the two opposing factors of safety and cost. Different countries have more or less similar track gauge standard and track cross section. Type of cross section for single or double track is selected based on transport modeling assessment. However, for this project single track cross section is incorporated as design criteria. The gauge width is 1435mm on AREMA and Network Rail (UK).

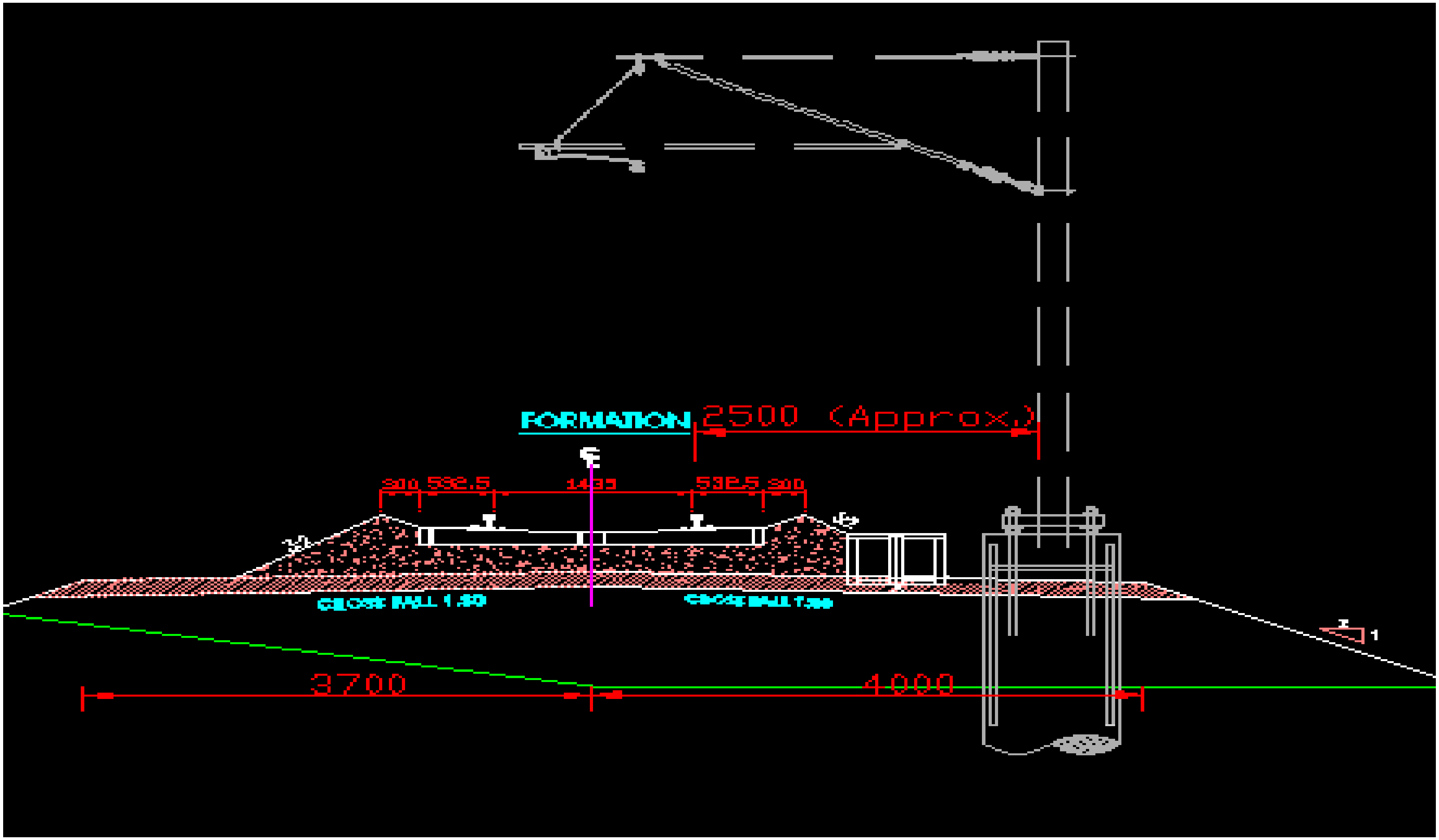

Figure4.1 Typical Track Cross Section for single track [9]

4.6 Computation of Earth work

Earthworks and formation design includes:

- cuttings
- embankments
- Capping layer.

New lines shall be constructed on a corridor wide enough to accommodate earthworks and formation designed and constructed in accordance with the requirements.

The guage applied to the project directly impacts the project cost and is typically related to the track design axle load.

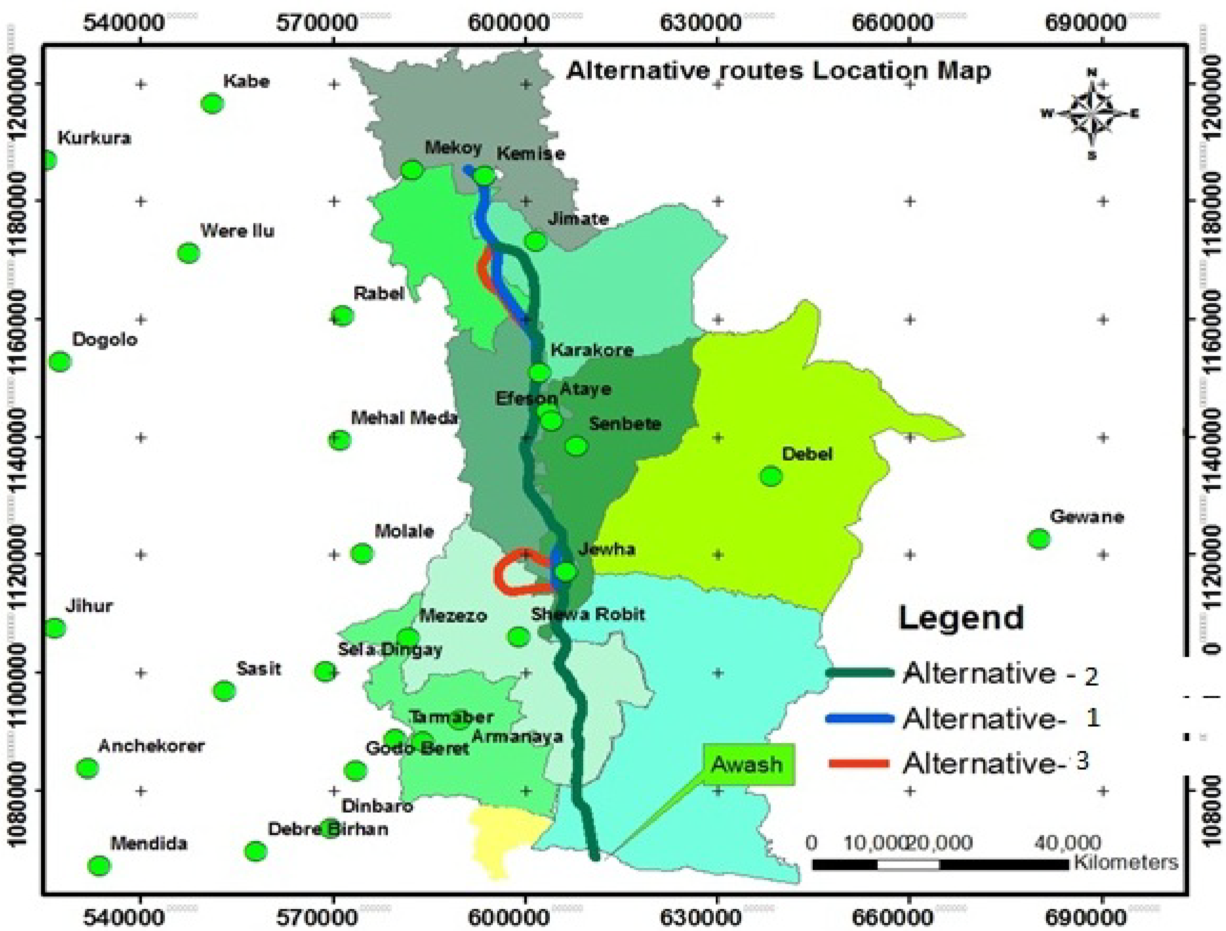

Figure 4.2 Location map for alternative routes

5. Analysis and Discussion

5.1 Description of the alternatives based on different findings

i) Alternative I

This alternative is the alignment proposed by the Ethiopian Railways Corporation. It starts at Armenia and ends at kemise town. The proposed alignment has a total length of 126.43Km. The overall length of tunnels expected to be constructed along this route is estimated to be about 11.69 Km and swamp section stretches of 8.303 Km length. There is an additional section of 3.174 km that requires deep excavation to about a depth of 30.0m to 70.0m. The earth work quantity estimated in this section is cut quantity of 40,665,372.00m^3 and fill quantity of 58,653,248.5 m^3 respectively. The findings are summarized in table 5.1.

Table 5.1 Findings of Alternative I

Description of Findings	Unit of Measure	Findings
Length of Project	Km	126.43
Length of Swamp Section	Km	8.303
Length of Tunnel	Km	11.69
Length of Section that require deep excavation	Km	3.174
Length requiring full surveying	Km	126.43
Number of cross drainages	number	41
Total Span of cross drainages	m	6277
Cut quantity	m^3	40,665,372.00
Fill quantity	m^3	58,653,248.50

ii) Alternative II

This alternative is the second alignment designed on survey data generated from digital elevation model for this thesis work. It starts at Armenia and ends at kemise town. It is proposed to the right of the alignment already proposed by ERC. The new proposal has a maximum offset of 5.3km to the right of the ERC proposal.

The new proposed alignment is between sta. 48+000 and sta. 57+000 and sta.92+000 and sta. 113+000 and is mainly proposed to reduce the length of tunnel and the swampy section around the two sections respectively.

Excavation depth greater than 70m is considered as tunnel according to ERC manual. Since vertical alignment is generated along with profiles, section of alignment with excavation depth greater than 70m can be identified from the vertical alignment. All sections along the alignment with excavation depth greater than 70m are measured and added to give total length of tunnels. Likely, excavation between 30m and 70m is considered as deep excavation. These sections are measured and added to get total section with deep excavation. Earth work area and volume is obtained by running typical single track cross section along the designed horizontal and vertical alignments by End-Area Volume method using Bentley rail track software. The number and span of cross-drainages are obtained by taking catchment area of greater than or equal to $0.5km^2$ which crosses the alignment. The distance from one stable bank to the other stable bank is measured to estimate crossing span. All spans of cross-drainages along the alignment are sum up to get the total span of cross-drainages.

Accordingly, the total length of tunnels expected to be constructed along this route is estimated to be about 9.558Km and the total length of swampy sections is also estimated to be 9.653 km. Deep excavation to about a depth of 30.0m to 70.0m is estimated to be 6.687km. Earth work quantities estimated in this section is cut quantity of 36,187,575.25m3 and fill quantity of 25,199,948.5m3 respectively.

The findings of alternative II are summarized in table 5.2

Table 5.2 Findings of Alternative II

Description of Findings	Unit of Measure	Findings
Length of Project	Km	113.104
Length of Swamp Section	Km	9.653
Length of Tunnel	Km	9.558
Length of Section that require deep excavation	Km	6.687
Length requiring full surveying	Km	113.104
Number of cross drainages	Number	42
Total Span of cross drainages	M	5564
Cut quantity	M3	36,187,575.25
Fill quantity	M3	25,199,948.5

iii) Alternative III

This alternative is the third alignment proposed on survey data generated from digital elevation model for this thesis work .It starts at Armenia and ends at kemise town. It is proposed to the left of the alignment proposed by ERC even though the alignments overlap in some sections. The new proposal has a maximum offset of 8.8km to the left of the ERC proposal. The new proposed alignment is mainly proposed to reduce the swampy section in between sta. 48+000 and 54+000 and between 95+000 and 104+000(stationing is as per alternative 1). This alternative has a total length of 130.942 Km.

From the design analysis, the total length of tunnels expected to be constructed along this route is 9.035Km and the total length of swampy areas is estimated to be 7.903 km. In this proposed route, section that requires deep excavation is 4.764km. The earth work quantity estimated in this section is cut quantity of 34,776,654.75m^3 and fill quantity of 39,647,228.00m^3 respectively. The length of section that requires full surveying is 130.942 Km. These findings are summarized in table 5.3.

Table 5.3 Findings of Alternative III.

Description of Findings	Unit of Measure	Findings
Length of Project	km	130.942
Length of Swamp Section	km	7.903
Length of Tunnel	km	9.035
Length of deep excavation	Km	4.764
Length requiring full surveying	Km	130.942
Number of cross drainages	number	41
Total Span of cross drainages	m	7,761
Cut quantity	m^3	34,776,654.75
Fill quantity	m^3	39,647,228.00

5.2 Summary of Findings of Alternatives based on Quantity

The findings of alternatives I, II and III based on quantity described in section 5-1 and tables 5.1, 5.2 and 5.3 are summarized in table 5.4.

From the summary of quantities, alternative III has greater project length and higher span of cross-drainages but lesser length of swampy section, length of tunnels and cut quantities compared to the other two alignments. Alternative I has lesser length of section that require deep excavation as compared to the other two alignments. The three alternative alignments almost have equal number of cross-drainages though alternative II has lesser span of structures.

Table 5.4 Summary of Findings of Alternatives Based on Quantity

Description of Findings	Unit	Alternatives		
		I	II	III
Length of Project	Km	126.43	113.104	130.942
Swamp section length	Km	8.303	9.653	7.903
Length of Tunnel	Km	11.69	9.558	9.035
Deep excavation length	Km	3.174	6.687	4.764
Length of full surveying	Km	126.43	113.104	130.942
Number of cross drainages	Number	41	42	41
Total Span of cross-drainages	m	6277	5564	7761
Cut quantity	m^3	40,665,372.00	36,187,575.25	34,776,654.75
Fill quantity	m^3	58,653,248.5	25,199,948.5	39,647,228.00

5.3 Description of the alternatives based on construction cost

i) Alternative I

The quantities generated from alternative I and described in table 5.1 have been multiplied by their respective unit prices to get total construction cost of 921,656,503.250 dollars as shown in table 5.5.

- Cost of temporary buildings and structures is taken as 2% of the summation of costs from number 1 up to 8.
- Consultancy and Construction management's costs can be taken as 0.5% of total costs from 1 up to 9.
- Survey and design fee costs are taken as 2% of total costs from 1 up to 10.
- Unforeseen expenses and other costs taken as 2% of total costs from 1 up to 11.

The three alternative alignments compared mostly sharing common axis and in sections where they depart, the offset distance is very short and doesn't bring variation in construction unit price. Hence, applied unit price to alignment proposed by ERC can also be applied to the other two alternative alignments.

Table 5.5 Construction Cost for Alternative I

No.	Name of object or work	Unit	Unit Rate (usd)	Indicators	
				Volume of work	Cost (usd)
1	Site Clearance and preparation	km	150.00	126.43	18,964.50
2	Sub grade	10^3. m^3	6,500.00	79,454.90	516,456,826.60
3	Structure				
	Tunnel	km	40,000,000.00	5.26	210,240,000.00
	Culvert	km	4,814,000.00	1.26	6,043,495.60
	Bridge	km	20,000,000.00	5.02	100,432,000.00
4	Track work	km	162,970.00	126.43	20,604,297.10
5	Signaling and communication	km	44,550.00	126.43	5,632,456.50
6	Buildings and facilities of production and service	km	25,641.00	126.43	3,241,791.63
7	Traction and power supply	km	9,793.00	126.43	1,238,128.99
8	Production equipment, general purpose tool	km	2,125.00	126.43	268,663.75
9	Temporary buildings and structures	% Σ 1_8		2^x	17,283,532.49
10	Consultancy and Construction managements	% Σ 1_9		$0,5^x$	4,407,300.79
11	Survey and Design fee	% Σ 1_10		2^x	17,717,349.16
12	Unforeseen expenses and other costs	% Σ 1_11		2^x	18,071,696.14
	Total				921,656,503.250
The average cost of 1 km in dollars				**7,289,856.073**	

ii) Alternative II

The quantities generated from alternative II and described in table 5.2 have been multiplied by their respective unit prices to get total construction cost of 792,866,614.667 dollars as shown in table 5.6.

Table 5.6 Construction Cost for Alternative II

No.	Name object or work	Unit	Unit Rate (usd)	Indicators	
				Volume of work	Cost (usd)
1	Site Clearance and preparation	km	150.00	113.10	16,965.60
2	Sub grade	103. m^3	6,500.00	61,387.52	399,018,904.38
3	Structure				
	Tunnel	km	40,000,000.00	5.558	222,320,000.00
	Culvert	km	4,814,000.00	1.11	5,343,540.00
	Bridge	km	20,000,000.00	4.45	89,000,000.00
4	Track work	km	162,970.00	113.10	18,432,558.88
5	Signaling and communication	km	44,550.00	113.10	5,038,783.20
6	Buildings and facilities of production and service	km	25,641.00	113.10	2,900,099.66
7	Traction and power supply	km	9,793.00	113.10	1,107,627.47
8	Production equipment, general purpose tool	km	2,125.00	113.10	240,346.00
9	Temporary buildings and structures	% Σ 1_8		2^x	14,868,376.50
10	Consultancy and Construction managements	% Σ 1_9		0,5^x	3,791,436.01
11	Survey and Design fee	% Σ 1_10		2^x	15,241,572.75
12	Unforeseen expenses and othe costs	% Σ 1_11		2^x	15,546,404.21
	Total				792,866,614.667
The average cost of 1 km in dollars				**7,010,066.971**	

iii) Alternative III

The quantities generated from alternative III and described in table 5.3 have been multiplied by their respective unit prices to get total construction cost of 905,393,325.492 dollars as shown in table 5.7.

Table 5.7 Construction Cost for Alternative III

No.	Name of object or work	Unit	Unit Rate (usd)	Indicators	
				Volume of work	Cost (usd)
1	Site Clearance and preparation	km	150.00	130.94	19,641.30
2	Subgrade	$10^3 . m^3$	6,500.00	74,423.88	483,755,237.88
3	Structure				
	Tunnel	km	40,000,000.00	5.035	201,400,000.00
	Culvert	km	4,814,000.00	1.55	7,461,700.00
	Bridge	km	20,000,000.00	6.21	124,200,000.00
4	Track work	km	162,970.00	130.94	21,339,617.74
5	Signaling and communication	km	44,550.00	130.94	5,833,466.10
6	Buildings and facilities of production and service	km	25,641.00	130.94	3,357,483.82
7	Traction and power supply	km	9,793.00	130.94	1,282,315.01
8	Production equipment, general purpose tool	km	2,125.00	130.94	278,251.75
9	Temporary buildings and structures	% Σ 1_8		2^x	16,978,554.27
10	Consultancy and Construction managements	% Σ 1_9		$0,5^x$	4,329,531.34
11	Survey and Design fee	% Σ 1_10		2^x	17,404,715.98
12	Unforeseen expenses and other costs	% Σ 1_11		2^x	17,752,810.30
	Total				905,393,325.492
The average cost of 1 km in dollars				**6,914,460.796**	

5.4 Summary of Findings of Alternatives based on Construction Cost

The findings of alternatives I, II and III based on construction cost described in section 5-3 and tables 5.5, 5.6 and 5.7 are summarized in table 5.8.From summary of construction cost, alternative II has the least construction cost.

Table 5.8 Summary Of Findings of Alternatives based on Construction Cost

No.	Name object or work	Construction Cost		
		Alternative		
		I	II	III
1	Site Clearance and preparation	18,964.50	16,965.60	19,641.30
2	Sub grade	516,456,826.60	399,018,904.38	483,755,237.88
3	Structure			
	Tunnel	210,240,000.00	222,320,000.00	201,400,000.00
	Culvert	6,043,495.60	5,343,540.00	7,461,700.00
	Bridge	100,432,000.00	89,000,000.00	124,200,000.00
4	Track work	20,604,297.10	18,432,558.88	21,339,617.74
5	Signaling and communication	5,632,456.50	5,038,783.20	5,833,466.10
6	Buildings and facilities of production and service	3,241,791.63	2,900,099.66	3,357,483.82
7	Traction and power supply	1,238,128.99	1,107,627.47	1,282,315.01
9	Production equipment, general purpose tool	268,663.75	240,346.00	278,251.75
10	Temporary buildings and structures	17,283,532.49	14,868,376.50	16,978,554.27
12	Consultancy and Construction managements	4,407,300.79	3,791,436.01	4,329,531.34
13	Survey and Design fee	17,717,349.16	15,241,572.75	17,404,715.98
14	Unforeseen expenses and other costs	18,071,696.14	15,546,404.21	17,752,810.30
	Total	921,656,503.250	792,866,614.667	905,393,325.492
The average cost of 1 km in dollars		7,289,856.073	7,010,066.97	6,914,460.796

5.5 Operational costs

5.5.1 Description of the alternatives based on Operational costs

Total operational cost is operating cost of moving train and operating cost of permanent devices or maintenance cost.

Operational cost of running the train is calculated using following formula [15]

$$\boxed{OP = C \cdot L + A\left(\Delta H + 0{,}012 \cdot \sum \alpha\right) + Б\left(H_C - 0{,}012 \cdot \sum \alpha_c\right) - B \cdot L_C} \qquad 5\text{-}1$$

Where,

OP = Operational cost of running the train per pair train per day

L= Total length of the alignment, km

ΔH= Algebraic difference marks the final and initial points of the alignment, m

∑α= The sum of all deflection angles of horizontal curve, degree

Lc= Length of alignment with gradient greater than 0.4%, km

H_{C}=The sum of the heights of all brake slopes for section with slope greater than 0.4%

α_c =The sum of deflection angles of horizontal curves where g is greater than 0.4%

A = Normative rate for each meter rising = 1.125

B =Normative rate for traveling 1km in section with gradient greater than 0.4%=4.053

Б = Additional normative rate for rising gradient greater than 0.4%=1.531

C = Normative rate for traveling 1km for normal terrain conditions. =8.373

A, B, Б, C are rates in dollar and are derived from world's experience on train operation and to be verified to apply to Ethiopia for the future when train operation starts but these cost relation factor values can be applied as a general indicative operational cost factors.

Operational cost of running the train calculated by the above formula is for pair train per day .This is changed to operational cost per train per year for comparison of alternatives.

Maintenance cost is taken as 2% of construction cost from usual trend of cost estimation.

<u>Alternative I</u>

Operational cost of running train of alternative I has been calculated using equation 5-1. The numerical value of parameters such as L, ΔH, ∑α, $H_{c,}$ $\sum\alpha_c$,L_c has been taken from the alignment as shown in table 5.9.these values have been multiplied by their respective unit prices to get running cost in traffic and non traffic direction as shown in table 5.10.Number of pair train which pass through the railway line per day and per year has been assumed as shown in tables 5.11 and 5.12 respectively. Finally total operational cost of alternative I is obtained by adding running cost and maintenance costs as shown in table 5.13.

Table 5.9 quantity of parameters for operational cost of alt.1

parameter	quantity	
	Traffic direction	Non traffic direction
L	126.43	126.43
ΔH	468	-468
∑α	1033.042	1033.042
H_c	46.8	24.2
$\sum\alpha_c$	309.9126	413.2168
L_c	23.98284	45.85816

Table 5.10 Running cost for alternative I

№	Measurement Symbol	Norm Unit	Norm Symbol	Norm Rate usd	Alignment indicators quantity	Alignment indicators Cost (usd,1000)
1	L	km	C	8.373	126.43	1058.640
					126.43	1058.640
2	ΔH+0.012 .∑α	m	A	1.125	480.40	540.606
					-455.60	-512.706
3	Hc -0.012.∑α	m	Б	1.531	43.08	65.943
					19.24	29.452
4	Lc	km	B	4.053	23.98	97.210
					45.858	185.878
Total	Per 1 Train				Traffic direction	1,762.40
	Per 1 Train				Non traffic direction	761.27

Table 5.11 Number of pair train per day for alt I

Train type/year	2016	2030
Passenger train	9	12
Frieght train	13	22

Table 5.12 Number of pair train per year

train type/year	2016	2030
Passenger train	3285	4380
Frieght train	4745	8030

Table 5.13 Running, maintenance, operation cost for alternative I

Running cost. 1000 usd	Maintenance cost, 1000 usd	Operation cost, 1000 usd
Alternative I		
62,637.37	**18,433.13**	**81,070.50**

<u>Alternative II</u>

Operational cost of running train of alternative II has been calculated using equation 5-1. The numerical value of parameters such as L, ΔH, $\sum\alpha$, H_c, $\sum\alpha_c$, L_c has been taken from the alignment as shown in table 5.14.these values have been multiplied by their respective unit prices to get running cost in traffic and non traffic directions as shown in table 5.15.Number of pair train which pass through the railway line per day and per year has been assumed as shown in tables 5.16 and 5.17 respectively. Finally total operational cost of alternative II is obtained by adding running cost and maintenance costs as shown in table 5.18.

Table 5.14 parameters and quantity for operation cost for alt II

	Traffic direction	Non Traffic direction
L	113.104	113.104
ΔH	468	-468
$\sum\alpha$	1281.75	1281.75
H_c	22.864	45.267
$\sum\alpha_c$	256.2	512
L_c	25.54	56.97

Table 5.15 Running cost for alternative II

№	Measurement			Norm	Alignment indicators	
	Symbol	Unit	Symbol	Rate	quantity	
					113.104	Cost (usd)
1	L	km	*C*	8.373	113.104	947.06
					483.381	947.06
2	ΔH+0.012 .∑α	m	*A*	1.125	-452.62	543.96
					19.79	-509.35
3	Hc -0.012.∑α	m	*Б*	1.531	39.12	30.29
					25.54	59.88
4	Lc	km	*B*	4.053	56.97	103.52
					56.97	230.92
	Per 1 Train				Traffic direction	1,624.84
	Per 1 Train				Non Traffic direction	728.51

Table 5.16 Number of pair train per day for alt II

Train type/year	2016	2030
Passenger train	9	12
Frieght train	13	22

Table 5.17 Number of pair train per year for alt II

Train type/year	2016	2030
Passenger train	3285	4380
Frieght train	4745	8030
Total train	16,060.00	24,820.00

Table 5.18 Running, Maintenance , Operational Cost for alt II

Running cost, 1000 usd	Maintenance cost, 1000 usd	Operation cost. 1000 usd
II	II	II
58,410.11	15,857.33	74,267.44

Alternative III

Operational cost of running train of alternative III has been calculated using equation 5-1. The numerical value of parameters such as L, ΔH, $\sum\alpha$, H_c, $\sum\alpha_c$, L_c has been taken from the alignment as shown in table 5.19.These values have been multiplied by their respective unit prices to get running cost in traffic and non traffic direction as shown in table 5.20.Number of pair train which pass through the railway line per day and per year has been assumed as shown in tables 5.21 and 5.22 respectively. Finally total operational cost of alternative III is obtained by adding running cost and maintenance cost as shown in table 5.23.

Table 5.19 parameters and quantity for operation cost for alt III

	Traffic direction	Non traffic direction
L	130.942	130.942
ΔH	468	-468
$\sum\alpha$	1555.41	1555.41
H_c	32.04	42.72
$\sum\alpha_c$	466.5	622
L_c	29.95	57.95

Table 5.20 Running cost for alternative III

№	Measurement				Alignment indicators	
	Item	unit	Symbol	Rate (usd)	alternative III	
					quantity	Cost (usd)
1	L	km	*C*	8.373	130.94	1096.42
					130.94	1096.42
2	ΔH+0.012 .∑α	m	*A*	1.125	486.66	547.66
					-449.34	-505.65
3	H_C -0.012.∑α	m	*Б*	1.531	26.44	40.47
					35.26	53.97
4	Lc	km	*B*	4.053	29.95	121.40
					57.95	234.89
	Per 1 Train				**Traffic direction**	**1,805.95**
	Per 1 Train				**Non traffic direction**	**879.63**

Table 5.21 Number of pair train per day for alt III

Train type/year	2016	2030
Passenger train	9	12
Frieght train	13	22
Total train	**22**	**34**

Table 5.22 Number of pair train per year for alt III

Train type	2016	2030
Passenger train	3285	4380
Frieght train	4745	8030
Total train	16,060.00	24,820.00

Table 5.23 Running, Maintenance, Operation cost for alternative III

Running cost, 1000 usd	Maintenance cost, 1000 usd	Operation cost. 1000 usd
III	III	III
66,656.04	18,107.87	84,763.90

5.6 Summary of Findings of Alternatives based on Operational Cost

The findings of alternatives I, II and III based on operational cost described in tables 5.13, 5.18 and 5.23 are summarized in table 5.24.From summary of operational cost, alternative II has the least operational cost.

Table 5.24 Summary of Operation Cost

Alternative I	Alternative II	Alternative III
1000 usd	1000 usd	1000 usd
81,070.50	74,267.44	84,763.90

5.7 Requirement of the Standard

During the design process, minimum requirement of the standard should be fulfilled. But deviation from the standard may happen due to topographic constraints. The deviation of the three alternative alignments from the standard is summarized in table 5.25.

Table 5.25 Requirement of the standard

Description of Findings	Unit	Minimum/maximum requirement as per ERC standard	Deviation from standard		
			alt I	alt II	alt III
curve radius used below minimum requirement	m	2000	1600	500,1500,1500	500
Maximum gradient	%	2	2.27	2.49	2.5
Maximum Fill height(doesn't include cross-drainage sections)	m	22	30	27	29

5.8 Category of the project by gradient

From tables 5.26, 5.27 and figure 5.1, it can be seen that major portion of the vertical alignments have gradient in range of 0% up to 2%.and small section of alignments have gradient ranges of 2% up to 3%.This is because the ruling gradient is 2% according to ERC standard, and therefore small section of the alternatives have gradient above 2%, which is due to topographic constraint.

Table 5.26 Category of the project by grade (gradient)

Gradient (%)	Stations		
	Alternate 1	Alternate 2	Alternate 3
0-1	7+242.37-11+524.53	15+349-19+148.82	29+450.57-52+090.60
	14+943.91-23+194.32	29+112.01-34+554.04	78+310.06-111+043.1
	29+381.8-33+605.20	39+021.83-44+140.4	
	38+447.22-44+219.95	66+201.54-76+537.6	
	60+666.66-65+374.43	76+537.6-91+181.61	
	84+445.56-124+344.68	99+094.43-113+105.15	
1-2	0+000-7+242.37	0+000-15+349.00	0+000-29+450.57
	23+194.32-29+381.8	19+148.82-29+112.01	
	44+219.95-60+666.66	44+140.4-50+438.68	
	65+374.43-71+664.2	91+181.61-99+094.43	
	124+344.68-130+943.38		
2-3	11+524.53-14+943.91	34+554.04-39+021.83	52+090.6-66+092.62
	33+605.2-38+447.22	50+438.68-55+344.10	
	71+664.2-84+445.56	55+344.1-66+201.54	

Table 5.27 Summary of Category of the project by grade (gradient)

Gradient (%)	Total length (Km)		
	Alternate 1	Alternate 2	Alternate 3
0-1	67.136	53.351	55.373
1-2	42.765	39.523	29.451
2-3	21.043	20.231	14.002

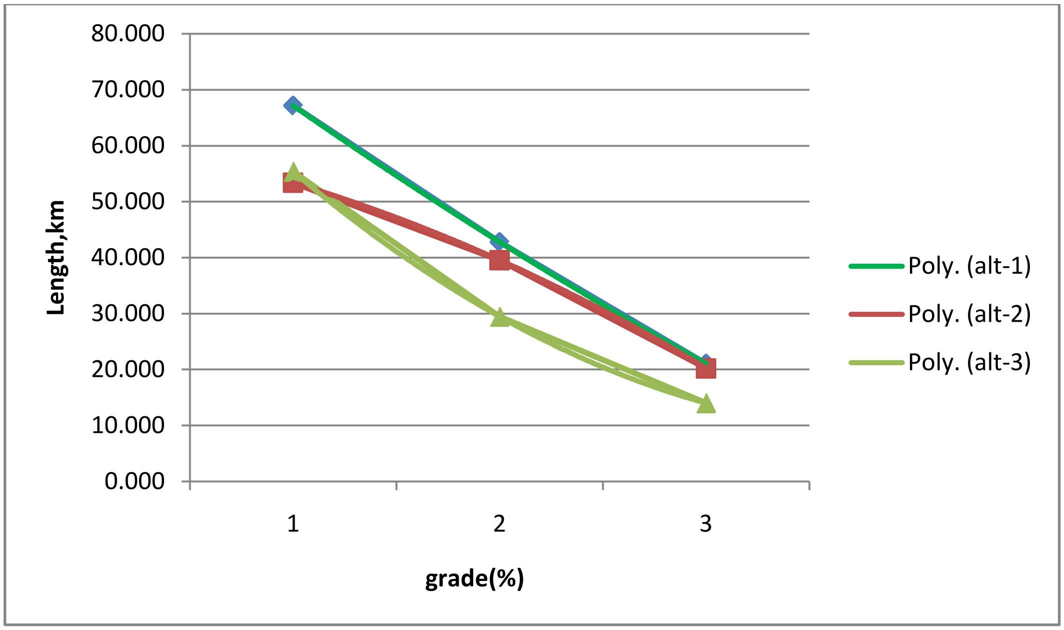

Fig 5.1 category of the project by grade

5.9 Sensitivity check for critical section of the project

Critical section of the project is the section where slight variation in geometric parameters can bring much difference in quantity. This can be section where there is tunnel, long span structures and deep excavation.

An attempt is made in this section to see the impact of track gradient on tunnel length and construction cost by taking the section between 93+200 to 123+200 of alternative I.

This section has been selected since there is tunnel and parameters can affect tunnel length and construction cost as shown in tables 5.28 and 5.29.

Table 5.28 grade effect on tunnel length and excavation quantity b/n 93+200 and 123+200 for alternative I

Station	Grade (%)	item	unit	Quantity	
	0.46			op-1	op-2
	0.4				
	0.59				
93+200--123+200	0.4	Excavation	m3	4,538,191.90	2,752,843.10
	0.65				
	0.55				
	0.75				
93+200--123+200	0.85	Tunnel length	km	6.615	6.371

Table 5.29 grade effect on construction cost for section between 93+200 to 123+200 for alternative I

Station	Grade (%)	item	unit rate (usd)	construction cost	
	0.46			op-1	op-2
	0.4				
	0.59				
93+200-123+200	0.4	Excavation	6,500.00	29,498,247,350.00	17,893,480,150.00
	0.65				
	0.55				
	0.75				
93+200-123+200	0.85	Tunnel	40,000,000.00	264,600,000.00	254,840,000.00
Grand total				29,762,847,350.00	18,148,320,150.00

Option -1 is applied for grade range between 0.46 and 0.4 and option 2 for grade range between 0.65 and 0.85.

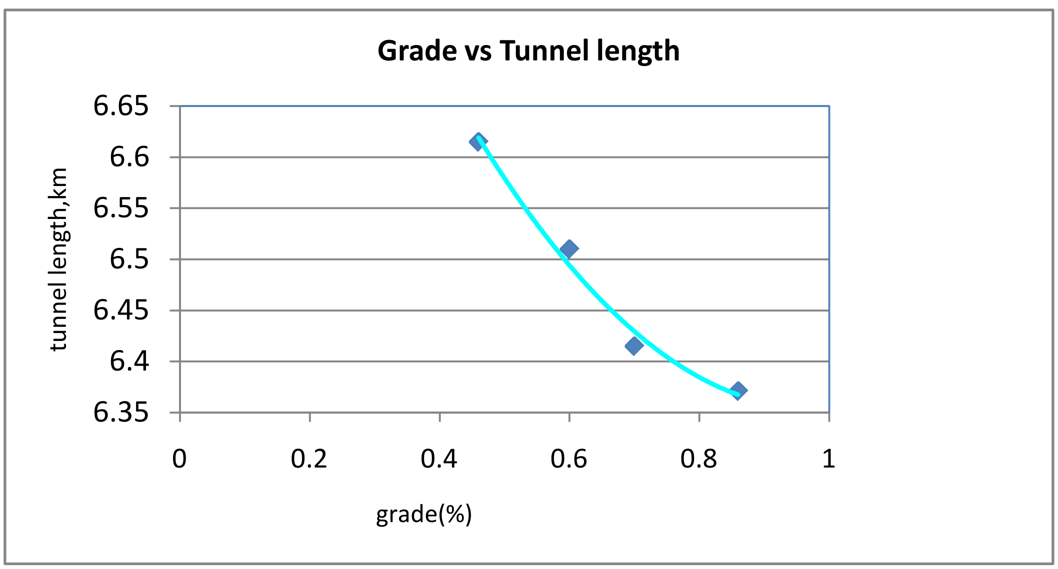

Figure 5.2 grade vs. tunnel length

From Figure 5.2 it can be seen that by slightly increasing the gradient ,reduction in tunnel length can be obtained since depth of excavation decreases.

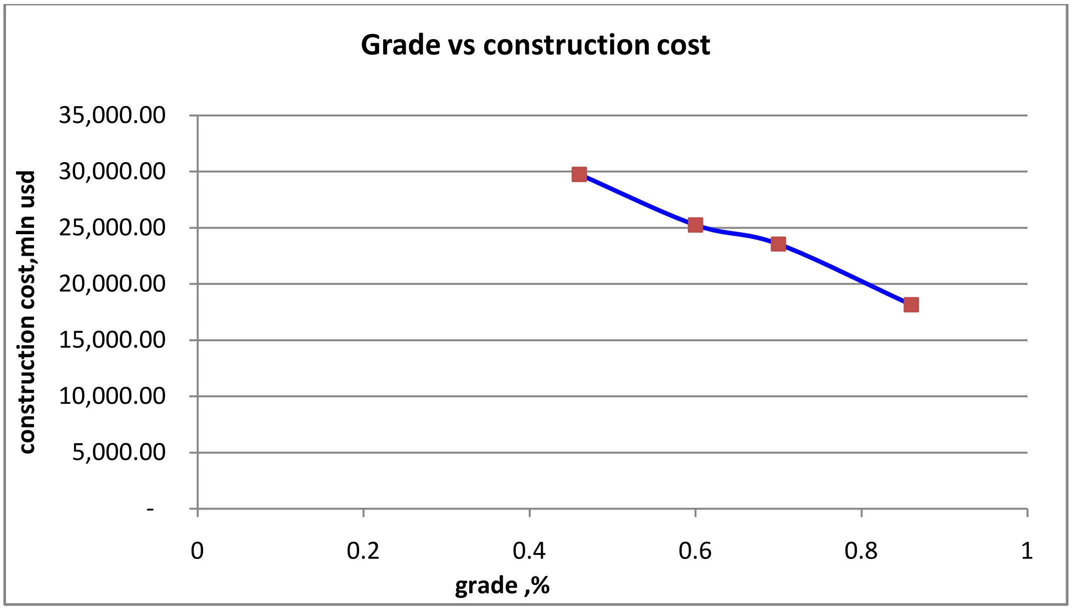

Figure 5.3 grade vs. construction cost

Figure 5.3 shows that as the gradient increases slightly, construction cost is reduced since the depth of excavation decreases and consequently the earth work quantity decreases.

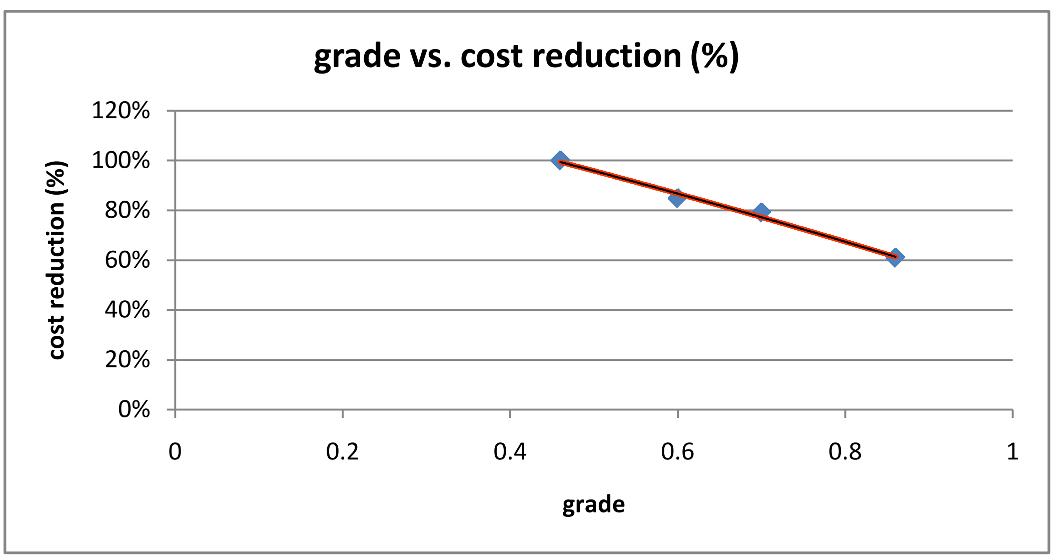

Fig 5.4 grade vs. cost reduction

From fig 5.4, it can be seen that by slightly increasing the grade(from 0.46 to 0.86),construction cost can be reduced to 61%.

6. Conclusions and Recommendations

6.1 Conclusions

Prioritization of alternative routes has been made with respect to construction cost, operational cost and safety comparison for deriving the most economical and low risk alternative. It has been noticed from grade vs. tunnel length and grade vs. construction cost analysis that slight increase in vertical gradient brought a significant change in tunnel length and corresponding reduction in construction cost of around 39%.

From the analysis made on different alternatives, alternative III has slightly longer length and slightly higher length of section with deep excavation than alternative I (alignment proposed by ERC), but shorter swampy section and length of tunnels as compared to the other two alignments. The cost, risk and time required to construct tunnels, and construct a railway on swampy section is high as compared to constructing other infrastructure parts. Risk assessment is associated with subsurface condition and moisture influence condition. Tunnel material composition may not be exactly assessed; there is possibility of being liable to risk conditions. Embankment settlement and erosion or unstability likely happens when alignment crosses in moisturized areas.

Alternative route comparison based on construction cost, operational cost and required design criteria show that alternative III has low risk of construction as compared to the other two alignments but alternative II has the least construction and operation cost. Alternative I is better than the other two alignments as per required design criteria though the highest fill height needs some mitigation measures like retaining walls.

Accordingly, alternative II is economical but alternative III has low risk of construction and alternative I fulfill required design criteria of the standard better than the other two alignments. Since intent of the research is to drive cost effective alignment, it can be concluded that alternative II is best alignment.

The geometric design of the alignments conducted on DEM data show that the alignments traverse through mountainous terrain that requires construction of long tunnels & deep cuts and swampy areas, which requires special consideration both during the design and the construction stages.

6.2 Recommendations

Slight variation in grade can bring much reduction in tunnel length and construction cost without reducing the speed significantly.

Accordingly, firms in the railway industry should identify critical section along potential corridor routes and then different sensitivity analysis should be made on these critical sections before final decision is made.

Analysis has been made mainly based on geometric design consideration however it is advisable to make comparison considering other basic criteria addressing Soil and Material Investigation, Hydrology & Hydraulics design, Structural design, Environmental Impact Assessment, and Resettlement Action Plan.

Swampy section influence risk analysis should be made and based on the risk analysis protection measures should be designed for sustainability of the project as the initial investment of constructing railways is very high.

Sharp curves and steep gradients should be avoided as much as possible while designing the alignments since these parameters have negative effect on speed and overall safety of the project.

Further research can be done for determining correct value of the rates A, B, Б, C that can be directly applied to Ethiopia for calculation of operational costs.

7. References

1. Bonnet C.F., (2005). Practical Railway Engineering, 2nd edition. Imperial College Press

2. HDR Decision Economics for the NH DOT,(2010).New Hampshire North cost Rail Road Improvements Cost –Benefit Analysis. Stanford and Carroll counties, NH, and York County

3. Elias Kassa, 2012. Lecture note. Professor of Railway Engineering, NTNU,Norway

4. ERC, (2010). Ethiopian Railway Corporation, Design team, Addis Ababa, Ethiopia

5. Dahlberg T., (2006), Handbook of Railway Vehicle Dynamics

6. Martin Lindahl, (2001). Track geometry for high-speed railways. A literature survey and simulation of dynamic vehicle response, KTH, Sweden.

7. Esveld C, Modern Railway Track, (2001), Professor of Railway Engineering, Delft University of Technology.

8. CEN Standard, (2010), BS EN 13803-1, 2010.European Committee for Standardization. Track alignment design parameters, Brussels.

9. ERC Standard, (2010). Ethiopian Railway Corporation Standard, Addis Ababa, Ethiopia

10. PRC Standard, (2010). National Standard of People's Republic of China, Code for Design of Railway, China.

11. AREMA, (2009). American Railway Engineering and Maintenance-of-Way Association, Manual for railway engineering, United States.

12. Handan U., (2009). Laboratory study for determining geotechnical engineering properties of cement-treated and untreated backfill soils used in high speed railway embankments. Master of Science Thesis, Izmir Institute of Technology.

13. PUNE,(2009).Notes on Curves for Railways,Indian Railways Institute of Civil Engineering.

14. ERA Manual, (2002). Ethiopian Roads Authority Manual, Addis Ababa, Ethiopia.

15. Professor EU Svintson, Dr. tech.sciences.Technical and economic comparison alignment options in the design of new railway line.

8. Appendixes

Appendix A: Definition

Circular curve: is alignment element of constant radius

Transition Curve: is alignment element of variable radius

Cant: is the amount by which one running rail is raised above the other running rail

Maximum permissible speed: maximum speed resulting from the application of track alignment limits given in the standard

Normal limit: limit not normally exceeded

Exceptional limit: extreme limit not to be exceeded

Gradient or grade: Any departure of the track from the level is known as grade or gradient

Ruling gradient: it is the maximum gradient allowed on track section

Horizontal Alignment: is the projection of the track centreline on a horizontal plane

Vertical Curve: Curve on the longitudinal profile of railway

Rail: Special steel section used to guide vehicles on a railway.

Sleeper: Transverse beam that provides vertical and lateral support to running rails and fastenings.

Appendix-B: Design output of some of the parameters

List of Horizontal Curve Data for Alt-1

Curve No	PI			Radius (m)	Curve Length (m)	Direction	Deflection Angle	Tangent Length (m)
	Chainage	Northing	Easting					
POB	0+000.000	1068505.76	610836.085	-	-	-	-	-
1	8+100.477	1076492.13	609482.928	2000	926.319	Left	26^32'13.47"	7488.857
2	10+441.740	1078323.97	607998.413	2000	1217.938	Right	34^53'28.88"	978.051
3	12+988.910	1080908.88	607924.975	5000	340.939	Right	3^54'24.74"	1577.21
4	14+426.928	1082343.98	608017.562	2000	150.979	Right	4^19'30.83"	982.089
5	15+903.914	1083791.9	608308.683	2000	459.735	Left	13^10'13.57"	890.647
6	18+631.783	1086512.19	608083.406	2000	800.274	Right	22^55'34.14"	1813.456
7	19+915.443	1087730.6	608520.257	1600	1056.391	Left	37^49'45.12"	50.691
8	21+169.154	1088947.86	608082.416	2000	559.514	Right	16^01'44.05"	173.982
9	21+968.125	1089749.8	608054.311	2000	152.562	Right	4^22'14.06"	164.735
10	24+103.042	1091868.94	608312.56	2000	282.36	Right	8^05'20.52"	1637.258
11	26+220.910	1093879.99	608977.306	2000	979.949	Left	28^04'24.51"	1196.905
12	28+183.824	1095810.73	608527.871	2000	991.906	Left	28^24'57.64"	696.607
13	29+748.099	1096949.55	607425.535	2000	1076.998	Right	30^51'13.38"	246.843
14	31+072.656	1098270.95	607143.307	2000	587.264	Left	16^49'25.96"	223.7
15	32+650.503	1099623.93	606323.706	2000	137.064	Left	3^55'35.79"	937.784
16	34+733.856	1101261.47	605036.112	2000	2073.276	Right	59^23'41.94"	594.184
17	38+644.021	1105056.41	606633.999	2000	2022.613	Left	57^56'36.98"	1590.221
18	41+856.183	1107785.15	604599.417	2000	1786.677	Right	51^11'04.32"	1058.972
19	47+194.920	1113026.74	606153.534	2000	1620.087	Left	46^24'43.51"	3372.517
20	49+810.747	1115322.01	604712.281	2000	1002.422	Right	28^43'02.18"	1061.216
21	54+491.928	1120023.92	604669.85	2000	837.257	Right	23^59'08.29"	3485.882
22	58+085.307	1123253.35	606272.641	2000	2570.656	Left	73^38'37.89"	1403.588
23	60+572.463	1125173.46	604084.798	2000	894.637	Right	25^37'46.06"	678.956
24	62+505.867	1126989.24	603378.348	2000	381.578	Left	10^55'53.05"	1022.327
25	67+804.803	1131326.85	600333.475	2000	1345.654	Right	38^33'00.52"	4129.315
26	71+747.058	1135295.93	600787.274	2000	788.321	Left	22^35'01.44"	2616.67
27	75+034.157	1138419.67	599732.542	2000	1607.061	Right	46^02'20.02"	1768.372
28	77+092.906	1140292.43	600790.417	2000	503.13	Left	14^24'49.04"	768.539
29	80+482.923	1143609.21	601502.212	2000	633.967	Left	18^09'42.54"	2540.123
30	82+703.888	1145804.89	601135.173	3000	863.956	Right	16^30'01.21"	1231.674
31	85+759.187	1148834.66	601573.228	5000	200.545	Left	2^17'53.09"	2356.046
32	88+450.360	1151514.55	601819.443	3000	261.118	Left	4^59'13.17"	2290.272
33	93+477.589	1156539.53	601667.777	3000	1503.457	Left	28^42'50.09"	3928.885

34	105+018.675	1166342.92	595516.925	4000	2319.821	Right	33^13'44.38"	9431.943
35	110+588.705	1171977.1	595702.86	4000	2413.285	Left	34^34'03.95"	3039.135
36	116+234.191	1176761.81	592565.846	4000	3545.171	Right	50^46'51.02"	2418.308
37	120+169.976	1180745.79	593855.806	4000	2114.656	Left	30^17'24.78"	1046.472
38	123+239.701	1183782.1	593138.172	2000	1183.88	Left	33^54'56.37"	1207.878
POE	126+430.906	1185830.29	590644.844	-		-	-	2477.178

List of Vertical Curve Data for Alt-1

Curve No	PVI		Grade In (g1) (%)	Grade Out (g2) (%)	Length of Curve (m)
	Chainage	Elevation			
1	9+178.529	1052.861	1.227	1.325	5.887
2	14+463.604	1122.871	1.325	1.164	9.611
3	22+979.911	1222.04	1.164	1.411	14.787
4	29+450.569	1313.34	1.411	-0.855	407.877
5	39+402.984	1228.229	-0.855	-0.609	44.379
6	52+090.597	1151.012	-0.609	2.275	518.852
7	66+092.615	1469.49	2.275	0.36	344.587
8	78+310.063	1513.417	0.36	0.405	8.202
9	91+186.428	1565.582	0.405	-0.785	214.27

List of Horizontal Curve Data for Alt-2

Curve No	PI			Radius (m)	Curve Length (m)	Direction	Deflection Angle	Tangent Length (m)
	Chainage	Northing	Easting					
POB	0+000.000	1068485.87	610851.144	-	-	-	-	-
1	8+253.241	1076618.217	609443.691	2000	1152.338	Left	33^00'43.36"	7660.585
2	10+349.963	1078180.058	607995.846	2000	1459.678	Right	41^49'00.15"	772.98
3	13+983.621	1081881.577	607930.321	2000	437.284	Right	12^31'38.19"	2718.522
4	15+930.291	1083790.794	608319.21	2000	595.118	Left	17^02'55.97"	1429.129
5	18+735.919	1086587.747	608048.132	1500	800.259	Right	30^34'03.47"	2100.386
6	19+961.641	1087716.042	608575.029	2000	1536.059	Left	44^00'17.46"	27.211
7	21+649.715	1089388.29	608000.11	2000	909.88	Right	26^03'58.10"	497.213
8	24+136.080	1091871.528	608309.112	3000	615.91	Right	11^45'46.85"	1730.396
9	26+305.767	1093926.83	609011.043	2000	1155.665	Left	33^06'26.52"	1268.353
10	28+303.460	1095895.289	608511.074	2000	1180.688	Left	33^49'27.15"	828.386
11	29+794.059	1096914.974	607375.598	2000	1374.68	Right	39^22'54.08"	202.276
12	31+079.341	1098241.642	607172.738	2000	793.631	Left	22^44'09.04"	224.239
13	32+735.049	1099663.456	606303.851	3000	489.471	Left	9^20'53.54"	1018.904
14	34+915.018	1101315.058	604879.344	2000	2351.908	Right	67^22'37.88"	602.518
15	38+615.846	1104905.498	606677.257	2000	2173.991	Left	62^16'48.90"	1473.792
16	42+006.471	1107856.84	604558	2000	1853.739	Right	53^06'20.59"	1425.554
17	47+110.603	1112865.279	606129.94	2000	1530.206	Left	43^50'13.85"	3445.113
18	48+198.154	1113910.322	605610.897	500	492.778	Right	56^28'05.45"	93.612
19	49+630.737	1115188.518	606350.527	2000	856.619	Left	24^32'25.23"	773.306
20	54+025.322	1119576.036	606774.199	2000	1421.855	Left	40^43'59.32"	3230.48
21	55+157.642	1120552.636	606084.835	2000	468.174	Right	13^24'43.92"	217.768
22	56+354.061	1121665.448	605639.62	2000	1182.122	Right	33^51'55.13"	354.515
23	58+174.328	1123480.415	606027.388	2000	2139.013	Left	61^16'41.52"	62.397
24	60+409.751	1125090.952	604160.359	2000	941.551	Right	26^58'24.40"	801.383
25	62+459.552	1127004.656	603377.643	3000	694.096	Left	13^15'22.55"	1239.313
26	67+687.049	1131262.918	600340.131	3000	2193.831	Right	41^53'56.71"	3733.443
27	71+514.637	1135169.317	600778.164	2000	854.563	Left	24^28'53.15"	2348.416
28	75+202.857	1138687.948	599629.224	2000	1906.756	Right	54^37'28.32"	2234.741
29	77+046.036	1140296.465	600821.25	2000	866.088	Left	24^48'41.70"	529.303
30	80+493.904	1143685.841	601524.976	2000	767.296	Left	21^58'53.06"	2633.297
31	82+591.244	1145759.095	601149.999	3000	900.573	Right	17^11'58.85"	1264.769
32	88+415.024	1151546.885	601855.296	3000	472.071	Left	9^00'57.22"	5140.382
33	91+243.362	1154374.356	601753.193	2000	774.887	Right	22^11'55.94"	2200.427
34	93+554.721	1156553.753	602552.066	1500	1875.927	Left	71^39'18.48"	845.904

35	95+521.499	1157957.84	600785.345	2000	2057.078	Right	58^55'51.42"	43.828
36	100+988.378	1163580.244	601516.224	3000	590.487	Left	11^16'38.90"	4243.555
37	104+207.480	1166793.912	601298.778	3000	1067.422	Left	20^23'10.51"	2385.402
38	109+299.897	1171447.123	599201.961	3000	2668.121	Left	50^57'26.49"	3134.853
POE	113+104.522	1172466.808	595338.648	-	-	-	-	2566.06

List of Vertical Curve Data for Alt-2

Curve No	PVI		Grade In (g1) (%)	Grade Out (g2) (%)	K - Value	Length of Curve (m)
	Chainage	Elevation				
1	10+869.791	1056.251	1.042	1.835	3781.067	3000
2	15+349.001	1138.453	1.835	0.936	2223.49	2000
3	19+148.815	1174.007	0.936	1.192	11683.221	3000
4	24+560.845	1238.544	1.192	1.643	6658.3	3000
5	29+112.011	1313.321	1.643	-0.392	1474.463	3000
6	34+554.042	1292.009	-0.392	-2.487	954.374	2000
7	39+021.835	1180.885	-2.487	0.55	658.473	2000
8	44+140.398	1209.043	0.55	-1.335	1060.785	2000
9	50+438.683	1124.943	-1.335	2.247	837.377	3000
10	55+344.103	1235.184	2.247	2.237	200651.85	2000
11	66+201.544	1478.104	2.237	0.353	1592.441	3000
12	76+537.597	1514.638	0.353	0.353	97979701	3000
13	91+181.607	1566.394	0.353	-1.113	1364.123	2000
14	99+094.426	1478.347	-1.113	-0.321	2526.496	2000
15	107+347.864	1451.845	-0.321	-0.695	5349.814	2000

List of Horizontal Curve Data for Alt-3

Curve No	PI			Radius (m)	Curve Length (m)	Direction	Deflection Angle	Tangent Length (m)
	Chainage	Northing	Easting					
POB	0+000.000	1068505.67	610836.053	-	-	-	-	-
1	8+158.855	1076552.13	609486.44	2000	1208.182	Left	34^36'42.73"	7535.697
2	10+323.721	1078133.27	607952.424	2000	1548.99	Right	44^22'31.05"	764.16
3	14+279.731	1082171.62	607969.479	5000	1041.987	Right	11^56'25.07"	2699.814
4	15+917.843	1083776.54	608315.956	2000	604.386	Left	17^18'51.75"	814.499
5	18+677.703	1086529.96	608068.665	2000	938.365	Right	26^52'55.83"	1982.004
6	19+962.097	1087739.27	608551.13	2000	1509.091	Left	43^13'56.14"	31.505
7	21+337.204	1089089.5	608019.745	2000	956.782	Right	27^24'35.27"	170.795
8	24+278.065	1092033.21	608325.381	3000	786.449	Right	15^01'12.23"	2076.316
9	26+225.593	1093856.26	609023.273	2000	1214.28	Left	34^47'11.65"	930.066
10	28+209.549	1095820.23	608539.461	2000	1106.844	Left	31^42'31.49"	828.187
11	29+740.902	1096913.07	607425.527	2000	1172.186	Right	33^34'50.34"	389.036
12	31+126.064	1098302.12	607131.111	2000	677.71	Left	19^24'53.86"	474.308
13	32+732.903	1099679.5	606290.948	2000	313.821	Left	8^59'25.16"	1114.031
14	34+754.040	1101219.8	604981.335	2000	2246.601	Right	64^21'37.37"	606.048
15	38+715.609	1105086.25	606701.829	2000	2424.257	Left	69^26'59.49"	1587.315
16	41+694.955	1107420.04	604330.119	3000	3374.562	Right	64^26'57.81"	50.236
17	48+835.547	1114557.39	606785.98	2000	3878.892	Left	111^07'19.48"	2740.367
18	51+797.579	1114374.27	601872.912	3000	400.65	Left	7^39'06.67"	1799.186
19	56+951.108	1113498.21	596793.786	2000	2613.452	Right	74^52'11.55"	3422.454
20	61+002.274	1117579.19	594898.033	3000	4194.543	Right	80^06'35.50"	446.559
21	66+093.412	1120970.36	599776.095	2000	2480.138	Right	71^03'02.59"	1990.877
22	69+642.291	1118650.04	602941.292	2000	1868.917	Left	53^32'25.92"	1487.692
23	71+289.607	1119184.12	604656.401	500	601.842	Left	68^57'57.79"	443.947
24	72+199.477	1120176.87	604721.253	2000	851.133	Right	24^22'59.41"	219.342
25	75+572.445	1123163.22	606317.203	2000	2655.436	Left	76^04'21.45"	1389.329
26	78+127.523	1125191.82	604068.017	2000	941.525	Right	26^58'21.68"	984.603
27	80+072.790	1127024.74	603365.189	3000	778.62	Left	14^52'13.95"	1091.886
28	85+432.639	1131372.76	600223.554	3000	2350.977	Right	44^54'01.27"	3733.154
29	89+298.722	1135317.31	600851.881	3000	1561.714	Left	29^49'35.55"	1955.709
30	92+643.240	1138478.24	599652.674	2000	1859.319	Right	53^15'56.04"	1578.829
31	94+635.614	1140282.44	600801.614	2000	719.298	Left	20^36'22.97"	772.435
32	98+058.340	1143639.5	601508.033	2000	753.09	Left	21^34'27.95"	2685.947
33	100+247.514	1145806.33	601137.994	3000	889.226	Right	16^58'58.70"	1369.245
34	105+978.193	1151497.18	601866.18	3000	495.811	Left	9^28'09.46"	5040.878
35	111+174.385	1156690.75	601668.706	3000	1708.027	Left	32^37'15.31"	4070.997

36	112+922.107	1158165.08	600644.084	3000	513.586	Left	9^48'31.56"	660.128
37	115+513.050	1160010.56	598823.731	3000	657.389	Right	12^33'18.73"	2004.763
38	121+184.230	1164819.51	595812.698	3000	1427.543	Left	27^15'50.62"	4616.256
39	122+953.465	1165736.42	594267.462	2000	1210.024	Right	34^39'52.66"	445.075
40	126+377.252	1168882.99	592823.432	2000	1901.004	Right	54^27'35.14"	1808.753
41	128+632.302	1170976.21	594022.639	3000	640.634	Left	12^14'06.73"	1061.685
42	129+932.020	1172217.61	594415.792	3000	944.387	Right	18^02'11.26"	504.492
POE	130+942.369	1173045.43	595008.664	-	-	-	-	-

List of Vertical Curve Data For Alt-3

Curve No	PVI		Grade In(g1) (%)	Grade Out (G2) (%)	Length of Curve (m)
	Chainage	Elevation			
1	1+912.210	960.29	1.05	1.37	2000
2	7+242.370	1033.17	1.37	0.67	2000
3	11+524.530	1061.76	0.67	2.5	2000
4	14+943.910	1147.24	2.5	0.92	2000
5	18+187.240	1177.2	0.92	0.9	2000
6	23+194.320	1222.07	0.9	1.21	2000
7	25+537.610	1250.52	1.21	1.83	2000
8	29+381.800	1320.95	1.83	-0.43	2000
9	33+605.200	1302.82	-0.43	-2.5	2000
10	38+447.220	1181.77	-2.5	0.58	2000
11	44+219.950	1215.52	0.58	-1.64	2000
12	48+571.810	1144.26	-1.64	1.27	3000
13	55+830.350	1236.09	1.27	1.31	3000
14	60+666.660	1299.55	1.31	-0.43	3000
15	65+374.430	1279.37	-0.43	-1.29	2000
16	71+664.200	1198.36	-1.29	2.5	3000
17	84+445.560	1517.9	2.5	-0.52	3000
18	91+632.840	1480.18	-0.52	0.46	3000
19	103+188.940	1532.87	0.46	0.57	3000
20	108+504.960	1563.2	0.57	-0.59	3000
21	117+240.630	1511.94	-0.59	-0.4	3000
22	124+344.680	1483.79	-0.4	-1.14	3000