REPUBLIC OF NAMIBIA
MINISTRY OF WORKS AND TRANSPORT

Feasibility Study for the Trans-Zambezi Railway Extension Grootfontein-Rundu-Katima Mulilo

Final Feasibility Study Report
(Vol I. Preliminary Design Report)

March 17th, 2022

Prepared and Submitted by

TECHNOFIN CONSULTANTS

M R Technofin Consultants Ltd.

954, Irish Moss Rd, Mississauga, Ontario, Canada, L5W1W5

E-mail: admin@mrtcpl.com

Web: www.mrtcpl.com

In Association with Namibia-based

BURMEISTER & PARTNERS (PTY) LTD CONSULTING ENGINEERS

Burmeister & Partners

Corner of Andimba Toivo Ya Toivo & Van Zyl Streets, Suiderhof

Email: bp@burmeister.com.na

Web: www.burmeister.com.na

ENVIRO DYNAMICS Environmental Management Consultants

Enviro Dynamics

16 Seder Street, Suiderhof PO Box 4039, Windhoek, Namibia

Email: info@envirod.com

Web: www.envirod.com

Ko&P PARTNERS

Koep & Partners

33 Schanzen Road, P. O. BOX 3516, Windhoek, Namibia

Email: pfk@koep.com.na

Web: www.koep.com.na

And International Partners

University of Cape Town

Private Bag X3, Rondebosch 7701, South Africa

Email: marianne.vanderschuren@uct.ac.za

Web: www.uct.ac.za

3TI PROGETTI

3TI Progetti

Lungotevere V. Gassman 22 00146 – Rome, Italy

Email: info@3tiprogetti.it

Details of Report

Project Name	**:**	**Feasibility Study for the Trans-Zambezi Railway Extension Grootfontein-Rundu-Katima Mulilo**
Contract/ Work Order No.	:	MWT/TIIP/ISCB/20/05
Document Name	:	Final Feasibility Study Report (Vol I. Preliminary Design Report)- Feasibility Study for the Trans-Zambezi Railway Extension Grootfontein-Rundu-Katima Mulilo
Document No.	:	MRTCL/Project/MoWT (GRN)/Final Feasibility Study Report/003A
Report Submitted to	:	Ministry of Works and Transport, Government of Republic of Namibia
Report Submitted by	:	**M R Technofin Consultants Limited,** Address: 954, Irish Moss Rd, Mississauga, Ontario, Canada, L5W1W5 Contact No.: +1 416-721-9460 Email: admin@mrtcpl.com Website: www.mrtcpl.com

Submission of Report

Revision#	Date	Prepared by	Reviewed by	Approved for Issue by
00	17th March, 2022	Project Team	Adriaan van der Merwe (Team Leader) Satish Raina (Railway Bridges and Structural Expert)	Sanjay Mittal (Project Director)

Letter for Submission of Report

Ref No.: MRTCL/Project/MoWT(GRN)/Final Feasibility Report/003A March 17th, 2022

To,
Executive Director
Ministry of Works and Transport
6719 Corner of Bell Street & Snyman Circle
Private Bag 13341,
Windhoek, Namibia

Project: Feasibility Study for the Trans-Zambezi Railway Extension Grootfontein-Rundu-Katima Mulilo

Reference: **Contract No. MWT/TIIP/ISCB/20/05 dated March 10th, 2021,** Between Ministry of Works and Transport (MoWT) and M. R. Technofin Consultants Ltd.

Subject: Submission of '**Final Feasibility Study Report** for Feasibility Study for the Trans-Zambezi Railway Extension Grootfontein-Rundu-Katima Mulilo

Dear Madam,

We are pleased to submit the 'Final Deliverable' for this project – **'Final Feasibility Report – Feasibility Study for the Trans-Zambezi Railway Extension Grootfontein-Rundu-Katima Mulilo'.**

The report is comprised of following volumes:

Vol I. – Preliminary Design Report

Vol II. – Project Feasibility

Vol III. – Project Drawings

This is Vol I. of the Report.

Following the written comments to the 'Draft Feasibility Study Report – Vol I. Preliminary Design Report' which were received on March 1st, 2022, we are pleased to submit the **'Final Feasibility Study Report – Vol I. Preliminary Design Report**' for the subject project.

We have addressed the Ministry's comments comprehensively as reflected in the 'Response Matrix', attached separately. We are available to discuss its contents at any time, if so required.

Yours Sincerely,

M.R. Technofin Consultants Ltd. CANADA

For M R Technofin Consultants Ltd.

Sanjay Mittal

President and Project Director

Acronym/ Abbreviations and Technical Terms

Acronyms	Full Forms
AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transport Officials
ACEN	Association of Consulting Engineers of Namibia
AfDB	African Development Bank
AMC	Antecedent Moisture Condition
AREMA	American Railway Engineering Maintenance of Way Association
ARF	Area Reduction Factor
BCM	Ballast Cleaning Machine
BOQ	Bill of Quantity
BRM	Ballast regulator Machine
BS	British Standards
CBR	California Bearing Ratio
Cc	Coefficient of Curvature
CCECC	China Civil Engineering Construction Corporation Ltd.
CCTV	Closed-Circuit Television
CITIC	China International Trust Investment Corporation
CMA	Concrete Manufacturers Association of South Africa
CN	Curve Number
COLTO	Community of Land Transport Officials
CORBWA	Cubango-Okavango River Basin Water Audit
CSL	Clear Standing Length
CSIR	Council of Scientific and Industrial Research
CSM	Continuous Action Tamping Machine
Cu	Uniformity Coefficient
DAF	Dissolved Air Floatation
DCP	Dynamic Cone Penetration
DR	District Roads
DRC	Democratic Republic of Congo
DTM	Digital Terrain Model
E	East
EI	Electronic Interlocking System
EN	European Standards
ESIA	Environmental and Social Impact Assessment
FACT	Fine Aggregate Crushing Test
FEED	Front End Engineering Design
FR	Farm Roads
Ft	Feet
GAD	General Arrangement Drawing

Acronyms	Full Forms
GDG	Geometric Design Guidelines
GM	Silty Gravels
GNSS	Global Navigation Satellite System
GRN	Government of Namibia
GSN	Geological Survey of Namibia
GW	Well-Graded Gravels
H	Hour
Ha	Hectare
HP	Horsepower
ICS	Initial Consumption of Stabiliser
In	Inch
ITS	Indirect Tensile Strength
IP	Internet Protocol
ISDN	Integrated Services Digital Network
KAZA TFCA	Kavango Zambezi Transfrontier Conservation Area
Kg	Kilograms
Kg/m	Kilogram per Metre
Km	Kilometre
Kmph	Kilometre per hour
LA	Local Authorities
LC	Level Crossing
LED	Light-Emitting Diode
LHT	Laser Heat Treatment
LV	Low Voltage
LHS	Left Hand Side
M	Metre
MAP	Mean Annual Precipitation
MC	Moisture Condition
MDD	Maximum Dry Density
MM	Millimetre
MoWT	Ministry of Works and Transport
MPT	Multi-Purpose Tamper
MR	Main Roads
MRTCL	M R Technofin Consultants Limited
MURD	Ministry of Urban and Rural Development
NamPAB	Namibia Planning Advisory Board
NDPs	Nationally Determined Parameters
OC	Object Controller
O&M	Operation and Maintenance
OMC	Optimum Moisture Content

Acronyms	Full Forms
PI	Panel Interlocking
PM	Project Management
POH	Periodic Overhaul
PPP	Public-Private Partnership
PQRS	Plasser Quick Relaying System
PSC	Pre-Stressed Concrete
PSD	Passing Sight Distance
PTO	Permission-to-Occupy
RA	Roads Authority
RAMS	Reliability, Accessibility, Maintainability and Safety
RAP	Resettlement Action Plan
RCC	Reinforced Concrete Cement
RDM	Road Drainage Manual
RHS	Right Hand Side
ROH	Routine Overhaul
RRI	Route Relay Interlocking
RL	Reduced Level
ROB	Road Over Bridge
RRI	Route Relay Interlocking
RUB	Road Under Bridge
S&T	Signalling and Telecommunications
S	South
SADC	South African Development Community
SANRAL GDG	South African National Roads Agency Geometric Design Guidelines
SANS	South African National Standards)
SAR	South African Railways
SATS	South African Transport Services
SBCM	Shoulder Ballast Cleaning Machine
SCS	Soil Conservation Service
SDH	Synchronous Digital Hierarchy
SEA	Strategic Environmental Assessment
Sec	Second
SSD	Stopping Sight Distance
STM	Synchronous Transport Module
TIIP	Transport Infrastructure Improvement Project
TOR	Terms of Reference
TM	Traction Motor
TR	Trunk Roads
TRH	Technical Recommendations for Highways
TRT	Track Relaying Train

Acronyms	Full Forms
TZR	Trans-Zambezi Rail
TSC	Turbo Super Charger
UCS	Unconfined Compressive Strength
UIC	International Union of Railways
VHF	Very High Frequency

Table of Contents

List of Figures

List of Tables

Executive Summary

This study is being undertaken under the authority of a contract signed between the Ministry of Works and Transport (MoWT), Government of Republic of Namibia (i.e., the 'Client') and M R Technofin Consultants Ltd. (MRTCL) (i.e., the 'Consultant') on March 10th, 2021 (Contract No. MWT/TIIP/ISCB/20/05).

The prime objective of the assignment is to 'research and analyse data and information pertaining to the Trans-Zambezi Railway extension of Grootfontein-Rundu-Katima Mulilo and provide the Ministry of Works and Transport adequate strategic, economic and technical information on the project feasibility'.

The Namibian Railway network and railway routes are as follows:

Table ES-1: Namibia Railway Line[1]

Railway Line	Route (km)	Gauge (m)
Nakop — Karasburg — Grünau — Seeheim — Keetmanshoop — Mariental — Rehoboth — Windhoek	865	1,067
Windhoek — Okahandja — Karibib — Kranzberg	210	1,067
Kranzberg — Usakos — Swakopmund — Walvis Bay	201	1,067
Kranzberg — Omaruru — Kalkfeld — Otjiwarongo — Otavi	328	1,067
Otavi — Tsumeb	64	1,067
Otavi — Grootfontein	90.5	1,067
Otjiwarongo — Outjo	69	1,067
Windhoek (Gammams) — International Airport — Omitara — Witvlei — Gobabis	228	1,067
Seeheim — Goageb — Aus — Lüderitz	318	1,067
Tsumeb – Ondangwa – Oshikango	306	1,067

Of note, the current axle load and speed on Walvis Bay – Grootfontein route are as follows:

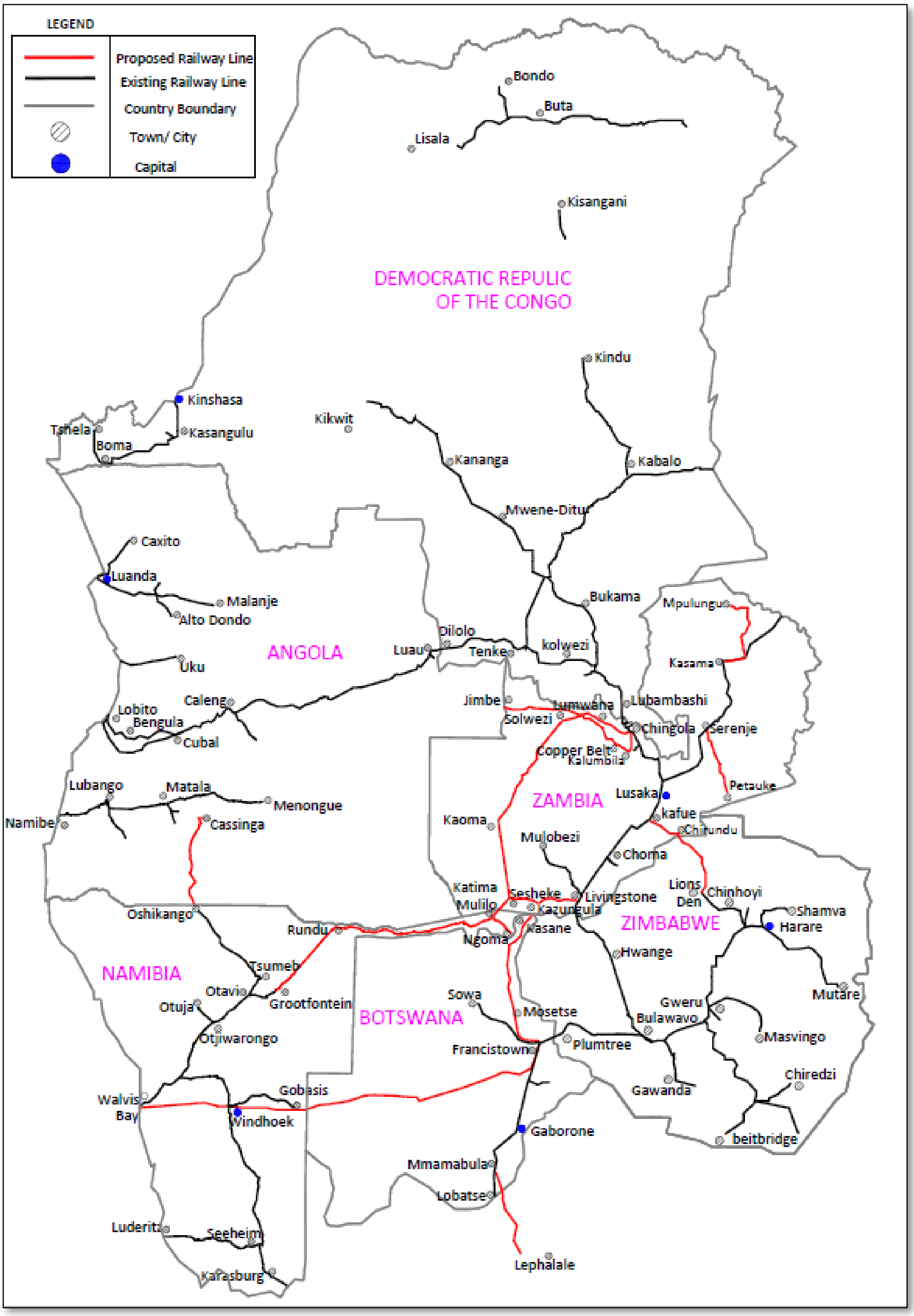
- **Axle-Load** - Walvis Bay to Grootfontein = 16.5 ton; however, it should be noted that the axle-load for the Otavi to Grootfontein section is 15.0 ton though 16.5 ton can be accommodated for commercial reasons.
- **Speed -** Walvis Bay to Kranzberg = 60 kmph; Kranzberg to Grootfontein = 50 kmph

1.1.1 Regional Rail Network

Figure ES-1 summaries the existing rail network in the region as well as proposed railway projects. Proposed railway projects were determined through desk research and regional consultations. The likelihood of proposed projects coming to fruition were also judged through consultations and are further discussed in Section 2 of Volume II of this Report.

[1] 2-Chapter 2 (klausdierks.com)

Figure ES-1: Proposed Rail Developments in Neighbouring Countries



1.1.2 Railway Design Criteria

The Design Criteria for key elements of a railway needs to be identified at the Initial stage itself to enable further work on route selection and alignment design.

Informed by the traffic study, the Consultant has considered that the Trans-Zambezi Rail (TZR) would primarily be used to carry regional freight traffic including dry and liquid bulk and containerized goods.

The recommended design parameters are based on 'Infrastructure Engineering- Manual for Track Maintenance' (2012) of Transnet, South Africa'. Further references, wherever necessary, have been made to the UIC standards.

Gauge

Namibia railway network operates about 2,680 km of route on 3 ft. 6 in (1,067 mm) track gauge, often referred to as 'Cape Gauge'.

In 2007, the Africa Union resolved that 'Standard Gauge' (SG) 1,435 mm should be adopted for the construction of new railway lines in order to promote interoperability on the continent. Member countries were encouraged to consider standard gauge corridors when studying and developing new lines.

The gauge for the TZR has been adopted as 'Cape Gauge'. To 'future-proof' the designs for possibly converting the alignment from cape to standard gauge, we suggest that the substructure of major and important bridges be built to standard gauge specifications with steel superstructure fit for cape gauge for now. The steel super structure could be changed for standard gauge when required.

Axle Load and Design Speed

Trans Zambezi railway line will fall under N2 Classification of Running lines.

Though the Transnet manual specifies the Axle Load for a given track structure, it is silent on the Allowable Speed. Given a particular track geometry, the overall stresses on the track are a combination of forces induced by superimposed load (axle-load), static as well as dynamic; tractive and braking forces (speed); and climatic stresses (temperature variation).

The design Axle Load for the TZR is recommended as 18.5-ton with the following speed potential (Table ES-2).

Table ES-2: Design Speeds for Proposed Line

Type of Terrain and Train	Design Speeds
Freight	80 kmph
Passenger	100 kmph

80 kmph for freight is suitable because (1) railway administrations in the SADC region specify this speed for goods trains and (2) the bogies for goods trains traveling at more than 80 kmph require specialized rolling stock designs and manufacturing. Such rolling stock would require more intensive maintenance and safety protocols/systems.

Traction

The Namibian Railway as well as the railways in Angola, Botswana and Zambia have been running on diesel traction. Maintaining diesel traction would maintain regional fluidity of train movements.

Furthermore, while the traffic potential for this study indicates that there is a commercial case for developing the line, it is not likely that traffic volumes would justify electrifying the line today. Rather, the cost may not be justified, if at all, even after couple of decades following the line's development.

By the time the first set of diesel locomotives procured for the project complete their useful life, it can be safely anticipated that 'battery' operated railway locomotives will have progressed far enough in their development particularly for use during short haul and yard operations. Therefore, it stands to reason that the technical and cost complexities of developing an electrified line may likely be bypassed with battery powered locomotives in the medium-to-long term.

Geometry

For passenger speed of 100 kmph and freight speed of 80 kmph, the **limiting radius for the purposes of geometric design of route/ alignment works out to 600 m (i.e., 2.91°).** Any radius less than 600 m would necessitate appropriate speed reduction.

Gradient

The topography of the proposed project area from Grootfontein to Katima Mulilo, in general, is not very undulating or steep. It evenly slopes downward from a level of about 1,450 m at Grootfontein to about 950 m at Katima Mulilo. Considering this and also the impact which ruling gradient has on train consists, haulage, and locomotive specifications, following Limiting Gradient values are proposed for the Trans Zambezi Railway corridor:

Table ES -3: Design Gradients

Characteristic	Design Criteria
Mainline Limiting Gradient	0.67% (1 in 150)
Exceptional Mainline Gradient	1.00% (1in 100)
Passing tracks and stations	0.00% - 0.25% (0 to 1 in 400)

The proposed railway line benefits from flat terrain and hence the relatively generous and beneficial gradients. For passing tracks and stations 1 in 400 gradient has been proposed to optimize the earthwork quantity and considering potential future crossing stations.

Track Centres

Considering the future potential for conversion from cape gauge to standard gauge and also likelihood of development of 'Wider' rolling stock in future, the inter track distance is recommended to be 5.0 m between track centers for Trans-Zambezi railway line.

Track Structure

The table below presents track structure proposed to be adopted for the TZR:

Table ES -4: Track Structure Parameters

Characteristic	Cape Gauge	
	Main line	Sidings & Yards
Rail	48 Kg/m R260 Grade	48 Kg/m R260 Grade
Welded/jointed	Continuously Welded	Continuously Welded/ Fish Plated
Sleepers	Concrete Sleepers P2	Concrete Sleepers P2
Sleeper Density (#/km)	1,429 per Km	1,429 per Km
Fastening System	Elastic Fastening	Elastic Fastening
Ballast depth (mm)	200	200
Ballast width at top (mm)	2,700	2,700
Turnouts **1 in 9** **1 in 12**	Rail-bound Frog with fully curved flexible point blade over Concrete Railroad Ties.	Rail-bound Frog with fully curved flexible point blade over Concrete Railroad Ties.

1.1.3 Other Design Criteria

The design criteria for the remaining elements of the proposed railway line and access roads are as follows:

- Road Design Criteria
- Traffic Design Criteria
- Bridge Design Criteria

Road Geometric Design Guidelines

The Roads Authority's geometric guideline primarily adopts the South African National Roads Agency Geometric Design Guidelines (SANRAL GDG) that sets out the geometric requirements for roads.

Road Design Controls

Road Design Speed

The recommended speed for the access roads, in rural terrain, are 80 kmph and 50 kmph in flat and undulating terrain respectively (Class C, standard drawings by the Roads Authority). The speed limit within urban areas is 60 kmph.

Road Design Vehicle

The access roads will be used by a combination of private and public small vehicles and occasionally single unit trucks, busses, and semi trailer trucks. The heavier vehicles will dictate practical design arrangements such as turning radii.

Road Horizontal Design

For a design speed of 80 kmph, the minimum radius of horizontal curve should be 210m and 250 m with superelevation of 10%and 6% respectively.

Road Vertical Design

The minimum k-value of 30 is recommended for sag curves (headlight illumination criteria) and 85 for crest curves.

Road Pavement Design

The following was assumed:

i) Smaller train station: 10-20 vehicles per day per lane. Pavement Class = ES0.03.

ii) Large train stations: 75-220 vehicles per day. Pavement Class = ES0.3.

The recommended pavement structure for surfaced roads is derived from the catalogue in TRH4.

Drainage Design

The drainage design should follow the Roads Authority's Drainage Design Manual.

Traffic Design Criteria

A road crossing is defined as the intersection in plan view between a roadway and the railway at grade. This applies to all public and private roads as well as designated animal/cattle crossings. When designing a railway there are two possible approaches for addressing these crossings - by providing a 'Grade Separator' or by providing a 'Level Crossing'. Grade separators are warranted at locations where road traffic is high and where necessity of closure of gates at level crossings is very frequent.

This also brings in safety issues and train operation difficulties. Ideal condition would be to provide all grade separators which unfortunately makes the project prohibitively expensive. Hence a balanced and logical approach in making the decision between Grade Separator and level Crossing needs to be made.

Criteria for provision of grade separators and level crossings needs to evolve based on the road traffic details, projected train traffic and method of operation of the gates. Generally, level crossings are provided at secondary roads and below.

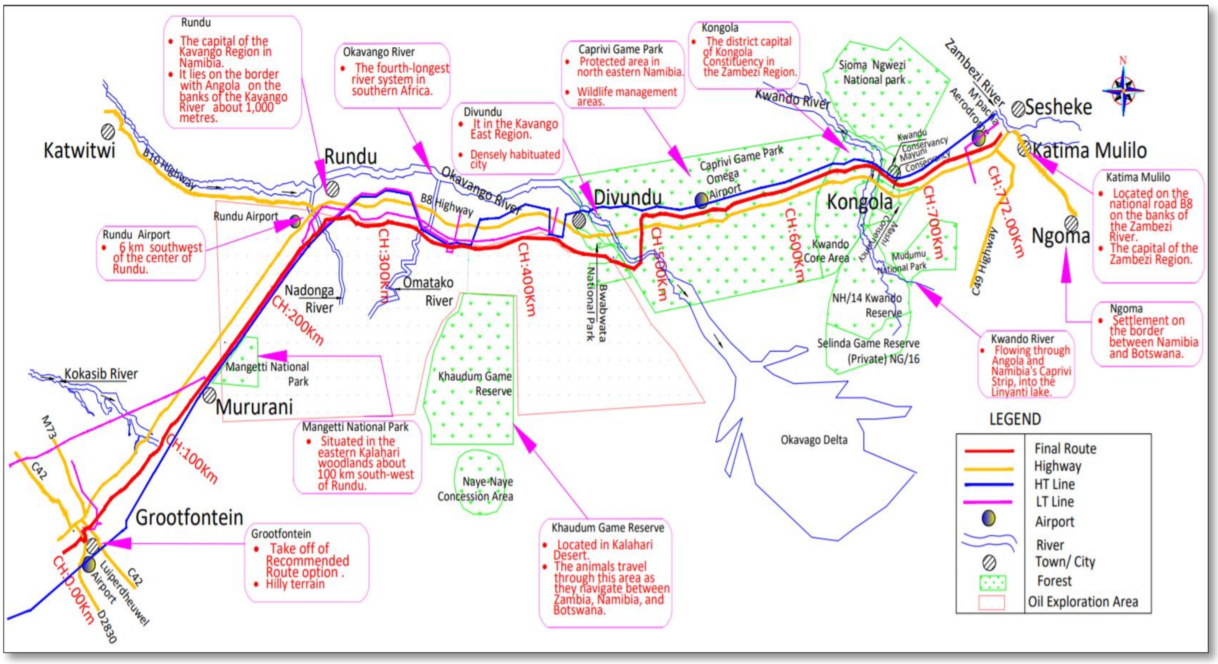
Bridge Design Criteria

It is recommended that the TZR adopt the present norms being followed by Namibian Railway i.e., South African Transport Services (SATS) bridge loading code for bridge design in conjunction with the highway bridge loading code TMH7. However, it is desirable that the bridge code for design of railway bridges be revised (preferably, uniformly for all southern African countries) and an updated document formulated for design of bridges on this railway corridor at the Detailed Design stage to align with the latest developments in the Eurocode.

1.1.4 Characteristics of Railway Alignment

The options that were considered towards arriving at the finalized route were discussed in the Travel Demand Report – Vol I - Route Options Assessment. Details of the finalized route are provided pictorially in Figure ES-2.

Figure ES -2: Final Route

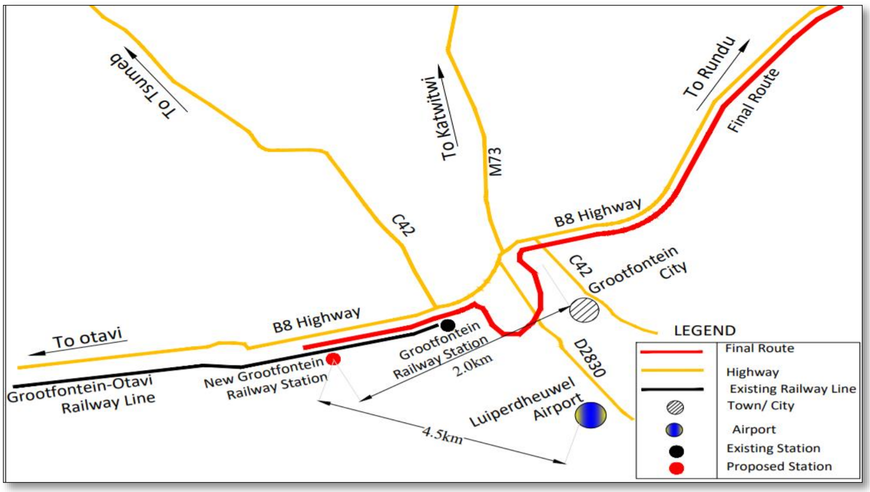


The Terms of Reference (TOR) for this study stipulates the take-off and termination points for the Trans-Zambezi Extension line as Grootfontein and Katima Mulilo respectively.

Starting Station-New Grootfontein

The take-off of the TZR from Grootfontein is proposed from about 2.0 km west of the existing Grootfontein station towards Otavi. Three loop lines are proposed which would provide direct connectivity to the proposed Grootfontein-Katima Mulilo line as well as to the existing Walvis Bay-Grootfontein line.

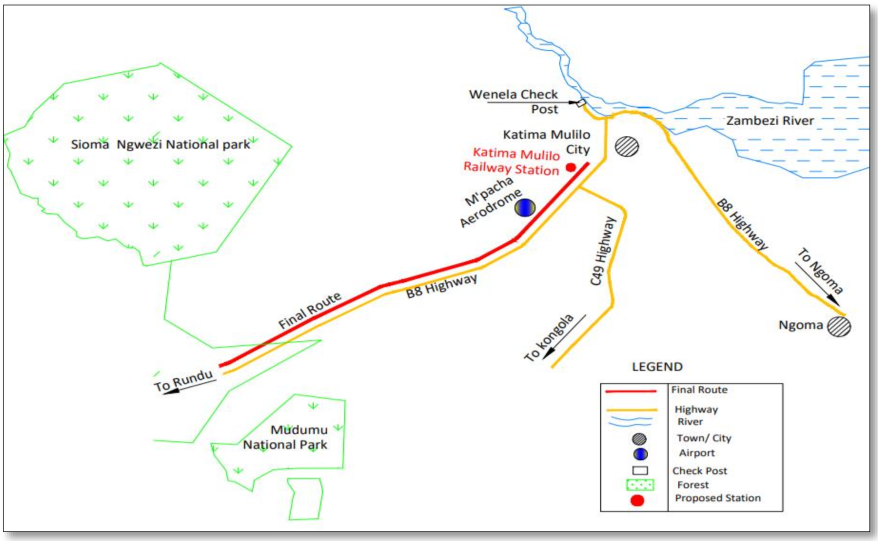
Figure ES-3: Take-off from Grootfontein



Terminating Station - Katima Mulilo

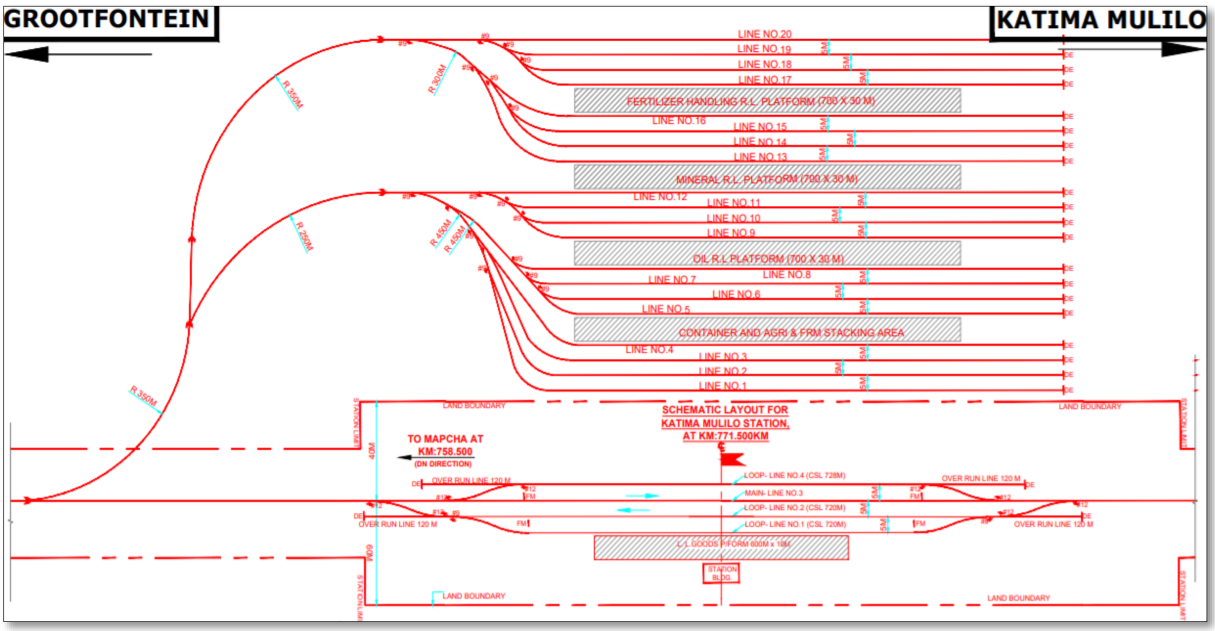
Katima Mulilo is the capital of the Zambezi Region of Namibia and is located on National Road B8 in the Caprivi Strip on the banks of the Zambezi River. The end coordinates of the route are 17°33'28.88"S and 24°15'12.31"E which is roughly 2.00 km from the centre of the city (see Figure ES-4 below).

Figure ES-4: Terminating Station-Katima Mulilo



The potential yard layout for Katima Mulilo station is as indicated below:

Figure ES-5: Line Diagram of Katima Mulilo Station-For Final Route



Summary of Key Features of Final Route:

Table ES-6: Summary of Key Features of Final Route

#	Description	Details
1	Colour Code	
2	Connectivity	Starts from Grootfontein, avoiding settlement at Grootfontein and then runs along south side of B8 upto Rundu. From Rundu bypassing densely habitated stretches in Rundu up to Kaisosi. From Kaisosi to Divundu along south side of B8 road. From Divundu to Katima Mulilo along north side of B8 road.
3	Route Length (km)	772.00
4	Curve Length (km)	44.10
5	Number of Curves	171
6	Road Crossings- LCs (#)	37
7	Road under bridges (RUBs) (#)	70
8	Road Over Bridges (ROBs) (#)	7
9	River Crossing (#)	5
10	Important Bridges (above 50 m span) (#)	2
11	Major Bridges (6 to 50 m span) (#)	7
12	Minor Bridges (below 6 m span) (#)	358
13	Proposed Eco crossing (#)	14
14	Major Cities / towns	Grootfontein, Mururani, Katjinakatji, Ncamagoro, Tien Myl, Rundu, Shitemo, Ndiyona, Divundu, Omega, Kongola, Sibbinda, Kasheshe, Katima Mulilo

1.1.5 Structures

Based on the study of structures and 'openings' provided on the adjacent B8 road corridor as well as preliminary hydrological studies, following is the summary of proposed bridges and culverts on the alignment at this feasibility stage (Table ES-7 and Table ES-8).

Table ES-7: Summary of Proposed Bridges on Final Route

#	Description	Qty.
1	Minor Bridge (Culverts)	358
2	Major Bridge	7
3	Important Bridge	2

Table ES-8: Summary of Road Bridges (ROB/RUB)

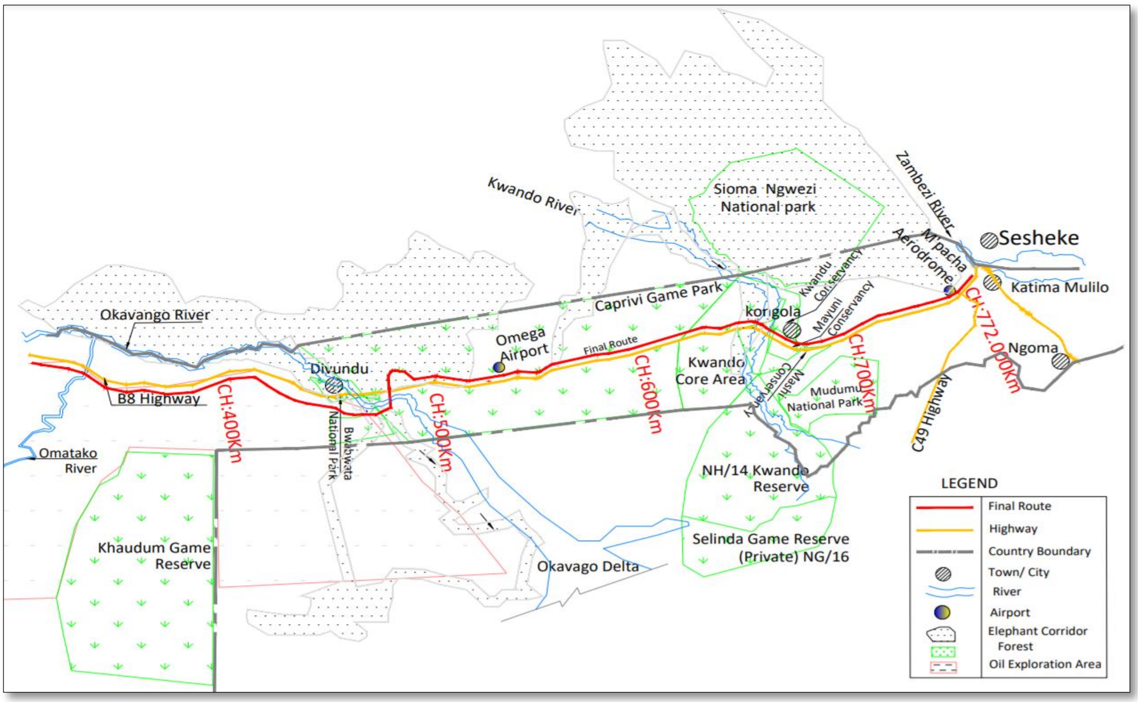
#	Description	Qty.
1	ROB (Road over Bridge)	7
2	RUB (Road Under Bridge)	70
3	Level Crossing	37

A detailed **Major/Minor/Important Bridge List** is as per Appendix -3 – Major/Minor/Important Bridge List to this report.

A detailed **ROB/RUB/Level Crossing List** is as per Appendix -4- ROB/RUB/Level Crossing to this report.

Eco Crossings

Figure ES-6: Eco Corridor along the Final Route



The final TZR route traverses the environmentally sensitive area from Divundu to Kongola where animals, generally elephants, could cross the existing B8 highway and the proposed TZR. To facilitate unhindered wildlife movement, 'Eco Crossings' have been proposed (see Table ES-9).

Table ES-9: Eco Crossings along the Final Route

#	Chainage (From –To)	#
1	From km 464.000 to 526.000 at every 10 km	7
2	From km 562.000 to 567.000 at every 10 km	1
3	From km 615.000 to 663.000 at every 10 km	5
4	From km 693.000 to 702.000 at every 10 km	1
	Total Eco Crossings (#)	**14**

The rationale of an eco- crossing is to create a continuous natural surface on a bridge type structure to enable wild and domestic animals to safely cross a railway line or road without conflict.

Also, adequate 'Fencing' has been proposed to protect wildlife on both sides of the railway corridor on this stretch.

1.1.6 Project Engineering

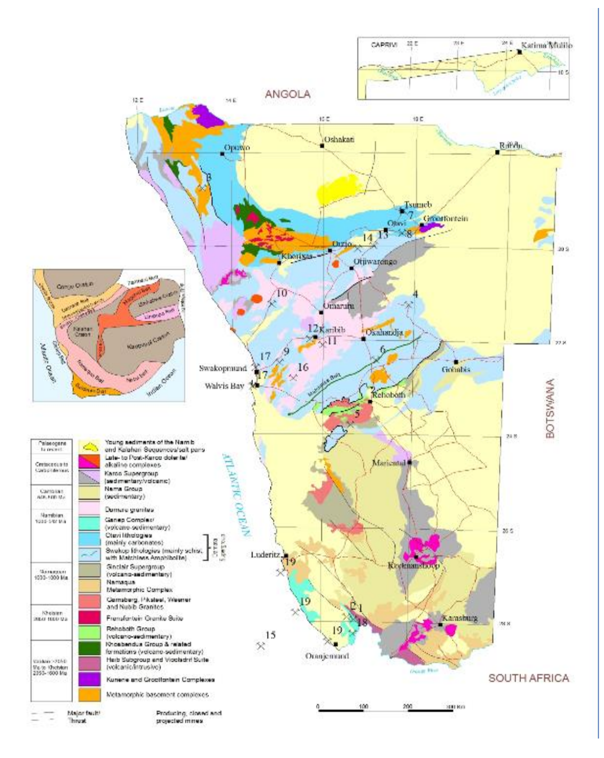
Geology and Geotechnical Engineering

The TZR runs mostly along the B8 road. The project area traverses four regions, Otjozondjupa; Kavango West; Kavango East and Zambezi.

A simplified Geological Map of Namibia is as indicated in Figure ES-7. The entire route of the railway line falls in the Palaeogene to recent age which generally comprises of young sediments of Nambi and Kalahari Sequences. A small portion near Grootfontein falling in Otavi lithologies comprising of mainly carbonates.

The project area is part of the Kalahari Basin, a vast inland depression that formed some 130 – 180 million years ago. Much of the Kalahari consist of sand shaped by wind into dunes.

Figure ES-7: Simplified Geological Map of Namibia



Simplified Geological Map of Namibia (GSN)	**Extent of Kalahari group (GSN)**

Source: Geological Survey of Namibia

Geological and geotechnical data has been gathered from prior ground investigations for road projects in the vicinity of the project as follows:

- material tests carried out on the samples taken from pits

- past data on investigations carried out on the samples sourced form the pits along the final route
- Dynamic cone penetrometer tests results along the road route as has been detailed above

It is concluded that no major challenges are likely to be encountered in constructing the railway embankment by fill material including structural layers.

The quality of the available materials in the project area is generally considered good for the purpose of fill for railway embankments. The foundations of cross drainage structures would also not pose any major problems and the majority of these structures can be provided with open foundations.

At major bridges, detail geotechnical investigation will have to be done to establish the type of foundations, at detail design stage.

Hydrology and Hydraulics

As far as hydrology and drainage is concerned, TransNamib has not developed any specific manual / code for the same. However, inspired by the first Road Drainage Manual (RDM) developed in South Africa in 1981, the former Department of Transport in Namibia adapted sections of the Road Drainage Manual and published its own "Drainage Manual" under the auspices of the Ministry of Works, Transport and Communication, Government of the Republic of Namibia in 1993. Later, the manual was updated in the year 2014 and is now known as Road 'Drainage Manual 2014'. TransNamib has accepted the Drainage Manual 2014 as one of the many Road Manuals suitable for use on railway projects too.

Furthermore, the TZR is proposed to run concurrently with the major arterial roads (in the same transport corridors). The proposed rail alignment runs along B8 road. Hence for the purpose of feasibility stage hydrological assessment for this project, road Drainage Manual 2014 has been considered as a base guiding document.

The project area between Grootfontein to Katima Mulilo is extremely flat, so much so that the topographical maps do not show many contours of this area except some stretch at Grootfontein. Although this area receives relatively high rainfall in the Namibian context, the topography is such that catchment areas in the conventional sense do not predominate, although (isolated) localised drainage lines do feature.

The perennial rivers that are traversed by the TZR in the East Kavango and Zambezi Regions – namely the Okavango and Kwando Rivers – are lifelines for the people and wildlife.

Engineering Survey Parameters

→ **Materials Manual (Geotechnical Survey)**

The Roads Authority's Materials Manual sets standard and norms to be adhered to in the execution of materials-related work. The Materials Manual of the RA sets out the geotechnical work to be carried out at the detail design stage.

→ **Centreline Materials Survey**

The properties of the soil in the bulk earthworks shall comply to Spoornet's specification no. S410. If the natural soils are unsuitable sub-ballast may be stabilised.

→ **Survey manual (Topographic Survey)**

The survey work consists of three phases namely:

i) Basic Survey,

ii) Digital Terrain Model (DTM) Survey and

iii) The Topographical Detail Survey (at the detail design stage)

→ **Compensation Survey**

The rail will pass through a substantial portion of communal land. The inhabitants are to be compensated for disturbance. The RA manuals does not specifically specify the time and extent of how the compensations should be dealt with. The MoWT has published a guideline on land acquisition and compensation that can be used as a guideline.

It is recommended that the compensation procedure should be clarified with the MoWT during the detail design phase.

1.1.7 Stations

The following factors are considered when selecting a site for a railway station:

- **Spacing:** Distance from adjacent station
- **Adequate land:** There should be adequate land available for the station building, not only for the proposed line but also for any future expansion on both sides of the station.
- **Level area with good drainage:** The proposed site should preferably be on a fairly level ground with good drainage arrangements.
- **Alignment:** The station site should preferably have a straight alignment so that various signals are clearly visible. The proximity of the station site to a curve presents several operational problems.
- **Easy accessibility:** The station site should be easily accessible for station staff.
- **Facilities:** The site selected for the station should have sufficient facilities (water and power supply, sewerage) for staff to perform their functions which is mainly booking and managing traffic.
- **Visibility:** The environment around the site selected for a station should be such that there exists clear and improved visibility for the drivers of trains.

Table ES-10 provides a comprehensive list of stations proposed on TZR.

Table ES-10: Station Locations on Final Route

#	Name of Proposed Station	From: KM	To: KM	Distance Between Stations(km)	Ruling Gradient between Stations	Gradient at Station
1	Grootfontein	0.000	1.000			1 in 800
				22.000	1 in 170	
2	Berg Aukas	22.000	23.000			1 in 400
				29.200	1 in 170	
3	Crossing Station	51.200	52.200			1 in 400

#	Name of Proposed Station	From: KM	To: KM	Distance Between Stations(km)	Ruling Gradient between Stations	Gradient at Station
				21.300	1 in 200	
4	Crossing Station	72.500	73.500			1 in 800
				28.000	1 in 200	
5	Henta	100.500	101.500			1 in 800
				24.500	1 in 200	
6	Mururani	125.000	126.000			1 in 400
				26.000	1 in 300	
7	Crossing Station	151.000	152.000			1 in 400
				26.000	1 in 170	
8	Crossing Station	177.000	178.000			Level
				27.000	1 in 200	
9	Kuseka	204.000	205.000			Level
				28.000	1 in 300	
10	Nkutu	232.000	233.000			1 in 400
				17.000	1 in 200	
11	Crossing Station	249.000	250.000			1 in 400
				14.000	1 in 200	
12	Rundu	263.000	264.000			1 in 400
				20.000	1 in 200	
13	Kambowo	283.000	284.000			1 in 400
				17.000	1 in 200	
14	Kaiango	300.000	301.000			1 in 800
				28.000	1 in 200	
15	Mabushe	328.000	329.000			1 in 400
				19.000	1 in 200	
16	Nyondo	347.000	348.000			Level
				17.000	1 in 200	
17	Nadiyona	364.000	365.000			1 in 1000
				16.000	1 in 200	
18	Kayaru	380.000	381.000			1 in 600
				21.000	1 in 170	
19	Crossing Station	401.000	402.000			Level
				28.000	1 in 300	
20	Shinyemba	429.000	430.000			1 in 800
				21.000	1 in 200	
21	Kake	450.000	451.000			1 in 800
				17.000	1 in 200	
22	Divundu	467.000	468.000			1 in 1200
				18.000	1 in 170	
23	Crossing Station	485.000	486.000			Level
				17.000	1 in 800	
24	Crossing Station	502.000	503.000			1 in 800

#	Name of Proposed Station	From: KM	To: KM	Distance Between Stations(km)	Ruling Gradient between Stations	Gradient at Station
				24.000	1 in 400	
25	Omega	526.000	527.000			1 in 400
				27.000	1 in 200	
26	Crossing Station	553.000	554.000			Level
				26.000	1 in 400	
27	Crossing Station	579.000	580.000			1 in 800
				24.000	1 in 200	
28	Omega III	603.000	604.000			1 in 800
				29.000	1 in 200	
29	Crossing Station	632.000	633.000			Level
				30.900	1 in 300	
30	Kongola	662.900	663.900			1 in 400
				23.600	1 in 170	
31	Crossing Station	686.500	687.500			Level
				22.500	1 in 1000	
32	Sibbinda	709.000	710.000			Level
				24.000	1 in 300	
33	Sachinga	733.000	734.000			Level
				25.000	1 in 200	
34	Mpacha	758.000	759.000			1 in 400
				13.000	1 in 200	
35	Katima Mulilo	771.000	772.000			Level

1.1.8 Signal and Telecommunications

Signal

Electronic Interlocking (EI) is the most modern and 'State of Art' technology in Railway Signalling and is recommended for the TZR considering the traffic potential and the number of trains which are anticipated to run on the route.

EI has several advantages in comparison to Panel Interlocking (PI) and Route Relay Interlocking (RRI) as under:

- System can be tested at factory level using simulation panels.
- Modular in design and easy for maintenance, thus requiring less staff.
- Expertise of hardware and software is not much needed for maintaining the equipment at initial stage.
- Requires a smaller number of relays - vital EI replaces interlocking circuits thus less space required for signal equipment room (Relay rooms).

- Less power supply as compared with existing PI/ RRI's. Less failures, less wiring, less soldering, less complexity in the circuit.
- Enables usage of optical fiber cable (with Object Controller) which reduces requirement of copper cables, their cost & maintenance.
- Remote operation of signals, points, and level crossings controls is feasible.
- Is compatible with Centralized Traffic Control.
- All EI's are designed and manufactured as per the international safety standards particularly European standards.
- Standard of safety and reliability is higher as compared to Panel Interlocking or Route Relay Interlocking systems.
- Datalogger / Event logger is an integral part of EI.
- Has Self-diagnostic in feature - easy for rectification of failures and reduces failure duration.

Telecommunications

The following technologies could be considered to design the telecommunication for the railway:

→ Fiber optic backbone or microwave links connecting different railway locations (stations and bungalows) and the railway control center.

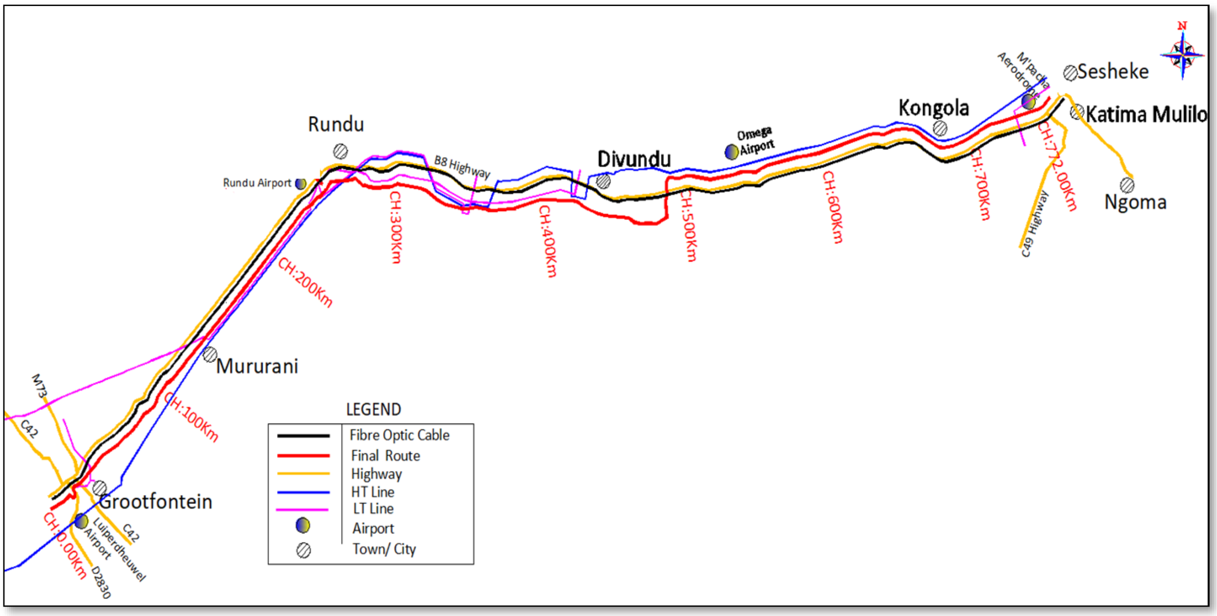
→ Transmission network equipment, such as Synchronous Digital Hierarchy (SDH) or IP/Ethernet to backhaul voice and data communications between these railway locations.

→ Fixed telephony at stations and at specific locations such as signals and switches.

→ Radio communications such as Very High Frequency (VHF) or cellular for track-to-train voice communications.

Trans-Zambezi Railway extention must utilise the optical cable of Telecom Namibia on the stetches were its optical cable runs close to the railway alignment and install long distance communication network laying optical cables along the railway line on other stretches. (Refer to Figure ES-8)

Figure ES-8: Fibre Optic Cable of Telecom Namibia along the Final Route



1.1.9 Railway Operations

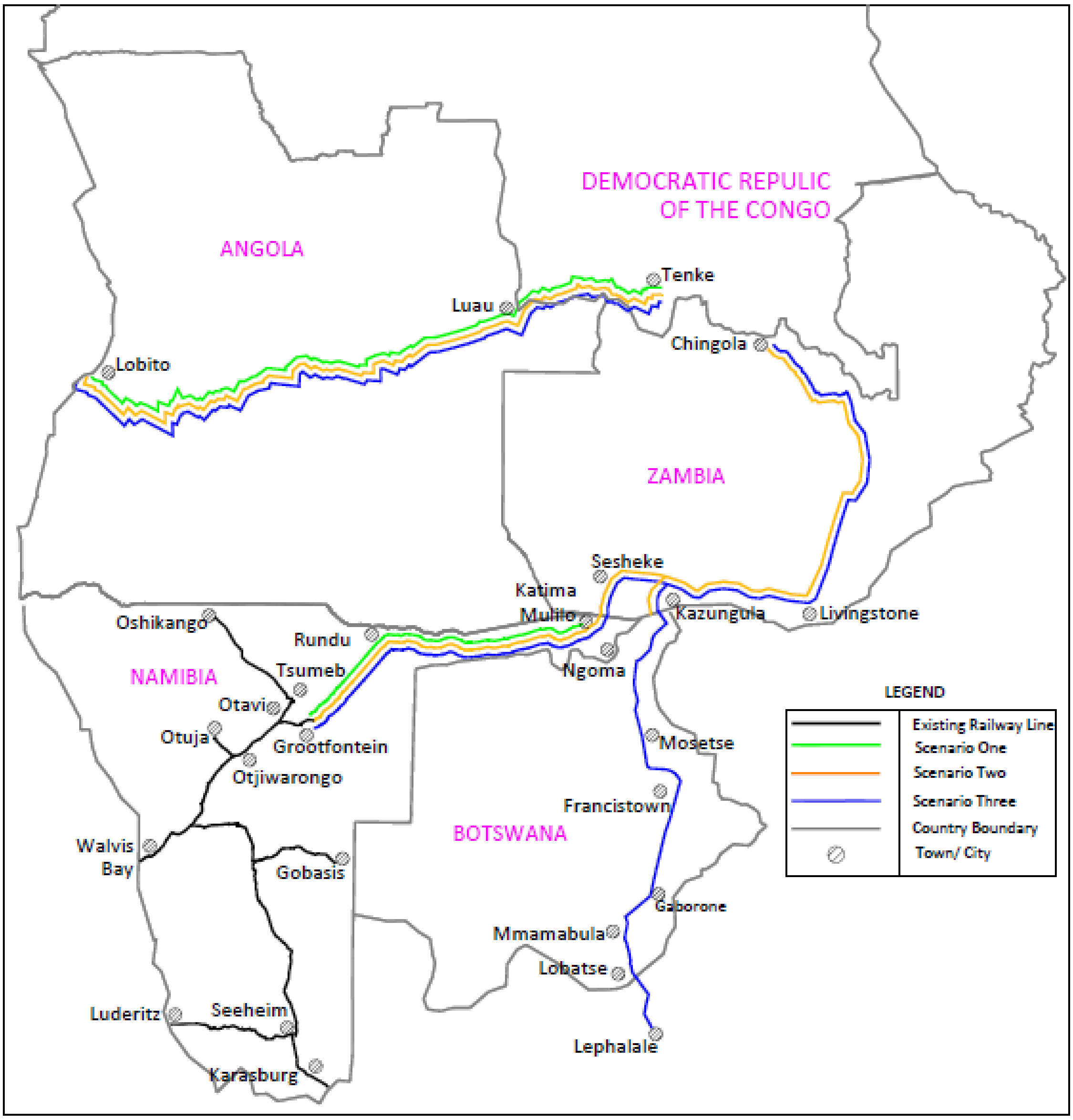
The traffic demand and forecast has been covered in detail in the previous Deliverable i.e., **'Travel Demand Model Report – Vol II.** (Transport Volume Estimation) prepared by the Consultant as part of the '*Feasibility Study for the Trans-Zambezi Railway Extension Grootfontein – Rundu – Katima Mulilo* this study'. The study considered 13 scenarios for assessment of traffic.

The table and figure that follow summarize the scenarios that were carried forward for preparing the operational requirements of the TZR, namely the rolling stock procurement.

Table ES-10: Scenario Descriptions used for Railway Operation Study

Updated Scenario #	Trans-Zambezi Rail is built	Benguela Line (including extension from Luau to Dilolo/Tenke) is successfully tendered	Zambia's existing network from Livingstone to Chingola is rehabilitated	Zambia East/West line from Sesheke to Livingstone via Kazungula is built	Botswana North/South Line (Kazungula to Lephalale) is built
Primary Funding Responsibility	Namibia	Angola	Zambia	Zambia	Botswana
1	Included	Included	Not Included	Not Included	Not Included
2	Included	Included	Included	Included	Not Included
3	Included	Included	Included	Included	Included

Figure ES-8: All Scenario Map for Railway Operation Study



Rolling Stock Features

There is a requirement of four types of wagons to transport the potential freight traffic. The basic features of proposed wagons which can give optimised output are as under:

Table ES-11: Basic Wagon features

#	Type of wagons	A/L(T)	Tare weight(T)	Pay load (T)	Gross load (T)	Pay to tare ratio	Wagon length over coupler	Commodities which can be loaded
1	Open	18.5 t	20t	54t	74 t	2.7	10.89 m	Iron ore, Minerals
2	Covered	18.5 t	23t	51t	74 t	2.22	14.45 m	Bagged commodities like food grains, fertilizers, cement etc.

#	Type of wagons	A/L(T)	Tare weight(T)	Pay load (T)	Gross load (T)	Pay to tare ratio	Wagon length over coupler	Commodities which can be loaded
3	Flat	18.5 t	19t	55t	74 t	2.89	13.16	ISO containers
4	Tank	18.5 t	25t	49t	74 t	1.96	12.42	Petroleum products

Presently Namibian railway system is using 2000 HP diesel locomotives. It is further understood that TransNamib in a process of acquiring 2250 horsepower diesel locomotive on lease. For working of completed Trans Zambezi railway system, there can be following options.

1. To continue with 2 X 2250 horsepower diesel locomotive. It is best option in the initial stage as connecting railway systems (Grootfontein- Walvis Bay and Zambian Railway) might not be able to upgrade to 18.5 t axle load uniformly. If required in future, 3 X 2250 horsepower diesel locomotive can be used to meet requirement of running time and line capacity.
2. However, if connecting railways permit use of 4000 HP diesel locomotive on their system from initial stage, this type of locomotive would be a better option.

Based on the traffic assessment, Table ES-12 summarizes the wagon requirements over the forecast period, based on 40 wagon train consists. The requirements include a 4%-time allowance for maintenance and servicing of wagons.

Table ES-12: Wagon Requirement by Scenario

Scenario 1	**Year**						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	40	264	361	487	639	735	801
Covered	44	154	236	362	559	697	795
Flat	2	28	73	158	321	440	528
Tank	24	81	121	182	274	338	384
Total	110	527	791	1,189	1,793	2,210	2,508
Scenario 2	**Year**						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	98	483	679	937	1,245	1,441	1,575
Covered	26	201	324	526	867	1,110	1,286
Flat	39	183	314	543	959	1,260	1,480
Tank	35	177	266	400	607	750	853
Total	198	1,044	1,583	2,406	3,678	4,561	5,194
Scenario 3	**Year**						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	91	456	629	857	1,129	1,302	1,420
Covered	13	152	252	419	703	906	1,053
Flat	22	121	227	415	761	1,012	1,196
Tank	42	151	227	342	518	641	729
Total	168	880	1,335	2,033	3,111	3,861	4,398

Locomotive requirements have been assessed considering requirements of two locomotives for each train. For all maintenance schedule and servicing, a 10%-time allowance has been considered for locomotives. Terminal detention i.e., waiting time for trains and shunting/placement has been considered about 5 hours at each end. Table ES-13 summarizes the locomotive requirements over the forecast period.

Table ES-13: Locomotive Requirement by Scenario

Scenario 1							
40 WAGON TRAIN	**Year**						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	3	12	12	17	20	26	28
Covered	3	6	9	12	17	20	26
Flat	6	12	14	20	28	34	37
Tank	3	6	6	6	9	12	12
Total	15	36	41	55	74	92	103
Scenario 2							
40 WAGON TRAIN	**Year**						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	3	14	20	28	39	45	50
Covered	3	11	16	23	35	43	49
Flat	6	17	25	37	54	66	75
Tank	2	6	7	11	16	19	22
Total	14	48	68	99	144	173	196
Scenario 3							
40 WAGON TRAIN	**Year**						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	3	14	19	26	34	40	45
Covered	3	9	14	20	30	37	42
Flat	5	14	21	31	47	57	65
Tank	2	5	6	9	14	11	19
Total	13	42	60	86	125	145	171

1.1.10 Bill of Quantities and Cost Estimate

Table ES-14 summarizes the key project quantities of the TZR.

Table ES-14: Key Project Quantities

#	Key Features	Quantity
i	Route Length (km)	772.00
ii	Track Length (km)	873.00
iii	Earthwork- Filling (million m3)	39.00
iv	Earthwork- Cutting (million m3)	8.00
v	Sub Ballast Layer (million m3)	2.00
vi	Ballast (million m3)	2.00

#	Key Features	Quantity
vii	Land (ha)	4,186.00

The rates of various items have been assessed on the basis of:

i. Comparable costs of Railway and Highway projects in Namibia
ii. Comparable costs of recent regional railway projects in Africa
iii. Consultants own library and database
iv. Current market rates for land in Namibia

Based upon extensive studies, surveys, and preliminary designs of the project, we have estimated the Project Cost for the Trans-Zambezi extension line as **US$ 2,267 million.** Table ES-15 summary of the TZR project cost estimates.

Table ES-15: Summary of Project Cost Estimate

#	Description of Work		Total Cost (In Mn. US$)
A	**Permanent Way Material**		**375**
B	**Permanent Way Linking**		**71**
	Total of Permanent Way (Material+ Labour) (A) + (B)		**446**
C	**Formation**		**929**
	Total for P-way and Earthwork (A +B + C)		**1,375**
D	**Structures**		**436**
	Total Cost for Civil Works (A+B+C+D)		**1,811**
E	**Land Acquisition & Resettlement Cost**		**35**
	Total Cost for Civil Works + Land (A+B+C+D+E)		**1,846**
F	**Workshop, T&P and Electrical**		**64**
G	**Signal & Telecommunication**		**128**
H	**Access Roads**		**5**
I	**Total Cost of Infrastructure (A+B+C+D+E+F+G+H)**		**2,043**
J	**Preliminary Expenses**	2%	41
K	**Contingencies and Misc.**	4%	82
L	**General Charges, Design and Project Management**	5%	102

#	Description of Work		Total Cost (In Mn. US$)
	TOTAL COST OF PROJECT (I+J+K+L) (Rounded)		**2,267**
	Route Identification		**Final Route**
	Route Length (km)		**772.00**
	Track Length (km)		**872.93**
1	Per Route km (Million US$)		**2.94**
2	Per Track km (Million US$)		**2.60**

2 Introduction

2.1 Authority of Assignment

This study is being undertaken under the authority of a contract signed between the Ministry of Works and Transport (MoWT), Government of Republic of Namibia (i.e., the 'Client') and M R Technofin Consultants Ltd. (MRTCL) (i.e., the 'Consultant') on March 10th, 2021 (Contract No. MWT/TIIP/ISCB/20/05). MRTCL is leading a consortium with Burmeister & Partners (Pty) Ltd., University of Cape Town, Enviro Dynamics, Koep & Partners, and 3TI Progetti.

2.2 Objectives of the Assignment

The overall objective of the assignment is to 'research and analyse data and information pertaining to the Trans-Zambezi Railway extension of Grootfontein-Rundu-Katima Mulilo and provide to the Ministry of Works and Transport, adequate strategic, economic and technical information on the project feasibility'.

The proposed Trans -Zambezi extension from Grootfontein - Rundu - Katima Mulilo will directly link the Namibian Railways with Zambia while also facilitating connectivity with Angola, Botswana and the Southern Democratic Republic of Congo (DRC). Securing Namibia's position as a regional hub is the main motivating objective for this study, with expectations that the Trans-Zambezi extension will spur trans-border to/from Walvis Bay from neighbouring countries and to give effect to Namibia's Vision 2030 to become the transport hub for land lock countries.

2.2.1 Specific Objectives of the Study

The specific objectives as per Section 2.2 of the Terms of Reference are as follows:

a) Assessment of regional railway infrastructure development projects in Zambia, Angola and Botswana through consultations with relevant Authorities and Institutions in the neighbouring countries.
b) Evaluation of the project transport demand: key users, commodities, annual freight volumes, transport prices, competing routes and modes.
c) Evaluation of alternative options for achieving the regional railway interconnection from Namibia and identification of the most favourable route. Elaboration of appropriate project implementation plan and financing.
d) Assessment of multimodal road + rail alternative.
e) Determination of the viability for the development of the Trans-Zambezi Railway Corridor.

2.3 Progress Made and Reports Submitted

2.3.1 Inception Report

The Consultant's team of experts was mobilized and the 'Kick Off' meeting for this study was held on 13th April 2021 at 14h00 Namibia time through Zoom video conference. This meeting was attended by the MoWT officials and the Consultant's team. The Consultant made a detailed 'Kick Off Presentation' to the attendees and the feedback from the ministry was noted. The 'Draft Inception Report' was submitted on 12th April 2021. Based on comments received from MoWT on 20th April 2021, the 'Revised Inception Report' was submitted to the Client on 30th April 2021.

2.3.2 Inception Report Workshop

A 'Workshop' on the Inception Report was conducted on 11th May 2021 by the Consultant, which was attended by MoWT officials and other stakeholders from TransNamib and others. Based on the observations received from MoWT on 14th May 2021, the Consultant made appropriate modifications and minor changes in the report. The 'Final Inception report' was submitted on 26th May 2021 and was accepted/approved by MoWT.

2.3.3 Engineering Working Paper

As an 'Interim' deliverable, the Consultant submitted an 'Engineering Working Paper' on 29th July 2021. The purpose of the Paper was to provide details of the design criteria and recommendation of railway route for Trans Zambezi Railway extension.

2.3.4 Workshop on Route Finalization

A 'Workshop' on the 'Route Finalization Discussion' was conducted on 1st September 2021 by the Consultant, which was attended by MoWT officials and other key stakeholders, and detailed deliberations were held. Further comments and observations were received from MoWT on 13th, 14th & 15th September 2021 and 16th September 2021. The Consultant responded to all the observations in a consolidated manner and key issues have further been dealt with in Travel Demand Model report.

2.3.5 Travel Demand Report – Vol I. Route Options Assessment

The Consultant's team prepared and submitted the first volume of the second milestone deliverable for the assignment – the Travel Demand Report – Vol I. Route Options Assessment on October 20th, 2021. The Report describes, in detail, the design basis for the proposed Trans-Zambezi railway line as well as potential route options that were assessed towards arriving at the recommended route.

Vol I. also includes a companion report which details the anticipated land acquisition and resettlement costs and how they were calculated.

2.3.6 Travel Demand Report – Vol II. Trans-Zambezi Railway Transport Volume Estimation

The Consultant's team prepared and submitted the second and final volume of the second milestone deliverable for the assignment – the Travel Demand Report – Vol II. Trans-Zambezi Railway Transport Volume Estimation on October 29th, 2021. The report describes the freight traffic assessment for the Trans-Zambezi Railway line, which will inform the commercial assessment at the feasibility stage of this assignment.

2.3.7 Project Discussion Workshop with AfDB

A 'Workshop' on the overall project discussion with African Development Bank (AfDB) was conducted on 12th November, 2021 by the Consultant. The workshop was attended by MoWT officials, the Walvis Bay Corridor Group, TransNamib and AfDB. Detailed deliberations included updating AfDB on the Consultant's route, technical and traffic assessment as well as the assignment's next steps. AfDB requested to have another workshop once the draft feasibility report was submitted (this report).

2.3.8 Field Mission Reports

On November 8th, 2021, the Consultant's team submitted field mission reports for Angola, Zambia and Botswana. The Field Mission Reports cover the outcomes of videoconference and in-person consultations in Angola, Zambia and Botswana as well as a summary of the data and documents reviewed as part of the mission.

2.3.9 Draft Feasibility Study Report

The Consultant's team prepared and submitted the milestone deliverable for the assignment – the Draft Feasibility Study Report – Vol I, Vol II & Vol III on January 7th, 2022. The Report describes, in detail, the design criteria and preliminary design for the proposed Trans-Zambezi railway line recommended route.

2.3.10 Draft Feasibility Study Report Workshop

A 'Workshop' on the Draft Feasibility Report was conducted on 17th Feb 2022 by the Consultant, which was attended by MoWT officials and other stakeholders from TransNamib and others. Based on written observations received from MoWT on March 1st, 2022, the Consultant made appropriate modifications to the report. This report is the 'Final Feasibility report'.

2.3.11 Presentation to Honourable Minister and Senior Management

A 'Project Appraisal' presentation was made to the Honourable Minister of MoWT, Namibia and the CEO of TransNamib on March 9th, 2022. The work done on the project by the Consultant was well received and appreciated. The Minister emphasized the importance of the project for Namibia and the region and conveyed the Government of Namibia's resolve to proceed further with developing the Trans-Zambezi rail line.

2.4 Purpose of this Report

This, Vol I of Final Feasibility Report, describes, in detail, the design criteria and preliminary designs for the proposed Trans-Zambezi Railway.

2.5 Structure of this Report

In order to keep the Final Feasibility Study Report handy and easy to read, the Report has been spilt into Three distinct sections as follows:

- → **Vol I. - Preliminary Design Report**
- → **Vol II. – Project Feasibility**
- → **Vol III. – Project Drawings**

This document is Vol I. - Preliminary Design Report and is organized as follows:

Section 1: Executive Summary

Section 2: Introduction

Section 3: Background

Section 4: Railway Design Criteria

Section 5: Other Design Criteria

Section 6: Railway Alignment

Section 7: Project Engineering

Section 8: Structures

Section 9: Stations

Section 10: Signal and Telecommunications

Section 11: Railway Operations

Section 12: Railway Asset Maintenance and Workshops

Section 13: Bill of Quantities & Cost Estimates

Section 14: Next Steps

Section 15: Appendices

(A) Vol II. – Project Feasibility broadly consists of:

(1) Traffic Background

(2) Financial Assessment

(3) Economic Assessement

(4) Environmental and Social Scoping Assessement

(5) Legal and Regulatory Assessment

(B) Vol III. –Project Drawings consists of:

(1) Key Plan (Overall)

(2) Key Longitudinal Section i.e. Alignment Profile (Overall)

(3) Project Sheets - Detailed Plan and L Sections – 25 Km stretches each (31 Sheets)

(4) Typical Cross-section in Cutting & Filling

(5) Key Plan of Track Layout for Grootfontein Station

(6) Key Plan of Track Layout for Rundu Station

(7) Key Plan of Track Layout for Divundu Station

(8) Key Plan of Track Layout for Kongola Station

(9) Schematic Track Layout for Katima Mulilo Station

(10) Key Plan of Track Layout for Two Loop Line Station

2.6 Project Design Stages

This section sets the stage for the designs that were prepared by the Consultant by describing the different descriptions and definitions and phases of a large transport project and to appreciate it in-line with the phase and scope of work for this railway line study.

The Road Authority (Namibia) Procedures Manual describes three phases which forms the 'initiation' of a project. Often, different names can be used to describe the same phase and so Table 2-1 summarizes each phase seeks to establish a common understanding.

Table 2-1: Road Authority Project Phase Definition

Phase	Reference Clause	Purpose	Cost Estimate Accuracy
Feasibility or "Study" (Basic planning or Project Proposal)	(Cl 2.1) / (Cl 2.4.1 (14))	To demonstrate the bankability of a project before major funds are committed	+-30%
Preliminary Design. (Concept design)	(Cl 3.1) / (Cl 3.5.1 (12))	The broad purpose of preliminary design is to define the selected route location and firmly establish the general design features	+-20%
Detail design	(Cl 4.1) / (Cl 4.9.3)	The detail design stage is defined as the work involved in the preparation of all the details necessary to enable the Works to be constructed	+-10%

The Association of Consulting Engineers of Namibia (ACEN), another leading and reputable organization also defines various specific phases of project development which is summarized in the table below.

Table 2-2: Various Specific Phases of Project Development

Phase	Reference Clause	Purpose
Reporting Stage	(Cl 9.1.1)	The Engineer shall prepare and submit a report embodying preliminary proposals or feasibility studies and estimates of cost and time where appropriate for consideration by the Client.
Preliminary Design	(Cl 9.1.2)	Following the Client's instruction to proceed, the Engineer shall develop preliminary proposals and begin the basic planning of the Project.
Design and Tender	(Cl 9.1.3)	Following the Client's instruction to proceed with the preparation of all documents necessary to enable tenders for the works to be invited.
Working Drawings	(Cl 9.1.4)	Unless and until the Client instructs him to the contrary, the Engineer shall continue to complete his working drawings. These will include any further plans, designs and drawings.

Construction	(Cl 9.1.5)	During construction of a building project the Engineer shall assist with administration and co-ordination of the Contract and shall monitor construction of the Engineering Works for compliance with his Contract Documents

The scope of this study would fall under the "Feasibility" phase as per the RA Manual and the "Reporting" phase as per ACEN. The information and cost estimates for this assignment would allow for the demonstration of bankability, which will enable MoWT to make informed decisions on how to proceed.

3 Background

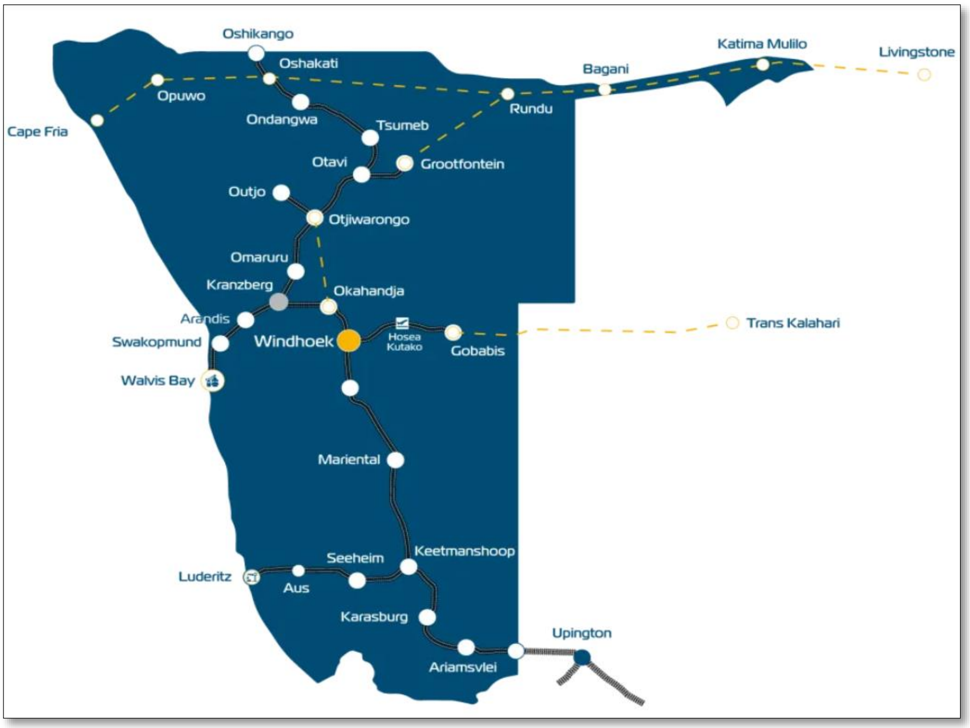
3.1 Existing Railway Infrastructure in Namibia

The Namibian Railway network and railway routes are as follows:

Table 3-1: Namibia Railway Line[2]

Railway Line	Route (km)	Gauge (m)
Nakop — Karasburg — Grünau — Seeheim — Keetmanshoop — Mariental — Rehoboth — Windhoek	865	1,067
Windhoek — Okahandja — Karibib — Kranzberg	210	1,067
Kranzberg — Usakos — Swakopmund — Walvis Bay	201	1,067
Kranzberg — Omaruru — Kalkfeld — Otjiwarongo — Otavi	328	1,067
Otavi — Tsumeb	64	1,067
Otavi — Grootfontein	90.5	1,067
Otjiwarongo — Outjo	69	1,067
Windhoek (Gammams) — International Airport — Omitara — Witvlei — Gobabis	228	1,067
Seeheim — Goageb — Aus — Lüderitz	318	1,067
Tsumeb – Ondangwa – Oshikango	306	1,067

Figure 3-1: Namibia — Rail Network[3] Source: TransNamib



3.2 Railway from Walvis Bay Port to Grootfontein

The current axle-load and speed on Walvis Bay – Grootfontein route are as follows:

---

[2] 2-Chapter 2 (klausdierks.com)
[3] Railway Network – TransNamib

- Axle-Load - Walvis Bay to Grootfontein = 16.5 ton; however, it should be noted that the axle-load for the Otavi to Grootfontein section is 15.0 ton though 16.5 ton can be accommodated for commercial reasons.
- Speed - Walvis Bay to Kranzberg = 60 kmph; Kranzberg to Grootfontein = 50 kmph

3.3 Railway Projects in Namibia

3.3.1 Ongoing And Recently Completed Works

MoWT has highlighted the following railway project currently being developed, on-going or recently completed (start and completion dates are unclear).

Table 3-2: Ongoing and Recently Completed Railway Projects in Namibia

Project Name	Summary
Railway Network Upgrading: Walvis Bay to Tsumeb	This project is for the upgrading of the earthwork embankment, strengthening of bridges and other permanent way infrastructure. It aims to increase the axle-load/ton of a 600 km stretch of railway line section to a minimum SADC standard of 18.5-ton axle-load by using 48 kg/m rail or other high profiles. To date some 183km has either been, repaired or (partially) upgraded. The project supports the expansion of the Walvis Bay Port as it will provide for an efficient flow of cargo on the Trans-Cunene rail corridor.
Northern Railway Line Extension Project	This a three phased project of which Phase I (246km) Tsumeb-Ondangwa and Phase II (60Km) Ondangwa-Oshikango of new rail are completed. Phase III (28Km) between Ondangwa and Oshakati is currently under construction. It will consist of 48 kg/m rails on concrete sleepers. Under phase III the following contracts are currently running: • Construction of Road over Rail Bridge at km 5.6 on the Ondangwa -Oshakati road- and the Earthworks embankment between km 14 and km 28 are completed. • Construction of Earthworks embankment between km 0 and km 14 is completed. o Station Buildings and Platforms commenced in May 2021 and is underway
Upgrading and Rehabilitation of the Aus-Luderitz Railway Line	Aus to the Lüderitz harbour railway line (140 km) was upgraded to 18.5-ton axle-load. The sand dune problem some 10 km outside Luderitz remains a big challenge since the dunes block train operations. Designs to construct a 4.5km sand tunnel to overcome this problem have been

Project Name	Summary
	completed and construction has been tabled for the next financial year while funding is secured.
Rehabilitation of the Sandverhaar — Bucholzbrunn railway line	This project entails upgrading the 40km railway section between Sandverhaar and Bucholzbrunn from the current carrying capacity of 16.0 ton/axle to 18.5 ton/axle. The project shall also involve redesigning curves to improve speed and improved drainage structures since the section lies in a flood prone valley. A new culvert was installed recently, and remaining upgrades are expected to commence soon.
Commuter Train Projects	In 2014 the Ministry of Works and Transport commissioned four pre- feasibility studies to investigate the viability of transporting commuters by rail between Windhoek Central and other major economic canters. The Feasibility Studies were done on the following routes. • Commuter Train Services from Windhoek to Hosea Kutako Airport • Commuter Train Services from Windhoek to Okahandja • Commuter Train Services from Windhoek to Rehoboth • Commuter Train Services from Windhoek to Central Katutura and other suburbs The next stage for these projects is detailed designs and this will commence soon. Additionally, the MoWT commenced conducting feasibility studies for commuter rails: Windhoek – Rehoboth and Windhoek – Katutura in February 2022 with expected completion dates of December 2022.
Development of the Trans Kalahari Railway Line, Coal Storage and Associated Loading Facilities	In 2010 the Governments of the Republics of Namibia and Botswana entered into a Memorandum of Understanding to facilitate the development of the Trans-Kalahari Railway Line Link in Namibia. In 2014 the two governments signed a Bilateral Agreement on the development of the 1500 km line, with its associated coal storage, conveying, loading and other ancillary facilities. An agreement led to the establishment of a Project Management Office in Windhoek which was mandated to run the day-to-day project office matters. It is envisioned that the project will be implemented on a Design- Built -Own -Operate and Transfer investment model.

Project Name	Summary
Walvis Bay to Kranzberg	Walvis Bay to Kranzberg: Due for completion in March 2023. The official new axle-load as per the Scope of Works is 18.50 ton/axle, but the upgrading design complies to 20 ton/axle. After upgrading speeds of 100 kmph for passenger trains and 80 kmph for freight trains apply but that can only be affected once the current Spoorbarber bogeys of the rolling stock are replaced with radial bogeys.
Kranzberg — Tsumeb	Of the total route length of 391.6 km, 61.60 km was fully upgraded to 18.50 ton per axle standard and 230 km partially upgraded (only sleepers and ballast replaced, old 30 kg/m rail reworked and re-fitted). The partially upgraded sections still have the 16.50 ton/axle limitation. The current program of partial upgrades is due for completion by mid-end 2023. About 60 km of partial upgrades are remaining. Thereafter the 30 kg/m rails still need to be replaced over a distance of 330 km and strengthening of formations and easing of curves as per the Consultant's design needs to be completed. Heavy maintenance on the steel bridges is also outstanding. There is no fixed budget for this project and funds are allocated annually.

Source: Ministry of Works and Transport, Namibia

3.4 Regional Rail Network

3.4.1 Regional Transport Developments

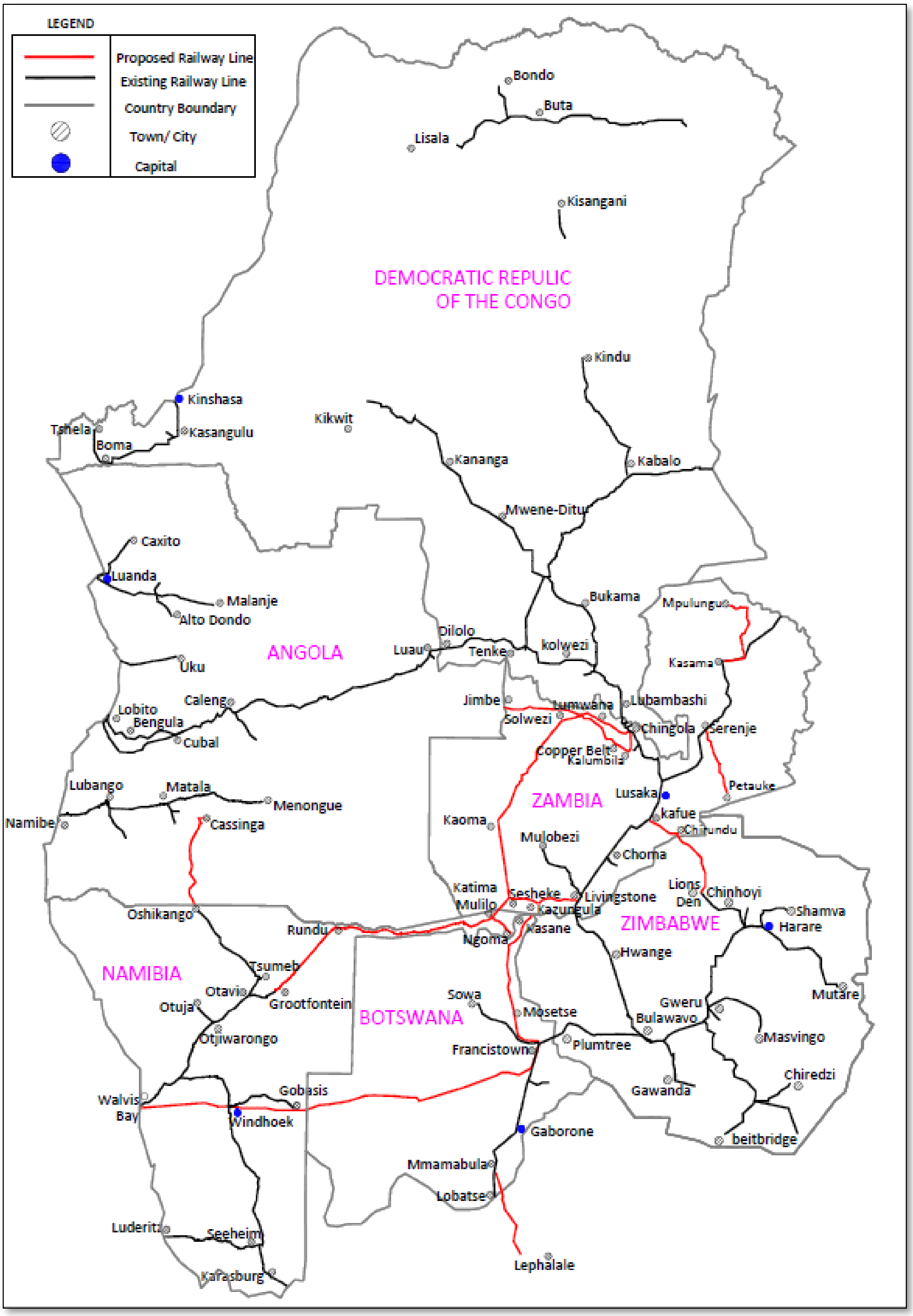
3.4.1.1 Angola

Angola has vast mineral resources including gold, diamonds, platinum, nickel, iron ore, chrome, copper, manganese and other minerals. It also includes the oil-rich enclave of Cabinda on its northern Atlantic coast.

Apart from Cabinda, the largest ports are found at Luanda, Lobito and Namibe (Mocamedes), with container terminals being available at both Luanda and Lobito.

Paved roads run through Angola from south to north but are mostly found in the west of the country along the Atlantic seaboard.

Figure 3-2: Proposed Rail Developments in Neighbouring Countries



With reference to the figure above, three separate railway systems, all of which are cape gauge (1.067 m), run inland from the ports of Luanda, Lobito and Namibe. From Luanda, the Luanda Railway runs 424 km to Malanje. From Lobito, the Benguela Railway runs 1,289 km across the country to Luau. The line further extends into the Democratic Republic of Congo though the section in DRC is in a state of disrepair.

This railway, which was a major carrier of copper from Zambia and DRC to Lobito port in the early 1970s, was largely destroyed during the Angolan civil war, but was rebuilt and substantially upgraded (with operating speeds of up to 90 kmph) by the Chinese Railway Construction Corporation between 2006 and 2014 and has been operational right through to Tenke since 2018.

Despite significant investments in rebuilding the Benguela railway line, certain challenges remain that inhibit operations (reduced use of infrastructure, interconnection to Zambia, loss-making financial situation and inoperability of part of the rolling stock fleet).

To reverse this, the Angola government issued a tender on September 8th, 2021, for the management, operation and maintenance of the Benguela railway including stations, warehouses, storage yards, and regional/local workshops. The standard concession period is 30 years though this may be extended to a maximum of 50 years if there is commitment to extend the railway line to Jimbe in the Republic of Zambia. Based on the latest media releases, the tendering process is to be concluded at the end of May 2023.

Finally, from Namibe the Mocamedes Railway runs for 860 km from Namibe through southern Angola to Menongue, having also been severely damaged during the war, but now rehabilitated by the Chinese Hyway Group between 2006 and 2015. A branch from this line to Cassinga, from where there are reported plans for an extension to join up with the Namibian railway on the border at Oshikango. Japanese interests are reportedly considering using this link to ship iron ore from Cassinga for export through Walvis Bay.

3.4.1.2 Botswana

As on date, there are three railway developments in Botswana as follows (see Figure 3-2) which were further confirmed during the field mission to Botswana:

1. 367 km railway line from Mosetse (Botswana) to Kazungula (Zambia) via the Kazungula Bridge (the bridge was completed in 2021; see discussion below under Section 3.4.1.3).

2. 56 km railway line from Mmamabula (Botswana) to Lephalale (South Africa) to connect coal deposits with heavy haul lines in South Africa.

3. 1,500 km Trans Kalahari railway line connecting Botswana to Walvis Bay in Namibia. A Project Management (PM) Office has been established in Windhoek with officials seconded from both the Namibian and Botswanan government. A feasibility and project structuring exercise are still to be initiated.

Feasibility tenders for the other two developments (item 1 and 2 above) were submitted (as a combined tender) in July 2019 and are currently being evaluated by Botswana Railways.

3.4.1.3 Zambia

The Project Team met with the Ministry of Transport and Communication, Zambia virtually and during the field mission to Zambia. During the course of our discussions, the Project Team was made aware of the following transport projects:

1. Kafue – Chirundu Railway Line (about 95 km)– the Detailed Feasibility Study and Engineering Design is ongoing and should be finalized in the next by the end of 2021. The line starts in Kafue and passes through to Lion's Den in Zimbabwe where the proposed line

connects with the existing rail network in Zimbabwe with furtherance to Beira Port. The Government wishes to implement the project as a Public-Private Partnership.

2. Livingstone – Kazungula – Sesheke Railway Line (about 200 km) – A pre-feasibility study was completed, and the estimated construction cost is US$ 824 million.

The new bridge completed in 2021 over the Zambezi River at Kazungula make provision for both road and a railway line.

3. Western Line from Sesheke to Solwezi and ultimately the Northwestern Province of Zambia (about 800 km).

4. Chingola to Kalumbila Railway Line (about 315 km).

5. Chingola to Solwezi Railway Line (about 166 km).

6. Serenje – Petauke - Chipata rail link (389 km– In 2016, the Zambian Government signed a contract agreement with CCECC to build this line. The estimated cost was US$ two billion based on the pre-feasibility study.

7. Kasama – Mpulungu Railway (about 205 km) – with potential to be linked to the Lake Tanganyika Transport Corridor (Burundi, Rwanda, Congo and Tanzania). The feasibility and design study were completed and tendered as a PPP. However, the Government has not moved forward with any of the bids received.

4 Railway Design Criteria

4.1 Introduction

The Design Criteria for key elements of a railway needs to be identified at the Initial stage itself to enable further work on final route and alignment design.

Informed by the traffic study, the Consultant has considered that the Trans-Zambezi Rail (TZR) would primarily be used to carry regional freight traffic including dry and liquid bulk and containerized goods.

Furthermore, based on the traffic study, the line can expect between four and ten million tons of traffic per annum in the initial years depending on the traffic scenario (further discussed below) and would double approximately every 12 years. The design standards discussed in this section have been developed considering this traffic potential.

The recommended design parameters are based on 'Infrastructure Engineering- Manual for Track Maintenance' (2012) of Transnet, South Africa'. Further references, wherever necessary, have been made to the UIC standards.

4.2 Gauge

The Rail gauge has an impact on the project costs, rolling stock characteristics, land requirements and train capacity as well as line capacity, and is one of the most important decisions to be taken while deciding a new Railway system.

Namibia railway network operates about 2,680 km of route on 3 ft. 6 in (1,067 mm) track gauge, often referred to as 'Cape Gauge'.

In 2007, the Africa Union resolved that 'Standard Gauge' (SG) 1,435 mm should be adopted for the construction of new railway lines in order to promote interoperability on the continent. Member countries were encouraged to consider standard gauge corridors when studying and developing new lines.

Breaks-of-gauge (i.e., when a particular point on a railway line changes from one gauge to another) creates numerous operational impediments and additional costs whether internally or at international borders.

Changing the gauge of a country's existing network is not economically prudent and viable. Furthermore, all Southern African Development Community (SADC) countries would have to agree to universally adopt and invest in converting their railway systems to standard gauge so that trains can travel seamlessly between borders which is far from practical.

The Namibian rail network stretches from the South (South African border) to the Northern part of the country (Angolan border) and from the middle of the country to its coast and harbour towns. The gauge in all the neighbouring countries i.e., Angola, Zambia, Botswana, Zimbabwe, Democratic Republic of Congo (DRC) and South Africa, is 'Cape Gauge'.

The stated objective of the proposed Trans Zambezi Railway (TZR) extension corridor is to link the Walvis Bay Port in Namibia to its hinterland as well as to provide efficient port access to adjoining land locked countries of Zambia, Botswana, DRC, and Zimbabwe.

A railway line already exists connecting Walvis Bay to Grootfontein station. The TZR will be an extension of the exiting Walvis Bay- Grootfontein corridor, which is in Cape Gauge.

Change of gauge at Grootfontein will either make 'transhipment' of goods necessary at Grootfontein or necessitate huge investments in change of gauge for the railway section between Walvis Bay and Grootfontein. Both the options are unviable. Furthermore, the purpose of the Trans Zambezi extension is connecting Namibia (Walvis Bay port) to neighbouring countries, all of which have Cape Gauge on their railways.

Considering all the above, the gauge for the TZR has been adopted as **'Cape Gauge'.**

This report deals with the subject of potential 'Gauge Conversion' in more details separately in 'Appendix 6 – Gauge Convertibility' of this Report.

4.3 Axle Load And Design Speed

The Axle Load is defined as the maximum allowable load for each axle on any given wagon or locomotive.

The design speed of a railway should strike an optimal balance between the capital cost of the infrastructure and the operational requirements defined by the existing and anticipated traffic. There are varying topographical conditions through which the new railway line will pass. Based on topography and traffic, theoretically, a differential design speed for different sections of the Trans Zambezi railway line can also be adopted.

As per the data provided by TransNamib, following are the Design Axle Load and Maximum Allowable Speed of the existing railway sections in the project influence are:

Table 4-1: TransNamib- Speed and Axle Load

Section	Type of Rail/Sleeper	Distance (km)	Max Allowable Speed (Kmph)	Max Axle Load (Tons)
Otavi-Grootfontein	30 kg/m rails; 30 kg steel sleepers	90.5	50 kmph (though there have been partial upgrades to accommodate 60 kmph)	15.0 though 16.5 ton can be accommodated for commercial reasons
Kranzberg - Tsumeb	48 & 30 kg/m rails; 30 kg steel & P2 concrete sleepers	391.6	60	16.5
Tsumeb - Ondangwa	51 kg/m rails; P2 concrete sleepers	305.5	80	18.5
Kranzberg - Walvis Bay	48 kg/m (& 11.3 km of 30 kg/m) rail; steel and F4/P2 concrete sleepers	210.4	60	16.5

From the above, it is noted that currently Walvis Bay - Kranzberg, Kranzberg - Tsumeb and Otavi- Grootfontein sections can carry a maximum of 16.5-ton axle-load at an allowable speed of 60 kmph.

As part of the Transport Infrastructure Improvement Project (TIIP) which is being co-financed by Government of Namibia (GRN) and African Development Bank (AfDB), upgrading of 210 km rail section between Walvis Bay and Kranzberg to 18.5-ton axle-load is being done. The speed potential for the upgraded railway section will be 80 kmph for freight and 100 kmph for passenger services as per AfDB's data portal. This work is scheduled for completion in late 2022. After upgrading, higher speeds can only be affected once the current Spoorbarber bogeys of the rolling stock are replaced with radial bogeys.

The track structure and ballast profile provided on Walvis Bay and Kranzberg section (48 kg/m rail, 700 mm sleeper spacing and 200 mm ballast cushion with a gross ton per year of 5 to 15 tons) is commensurate with N2 Class of Line as defined in 'Infrastructure Engineering-Manual for Track Maintenance' (2012) of Transnet, South Africa'. As per the Annexure 3 of the Manual (extracted below), the allowable Axle Load for N2 class of lines is 20 ton.

Figure 4-1: Track Structure Specifications (Extract of Transnet Manual)

CLASSIFICATION AND STANDARDS FOR RUNNING LINES : 1 065mm TRACK GAUGE

CLASSIFICATION OF RUNNING LINES			TRACK STANDARDS FOR RUNNING LINES				
CLASS OF LINE	MAXIMUM AXLE LOAD (Ton)	GROSS TON PER YEAR (Million)	RAIL TYPE AND MASS	SLEEPER AND SPACING	BALLAST DEPTH (mm)	BALLAST QUANTITY (m^3/ km) CONCRETE	BALLAST QUANTITY (m^3/ km) WOOD / STEEL
S	26	–	60kg/m	FY/PY 650mm	300	1 600	–
N1	20	>15	57kg/m	FY/PY/ #700mm	280	1 500	–
N2	20	5–15	48kg/m	P2/F4 STEEL/WOOD 700mm	200	1 200	1 100
N3	–	<5	REQUIRES THE PRIOR APPROVAL OF THE CJIEF ENGINEER (INFRASTRUCTURE MAINTENANCE).				

REMARKS:
1. ANY DEPARTURE FROM THESE STANDARDS REQUIRE THE APPROVAL OF THE CHIEF ENGINEER (INFRASTRUCTURE MAINTENANCE).
2. CLAUSES 6.2 AND 6.7, AS WELL AS ANNEXURES 4 AND 15 SHEET 2, MUST BE READ TOGETHER WITH THIS TABLE.
3. # P2, F4 AND WOODEN SLEEPERS ARE ALSO ACCEPTABLE. SEE ANNEXURE 4 SHEET 1 FOR BALLAST QUANTITY.

ANNEXURE 3
SHEET 1 of 1

BE 97-03 Sht 1 Version 1

Trans Zambezi railway line will fall under N2 Classification of Running lines.

Though the Transnet manual specifies the Axle Load for a given track structure, it is silent on the Allowable Speed. Given a particular track geometry, the overall stresses on the track are a combination of forces induced by superimposed load (axle-load), static as well as dynamic; tractive and braking forces (speed); and climatic stresses (temperature variation).

As previously stated, the design axle-load for the upgraded Walvis Bay – Kranzberg section of the proposed Trans Zambezi railway line is 18.5-ton which is less than the allowable load of 20 ton for N2 classification. 7.5% reduction in the allowable axle-load (18.5 instead of 20 ton) affords the project to enhance the speed potential of the line.

Considering all the above, the design Axle Load for the TZR is recommended as 18.5-ton with the following speed potential (Table 4-2).

Table 4-2: Design Speeds for Proposed Line

Type of Terrain and Train	Design Speeds
Freight	80 kmph
Passenger	100 kmph

80 kmph for freight is suitable because (1) railway administrations in the SADC region specify this speed for goods trains and (2) the bogies for goods trains traveling more than 80 kmph requires specialized rolling stock designs and manufacturing. Such rolling stock would require more intensive maintenance and safety protocols/systems.

4.3.1 Speed In Yards

Speed of Trains Over Facing Points and Cross Overs

- 40 kmph when points are situated on the straight line and are set for main line (this can potentially be increased to the maximum permissible speed of section with the highest standard of interlocking).
- 20 kmph, when points are situated on the straight line and are set for the loop line.

Speed of Trains Over Trailing Points

- Mainline: Design Sectional Speed
- Loop line: Maximum of 25 kmph

4.4 Traction

The energy source for locomotive propulsion is either Diesel or Electric.[4] Diesel traction is less capital intensive and as Namibia's network and the region in general are already functional on diesel traction, affords flexibility of operations, and is suitable for even low volumes of traffic.

On the other hand, electric traction needs high capital investments on fixed infrastructure (Overhead Electric Lines, Substations, Transmission lines, etc.), perpetual expenditure in maintenance of electric infrastructure, a very reliable electricity supply, and decreased flexibility of operations.

Securing (i.e., safety from vandalism) of an electrified line is also a major concern for railway lines passing through remote areas where trains frequency is not very high. This problem has been evidenced by recent developments in South Africa.

The Namibian Railway as well as the railways in Angola, Botswana and Zambia have been running on diesel traction. Maintaining diesel traction would maintain regional fluidity of train movements.

Furthermore, while the traffic potential for this study indicates that there is a commercial case for developing the line, it is not likely that traffic volumes would justify electrifying the line today. Rather, the cost may not be justified, if at all, even after couple of decades following the line's development.

[4] Diesel-electric locomotives exist whereby a **diesel engine** drives an electrical DC generator or AC alternator-rectifier the output of which provides power to the traction motors that drive the locomotive. The main energy source of a diesel-electric locomotive is still diesel. External electricity sources do not propel this type of locomotive.

By the time the first set of diesel locomotives procured for the project complete their useful life, it can be safely anticipated that 'battery' operated railway locomotives will have progressed far enough in their development particularly for use during short haul and yard operations. Therefore, it stands to reason that the technical and cost complexities of developing an electrified line may likely be bypassed with battery powered locomotives in the medium-to-long term.

On the request of AfDB a high-level unit per-km cost estimation for railway electrification has been indicated in Section 15.6.12 (Electric Traction).

4.5 Geometry

Railway alignments are designed with the objective of providing conditions best suited to a particular mix of traffic and the topography. Grades and Curvatures are selected with the goal of arriving at a 'best fit' solution between, sometimes conflicting objectives of:

The most suitable alignment depends on a number of factors such as:

(1) The topography of the area,

(2) The water body crossings and the waterway requirements for cross-drainage,

(3) Road crossings,

(4) Availability of materials,

(5) Habitation and industrial development in the nearby areas,

(6) Ease of construction,

(7) Cost of Construction

(8) Promoting efficient operation of trains at possibly varying design speeds.

(9) Minimizing maintenance costs.

The principal objective of an efficient alignment design criteria is to reduce the overall cost (Capital, as well as Operation and Maintenance Costs). Much depends on the type of traffic likely to ply on the new railway.

The geometric design of a railway track includes all those parameters which determine or affect the geometry of the track. These parameters are:

1. Gradients in the track, including grade compensation, rising gradient, and falling gradient.
2. Alignment of the track, including straight as well as curved alignment.
3. Curvature of the track, including horizontal and vertical curves, transition curves, sharpness of the curve in terms of radius or degree of the curve, cant or super elevation on curves, etc.

Necessity for Appropriate Geometric Design:

The need for proper geometric design of a track arises because of the following considerations:

→ To ensure a smooth and safe running of trains,

→ To achieve maximum speeds for a given axle-load,

- To prevent accidents and derailments,
- To ensure that the track requires least maintenance.,
- For good aesthetics

4.5.1 Curvature – Horizontal Alignment

Curves are introduced on a railway track to bypass obstacles, to provide longer and easily traversed gradients, and to pass a railway line through obligatory or desirable locations. Horizontal curves are provided to follow a natural topography, i.e., when a change in the direction of the track is required.

A railway curve is defined either by radius or by its degree. The degree of a curve (D) is the angle subtended at its center by a chord of 30.5 m, or 100 feet.

Circumference of a Curve = 2 π R

Angle subtended at the center by full circumference = 360°

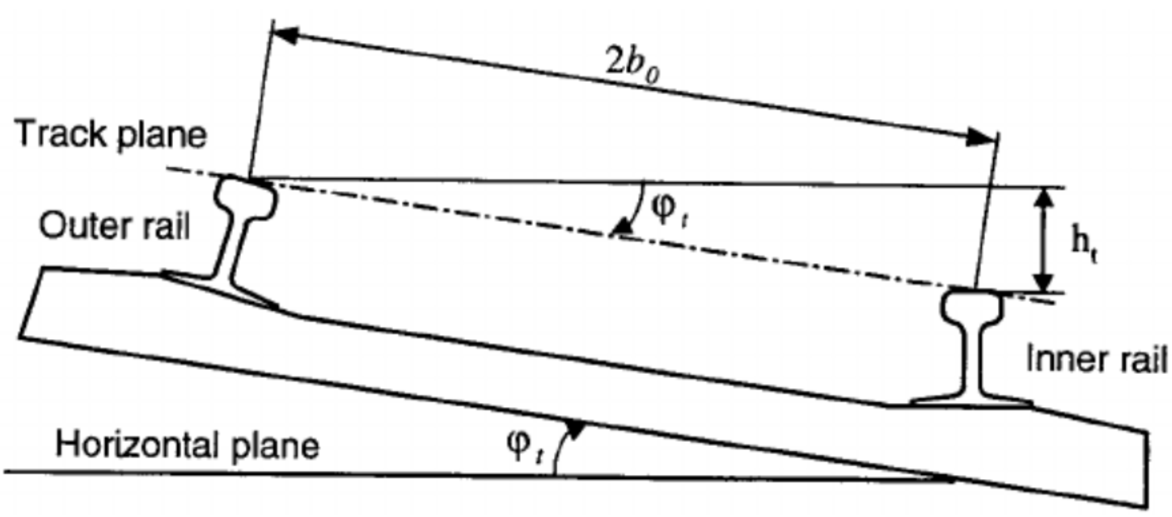
Hence, angle subtended at the center

By 30.5 m chord = 360° / 2 π R X 30.5
Degree of Curve = 1,746/ R say **1750/R**

4.5.1.1 Super-elevation or Cant

To provide a comfortable ride on a horizontal curve, the level of the outer rail is raised above the level of the inner rail. This is known as Super elevation (or Cant) and is typically represented in mm and Cant angle in degrees.

Figure 4-2: Example of Super elevation (or Cant)



Source: General Spatial Curve Joint for Rail Guided Vehicles: Kinematics and Dynamics (2003)

Super-elevation or Cant is the difference in height between the outer and the inner rail on a curve. It is provided by gradually lifting the outer rail above the level of the inner rail. The super-elevation is necessary because of the following:

(1) To have a better distribution of load on both rails,

(2) To reduce the wear and tear of rails and rolling stock,

(3) To neutralize the effect of lateral forces,

(4) To provide comfort to passengers.

4.5.1.2 Equilibrium Speed

The equilibrium speed is the speed at which the effect of centrifugal force on a curve is exactly balanced by the cant provided.

4.5.1.3 Maximum Permissible Speed

This is the highest speed which may be permitted on a curve takes into consideration the radius of curvature, actual cant, cant deficiency and the length of transition. When the maximum permissible speed of the curve is less than the maximum sectional speed of the section of line, a permanent speed restriction becomes necessary.

4.5.1.4 Cant Deficiency

Cant deficiency occurs when a train travels around a curve at a speed higher than the equilibrium speed. It is the difference between the theoretical cant required for such higher speeds and the actual cant provided. This is generally the case for passenger trains.

4.5.1.5 Cant Excess

Cant excess occurs when a train travels around a curve at a speed lower than the equilibrium speed. It is the difference between the actual cant provided and the theoretical cant required for such lower speeds.

The equilibrium speed of a section is decided based on a number of factors, viz:

(1) Maximum permissible speed which can actually be achieved by Passenger and Freight trains,

(2) Number of stoppages,

(3) Gradients,

(4) Proportion of slow and fast trains.

Based on the equilibrium speed as decided above by the railway engineers, the super-elevation is calculated as:

$e = GV^2/ 127 R$

where, e= Super elevation in mm

V = Speed in kmph

G = Dynamic gauge, which could be considered as 1,150 mm for Cape Gauge

R = Radius in m

However, the maximum value of super-elevation is generally laid down for overturning velocity and on consideration of track maintenance standards. Based on experiments carried out in Europe on standard gauge track, the maximum value of super-elevation, generally adopted on many railways in the world, is approximately 1/10th to 1/12th of the gauge. The same may be approximated on other gauges.

4.5.1.6 Transition Length

The transition between straight and curve and vice-versa, is introduced by means of a transition curve which is of the shape of a cubic parabola. The transition curve facilitates gradual introduction of super-elevation as well as ensuring proper cant gradient (x %) and rate of change of cant (mm/sec).

For non-transitioned curves, the concept of virtual transition is applied. The change in motion of the vehicle from straight to curve condition takes place over the shortest distance between the bogies which is considered as the 'virtual transition'.

4.5.1.7 Speed on Curves

By further deducing the above-mentioned equation, the maximum permissible speed on a fully transitioned curve can be calculated as follows:

For Cape Gauge: $V = 0.332 X ((Ca+Cd) XR)^{0.5}$

Where, V = Max permissible speed in kmph

Ca= Actual cant provided in mm (subject to a maximum value)

Cd = Cant deficiency in mm

R = Radius of curve in m

The actual cant provided (for higher speed) is limited to a certain absolute value, since for slower traffic high cant will result in cant excess. High cant excess, apart from being unsafe for low-speed traffic, also results in excessive wear of the inner rail.

Considering the following limiting values:

Maximum cant, Ca = 100 mm

Maximum cant deficiency, Cd = 50 mm

Maximum cant excess, Ca = 65 mm

for passenger speed of 100 kmph and freight speed of 80 kmph, the **limiting radius for the purposes of geometric design of route/ alignment works out to 600 m (i.e., 2.91°).** Any radius less than 600 m would necessitate appropriate speed reduction.

Annexure 9 of 'Infrastructure Engineering- Manual for Track Maintenance' (2012) of Transnet, South Africa' provides a detailed table of 'Radius- Speed-Super elevation' for various combinations.

While designing the alignment, the Consultant endeavoured to provide curves that are as flat as possible in an effort to reduce the overall wear and stresses on the track.

4.5.2 Gradient – Design Criteria

Gradients are provided to negotiate the rise or fall in the level of the railway track. A rising gradient is one in which the track rises in the direction of the movement of traffic and a down or falling gradient is one in which the track loses elevation in the direction of the movement of traffic.

A gradient is normally represented by the distance travelled for a rise or fall of one unit. Sometimes the gradient is indicated as per cent rise or fall. For example, if there is a rise of 1 m in 400 m, the gradient is 1 in 400 or 0.25%.

The 'Longitudinal Section' (L-Section) or 'Profile' of a Railway line is the product of the design of gradients – rises, falls and levels. The 'Profile' of a railway line defines the quantum of 'Earthwork' (Cutting/ Filling) of a railway project and has the maximum impact on the cost of the project as well as the haulage capacity and locomotives specifications.

4.5.2.1 Ruling Gradient

The 'Ruling Gradient' is the steepest gradient that exists in a railway section. It determines the maximum load that can be hauled by a locomotive on that section. While deciding the ruling gradient of a section, it is not only the severity of the gradient but also its length as well as its position with respect to the gradients on both sides that must be taken into consideration.

The power of the locomotive to be put into service on the track also plays an important role in taking this decision, as the locomotive should have adequate power to haul the entire load over the ruling gradient at the maximum permissible speed.

Once a ruling gradient has been specified for a section, all other gradients provided in that section should be flatter than the ruling gradient after compensating for curvature.

The data provided by TransNamib on Ruling Gradients on the existing railway sections from Walvis Bay to Grootfontein are as follows:

Table 4-3: Existing Ruling Gradients

Section	Ruling Gradient
Walvis bay - Kranzberg	1 in 89
Kranzberg – Otavi - Tsumeb	1 in 66
Otavi - Grootfontein	1 in 66

The topography of the proposed project area from Grootfontein to Katima Mulilo, in general, is not very undulating or steep. It evenly slopes downward from a level of about 1,450 m at Grootfontein to about 950 m at Katima Mulilo. Considering this and also the impact which ruling gradient has on train consists, haulage, and locomotive specifications, following Limiting Gradient values are proposed for the Trans Zambezi railway corridor:

Table 4-4: Design Gradients

Characteristic	Design Criteria
Mainline Limiting Gradient	0.67% (1 in 150)
Exceptional Mainline Gradient	1.00% (1in 100)
Passing tracks and stations	0.00% - 0.25% (0 to 1 in 400)

The proposed railway line benefits from flat terrain and hence the relatively generous and beneficial gradients. For passing tracks and stations 1 in 400 gradient has been proposed to optimize the earthwork quantity and considering future crossing stations.

4.5.2.2 Grade Direction Change

The target minimum length between changes in direction of grade should be long enough to contain a full train length so that dealing with reversal of grades is minimized. As the implementation of this criteria may significantly impact the overall cost of the project, this is generally implemented as a 'Recommended' criteria.

4.5.2.3 Grade Compensation

Grade compensation is the reduction of the gradient through a horizontal curve to ensure that the total resistance (curve plus grade) experienced by a train does not exceed the resistance of the design ruling grade on tangent track.

The standard formula for curve compensation using curve radius in meters is:

- Effective gradient $= ActualGradient(\%) - \left(C \text{ x } \frac{1{,}747.26}{R} \right)$
- C = 0.04%
- R = horizontal curve radius (m)

4.5.2.4 Vertical Curves

The angle formed at the point of contact of two different gradients can be smoothened by providing a curve called the vertical curve in the vertical plane. In the absence of a vertical curve, railway vehicles are likely to have a rough run on the track.

Besides this, a change in the gradient may also cause cluttering of wagons/vehicles in the 'Sags' and variation in the tension of couplings at the 'Summits', resulting in train parting and an uncomfortable ride.

To avoid these ill effects, the change in gradient is smoothened by providing a vertical curve. A rising gradient is normally considered positive and a failing gradient is considered negative.

Transnet recommends provision of a Parabolic vertical curve which is recommended for the TZR as well.

The standard for provision of a Vertical Curve on the South African railway network is as follows:

(1) For main lines, maximum rate of change of grade is 40 mm per 20 m per 20 m for sags and summits

(2) For railway yards, maximum rate of change of grade is 150 mm per 20 m per 20 m for sags and summits

4.6 Track Centers

The minimum Center to Center distance of tracks is an important parameter which needs to be prudently decided since it has large repercussion on design of the railway system and the potential gauge conversion in the future. The embankment widths, land requirements, rolling stock movements, safety of operations, etc. are affected by this parameter.

Inter-Track distance is defined by the requirements of static and dynamic safety clearances for railway rolling stock.

The following track spacing criteria has been specified by Transnet as per para 8.3 of 'Infrastructure Engineering- Manual for Track Maintenance' (2012) of Transnet, South Africa':

1. Minimum distance between centers of parallel tracks at 4.0 m
2. Minimum distance between centers of parallel tracks with traction masts, telegraph poles, water columns, signal poles or parachute tanks 5.5 m
3. In yards, up to four adjacent tracks may be at 4.0 m centres. Distance to the next track 5.5 m
4. Centers of tracks at clearance marks 3.45 m
5. Minimum track centers at derailing devices 3.65 m

The limitation of Transnet's track spacing criteria is that the criteria do not afford future conversion from cape to standard gauge.

Considering the future potential for gauge conversion, as well as the likelihood of an industrial shift to 'Wider' rolling stock, a 5.0 m inter track distance is recommended for the TZR.

4.7 Track Structure

The track structure proposed for the 'Cape Gauge' Trans Zambezi Railway (TZR) needs to fulfill the following objectives:

(1) Provide optimum strength to support the anticipated train loads

(2) Provides ease of construction

(3) Minimize overall construction costs (capital costs)

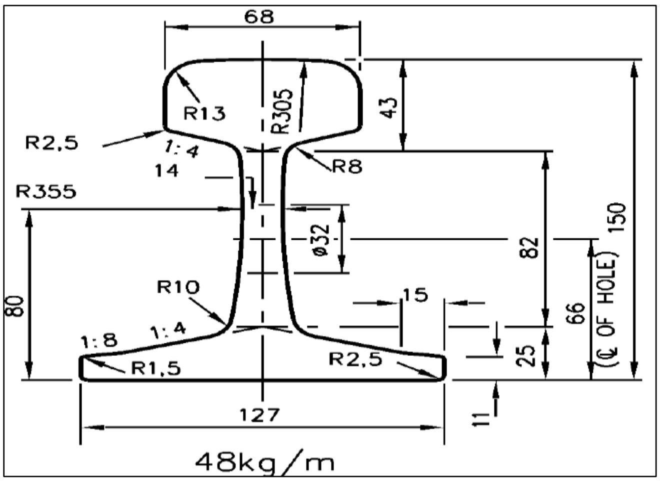
(4) Minimize long term maintenance costs

4.7.1 Rails

As discussed in the previous section, the TZR would be an N2 Class railway line. As per the Infrastructure Engineering- Manual for Track Maintenance' (2012) of Transnet, South Africa, the track structure specified for N2 Class of track comprises rail section of 48 Kg/m over P2 sleepers for 20-ton axle-loads and 5–15-million-ton annual traffic. Accordingly, 48 Kg/m rail grade R260 having minimum hardness of 260 HB is being recommended for use on this corridor for now. As and when the traffic increases beyond 15 million ton per annum and on completion of useful life of 48 kg/m rails, the rails on TZR could be replaced in accordance with N1 Class of track (*dealt in more detail later in this report*).

The rail profile for 48 kg/m rails as per TransNamib Manual is as under:

Figure 4-3: Rail Profile – 48Kg/m



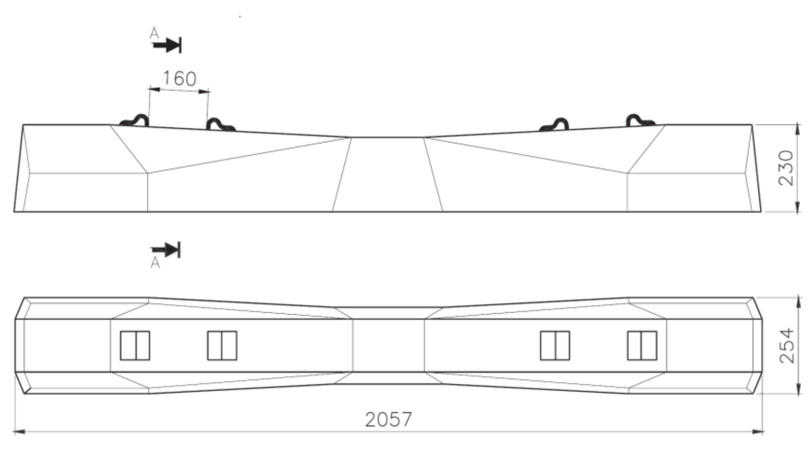
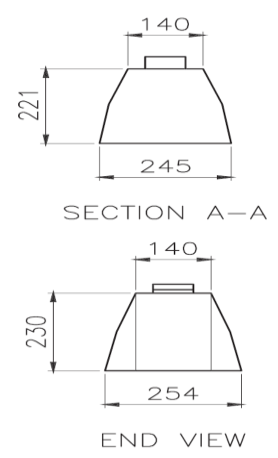
The rails would be manufactured to European Specification EN 13674 – 1.

4.7.2 Sleepers (Ties)

The choice of sleepers for a railway project depends on the track design, construction methodology and maintenance methods to be adopted. Pre-stressed concrete sleepers are being extensively used in the region.

In Namibia, the newly constructed sections and also sections which are being upgraded are being provided with P2 type of concrete sleepers. Accordingly, P2 sleepers are being recommended for the Trans-Zambezi line with a sleeper spacing of 700 mm. The main dimensions and salient features of the P2 sleepers are as under:

Figure 4-4: P2 Sleeper Dimensions

Top and Side View	Cross A-A and End view
	

The salient features of P2 Concrete Sleepers are as under:

Table 4-5: Salient Features of P2 Sleepers

Maximum Axle Load	**22.5 Ton**
Rail Section	40 kg/m and 48 kg/m
Approximate Weight of each sleeper	222 kg

Type of Fastening	20 mm Pandrol "e" clip
Type of Shoulder	Pressed steel or galvanised
Rail Seat Slope	1:20

4.7.3 Fastenings

The type of fastening for a railway track largely depends upon the type of sleepers used. Elastic fastenings which have an e-clip with liners (generally glass filled Nylon) and a neoprene pad below the sleepers are recommended. The e-clip is provided with shoulders pre-casted in the P2 sleepers.

4.7.4 Ballast

The ballast should be hard, tough, angular, and non-abrasive so that particles are not prone to cementing. To meet the desired performance requirements for concrete sleepers, ballast must be limited to crushed granites, trap rocks, or quartzite.

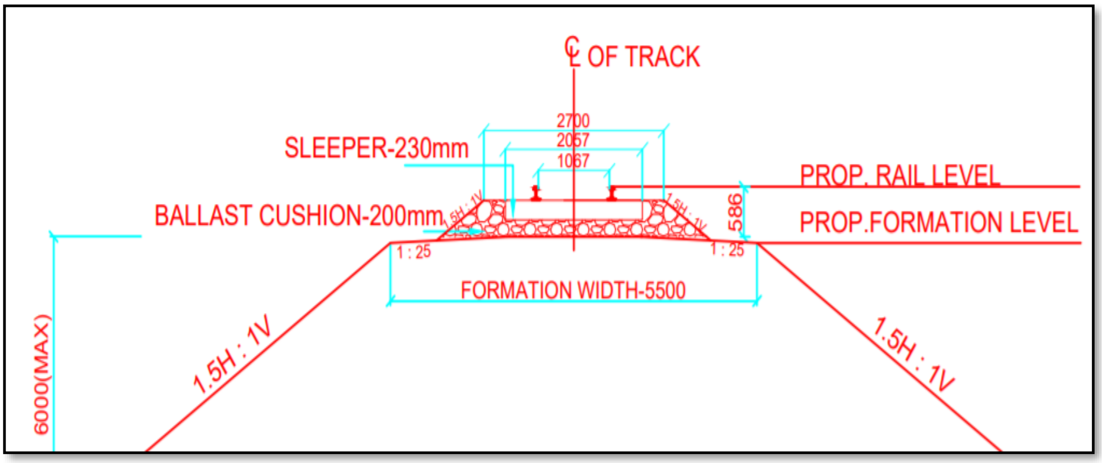
For an N2 class of line, the ballast depth of 200 mm has been recommended in the Transnet Manual.

The salient dimensions are as under:

- Ballast depth - 200 mm
- Ballast width at top (mm) - 2,700 mm
- Width from centre of sleeper to edge of Ballast Shoulder at top- 1,350 mm

The formation and ballast profile for the N2 class is as under:

Figure 4-5: Ballast Profile for N2 Class



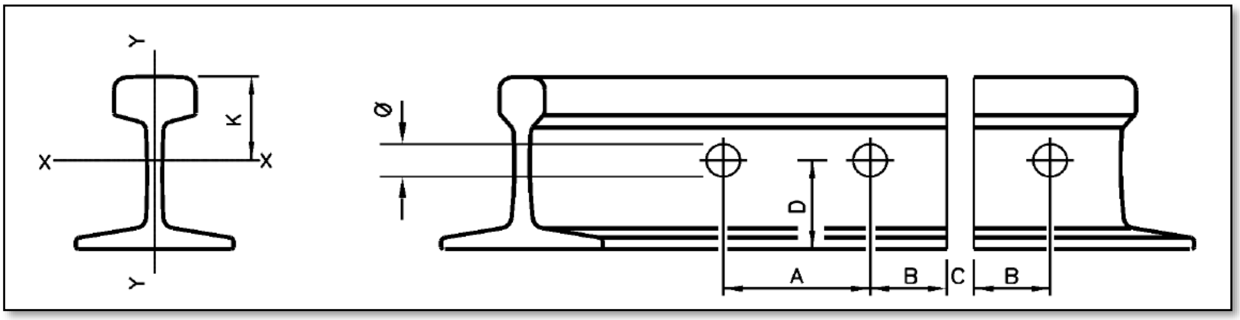
4.7.5 Rail Welding and Joint Bars (Fish Plates and Bolts)

Rail Welding: It is proposed that the entire route have continuously welded rails which will provide a higher quality track while also lowering maintenance and fuel costs.

The rails are proposed to be procured through international rail manufacturers with lengths of 18/36 m which will then be centrally welded by flash butt welding technique at site depots or by mobile flash welding machines. Isolated welds are proposed to be done at site by exothermic welding technique.

Rail Joints: At very isolated locations where rail welding is not practically possible, it is recommended that rails be joined by means of fish plates and fish bolts. Rails of 48 Kg/m are joined with fish plates and fish bolts having four holes of 32 mm diameter in the rail as detailed in Figure 4-6.

Figure 4-6: Rail Joints



Where A =100 mm, B=67 mm, C=6 mm, D=66 mm.

However, it is recommended that the fish plated joints on concrete sleepers be provided with longer fish plates (one meter) with six holes instead of four holes so as to avoid damage to concrete sleepers at joints and frequent maintenance.

4.7.6 Turnouts

A turnout assembly comprises of following three major components:

- Crossing assembly,
- Points blade and Stock Rail assembly,
- Ties (Sleepers) over which the entire turnout assembly is fixed by help of fastening system.

Turnout assemblies are an important component of track structure. Adoption of appropriate designs for the given traffic load, and for low maintenance with high degree of safety are important considerations in selecting turnouts.

Our turnout recommendations for the TZR are based on the turnouts adopted along the Walvis Bay-Kranzberg section which is currently being upgraded as well as the recently constructed Tsumeb – Ondangwa- Oshikango sections.

1 in 12 turnouts are recommended for use on mainline and 1 in 9 turnouts in yards where the siding/loops take off from loops connected to the mainline including over run lines provided for signal overshoots.

The turnouts will comprise of 'Secant' design on concrete sleepers with elastic fastenings and fully curved flexible point blade manufactured from 51 kg/m rail (switch blades fit undercut to the stock rail). Rest of the rails in the turnouts would be of 48 kg/m rail of grade R350 LHT (head hardened). The crossing assembly would be made up of 'Rail-bound Frog' with a manganese casting insert.

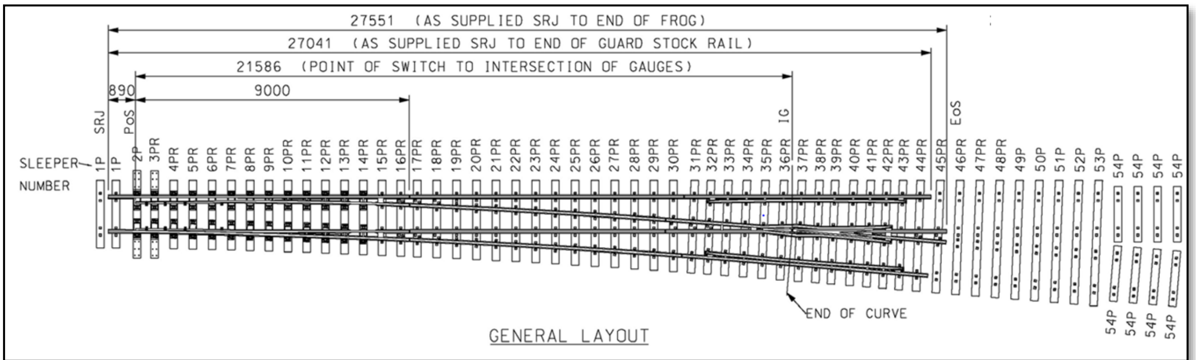
Salient features of the turnouts design are:

- Is provided with fully curved flexible points blades made up of SAR 51 Kg/m Rail.
- Has Rail bound crossing frog with cast manganese steel insert

- Non-adjustable guard rail assemblies
- Pandrol fasteners
- Hytrel pads
- Concrete railroad ties
- Special Point operation Stand
- Entire Turnout is welded with Exothermic welding (for 1:12 turnout there are 20 joints in all within the turnout which are welded with SKV-F 48/48HH 26 mm gap; SKV-F 48 HH 26 mm gap; SKV-F 48HH/51HH 26 mm gap).

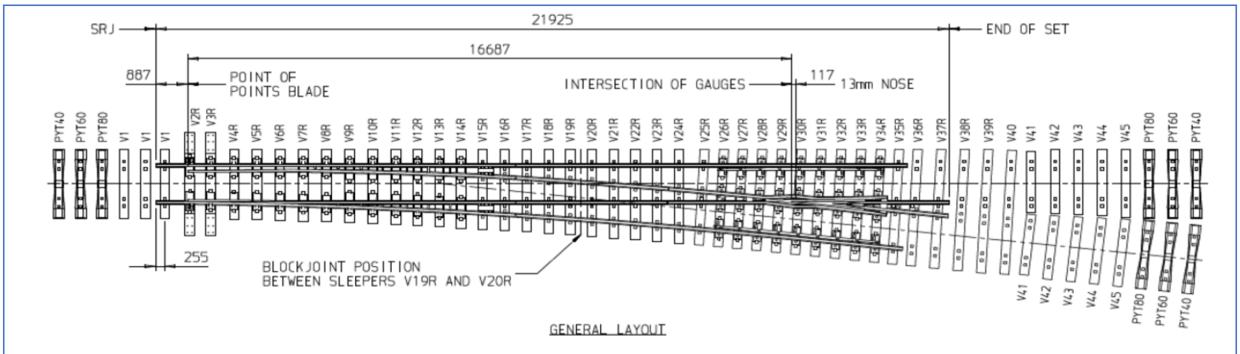
The general layout and assemblies of Point Blade & Stock Blade and crossing are shown as under[5].

Figure 4-7: General Layout of 1:12 Right Hand Turnout



General Layout of 1:12 Right hand Turnout
(SAR 48 –1065 mm Gauge Insulated Secant turnouts on Concrete Railroad Ties)

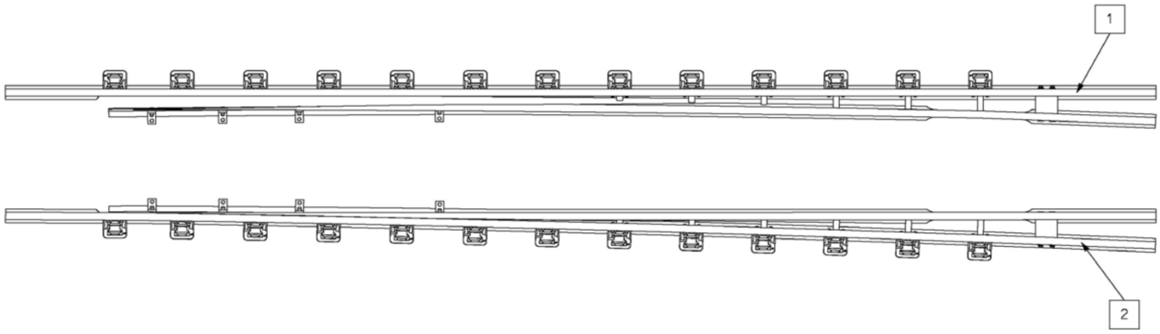
Figure 4-8: General Layout of 1:9 Right Hand Turnout



General Layout of 1:9 Right Hand Turnout
(48/51kg 1:9 Secant Right Hand Turnout on Concrete Railroad Ties)

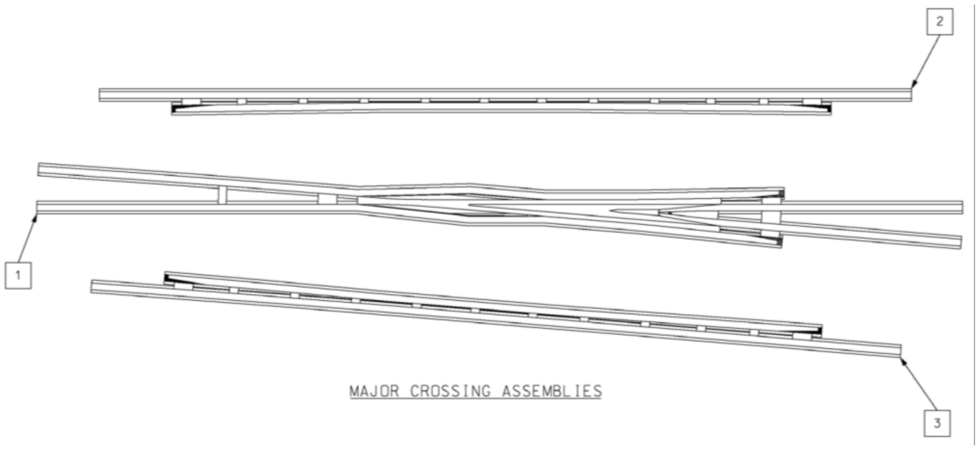
[5] VAE SA (Pty) reference document ENG/M TO/011-01 and ENG/M TO/007-00

Figure 4-9: Stock and Points Blade Assembly



(1- Stock Rail & Point Blade assembly 51 Kg/m left rail; 2- Stock Rail & Point Blade assembly 51 Kg/m right rail)

Figure 4-10: Crossing Assembly



1-Railbound Frog 48 Kg Right Hand; 2- Straight Stock and Guard Rail assembly left rail; 3- Semi-curved stock & Guard Rail assembly right rail

4.7.7 Final Track Structure

The table below presents track structure proposed to be adopted for the TZR:

Table 4-6: Track Structure Parameters

Characteristic	Cape Gauge	
	Main line	Sidings & Yards
Rail	48 Kg/m R260 Grade	48 Kg/m R260 Grade
Welded/jointed	Continuously Welded	Continuously Welded/ Fish Plated
Sleepers	Concrete Sleepers P2	Concrete Sleepers P2
Sleeper Density (#/km)	1,429 per Km	1,429 per Km
Fastening System	Elastic Fastening	Elastic Fastening
Ballast depth (mm)	200	200
Ballast width at top (mm)	2,700	2,700
Turnouts **1 in 9** **1 in 12**	Rail-bound Frog with fully curved flexible point blade over Concrete Railroad Ties.	Rail-bound Frog with fully curved flexible point blade over Concrete Railroad Ties.

4.7.7.1 Track Structure on Higher Traffic

As per the traffic assessment of this study, subject to fulfillment of many prerequisites, the traffic on TZR might increase beyond 15 million ton per annum after about 25 years of operations. If it so happens, the rails will need to be replaced by a higher 'poundage' rail. The 'useful' life of rails is generally considered between 25 to 30 years though it is also depended on the gross lifelong traffic.

With increase in traffic beyond 15 gross million tons per annum, as per the Manual, the route will now fall under N1 category for which the stipulated track structure is as follows:

- → Rail Section : 57 Kg/m
- → Concrete Sleepers Design: PY
- → Depth of Ballast : 280 mm
- → Quantity of Ballast required per km : 1500 m^3

Figure 4-11: Track Standards (Extract of Transnet Manual)

CLASSIFICATION AND STANDARDS FOR RUNNING LINES : 1 065mm TRACK GAUGE

CLASSIFICATION OF RUNNING LINES			TRACK STANDARDS FOR RUNNING LINES				
					BALLAST		
CLASS OF LINE	MAXIMUM AXLE LOAD (Ton)	GROSS TON PER YEAR (Million)	RAIL TYPE AND MASS	SLEEPER AND SPACING	DEPTH (mm)	QUANTITY (m^3/ km) CONCRETE	QUANTITY (m^3/ km) WOOD / STEEL
S	26	–	60kg/m	FY/PY 650mm	300	1 600	–
N1	20	>15	57kg/m	FY/PY/ #700mm	280	1 500	–
N2	20	5–15	48kg/m	P2/F4 STEEL/WOOD 700mm	200	1 200	1 100
N3	–	<5	REQUIRES THE PRIOR APPROVAL OF THE CJIEF ENGINEER (INFRASTRUCTURE MAINTENANCE).				

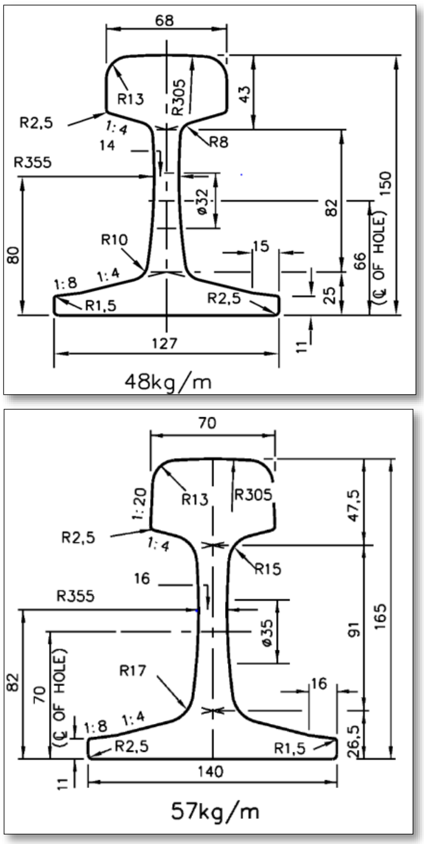
REMARKS:
1. ANY DEPARTURE FROM THESE STANDARDS REQUIRE THE APPROVAL OF THE CHIEF ENGINEER (INFRASTRUCTURE MAINTENANCE).
2. CLAUSES 6.2 AND 6.7, AS WELL AS ANNEXURES 4 AND 15 SHEET 2, MUST BE READ TOGETHER WITH THIS TABLE.
3. # P2, F4 AND WOODEN SLEEPERS ARE ALSO ACCEPTABLE. SEE ANNEXURE 4 SHEET 1 FOR BALLAST QUANTITY.

ANNEXURE 3
SHEET 1 of 1

BE 97–03 Sht 1 Version 1

For dealing with track upgradation, the 48 kg/ m rails will continue to be used even when traffic increases beyond 15 Gross million ton per year which would be replaced by 57 Kg/m Rail when 48 Kg/m rail start showing signs of excessive wear and fatigue.

Figure 4-12: Width Difference of Rails



The difference in the width of rail foot between 57 Kg/m and 48 Kg/m Rail is 13 mm. In order to fully utilize the useful life of Concrete Sleepers, which goes even upto 50 years, the sleeper manufacturing plants for the project should be asked to design and manufacture a special PY sleeper for TZR extension which is capable of taking both 48Kg/m as well as 57 Kg/m rail. The rail seat on the sleeper will be for 57 Kg/m rail section and 48 Kg/m Rails would be provided with specially designed 'Combination Liners' to take care of the 13 mm foot width difference, Accordingly, fastening system suitable for such a combination will also need to be procured which is possible since huge quantities of fastenings will be ordered for the project.

Ballast depth would be increased when traffic increases as part of maintenance activity by raising the track and providing additional ballast during regular 'Tie Tamping' cycles.

Similar arrangment is in place on Indian Railway Broad Gauge System for last many decades, where the concrete sleepers are designed for 60 Kg/m UIC rail section over which IRS Rail section of 52 Kg/m are also used. The difference in foot width of 60 Kg/m UIC and IRS 52 Kg/m is 14 mm.

4.8 Earthworks

4.8.1 Formation

Subgrade is the naturally occurring soil which is prepared to receive the ballast. The prepared flat surface, which is ready to receive the ballast, sleepers, and rails, is called the Formation. The formation is an important constituent of the track, as it supports the entire track structure. It has the following functions:

- → To provide a smooth and uniform bed for laying the track.
- → To bear the load transmitted to it from the moving load through the ballast.
- → To facilitate drainage.
- → To provide stability to the track.

The formation can be in the shape of an embankment or a cutting. When the formation is in the shape of a raised bank constructed above the natural ground, it is called an *embankment*. The formation at a level below the natural ground is called a *cutting*. Normally a cutting or excavation is made through a hilly or natural ground for providing the railway line at the required level below the ground level.

The height/depth of the formation depends upon the ground contours and the gradients adopted. The side slope of the embankment depends upon the shearing strength of the soil and its angle of repose. The width of the formation depends upon the number of tracks to be laid, the gauge, and such other factors.

4.8.2 Cuttings

Cutting in Soils: Cuts in geologic materials have by nature a potential to trigger slope instability of varying degrees as they are associated with removal of support to the natural slope that counter the influence of gravity. The likelihood of the occurrence of instability varies according to the nature and engineering characteristics of the soil or rock mass under consideration.

In soils, the cut slope to be provided is dependent on the moisture condition, drainage provisions, nature of stratification, the cut height and the engineering behaviour of the soil including density, permeability and strength parameters. Special attention is needed in minimizing the development of pore-water pressure in soil slopes.

Due to the nature of granular soil deposits like sands and gravels are pervious by nature. Cuts in such soils can stand relatively steeper slopes.

Because of the erratic nature of cohesive soils both temporally and in terms of location, caution should be exercised in deciding cut slopes in such soils. It is not uncommon to come across a sudden failure of slopes in cohesive soils which stood stable for a long time. Generally, flatter slopes prove to be more stable.

Slopes of cuts of any height in stratified soils, especially those with alternating granular soils likely to hold water, can be decided after conducting slope-stability analysis at the Detailed Design stage.

Cuts in Rocks: Cut slopes in rocks are highly influenced by the inclination, orientation and patterns of discontinuities like bedding planes, fractures, joints and faults. Knowledge of each of these characteristics three-dimensionally is essential to make a proper assessment and to decide on the slope(s) to be adopted. Subsurface water is another important factor to be taken into account especially in fissures. Drainage provisions play an important role in stabilizing rock cuts.

Slope stability analysis of rock slopes focus on potential sliding surfaces that include rock joints and bedding planes that are likely to have influence. The use of varying slopes within the same cut has to be considered in layered, fractured and jointed rock formations.

In hard rock with randomly distributed joints and bedding planes not adversely affecting slope stability and in conditions of low groundwater pressure, cut slopes of up to 1H:3V may be employed. A similar slope can also be used in bedded rock with horizontal bedding planes or with bedding planes dipping into the slope. If, however, the bedding planes dip towards the road, the critical angle of the cut would be the angle of dipping even if the friction angle is larger.

In fractured and weathered rocks, a good estimation of the angle of friction, which is around 45º to 50º, suggests the use of a slope not exceeding 1V:1H.

4.8.3 Earthwork in Embankment

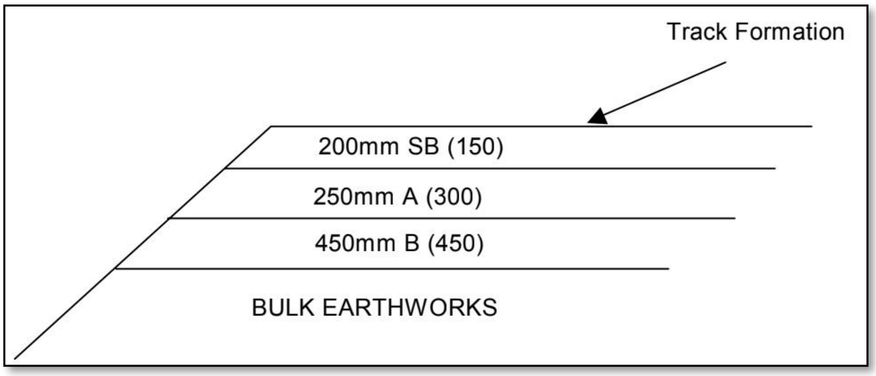
The earthwork in embankments requires detail geotechnical studies/tests on the fill material being used. Bad and poor soils need to be avoided for use on embankments. The quality of earthwork in embankment decides the way it will behave during the service life. Multi-layer thickness of prepared subgrade layer is to be provided as per the quality of the fill material.

As per Spoornet's 'Technical Specification for Railway Earthworks S410 (March 2006)', the following properties and classification of materials for placing purposes have been specified:

- Material that consists of soil with rock not larger than two-thirds of the loose layer thickness is classified as soil. All other material is classified as rock.
- Rock shall not be used within 900 mm of the formation except with the permission of the Engineer.
- Stabilisation of the sub-ballast layers shall be performed only when suitable natural soils is not available and when directed by the Engineer.

For 20 tons axle-load, the structural layers specified by Spoornet are as indicated in the figure below:

Figure 4-13: Earthwork Structural Layers For 20t Axle Load



Note: Dimensions in brackets apply when layer SB is stabilised

The material properties have been specified as follows:

Figure 4-14: Spoornet Table 1 For Material Properties

LAYER		MATERIAL PROPERTIES									Minimum compaction % of modified AASHTO Density	Minimum strength after compaction CBR
		SAR Index	Min. Grading Modulus	% BY MASS PASSING SIEVE (sieve size in mm)					PI	Max. CBR Swell %		
				75	13.2	2.0	0.425	0.075				
SUB LAYERS	SSB	<50	2.0	100	60-85	20-50	10-30	5-15	3-10	0.5	98	60 (o) (1.5-3 MPa)
SUB LAYERS	SB	<80	1.8	100	70-100	20-60	10-40	5-20	3-10	0.5	95	+ 30 (o) (1.5-3 MPa)
A		<110	1.0					<40	<12		95 100*	20
B		<155	0.5					<70	<17		93 98*	10
Bulk earth works									<25	2	90 95*	5

* These densities apply to non-cohesive soils
(o) Strengths in brackets apply in place of CBR values where sub-ballast is stabilised
\+ Increase to 45 in the absence of Layer SSB unless otherwise specified (Increase not normally required in dry areas.)

Note:- See Appendix A for comparable road materials. The classifications shown may be used by the Contractor at his discretion when preparing preliminary assessments of availability of materials for use in the listed layers.

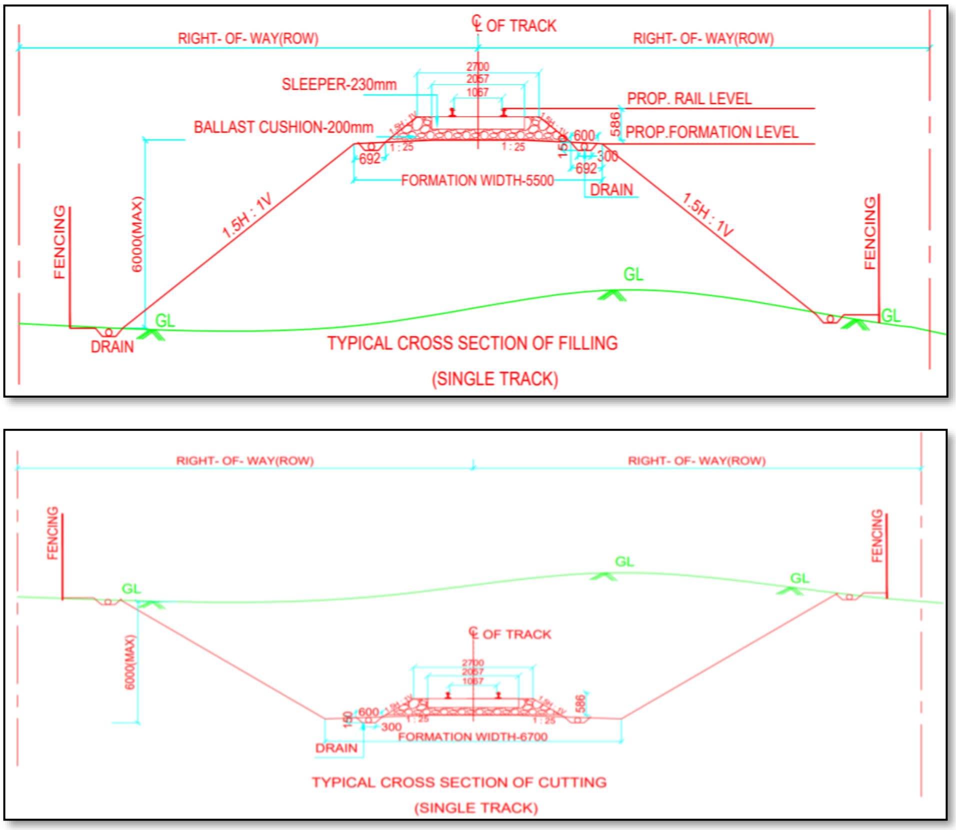
In the table above:

- The SAR Index is the sum of the Liquid Limit, the Plastic Limit and the percentage passing the 0.075 mm sieve, expressed as a number (the sum of Liquid Limit and Plastic Limit shall be taken as 45 if tests for these limits cannot be performed by virtue of the nature of the material).
- The grading modulus is the sum of the cumulative percentages of material retained on the 2.00, 0.425- and 0.075-mm sieves divided by 100.
- The maximum CBR swell is determined at 100% of modified AASHTO density.
- The strength after compaction of stabilised layers is the unconfined compressive strength (UCS) determined when applying the curing times and methods are indicated in Table 2 of Spoornet Specifications.

4.8.4 Design Provisions

Annexure 4 of the 'Infrastructure Engineering- Manual for Track Maintenance' (2012) of Transnet, South Africa' provides the following details for formation in Embankments and Cuttings:

Figure 4-15: Formation- Embankment and Cutting



The details are as below:

(1) The finished top of the formation is 5.5 m.

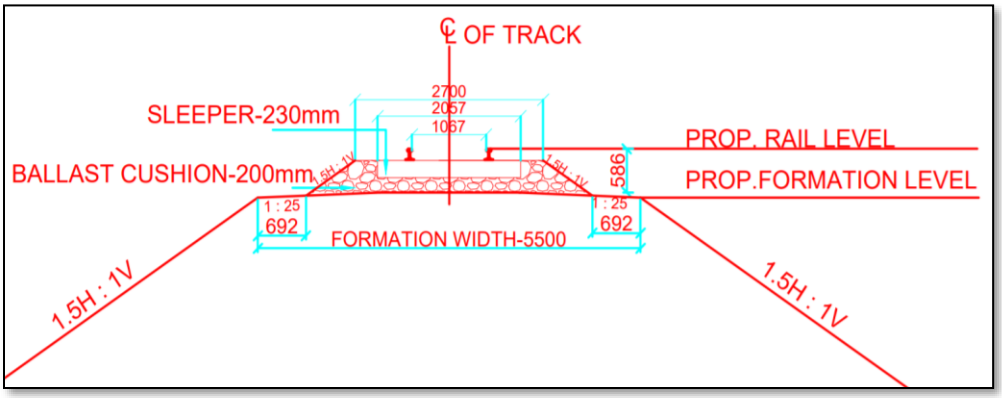
(2) In cuttings, additional width of 600 mm on each side needs to be provided for 'Side Drains'. Hence, the overall width of formation in cutting is 6.7 m.

(3) The formation is to be 'level' for 1 m on either side of the center line and thereafter a cross slope i.e., Camber of 1:25 is to be provided.

(4) The general 'Side Slopes' for formation has been considered as 1V:1.5H.

The specified ballast profile is as follows:

Figure 4-16: Ballast Profile



The side slope for ballast has been considered as 1V:1.5H.

5 Other Design Criteria

5.1 Introduction

The design criteria for the remaining elements of the proposed railway line and access roads are described in this section and include:

- Road Design Criteria
- Traffic Design Criteria
- Bridge Design Criteria

5.2 Road Design Criteria

The railway primarily follows the existing trunk road from Grootfontein to Katima Mulilo with varying distances from the trunk road to the railway. Access roads are required from the trunk road to the rail stations (35 stations in total).

The total length of access roads for the project has been estimated at approximately 6 km with an average road length of 172 m at each station. These rural access roads will connect to the national road network, primarily to trunk roads and the Roads Authority's design requirements would apply.

The Roads Authority has a complete set of manuals covering all aspects of the road design (procedures-, survey-, drainage-, materials- and geometrics manuals). Please refer to Section 5 of this report for further elaboration on these manuals and their relevance.

5.2.1 Road Geometrics Design Guidelines

The Roads Authority's geometric guideline primarily adopts the South African National Roads Agency Geometric Design Guidelines (SANRAL GDG) that sets out the geometric requirements for roads.

5.2.2 Road Design Controls

There are typical important design controls which impose geometric limitations on the design.

5.2.2.1.1 Driver Characteristics

The recommended driver characteristics are indicated below.

Table 5-1: Recommended Driver Characteristics

Parameter	SANRAL GDG
Driver Height (m)	1.05
Break Reaction Time (secs)	2.50
Object height (Stopping) (m)	0.60
Object Height (Passing) (m)	1.30

5.2.2.1.2 Design Speed

The majority of the access roads are short in distance and speeding should not be a problem. The recommended speed for the access roads, in rural terrain are 80 kmph and 50 kmph in flat and undulating terrain respectively (Class C, standard drawings by the Roads Authority). The speed limit within urban areas is 60 kmph.

5.2.2.1.3 Design Vehicle

The access roads will be used by a combination of private and public small vehicles and occasionally single unit trucks, buses and semi-trailer trucks. The heavier vehicles will dictate practical design arrangements such as turning radii.

5.2.2.1.4 Sight Distances

The values of Stopping Sight Distance (SSD) and Passing Sight Distance (PSD) recommended are shown underneath.

Table 5-2: Minimum Stopping (SSD) and Passing (PSD) Sight Distances

Design Speed (kmph)	SANRAL GDG	
	SSD(m) (recommended)	PSD(m) (recommended)
40	50	350
50	70	400
60	90	450
70	110	550
80	140	650
100	200	900

5.2.3 Road Horizontal Design

For a design speed of 80 kmph, the minimum radius of horizontal curve should be 210 m and 250 m with super elevation of 10% and 6% respectively.

5.2.4 Road Vertical Design

The minimum k-value of 30 is recommended for sag curves (headlight illumination criteria) and 85 for crest curves.

5.2.5 Rural Road Cross Section

The access roads will primarily be used by operational staff at the smaller rail stations while the larger and busier train stations will receive substantially more traffic. It is recommended that that smaller train stations can have gravel access roads as is common in Namibia and bitumen roads for the larger train stations.

Figure 5-1: Recommended Profile for Bitumen Access Road

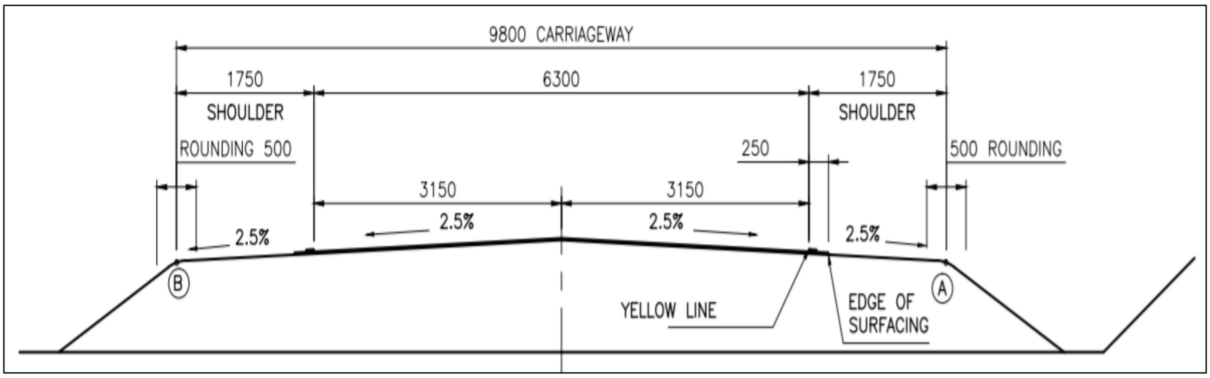
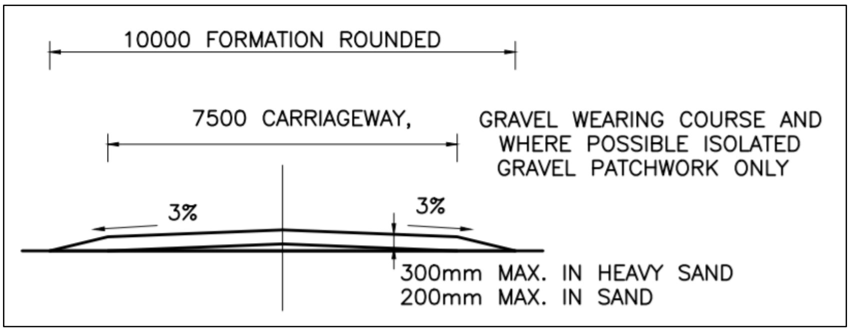


Figure 5-2: Recommended Profile for Gravel Access Road



5.2.6 Intersections and Accesses

Access roads will primarily connect to the trunk road by means of a T-junction (intersection). The location of the T-junctions should be carefully considered and determined during the detail design stage.

T-junctions can be located on horizontal curves, but the minimum radii should be adhered to which is 2,200 m radius for a 120 kmph design speed on the trunk road.

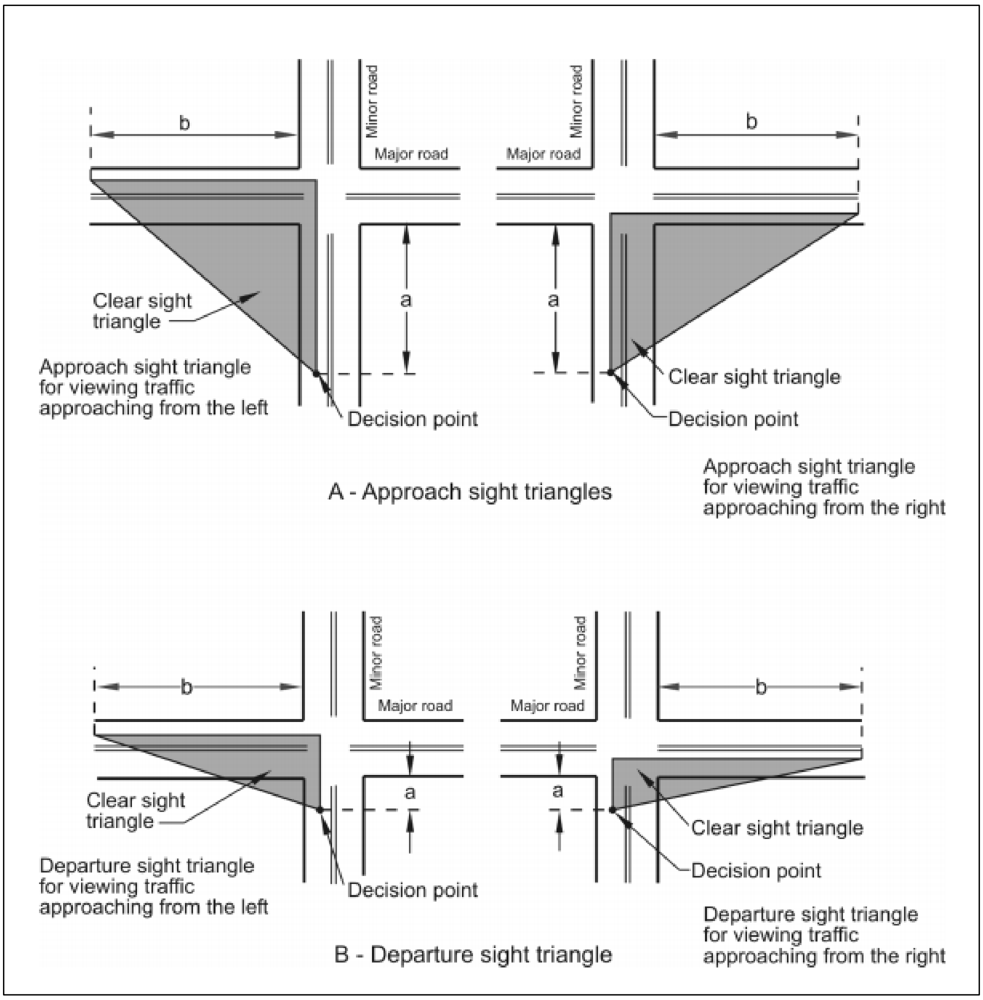
Rail access roads should be combined with existing accesses, if possible, to eliminate additional accesses to the trunk road.

The angle of the access road to the trunk road should be kept perpendicular as far as is possible and skew angles should be avoided.

The provision of adequate sight distances is essential for safe intersection operation. Adequate stopping sight distance, decision sight clearance and intersection sight distance should be provided. Each quadrant of an intersection should contain a clear sight triangle free of obstructions that may block the driver’s view of potentially conflicting vehicles on the opposing approaches. There are approaching sight triangles, which should give a driver approaching an intersection sufficient time to slow should the driver see a conflicting vehicle before entering the intersection.

For the departure sight triangle, the line of sight described by the hypotenuse of the sight triangle should be such that a vehicle just coming into view on the major road will, at the design speed of this road, have a travel time to the intersection corresponding to the gap acceptable to the driver of the vehicle on the minor road. The sight triangles are depicted Figure 5-3 and the shaded areas should be kept clear of any obstruction where the line of sight assumes a driver eye height of 1.05 m and an object height of 1.3 m.

Figure 5-3: Sight Triangles



Source: SANRAL GDG, 2017

The sight distances vary with the type and traffic control of the intersection. The types of traffic control are:

i) Intersections with no control (Case A).

ii) Intersections with Stop control on the minor road (Case B).

iii) Intersections with Yield control on the minor road (Case C).

iv) Intersections with traffic signal control (Case D). Sight triangles normally not required but due to power failures it is recommended to follow Case B.

v) Intersections with all-way Stop control (Case E). Sight triangles normally not required.

Case B and C will apply to most intersections in rural settings while Case D and E could apply in urban areas. The summary of the sight triangle distances (A & B) are given in Table 5-3 for a major road speed of 120 kmph and a minor road of 80 kmph.

Table 5-3: Intersection Sight Distances

	All manoeuvres			**A = ± 5m**
Case B	Right & left turn from minor road onto major road	Passenger Car	7.5 seconds required	B = 250m
		Semi-Trailer Truck	11.5 seconds required	**B = 383m**
	Crossing the major road	Passenger Car	6.5 seconds required	B = 215m
		Semi-Trailer Truck	10.5 seconds required	B = 350m
Case C	Right & left turn from minor road onto major road	Passenger Car	8 seconds required	A = 25m B = 265m
		Semi-Trailer Truck	12 seconds required	**A = 25m** **B = 400m**
	Crossing the major road		Based on 80 kmph on minor roads	**A = 110m**

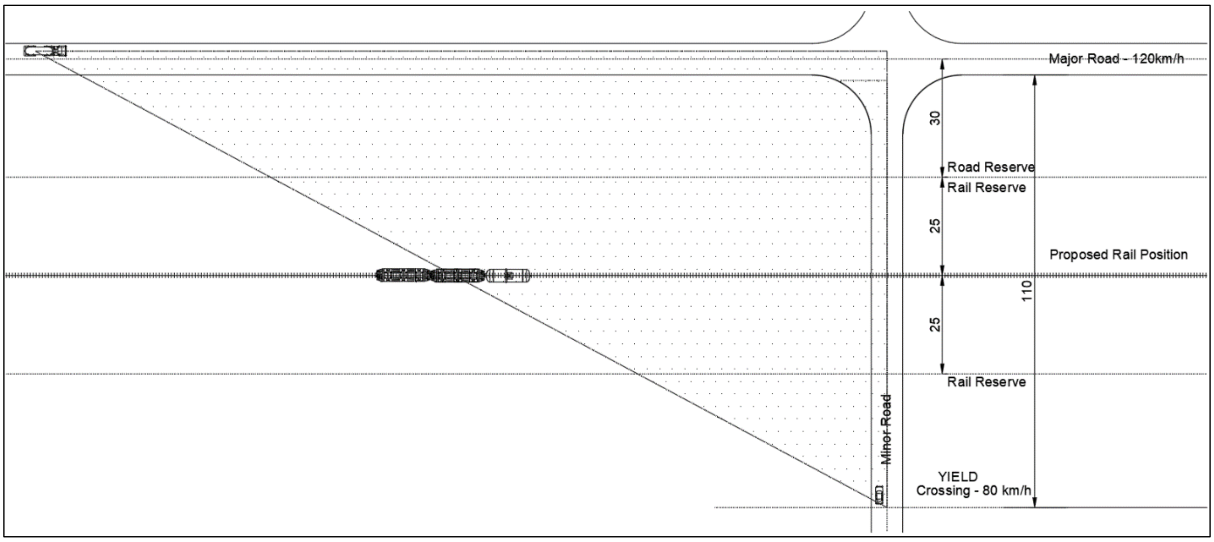
Source: SANRAL Geometric Design Guidelines, 2017

For both yield and stop control the sight distance required on the major road is about 400 m.

For the yield control and crossing manoeuvres a distance of 110 m is required on the approaching minor road (see Figure 5-4). If the rail is positioned as proposed, with the road and rail reserves adjacent to each other, a train could obstruct the sight distance required for a vehicle approaching the major road when considering a crossing manoeuvre.

The majority of the train access roads are envisaged to be T-junctions with no crossing manoeuvres and the location of the rail would therefore not be a problem. However, should there be intersections, allowing crossing manoeuvres, it is recommended that the traffic control on the minor approach is changed to stop control.

Figure 5-4: Yield Sight Distance Required (Crossing Manoeuvre)



5.2.6.1 Intersection (T-Junction) Type

The Roads Authority (RA) has three access types:

i) Type A: Surfaced access used for proclaimed district and farm roads.

ii) Type B: Surfaced access used for private access roads.

iii) Type C: Gravel access used for cattle crossings, access to camps etc.

The RA does however qualify those special intersections that are to be designed on all trunk roads where required.

It is recommended that for the larger train stations a custom intersection would be required (see Figure 5-5 on the following page) and the remainder to receive Type A intersections (see Figure 5-6 on page 80).

Figure 5-5: Recommended Intersection at Large Train Stations

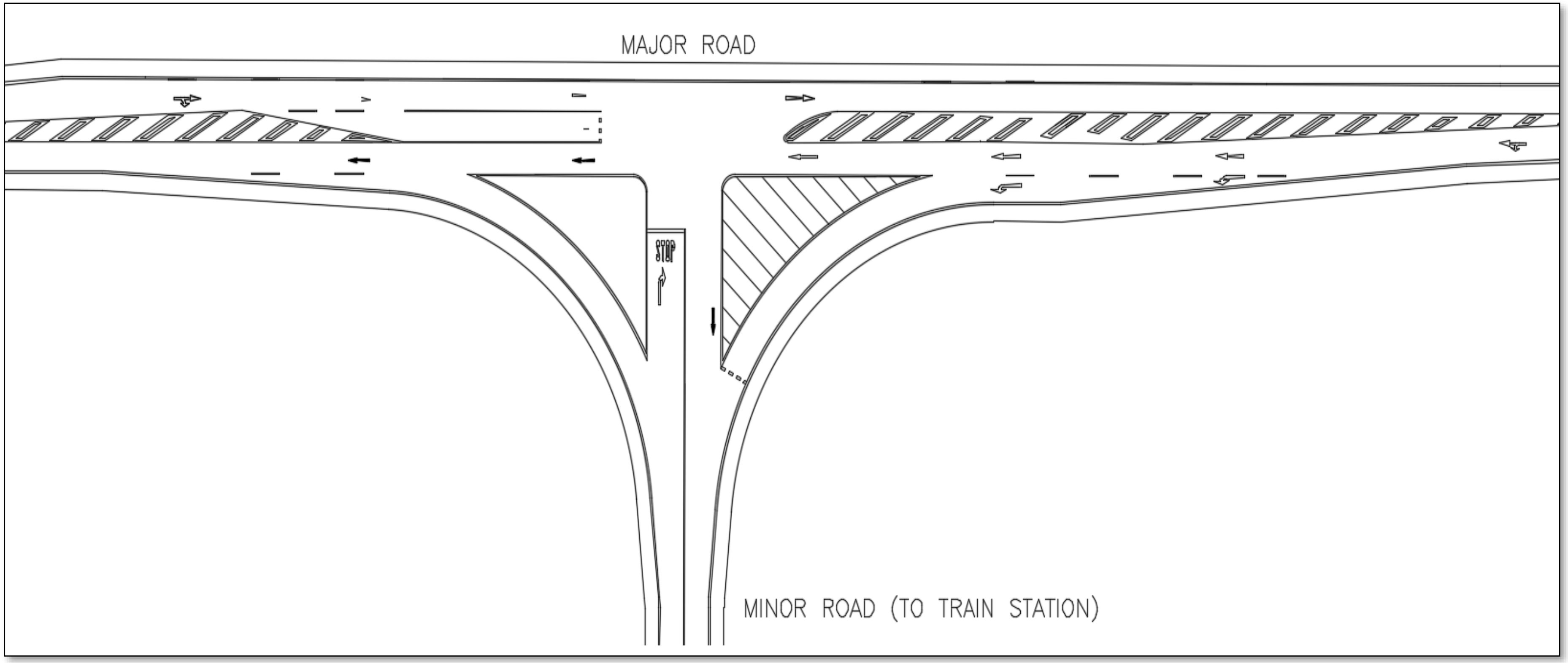
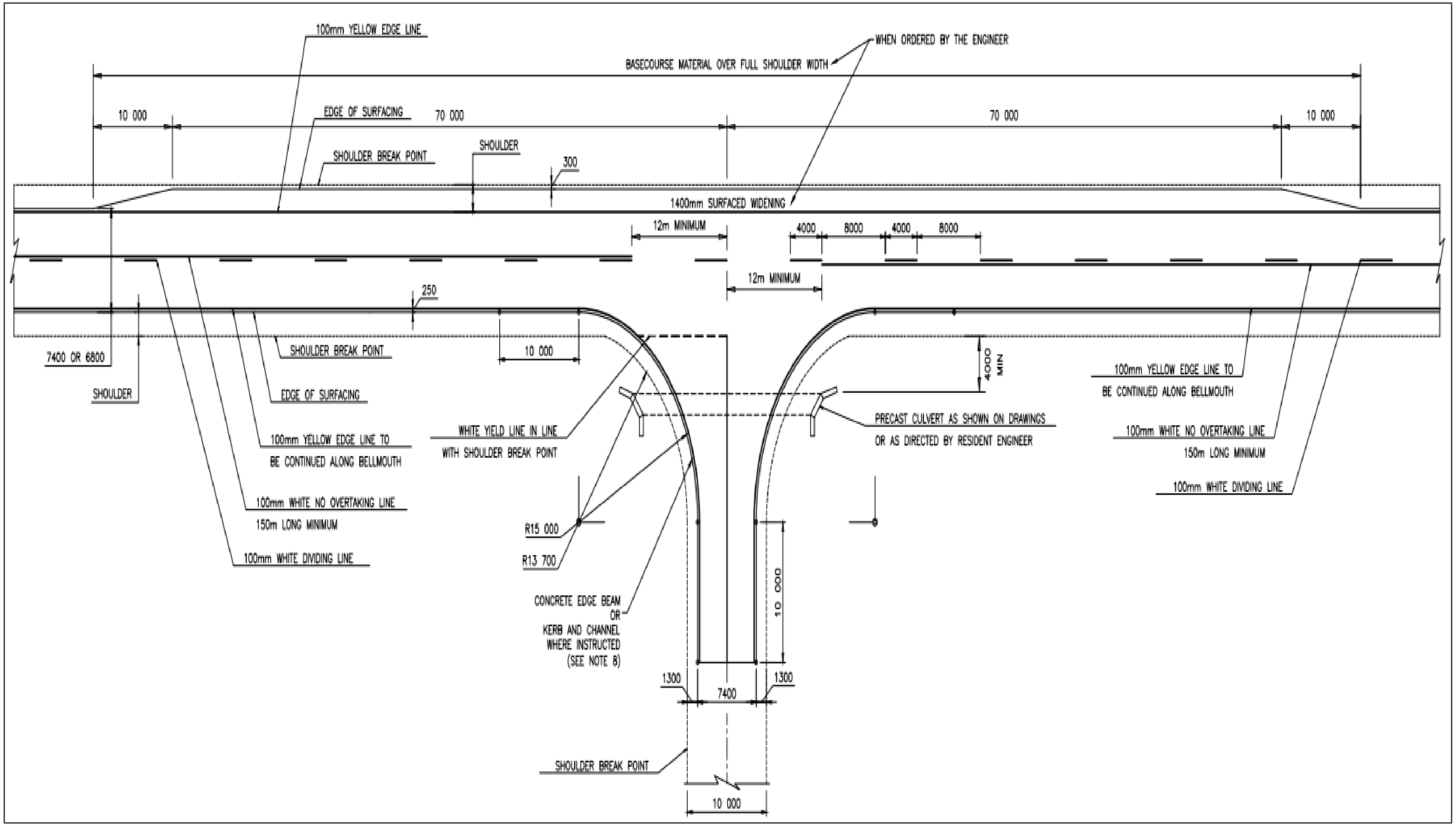


Figure 5-6: Type A Intersection



Source: Roads Authority

5.2.7 Road Pavement Design

The function of the pavement is to provide a surface condition that allows a safe, comfortable and economical ride for the vehicles using it. The design aims to provide the following functions and properties:

- Subgrade protection.
- A stable layer structure.
- Durability, and
- An appropriate wearing-course.

The pavement design of the access roads is recommended to follow the guidelines of TRH4 in accordance with the RA Materials Manual.

The access roads are considered Category D roads (rural access roads with daily traffic of less than 500 vehicles). A Category D Road comes with a design period of 10 years.

The following was assumed:

iii) Smaller train station: 10-20 vehicles per day per lane. Pavement Class = ES0.03.

iv) Large train stations: 75-220 vehicles per day. Pavement Class = ES0.3.

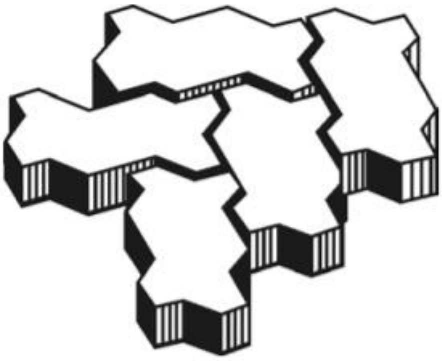
The recommended pavement structure for surfaced roads, derived from the catalogue in TRH4 are depicted below. Bitumen seals of short roads are not always practical and segmented paving can be an alternative. The Guidelines for Human Settlement Planning and Design published by the Council of Scientific and Industrial Research (CSIR) (Red Book) suggests pavement structures for segmented paving and this is also included in the table below.

Table 5-4: Recommended Pavement Structure, Surfaced Roads (TRH4)

Smaller Train Stations	Large Train Stations
Surface Treatment (13.2mm Cape Seal)	Surface Treatment (13.2mm Cape Seal)
100mm G5/ gravel base	150mm G5/ gravel base
125mm G7/	150mm G7/sub-base
Foundation Treatment	Foundation Treatment
150mm G7 rip and re-compact in-situ subgrade	150mm G7 rip and re-compact in-situ subgrade
60mm Segmented Paving (type S-A)	60mm Segmented Paving (type S-A)
20mm sand layer	20mm sand layer
	150mm G5
Foundation Treatment	Foundation Treatment
150mm G7 rip and re-compact in-situ subgrade	150mm G7 rip and re-compact in-situ subgrade

A type S-A paver allows geometrical interlock between all faces of adjacent blocks (see Figure 5-7).

Figure 5-7: Type S-A Segmented Paver Block



As mentioned, the majority of the smaller access roads will not be required to be surfaced. The gravel roads are classified as Class C roads (less than 25 vehicles per day). The alternative gravel road pavement structure is depicted below.

Table 5-5: Recommended Pavement Structure, Gravel Roads (TRH4)

Smaller Train Stations	
	150mm G5/ gravel wearing course
	150mm G6/gravel base
Foundation Treatment	
	150mm G7 rip and re-compact in-situ subgrade

5.2.8 Road Drainage Design

The drainage design should follow the Roads Authority's Drainage Design Manual. The design return periods shall be as recommended by Table 3.1 of the RA's Drainage Manual. It is recommended that the train access roads are classified as District Roads.

Table 5-6: Basic Design Return Periods

1:20 year peak discharge (m^3/s)	District Road
0 to 20	1:5
20 to 150	1:10
More than 150	1:15

Source: Drainage Manual: Roads Authority

The design floods shall be calculated as per the methods defined in the Drainage Manual (Table 5-6). The applicable bridges, pipe or box culverts shall be designed using the Drainage Manual. Surface drainage shall follow the drainage guidelines and kerb inlets shall be used in urban settings where required.

5.3 Traffic Design Criteria

5.3.1 Rail/Road Crossings

A road crossing is defined as the intersection in plan view between a roadway and the railway at grade. This applies to all public and private roads as well as designated animal/cattle crossings. When designing a railway there are two possible approaches for addressing these crossings - by providing a 'Grade Separator' or by providing a 'Level

TECHNOFIN CONSULTANTS

Crossing'. Grade separators are warranted at locations where road traffic is high and where necessity of closure of gates at level crossings is very frequent.

This also brings in safety issues and train operation difficulties. Ideal condition would be to provide all grade separators which unfortunately makes the project prohibitively expensive. Hence a balanced and logical approach in making the decision between Grade Separator and level Crossing needs to be made.

Criteria for provision of grade separators and level crossings needs to evolve based on the road traffic details, projected train traffic and method of operation of the gates. Generally, level crossings are provided at secondary roads and below.

Level crossings may be guarded or unguarded. One or more gate person is posted at staffed level crossings to regulate the traffic. At an unstaffed level crossing, there is no gate person and road users cross the railway line at their own risk after taking the necessary precautions.

Level crossings are vulnerable to accidents due for several reasons, but the main reason behind these accidents is the negligence of road users. Whatever may be the cause of an accident on a level crossing, the railways come under severe criticism whenever such an accident occurs. Some of the safety measures that can be taken to reduce accidents on level crossings are as follows:

(ii) **Staff level crossings:** Busy unstaffed level crossings, particularly at locations where buses ply, should be manned in a phased manner.

(iii) **Providing lifting barriers:** Lifting barriers should be provided in preference to gates to quickly clear road traffic.

(iv) **Level crossing indicators:** At the approaches to all level crossings where the view is obstructed, whistle boards should be erected along the track at a distance of 600 m from the level crossing to enjoin the drivers of approaching trains to give an audible warning of the approach of the train to road users. The drivers of approaching trains should blow the train whistle continuously from the time they pass the whistle boards till the time they have negotiated the level crossing.

(v) **Stop signs for level crossings:** Stop signs should be provided on either side of the road approaches at suitable points within the railway boundary.

(vi) **Rumble strips at level crossings:** Rumble strips should be provided on either side where road travellers face poor visibility conditions with a view to making them alert and vigilant. Rumble strips consist of intermittent raised bituminous overlays of 15–20 mm height and 200–300 mm width across the roadway. About 15 to 20 such strips spaced at about 1 m centre-to-centre distance are provided in the approaches to level crossings to caution the motorist.

(vii) **Visibility:** Approaching trains should be adequately visible from the road. Whenever an obstruction is discovered on the track, immediate action must be taken to remove it.

For level crossing, different levels of protection through signalling and telecommunication systems are required depending on the location and the functioning of the road.

5.4 Bridge Design Criteria

5.4.1 Railway Bridges

Bridge structures are very important elements of a railway system. Railway bridges are designed to have a significantly longer life to that of road/highway bridges and are generally designed for a life span of 100 years.

Railway bridge structures require a much greater consideration of longitudinal loading than a typical road/highway bridge. When comparing railway bridges to road/highway bridges, the live load relative to the dead load is much greater and more consistent. This consistent loading and unloading over a long period result in critical fatigue stresses.

Design criteria for railway bridges need to consider the constructability, local availability of material, geotechnical conditions, and the type of substructure and superstructure planned.

Railway Bridge Design Loads:

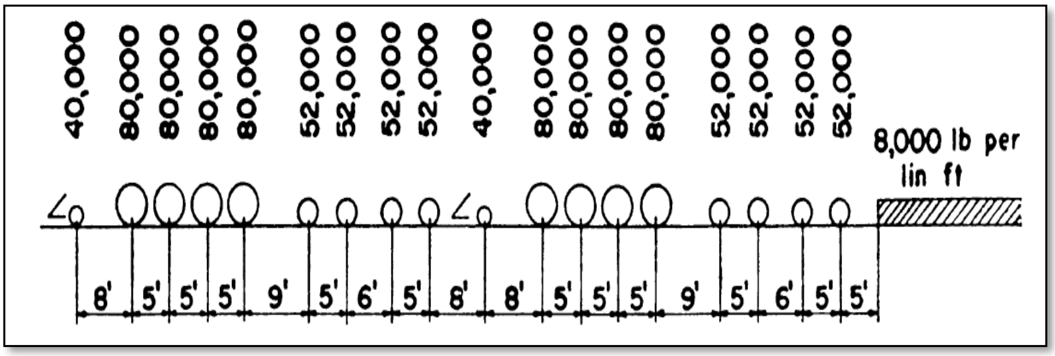
Railway bridges are designed considering the following loads (AREMA 2003) and their combinations:

- Dead Load
- Live Load
- Impact (Dynamic effects)
- Centrifugal Forc
- Earth Pressure
- Buoyancy
- Wind Load on Structure
- Wind Load on Live Load
- Longitudinal Force from Live Loa
- Longitudinal Force due to Friction or Shear Resistance at Expansion Bearings
- Earthquake (Seismic)
- Stream Flow Pressur
- Ice Pressure (where applicable
- Other Forces (Rib Shortening, Shrinkage, Temperature and/or Settlement of Supports)

For structural design of bridges, bridge loading standards are to be considered. Each country has its own loading code that is based on the requirements and conditions of that particular country. Due to the complexity of train loads, all rail traffic live loads are simplified as load models in design codes. The load models are depicted as point (axle) loads and/or uniformly distributed loads that represent the predicted external loads, which are applied to the railway bridges. Some of the Load Models adopted for Railway bridge design are indicated as under:

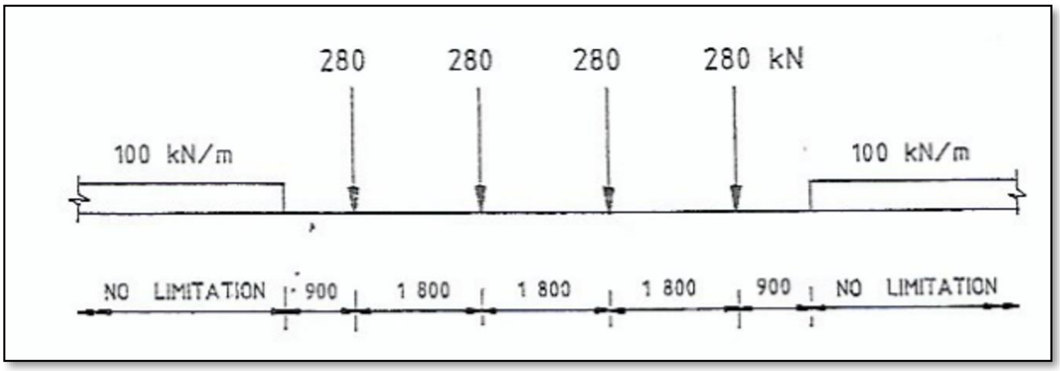
American Railway Engineering Maintenance of Way Association (AREMA) Manual for Railway Engineering – Cooper E 80 Axle Load Diagram

Figure 5-8: Cooper E 80 Axle Load Diagram



South African Transport Services (SATS) Bridge Code 1983

Figure 5-9: NR Loading (SATS)



European Code EN -1991-2

The EN 1991 the rail traffic actions are defined by means of load models. Five models of railway loading are given as under:

- Load Model 71 (and Load Model *SW/O* for continuous bridges) to represent normal rail traffic on mainline railways,
- Load Model SW/*2* to represent heavy loads,
- Load Model HSLM to represent the loading from passenger trains at speeds exceeding 200 kmph,
- Load Model "unloaded train" to represent the effect of an unloaded train.

The load model 71 and SW/0 are the one which would be applicable for design of bridges on Trans-Zambezi Railway Corridor:

Figure 5-10: Load Model 71 And Characteristic Values for Vertical Loads

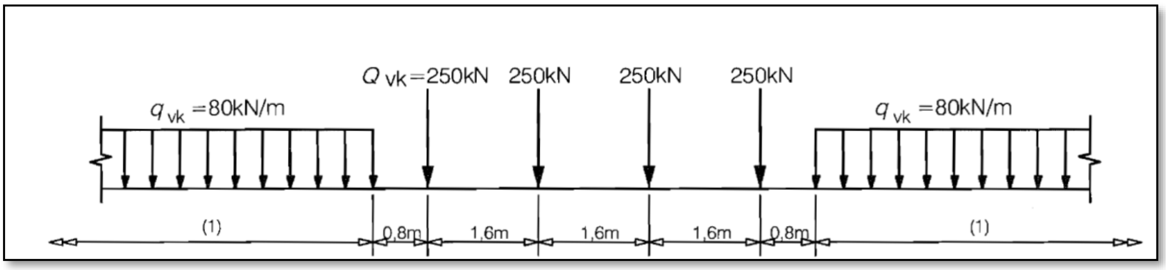
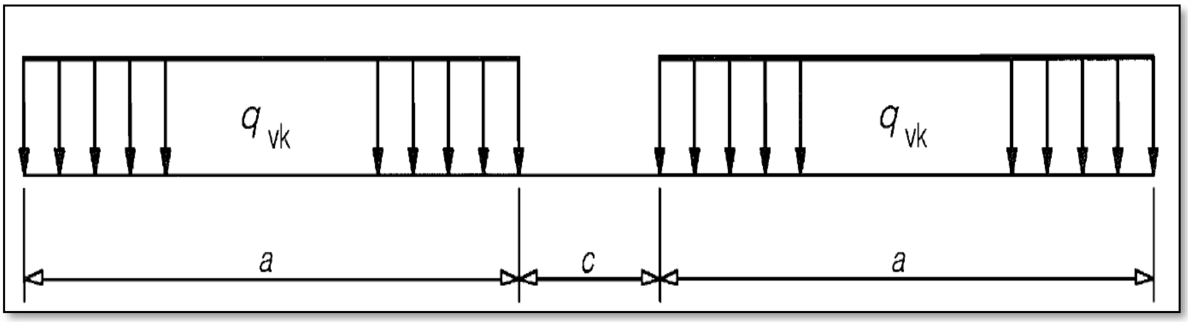


Figure 5-11: Characteristic Values for Vertical Loads for Load Models SW /0

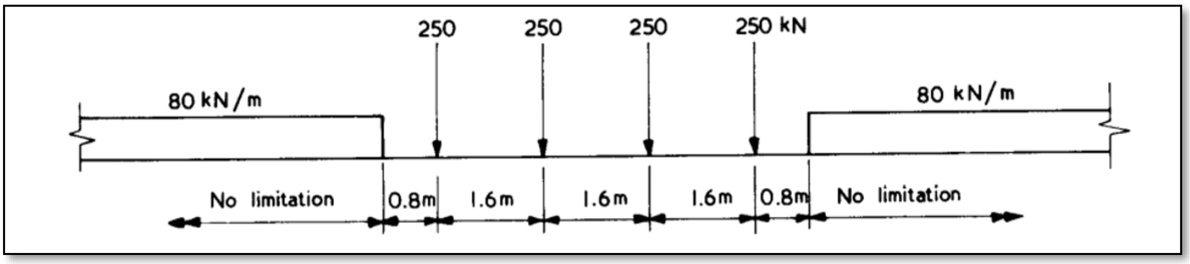


Where q_{vk} is 133 kN/m; *a = 15 m and* c= 5.3 m

British Standards (BS) 5400

Standard Railway loading consists of two types of live loading RU and RL. RU loading allows for all combinations of vehicles currently running or projected to run on railways in the continent of Europe and is to be adopted for design of bridges carrying mainline railways of 1.4 m gauge and above. RL loading is reduced loading for use on passenger rapid transit railway systems on lines where mainline locomotives and rolling stock do not operate.

Figure 5-12 RU Loading as per BS 5400



5.4.1.1 Namibian Railway Bridge Design standards

Namibian Railway bridge designs are based on design standards adopted in South Africa.

In South Africa, railway bridge load models are specified in the South African Transport Services (SATS) bridge code. The live load models in SATS are based on BS 5400-2:1978 (SATS Bridge Code, 1983). South African railway bridge design uses the structure of the RU load model specified in BS 5400- 2:1978. The values for the point (axle) and uniformly distributed loading have however, been increased to suit the conditions for South African bridges.

In 2010, BS 5400-2:1978 was superseded by Euro code structural codes for design of new bridges. The structure of the RU load model as well as the load values, remained the same, but the load model was renamed as load model LM71 in the Euro code standard. Despite the replacement of BS 5400-2:1978 and the standardization of European countries' design codes into a harmonized national document, South Africa continues to use the SATS bridge loading code for bridge design, in conjunction with the highway bridge loading code TMH7.

The superseding of national design rules applicable to European member states with a set of standardized Euro code structural design codes, presented many challenges for European member states (EN 1991-2:2003). Implementation of the standardized Euro code design codes compelled European member states to establish ways to align country specific design codes with those of Euro code (EN 1991-2:2003). This entailed incorporating additional country specific information to meet the conditions and requirements of each country. Euro code design codes accommodate any additional information through the introduction of National Annexes. The National Annex document contains country specific information in the form of Nationally Determined Parameters (NDPs), reserved to replace information left open in Euro code for national choice.

An important challenge to the revised standardized design code to be adopted for design of new bridges was the specification of traffic load models defined in each country and assessing how the effects of these load models aligned with the standard models defined in the Euro code. Several European countries conducted studies to harmonize the Euro code load models. The aim was to adjust the characteristic values given for vertical loads in load model LM71, by applying the factors (α) proposed by Euro code (Cl 6.3.2 (3P) to convert the characteristic load values to classified load values.

To address such challenges, some member states embarked on desk study and actual field related research to analyze traffic load models on structures and determine how the different aspects of design standards could be combined. Considering this background, it seems necessary to revisit the bridge codes presently used in Namibian Railways so as to align this to the latest developments and proposed railway traffic needs of the region.

5.4.1.2 Adoption of Bridge standards for Trans Zambezi Railway Corridor

On the basis of above background, for the Trans Zambezi railway line, it is recommended to adopt the present norms being followed by Namibian Railway i.e., South African Transport Services (SATS) bridge loading code for bridge design in conjunction with the highway bridge loading code TMH7. However, it is desirable that the bridge code for design of railway bridges be revised (preferably, uniformly for all southern African countries) and an updated document formulated for design of bridges on this railway corridor at the Detailed Design stage to align with the latest developments in the Euro code.

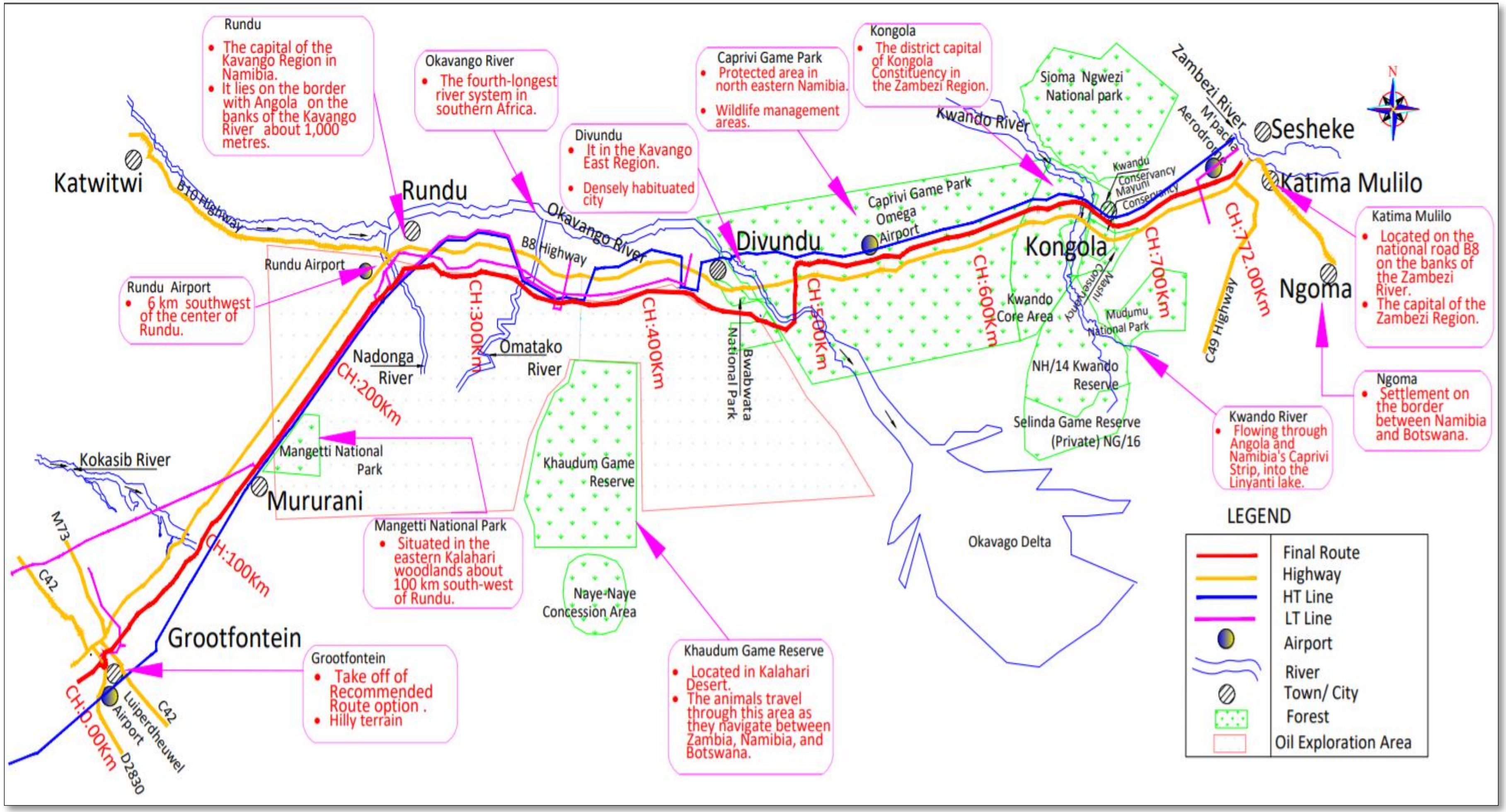
6 Railway Alignment

6.1 Introduction

The options that were considered towards arriving at the finalized route were discussed in the Travel Demand Report – Vol I - Route Options Assessment. Details of the finalized route are provided pictorially in Figure 6-1.

The figure includes key characteristics of final route including economic and population centres, important infrastructure (airports, transmission lines, etc.), environmentally sensitive areas, etc.

Figure 6-1: Final Route Details



Note: The low and high voltage lines in the figure above are based on information received from NamPower. However, an additional power line was observed for long stretches next to the B8 road reserve from Grootfontein to Rundu. This power line is not captured in the information provided by NamPower.

6.2 Route Take-off and Termination

The Terms of Reference (TOR) for this study stipulates the take-off and termination points for the Trans-Zambezi Extension line as Grootfontein and Katima Mulilo respectively.

6.2.1 Starting Station-New Grootfontein

Grootfontein is a city in the Otjozondjupa Region of central Namibia. It is one of the three major towns in the Otavi Triangle, situated on the National Road B8 that leads from Otavi to the Caprivi Strip.

The termination point of the existing Grootfontein station is in the middle of city. Grootfontein is a densely inhabited city and as such, creating additional railway infrastructure at the existing location of Grootfontein railway station would lead to substantial urban land acquisition and relief and rehabilitation for 'Resettlement'. Additional railway infrastructure at the exiting location would also lead to cutting across the city roads and disruption of road traffic.

Consequently, the take-off of the greenfield Trans Zambezi railway line from Grootfontein is proposed about 2.0 km west of the existing Grootfontein station towards Otavi. Three loop lines are proposed which would provide direct connectivity to the proposed Grootfontein-Katima Mulilo line as well as to the existing Walvis Bay-Grootfontein line. The Grootfontein Airport is about 4.50 km from proposed New Grootfontein station.[6]

The Coordinates of take-off are 19°34'39.77"S and 18° 4'25.55"E (see Figure 6-2 and Figure 6-3).

---

[6] *At the time of submitting this report (March, 2022), updating of Grootfontein and Rundu's 'Structural Plans' (i.e. Master-plans) have commenced and are in the early stages of development. This Consultant (M R Technofin) has provided the necessary inputs to the planning consultant (Stubenrauch Planning Consultants) regarding the 'feasibility stage' finalized route and the planning consultant was made aware that the route would be further refined at the detailed design stage.*

Since Structure Plans becomes a statutory document once approved, it was agreed that the town planning consultant would – if required - propose alternative routings through Grootfontein and Rundu to suite related planned developments. With the consent of MoRD, this Consultant is willing to conduct a review of the proposed alternative routings for geometric and railway operational.

Figure 6-2: Take-off from Grootfontein (1)

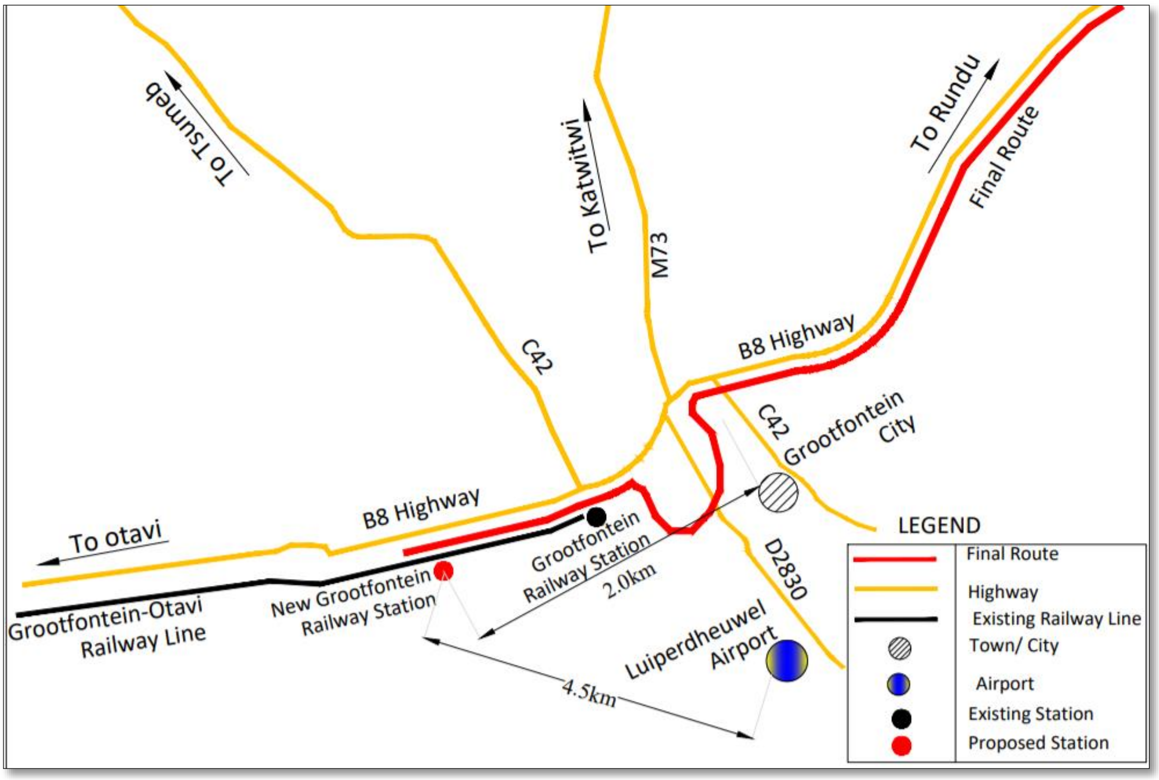
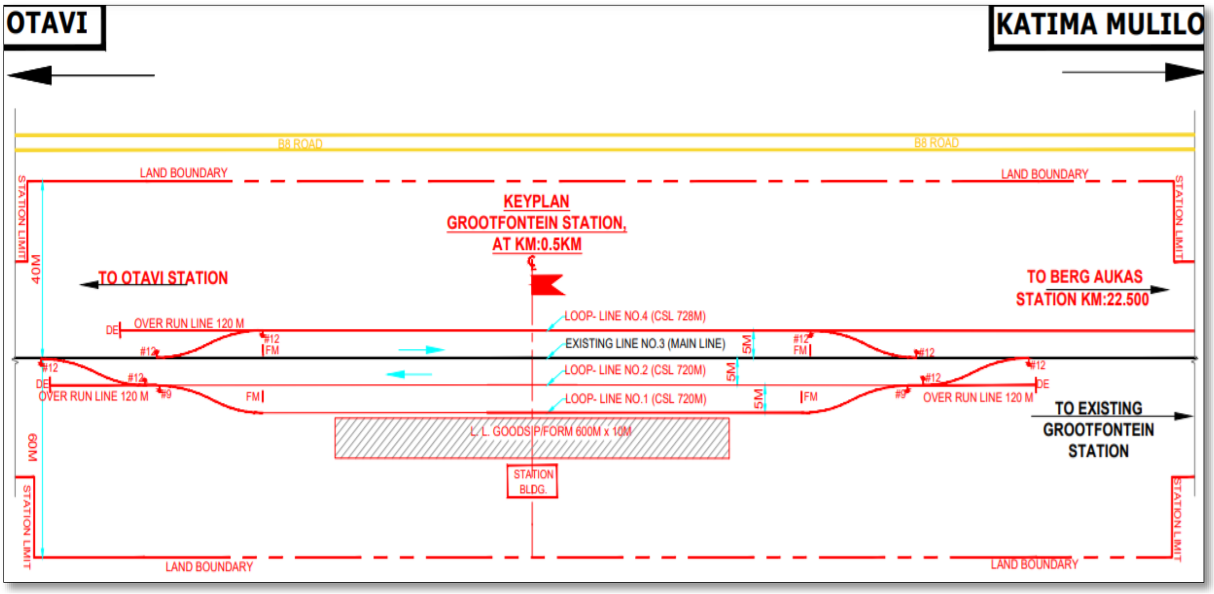


Figure 6-3: Take-off from Grootfontein (2)

The proposed yard layout of the New Grootfontein station is as indicated in Figure 6-4.

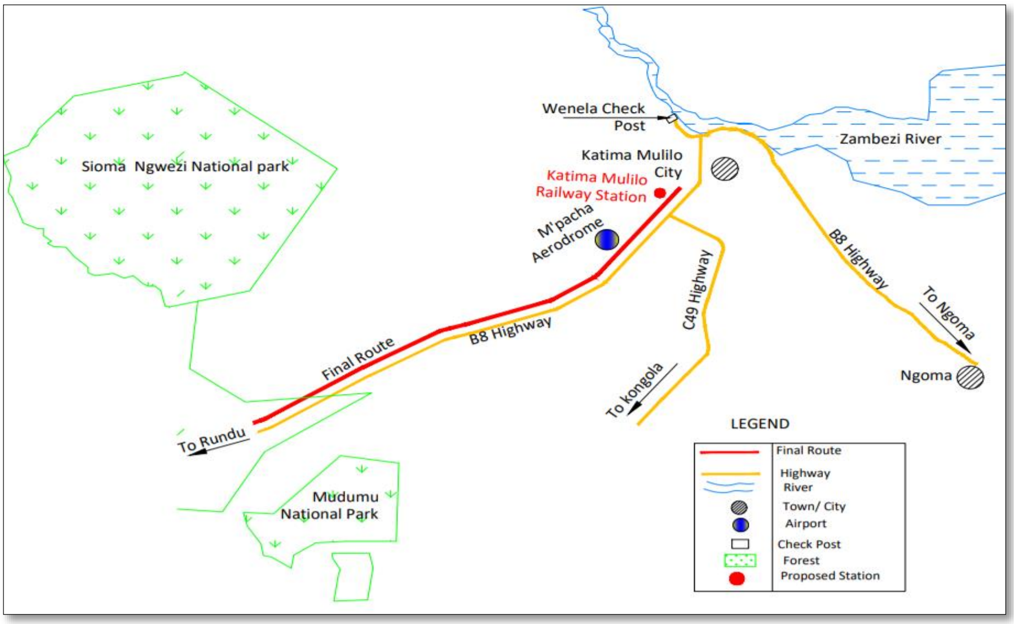
Figure 6-4: Line Diagram of New Grootfontein Station-For Final Route



6.2.2 Terminating Station - Katima Mulilo

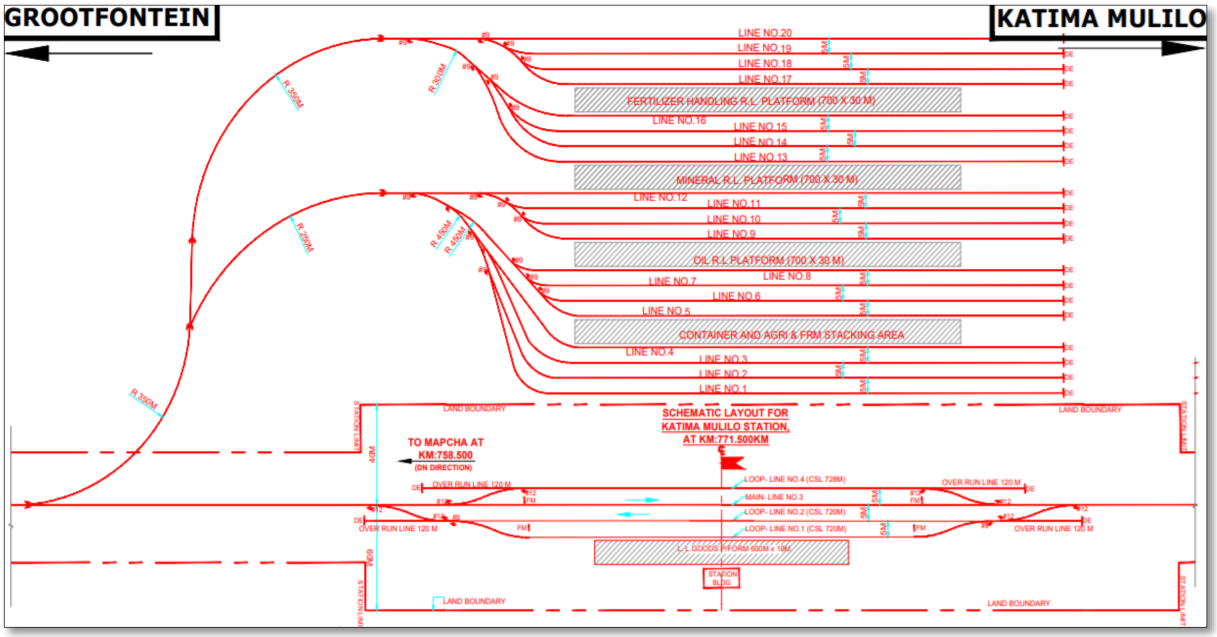
Katima Mulilo is the capital of the Zambezi Region of Namibia and is located on National Road B8 in the Caprivi Strip on the banks of the Zambezi River. The end coordinates of the route are 17°33'28.88"S and 24°15'12.31"E which is roughly 2.00 km from the centre of the city (see Figure 6-5 below).

Figure 6-5: Terminating Station-Katima Mulilo



The potential yard layout for Katima Mulilo station is as indicated below:

Figure 6-6: Line Diagram of Katima Mulilo Station-For Final Route



6.3 Other Key Locations on the Final Route

The final route passing through following regions:

1 132.5 km of the total route traverses Otjozondjupa region

2 122.1 km of the total route traverses Kavango West region

3 313.82 km of the total route traverses Kavango East region

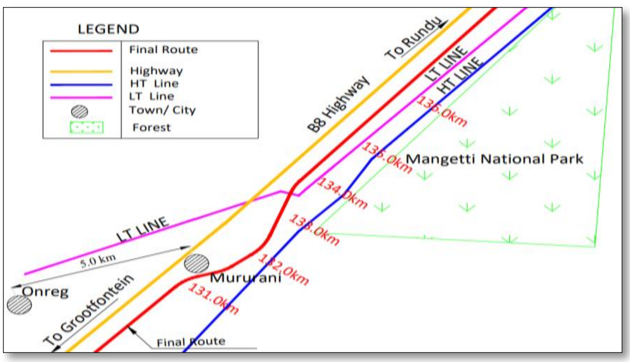
4 203.58 km of the total route traverses Zambezi region

This section covers other key locations/ stretches on the final route.

6.3.1 Mururani

- Mururani is a village in Otjozondjupa Region.
- The entrance of Mangetti National Park is about 15.00 km northeast from proposed Mururani station.
- The Onreg village is about 5.00 km west from Mururani.
- The proposed Mururani station is about 0.50 km from the city centre of Mururani.

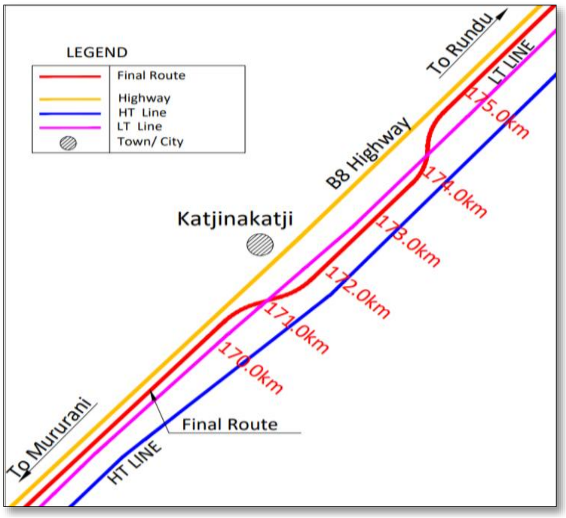
Figure 6-7: Mururani City location on Final route



6.3.2 Katjinakatji

- Katjinakatji is a village under Kavango West Regional Council, Mankumpi Constituency located 90.00 km south of Rundu. The population of the village is estimated to be 2,756 people while the surrounding communities (excluding Mururani East) has an estimated population of 1,683 people[7].
- The entrance of Mangetti National Park is about 24.00 km on southeast of the village.
- The final route avoids disturbing the settlement at Katjinakatji.
- The HT & LT lines pass along the B8 road at Katjinakatji.

Figure 6-8: Katjinakatji Location on Final Route

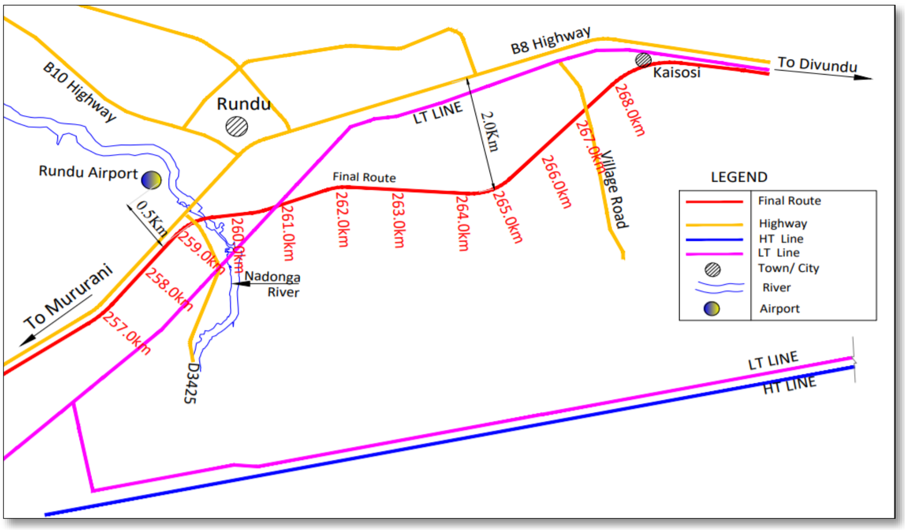


6.3.3 Rundu

- Rundu is the capital and largest city of the Kavango in northern Namibia.
- It lies on the border with Angola on the banks of the Kavango River about 1,000 m (3,300 feet) above sea level.
- The Rundu Airport is about 0.50 km from the final route.
- To avoid substantial 'Resettlement', the final route has been 'detoured' from Rundu airport area up to Kaisosi.
- The final route is about 2.0 km from city centre.

[7] Environmental management plan for katjinakatji interim water supply project- July 2019

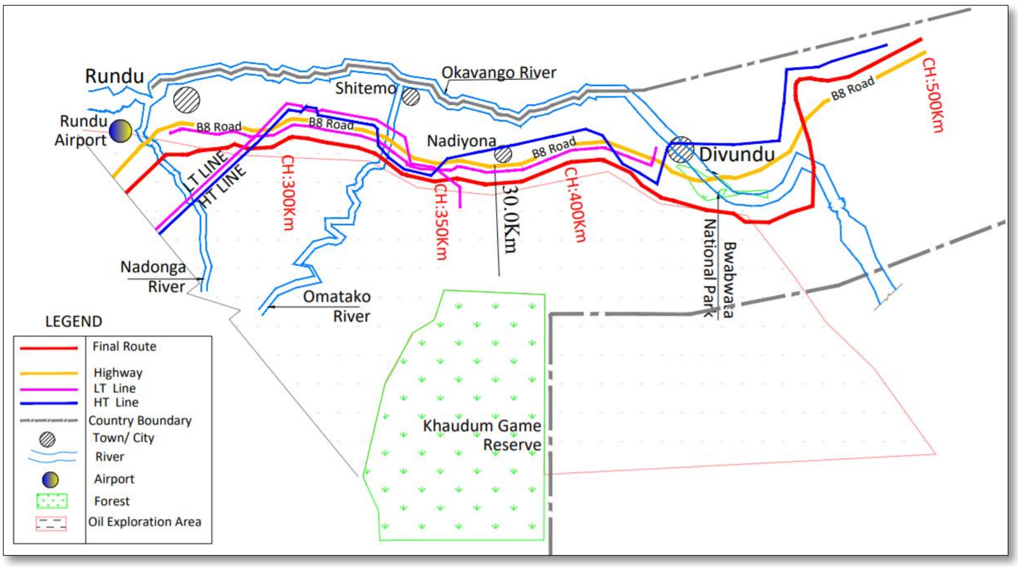
Figure 6-9: Rundu Town location on Final route



6.3.4 Rundu to Divundu Section

- The route crosses Ndonga River, Omatako river, Okavango river in Rundu to Divundu Section.
- The Okavango River flows along Rundu to Divundu as shown in the figure below.
- The Khaudum Game reserve is about 30.00 km from the Ndiyona village.
- Due to the Okavango River, most of the agricultural land is on the north side of B8 road. To minimize the disturbances to agricultural land, the route runs along south side of B8 road in this section.
- High and low voltage transmission lines runs along both side of the B8 road corridor in this section. To avoid crossing of transmission line, it is proposed that the railway route run alongside of the transmission line corridor (i.e., 60.00 m) on the south side of B8 road.

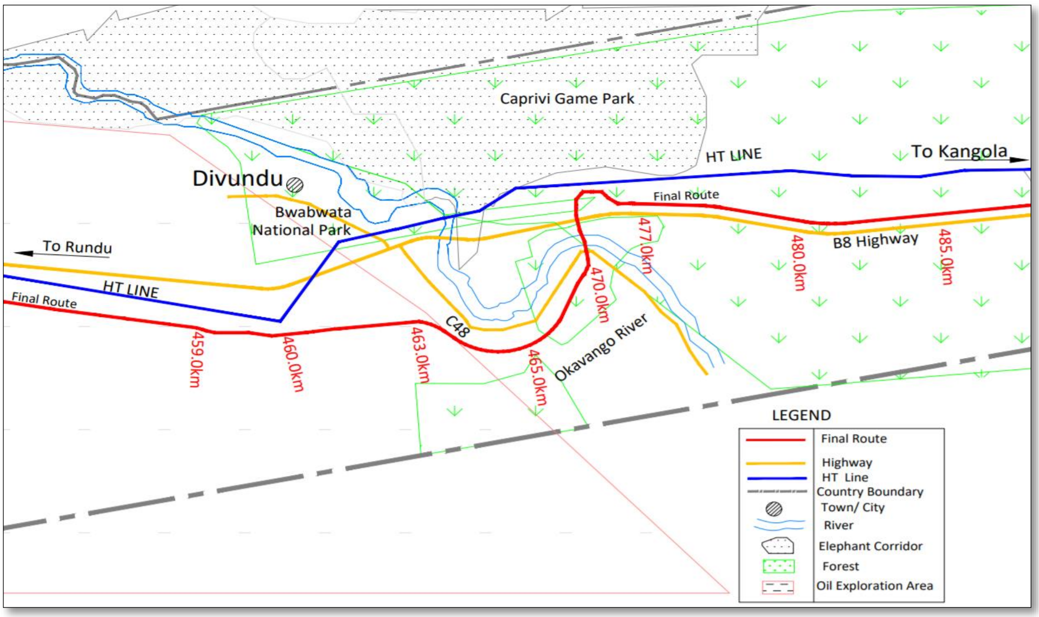
Figure 6-10: Rundu to Divundu Section on Final Route



6.3.5 Divundu

- Divundu is a relatively sparse town. Importantly, Bwabwata national park starts from here.
- Okavango River passes through the centre of the Divundu. The B8 road crosses Okavango River where the waterway spans 5 X 50.5 m (Divundu Road Bridge).
- Based on the inputs from the field reconnaissance which took place during the first week of October 2021, it is proposed that the route cross the Okavango River at Bagani instead of crossing the river where the Divundu road bridge currently is. This will minimize resettlement and land acquisition in Divundu.
- The high voltage transmission line crosses B8 road near Divundu and moves north of the B8 road as shown in figure below (blue line).

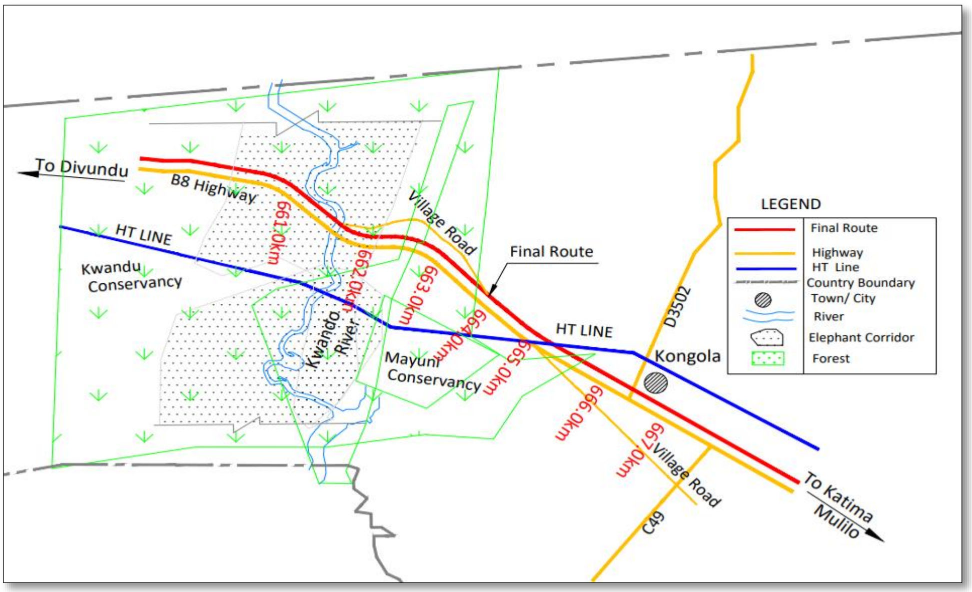
Figure 6-11: Divundu town location on Final Route



6.3.6 Kongola

- Kongola is a settlement in Namibia's Caprivi Strip and the district capital of Kongola Constituency in the Zambezi Region. Some of the settlements in this consistency are Chetto, Pipo, Kachenje, Nxtohei, Omega, Poca, Mashambo, Mwanzi, Izwi, Mulanga, Munguza, Kahunikwa, Queensland, Kakuwa and Mitondo.
- The final route crosses Kwando River where the waterway spans 120 m.
- Kongola is situated on the national road B8.
- High voltage transmission line crosses B8 road near Kongola and runs along north of the B8 road.

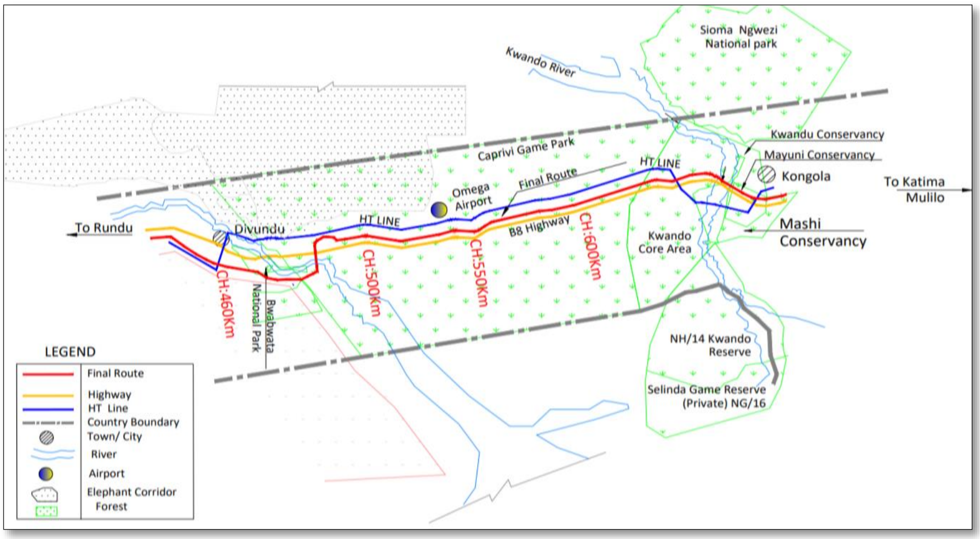
Figure 6-12: Kongola City Location on Final Route



6.3.7 Divundu to Kongola Section (Elephant Corridor)

- → High voltage transmission line runs along the north side of B8 road.
- → The final route runs along north side of B8 road.

Figure 6-13: Divundu to Kongola Section on the Final Route

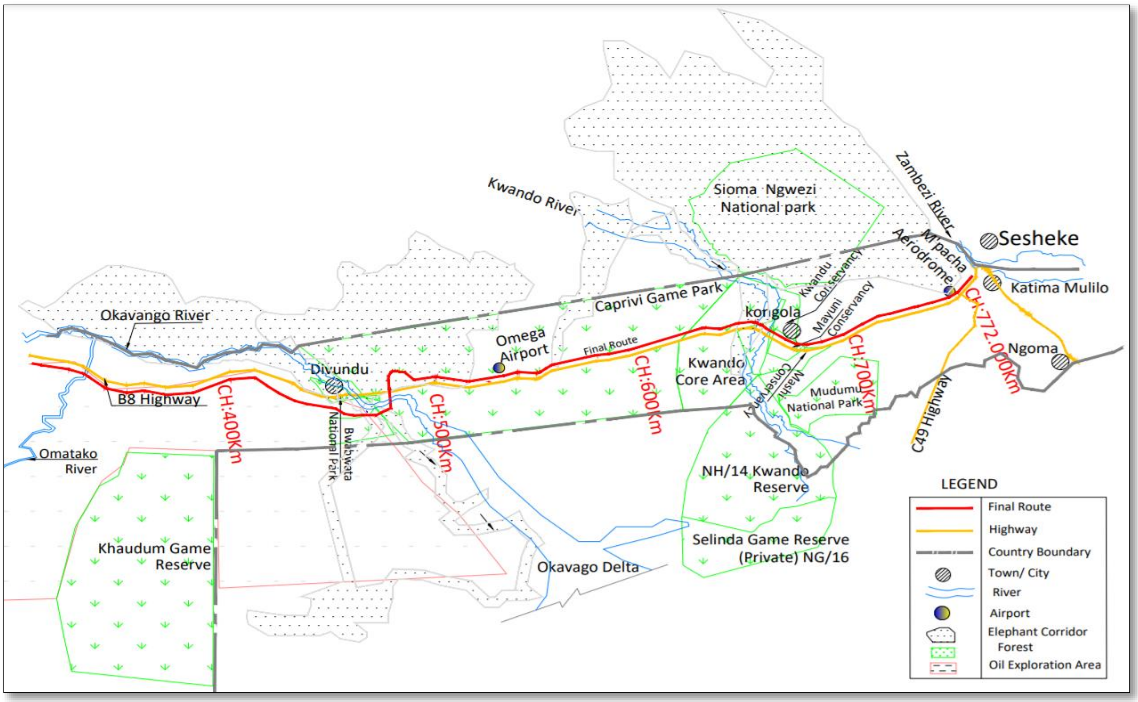


6.4 Eco Crossing- Caprivi Strip

The Strategic Environmental Assessment Report prepared by the Walvis Bay Corridor Group in 2019 mentions that the "healthy state of wildlife populations in East Kavango and Zambezi Regions, and the growing importance of conservation as an economic driver in Namibia and the KAZA[8] area as a whole, demand that careful consideration should be given to the infrastructure proposals in this part of the Walvis Bay-Ndola-Lubumbashi Development Corridor"[9].

[8] Kavango-Zambezi
[9] Walvis Bay – Ndola – Lubumbashi Development Corridor

Figure 6-14: Caprivi Strip



To preserve the north-south migration of elephants and other wildlife where the TZR cuts through the Caprivi Game Park, the Consultant have accounted for both 124.00 km of fencing and 14 number eco-crossings as part of our infrastructure assessment.

6.5 Servitudes

It should be noted that our final route (and ultimately, the rail servitude) will have to negotiate the B8 road servitude (60 m) and a number of transmission lines which have their own servitude widths as described below:

1. Corridor width of 11, 19, 22, 33 & 66 kV line is 22.00 m wide (11.00 m on either side from the center line).
2. Corridor width of 132kV and 220kV is 50.00 m wide (25.00 m on either side for the center line).
3. Corridor width of 330kV and bigger is 80.00 m wide (40.00 m on either side of the center line).
4. Other services can be on the adjacent if outside the corridor of the power line.

Additionally, when it comes to power lines, the railway may cross the related corridor provided that there are consultations and approval with NamPower.

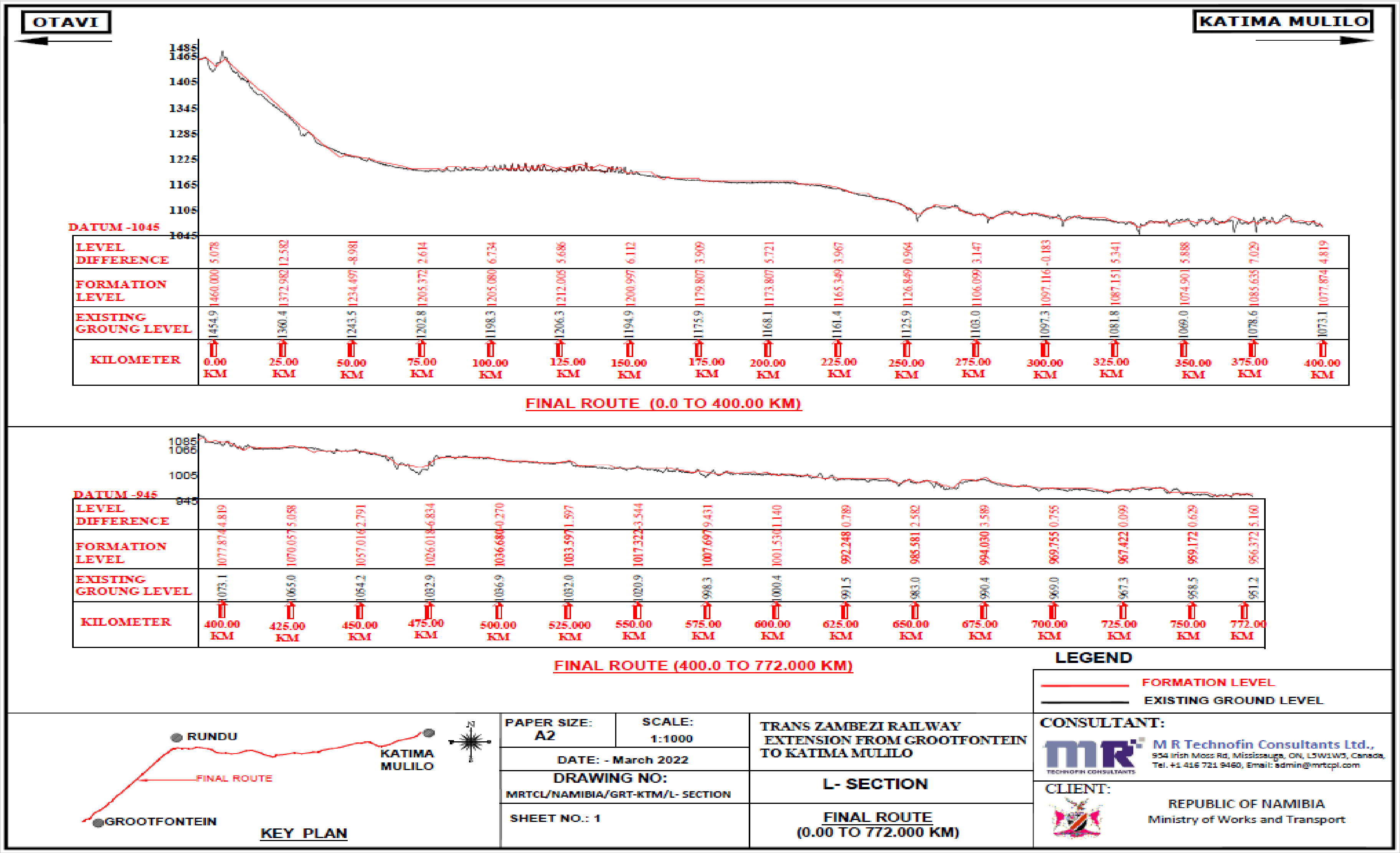
Having traversed the route during the reconnaissance mission in October 2021, it would be technically, commercially and aesthetically beneficial to allow for the road, rail and power line servitudes to overlap so as to make use of 'spare' land in each servitude. It is strongly suggested that the Ministry of Works and Transport, NamPower and the Road Authority work together to this end.

6.6 Salient Features of the Final Route

6.6.1 Longitudinal Section of the Route

The terrain of the final route is generally flat terrain except for small stretches near Grootfontein.

Figure 6-15: Longitudinal Section of the Final Route



6.6.2 Gradient along the Final Route

On the basis of the preliminary design for the Longitudinal Section (Profile), Table 6-1 below is the summary of gradient across the route.

It is seen that less than 6.32 % of the route is on a gradient steeper than 1 in 200. The rest of the route is flatter with almost 37.63 % of the route 'at level'.

Table 6-1: Gradient along the Final Route

Gradient (1 in)	Gradient (In %)	Length (km)	% Of Route
1 in 170	0.59%	44.20	5.73%
1 in 180	0.56%	3.20	0.41%
1 in 185	0.54%	1.40	0.18%
1 in 200	0.50%	61.40	7.95%
1 in 250	0.40%	3.30	0.43%
1 in 300	0.33%	40.90	5.30%
1 in 400	0.25%	82.20	10.65%
1 in 500	0.20%	22.10	2.86%
1 in 600	0.17%	11.50	1.49%
1 in 700	0.14%	13.00	1.68%
1 in 800	0.13%	150.90	19.55%
1 in 1000	0.10%	20.90	2.71%
1 in 1200	0.08%	19.90	2.58%
1 in 1800	0.05%	6.60	0.85%
Level		290.50	37.63%
		772.00	**100.00%**

6.6.3 Curvature along the Final Route

There are a total of 171 curves on the final route. All curves are 600 m radius or greater except for one curve i.e., 300 m radius and is near Grootfontein.

Table 6-2 gives a summary of the curvature details along the final route.

Table 6-2: Curvature along the Final Route

Radius (m)	Length (km)	% Of Route
Straight/Tangent	**727.89**	94.29%
300	0.50	0.07%
600	1.31	0.17%
700	0.25	0.03%
750	0.01	0.00%
850	4.05	0.52%
900	1.86	0.24%
960	0.90	0.12%

Radius (m)	Length (km)	% Of Route
1000	17.50	2.27%
1200	4.26	0.55%
1500	2.31	0.30%
2000	2.83	0.37%
2500	1.46	0.19%
3000	1.16	0.15%
3500	0.80	0.10%
4000	3.41	0.44%
4500	1.42	0.18%
	772.00	**100.00%**

6.6.3.1 Stations on Final Route

Trans Zambezi Railway extension is primarily being developed as a Freight Railway. The purpose of 'Stations' on such railway is primarily 'Operational' one i.e., to facilitate stoppage and bypassing / crossing of trains on a single line railway route. The stations serve crucial operational functions of train management and control, breakdown and disaster management, crew management as well as commercial management.

For operational reasons, a total of 35 stations are proposed on TZR extension, as summarized in Table 6-3 below:

Table 6-3: Stations on Final Route

#	Name of Proposed Station	From: KM	To: KM	Station Chainage (KM)	Gradient at Station
1	Grootfontein	0.000	1.000	0.500	1 in 800
2	Berg Aukas	22.000	23.000	22.500	1 in 400
3	Crossing Station	51.200	52.200	51.700	1 in 400
4	Crossing Station	72.500	73.500	73.000	1 in 800
5	Henta	100.500	101.500	101.000	1 in 800
6	Mururani	125.000	126.000	125.500	1 in 400
7	Crossing Station	151.000	152.000	151.500	1 in 400
8	Crossing Station	177.000	178.000	177.500	Level
9	Kuseka	204.000	205.000	204.500	Level
10	Nkutu	232.000	233.000	232.500	1 in 400
11	Crossing Station	249.000	250.000	249.500	1 in 400
12	Rundu	263.000	264.000	263.500	1 in 400
13	Kambowo	283.000	284.000	283.500	1 in 400
14	Kaiango	300.000	301.000	300.500	1 in 800
15	Mabushe	328.000	329.000	328.500	1 in 400
16	Nyondo	347.000	348.000	347.500	Level
17	Nadiyona	364.000	365.000	364.500	1 in 1000

#	Name of Proposed Station	From: KM	To: KM	Station Chainage (KM)	Gradient at Station
18	Kayaru	380.000	381.000	380.500	1 in 600
19	Crossing Station	401.000	402.000	401.500	Level
20	Shinyemba	429.000	430.000	429.500	1 in 800
21	Kake	450.000	451.000	450.500	1 in 800
22	Divundu	467.000	468.000	467.500	1 in 1200
23	Crossing Station	485.000	486.000	485.500	Level
24	Crossing Station	502.000	503.000	502.500	1 in 800
25	Omega	526.000	527.000	526.500	1 in 400
26	Crossing Station	553.000	554.000	553.500	Level
27	Crossing Station	579.000	580.000	579.500	1 in 800
28	Omega III	603.000	604.000	603.500	1 in 800
29	Crossing Station	632.000	633.000	632.500	Level
30	Kongola	662.900	663.900	663.400	1 in 400
31	Crossing Station	686.500	687.500	687.000	Level
32	Sibbinda	709.000	710.000	709.500	Level
33	Sachinga	733.000	734.000	733.500	Level
34	Mpacha	758.000	759.000	758.500	1 in 400
35	Katima Mulilo	771.000	772.000	771.500	Level

6.6.4 Details of Final Route

A summary of key features of the final route are provided in Table 6-4.

Table 6-4: Details of Final Route

#	Description	Details
1	Final Route Colour Code	
2	Connectivity	Starts from Grootfontein, avoiding settlement at Grootfontein and then runs along south side of B8 up to Rundu. From Rundu bypassing densely inhabited stretches in Rundu up to Kaisosi. From Kaisosi to Divundu along south side of B8 road. From Divundu to Katima Mulilo along north side of B8 road.
3	Route Length (km)	772.00
4	Curve Length (km)	44.10
5	Number of Curves	171
6	Road Crossings- LCs (#)	37
7	Road under bridges (RUBs) (#)	70

#	Description	Details
8	Road Over Bridges (ROBs) (#)	7
9	River Crossing (#)	5
10	Important Bridges (above 50 m span) (#)	2
11	Major Bridges (6 to 50 m span) (#)	7
12	Minor Bridges (below 6 m span) (#)	358
13	Proposed Eco crossing (#)	14
14	Major Cities / towns	Grootfontein, Mururani, Katjinakatji, Ncamagoro, Tien Myl, Rundu, Shitemo, Ndiyona, Divundu, Omega, Kongola, Sibbinda, Kasheshe, Katima Mulilo

6.7 Land Use Parameters and Land Details

There are Eight 'Categories' of land in Namibia, as follows:

1. Agriculture and tourism on commercial land
2. Government agriculture
3. Other government
4. Small- and large-scale agriculture on communal land
5. Resettlement farms
6. National parks
7. Urban
8. Transport related land use

Land Categories[10] are described as below:

6.7.1 Agriculture and Tourism on Commercial Land

Commercial land mostly occurs in the central and southern parts of the country. It comprises farms owned and controlled by private individuals or companies and used mainly for livestock production, with a growing trend of including wildlife and using the land and facilities for professional hunting and private tourism. As on communal land, there are 'nature conservancies' where landowners collaborate towards an overall objective of conservation and sustainable offtake of game species through preservation and controlled hunting. Commercial farming land ownership is regulated with a system of registered "title deed" and "survey diagrams".

6.7.2 Government Agriculture

GRN owns land that is suitable for agricultural purpose, mostly in the northern part of Namibia. Portions of such land is made available for production on a concession/tender /PPP basis also referred to green schemes.

The GRN has embarked on "Green Scheme" projects on GRN owned land. These schemes can be developed and managed either by the GRN or on a Public-Private Partnership basis. A good

[10] Strategic Environmental Assessment for Development of Namibia into a Logistics Hub along the Walvis Bay-Ndola-Lubumbashi Development Corridor-2019

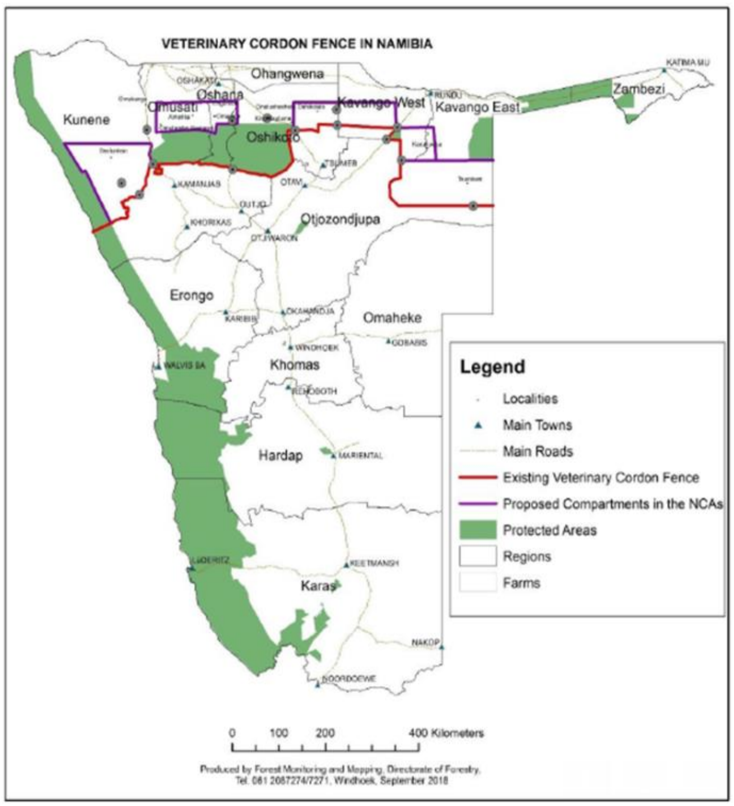
example is the newly and very successful Blueberry export development located close to the Okavango River between the Mashare and Mupapama villages in Kavango East.

6.7.2.1 Veterinary Cordon Fence in Namibia (Red Line)

Established in the 1890s, Namibia has a Veterinary Cordon Fence that restricts the movement of livestock in order to minimize the spread of disease. Recently, there have been works to further demarcate areas as cattle free zones (see the areas marked in purple in Figure 6-16).

Though these demarcated areas could be traversed by the proposed TZR based on the final alignment, it is not expected that these cattle free zones would negatively interact with the railway line such as causing delays. Currently, trains passing the Veterinary Cordon Fence (red line in Figure 6-16) have to stop and are allowed through the fenced boundary with an effective delay of five minutes. The same can be expected when passing the demarcated areas.

Figure 6-16: Veterinary Cordon Fence in Namibia



6.7.3 Small- and Large-Scale Agriculture on Communal Land

Communal land that is traversed is in the north and north-eastern parts of the country. The state has ownership of the land, but the residents who live on the land are allowed to use the resources it provides, under the control of Traditional Authorities. This system is referred to as "PTO" (Permission-to-Occupy) which is granted verbally by the Headman/Traditional leader.

Land use is predominantly subsistence and commercial agriculture, usually a combination of small fields for rain-fed crops and livestock grazing on communal pastures. These and other natural resources (e.g., wood, fruits and products from trees) are used for household-level consumption.

Some communal areas are exclusively owned as individual farms, such as the 'Mangetti Block' farms in West Kavango and are known as 'Large scale agriculture on communal land'. Communal conservancies and community forests are found on communal land, where communities have formed organisations which are allowed to harvest resources such as wildlife and wood under principles of sustainable offtake. Tourism also plays a large role in the communal conservancies.

6.7.4 Other Government

All parastatals have an enabling act in which, inter alia, their authority to "own" land and property is defined. In most cases it is restricted to land/property required to fulfil their obligation as parastatal. Such land/properties were either transferred from the state to the parastatal when instituted, obtain in the free market.

6.7.5 Resettlement

Farms obtained by government for resettlement purposes are usually split into several sections, and dozens of families are being resettled on what had previously been one farm.[11]

Until 2018, the government had purchased 496 farms for resettlement – allocating them to over 5,000 beneficiaries.[12]

Namibian citizens may obtain a portion of a farm for resettlement if they do not yet own farmland, and if they were previously disadvantaged person. In the allocation process, females score higher than males, people 25 years of age or older score higher than those below 25, and people with farming experience score higher than those without.[13]

6.7.6 National Parks

Namibia is recognized internationally for its conservation record which rests in the country's commitment to conservation of biological diversity through the establishment and management of Protected Areas. This commitment is reflected in Namibia's constitution under Article 95 (1).

Namibia has 20 state-run protected areas covering about 17 % of the country's land surface. The Protected Areas conserve biodiversity and ecosystem by protecting some of the country's most important habitats and species of national and global significance.

6.7.6.1 Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA)

In December 2006, the governments of Angola, Botswana, Namibia, Zambia and Zimbabwe signed a Memorandum of Understanding regarding the establishment of the Kavango Zambezi

[11] Land reform reproducing poverty IRIN News, 15 November 2007
[12] Colonialism, Land, Ethnicity, and Class: Namibia after the Second National Land Conference - Henning Melber, 2019
[13] Immanuel, Shinovene (7 May 2015). "Hanse-Himarwa questions resettlement scores". The Namibian.

Transfrontier Conservation Area (KAZA TFCA) over a huge area of land that stretches from the Khaudum National Park in Namibia in the west to Lake Kariba in Zimbabwe to the east.

The vision for the KAZA TFCA is 'to establish a world-class transfrontier conservation area and tourism destination in the Okavango and Zambezi river-basin regions within the context of sustainable development'.

One of the main objectives of the KAZA TFCA is to join fragmented wildlife habitats into an interconnected mosaic of Protected Areas and transboundary wildlife corridors, which will facilitate and enhance the free movement of animals across international boundaries. The KAZA TFCA area incorporates the largest contiguous elephant population in Africa.

The KAZA TFCA would also promote cross border tourism, linking some of the world's premier tourism destinations, including the Victoria Falls in Zimbabwe and the Okavango Delta in Botswana. The Namibian component of KAZA TFCA plays a pivotal role in providing migration routes for wildlife between Angola, Botswana and Zambia.

6.7.7 Urban

Urban property is also regulated with a system of "title deeds" and "registered survey diagrams". Urban areas are managed by Local Authorities (LA) with their line being the Ministry of Urban and Rural Development (MURD).

There are three levels of LA, classified on size and extent of their budget, namely municipalities, towns, villages, and settlements. Where a transport route/corridor crosses an urban area, the order of involvement would be the LA council on a "town planning" basis.

6.7.8 Transport Land Use

Road and rail reserves differ between urban and rural. In urban areas there is town planning structure plans, followed by detailed township layout plan and then proper land surveyed and registered plots/erven. In the structure plan, provision is made for road/rail reserves in consultation process through the Namibia Planning Advisory Board (NamPAB). In cases of a new reserve through existing urban area, the land required must be bought and the necessary subdivision and rezoning will be required.

In the commercial rural areas, for roads, road reserves are created and protected with proclamation notices enabled in the Road Ordinance.

There are four road reserve classification with varying conditions and requirements namely in order of priority and importance:

- Farm roads (FR)
- District roads (DR)
- Main roads (MR)
- Trunk Roads (TR)

Recently, "Freeways" have also been added.

The variant conditions are:

- Road reserve width
- Access control
- Fencing requirement and responsibility to maintain fences
- Building line restriction, i.e., what is permitted a certain distance from the centreline but outside the road reserve. This normally deals with advertising and what infrastructures are allowed with in the building line
- Protected areas

Ownership of the road reserve effectively remains with the farm owner. There are certain guidelines for possible compensation which are linked to the percentage of land required for the road reserve relative to the area of the farm. Below a certain percentage, there is no compensation. If improvements are affected, the farm owner will be compensated.

In the case of communal land, the occupant is only compensated for improvements, fencing, kraals, water installations, dwellings and fruit trees. There are gazette rates for compensation and a specific consultation process is normally followed through the Headmen and Traditional Leaders.

For rail, the National Transport Holdings Company Act regulates new railway lines:

The follow extract from Section 13, subsection (10) of the said Act:

(10) Subject to subsection (11), no new line of the railway for the transport of passengers or goods shall, without the prior written approval of the Minister and subject to such conditions as may be agreed upon by the Minister and the Holding Company or any other person, as the case may be, including conditions relating to the financing, operation and maintenance of such line and the rights (including proprietary rights) and obligations of the parties to such agreement, be constructed or acquired by the Holding Company or by any such other person.

(11) An approval referred to in subsection (10) shall not be required for - the construction of sidings or of short branch lines to mines, stores, warehouses or other works or premises, if such sidings or branch lines are not intended for the transport of passengers or goods; the construction of any line of the railway, not exceeding five km in length, which shall be required for the purpose of facilitating the movement of trains and which shall - provide a connection between two existing lines of the railway; or serve as an avoiding line between two points on the same existing line of the railway; or the construction of a line of the railway intended to provide access between a marshalling yard and one or more existing lines of the railway over the shortest practical route.

The procedures to obtain land for new railway lines reserves would be to determine whether it is in the communal area or in the commercial farming:

In the communal area, the same compensation provision for roads would be applicable, i.e., the affected people are compensated for the loss of income for fruit trees and cultivated land area and affected fencing and water infrastructures and any dwellings.

Based on the most recent railway line that was constructed, farmers would be compensated for the area required for the railway line reserve and a right of way servitude would have to be registered. The guiding price would be based on market related farmland price of the specific area.

6.8 Land Acquisition and Resettlement Costs

The Companion Report that was submitted with Volume I of the Travel Demand Report provides a full and detailed assessment of land requirements and acquisition and resettlement costs for the proposed TZR. The purpose of this section is to briefly describe the cost components along with the cost estimate.

6.8.1 Urban & Commercial Cost Components

In urban- and commercial rural areas, land is privately owned but portions can still be under ownership of the Municipalities or Town Councils if not sub-divided and registered yet (so-called town lands within town lands boundaries).

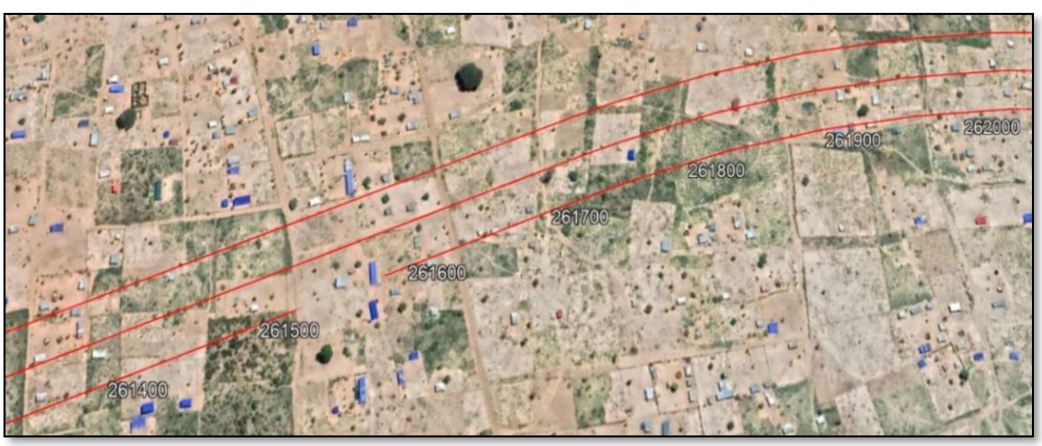
Obtaining privately owned land for the proposed railway line would require the registration of servitude, the compensation of the land value and compensation of resettlement (removal of all related structures in addition to the land).

Obtaining unregistered land owned by the Town Councils would require the registration of servitude and the compensation of all resettlements (removal of all related structures). The land within town lands should typically not attract compensation. In initial discussions with the Rundu Town Council, their indication was that the route through town traverses an area that is at an advanced stage of being formalised. This would require further consultation with the Council to determine if land acquisition costs, in addition to the removal of structures, should be allowed for. For the purposes of this compensation cost estimation, it was assumed that land within Rundu will not require compensation.

Where the final route passes through urban areas – namely in Grootfontein and Rundu - a high level assessment was conducted with acquisition costs calculated for land and structures (buildings, houses etc.) in Grootfontein and Rundu. Market related values were used.

The alignment at Rundu largely passes through unregistered town lands. There are dense informal settlements in this area.

Figure 6-17: Portion within Rundu Townlands indicating dense settlement



For the commercial rural areas, that include plots and farms, market related values were used to calculate land acquisition costs. Furthermore, resettlement costs for formal structures, fencing etc. was also calculated.

The following cost was used for urban- and commercial areas. The values were obtained from online property agencies and reflect market related prices.

i) Vacant commercial & registered urban land = N$ 650/m^2.
ii) Formal structures/ buildings = N$ 6500/m^2.
iii) Plots in close proximity to towns = N$ 150,000/Ha. The agricultural land, within close proximity of Grootfontein is sought after. There are several small holdings/ plots adjacent to the town with market values far exceeding larger commercial farms.
iv) Farms (rural, commercial) = N$ 2,200/ Ha

6.8.2 Communal Cost Component

The acquisition of land and displacement in communal land differs when compared to privately owned land. The Compensation Policy Guidelines for Communal Land was used to estimate the cost in the communal areas.

The communal compensation components, and typical costs, are summarised in Table 6-5.

Table 6-5: Compensation Cost Components

Compensation Cost Component	Recommended Compensation	Comments
Cultivated Land	N$ 5,000/ Ha	Compensation for land that has been prepared and ready for cultivation.
Uncultivated land with potential for cultivation	N$ 2,500/ Ha	This component is for land not yet cultivated but that could be seen as potential cultivation land.
Replacement of wire fencing, cattle kraals	N$ 105/m	-
Replacement of wooden fencing/ wooden pole fencing	N$ 90/m	-
Informal Huts	N$ 300/m^2	The recommended compensation ranges from N$ 150/m^2 to N$ 300/m^2 depending on the nature of the structure.
Formal Building/ Structures	N$ 3,000/m^2	The current rate is set at N$ 400/m^2 while the recommended rate is set at N$ 3,000/m^2. From the satellite image assessment, it can be seen that the formal structures differ substantially and are difficult to differentiate from imagery alone. Some structures could appear to be formal and

		only be a very basic corrugated shed structure. The N$ 3,000/m^2 could therefore be considered on the high side.
Fruit Trees	N$ 15,000/ tree	Fruit tree compensation ranges from N$ 1,000 up to N$ 15,000.
Disturbance Cost	15% of total cost	

Source: Communal Land Compensation Guidelines by the Ministry of Works and Transport (2009)

6.8.3 Land Acquisition and Resettlement Cost Estimate

The Consultant undertook to counting settlements along the proposed final route using a representative sample for the counts. Table 6-6 summarizes the total estimated land acquisition and resettlement cost.

Table 6-6: Land Acquisition and Resettlement Cost Estimate for the Final Route

Land Category	Cost
Urban and Commercial	N$ 245 million
Communal	N$ 233 million

6.9 'Last Mile' Connectivity to Botswana and Zambia

For final route options, it is important to provide effective connections beyond Katima Mulilo to the Zambian rail network, and potentially also to an extended Botswana network reaching north to the new Kazungula bridge over the Zambezi River.

Although such connections are not within the remit of the present study, it will be essential for through rail connections to be constructed to minimise through transport costs, eliminate the need for inter-modal transhipments, and reduce transit times. If they are not constructed, potential advantages of through rail transport will be greatly reduced, rail traffic levels will be lower than with a connected network, and overall project benefits are likely to be relatively much lower.

Presently, the Zambian rail network reaches its southern extremity at the Victoria Falls border bridge to Zimbabwe, a few km south of Livingstone, while the northernmost point of the Botswana network is at Sowa, about 150 km north-west of Francistown. The Zambian and Botswanan governments have agreed to extend their systems from Livingstone and Mosetse (100 km north-west of Francistown) through the new Kazungula bridge, which has been constructed with a central rail track.

Additionally, there are plans within Zambia to extend the projected Livingstone-Kazungula line to Sesheke (across the river from Katima Mulilo), and also to construct a new Western Line from Sesheke to Solwezi in North-Western Province, centre of the 'New Copper Belt', and on to Lubumbashi in DRC.

While it is not known when these further plans are likely to be realised, the recent opening of the Kazungula bridge, together with comment received from the Ministry of Transport and Logistics in Zambia, indicates that the Livingstone-Kazungula-Mosetse through route is likely to have the highest chance of early fruition.

Even if the Zambian network is extended to Sesheke, there will still be a need to connect it across the Zambezi to the Trans-Zambezi line at Katima Mulilo. Since the existing road bridge at Katima Mulilo is not designed to carry railway tracks, a new separate rail bridge would be required.

Furthermore, it would only be desirable to construct such a bridge if it were certain either that the Livingstone-Kazungula-Sesheke line would be built in its entirety, or that the Western Line from Solwezi to Sesheke would be built.

The road bridge at Katima Mulilo lies entirely within Zambian territory, and it might be logical for the new rail bridge to be built also within Zambian territory, with only a short rail section continuing on the south bank of the Zambezi River to join the Trans-Zambezi route.

However, this could leave Zambia facing the full costs of construction and subsequent maintenance of the new bridge at a time when government financial resources are limited. Environmentally this route would be the most favoured since it involves the least sensitive riverine and other habitats.

An alternative approach would be to extend the Trans-Zambezi line from Katima Mulilo along the southern bank of the Zambezi to join the projected Mosetse-Kazungula line south of the new Kazungula bridge. This line might run close to existing highways to cross into Botswana at Ngoma and continue through the Chobe National Park via Kasane to the Kazungula bridge. An additional, though shorter, crossing of the Chobe River would be required at or near Ngoma.

While this solution would remove the need for another major Zambezi bridge, it would require the consent and support of Botswana, and might raise serious environmental issues regarding encroachment into the Chobe Park. It would be necessary to reach equitable agreement with Botswana on costs of bridging the Chobe River. Wildlife movement to and from the Chobe River in Botswana, in an area with significant tourist activity, is expected to be a significant concern.

A third solution could be to select a new crossing point along the Zambezi. While it is not known whether other possible bridge sites are available, it is noted that much of the riverside terrain on both north and south banks between Katima Mulilo and Kazungula is swampy.

The eastern Zambezi floodplains are inundated with sheet flow in the rainy season, and from an ecological and technical perspective not suitable for major infrastructure such as a railway line. It would cause significant effects on aquatic life in the Zambezi and would conflict significantly with buffalo and elephant herd movements. From what is known of the terrain, it appears that Katima Mulilo/ Sesheke and Kazungula are the two most suitable sites for crossing the Zambezi.

The issue is complex, but of great importance if a future rail-based network is to be developed to best effect. We would suggest that Namibia, Zambia and Botswana should seek to engage in a tri-partite agreement on the best way forward.

Figure 6-18 provides a map of the regional connectivity options discussed. A corresponding table (Table 6-7) provides the 'pros and cons' of each of the connectivity options discussed.

Figure 6-18: Regional Connectivity (Not to Scale)

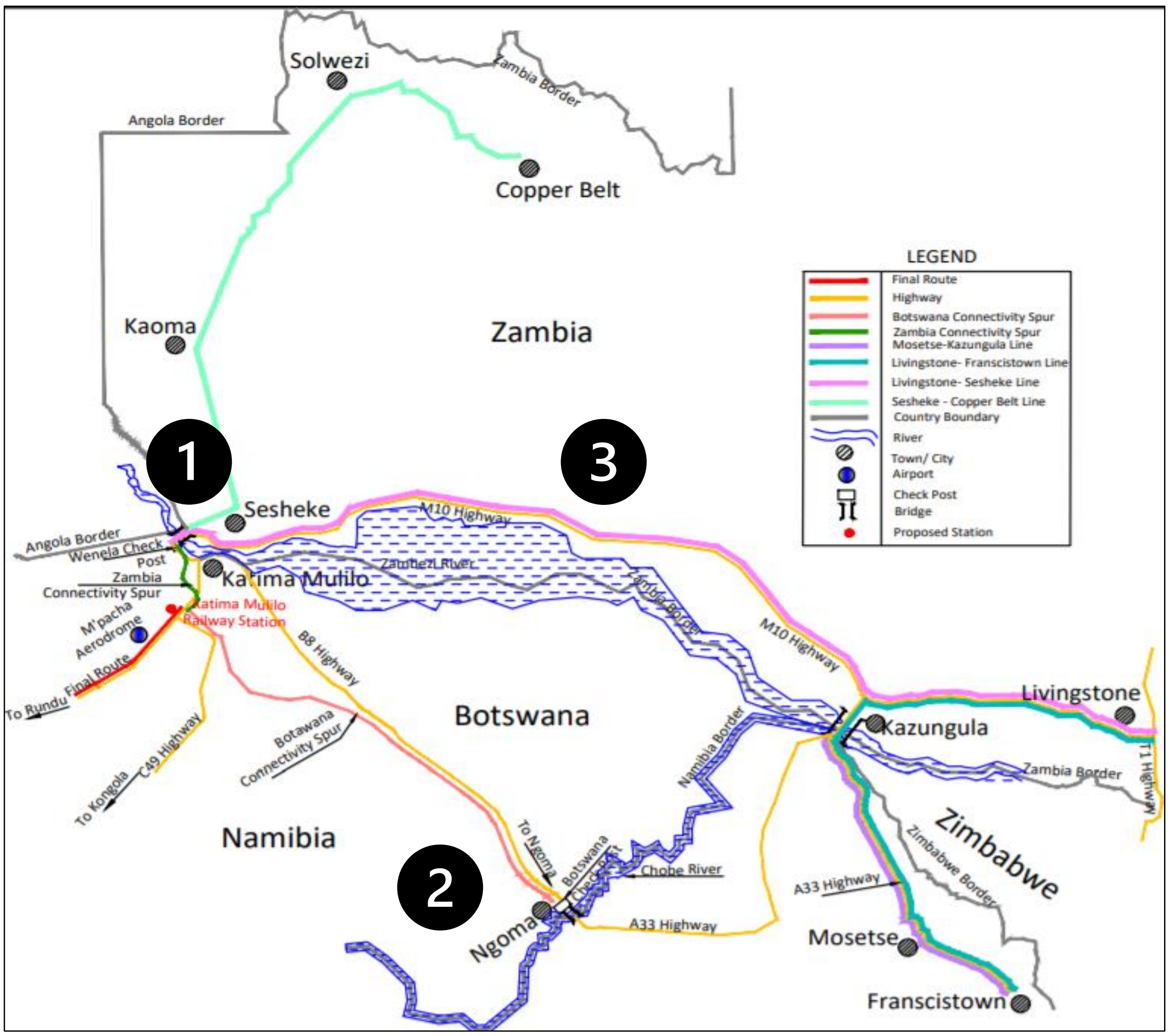


Table 6-7: Pros and Cons of Regional Connectivity Options

No. As per Figure 6-18	Connectivity Option Description	Pros	Cons
1	From Katima Mulilo, extend the railway line over the Zambezi River into Sesheke	Potentially, the most favoured route option from an environmental perspective as it involves traversing the least amount of sensitive riverine and other habitat areas.	• Current road bridge at Katima Mulilo/Sesheke is road-only. A new separate railway bridge would be required to cross the Zambezi River (+900m length). • New railway bridge would be entirely within Zambian territory, leaving Zambia to bear the full cost of construction/maintenance at a time when government resources are limited. • Greenfield railway line required between Sesheke and Livingstone (roughly 200km) to connect to Zambia's existing network.
2	Extend the current proposed alignment to Ngoma with further connectivity through Botswana to the Kazungula Bridge	Relative to the Katima Mulilo/Sesheke option, this option requires less 'Greenfield' route (track-km) and bridge length to create regional connectivity.	• Present proposed route to be further extended in Namibia from Katima Mulilo to Ngoma (roughly 65 km). • Greenfield railway line required in Botswana from Ngoma to existing / proposed Botswana's railway network (roughly 60 km). • Greenfield railway line required in Zambia from Kazungula to Livingstone to connect with Zambia's existing rail network (roughly 60km). • A new railway bridge would be required to cross the Chobe

No. As per Figure 6-18	Connectivity Option Description	Pros	Cons
			River at Ngoma. • Potential environmental issues as the Greenfield line in Botswana would traverse Chobe National Park with potential impacts of wildlife migration and tourism. • Traffic from Zambia (major traffic source) would be routed through Botswana before arriving at Walvis Bay.
3	Extend the current proposed alignment to a point that is between Katima Mulilo/Sesheke and the Kazungula Bridge for direct connectivity into Zambia		• The eastern Zambezi floodplains are inundated with sheet flow in the rainy season, and from an ecological and technical perspective less suitable for major infrastructure. • It would cause significant effects on aquatic life in the Zambezi and would conflict significantly with buffalo and elephant herd movements. • A new separate railway bridge would be required to cross the Zambezi River along with a Greenfield railway line from the bridge to Livingstone.

6.10 Medium Term Multi-Modal Rail + Road Solution

The Terms of Reference of this study identifies railway projects as requiring long implementation periods and relatively large investments and suggests taking advantage of Namibia's existing road and rail infrastructure and explore certain medium-term initiatives which can be implemented to potentially attract additional volumes in the interim till the TZR is developed.

The potential for attracting additional volumes was tested in the second milestone deliverable (Travel Demand Report – Vol II. Transport Volume Estimation) by modeling the following medium-term improvements (see Table 6-8 below).

Table 6-8: Interim Infrastructure Improvements

Infrastructure Initiative	Modelled Impact
One Stop Border Post at Katima Mulilo	Reduces truck border wait times from 12 hours to 2.4 hours.
'2+1 Lane' from Grootfontein to Katima Mulilo	Improves average truck speeds from to 32 kmphto 45 Kmph.
State of the Art Intermodal Transfer Facility at Otavi or Grootfontein	Reduces the intermodal transfer time from five hours to three hours.

Source: M. R. Technofin Estimate

The result of the analysis indicated that the impact of these improvements was minimal relative to the baseline ('as is') scenario. The optimal traffic assignment in this model assigned a slightly lower total volume to the Walvis Bay port relative to the base case.

The result aligns with feedback through consultations with shippers. Anecdotally, shippers prefer to avoid intermodal transfers (as would be the case at Grootfontein/Otavi) and instead, will direct their freight to its land destination using one mode of transport.

Given the modeling results and consultation feedback, it does not seem that the cost of medium-term solutions such as those in Table 6-8 would be outweighed by its benefits (attracting additional regional freight volumes). Therefore, medium-term 'multi-modal rail + road' options ahead of a full-fledged railway line connecting Walvis Bay port to Katima Mulilo are not recommended.

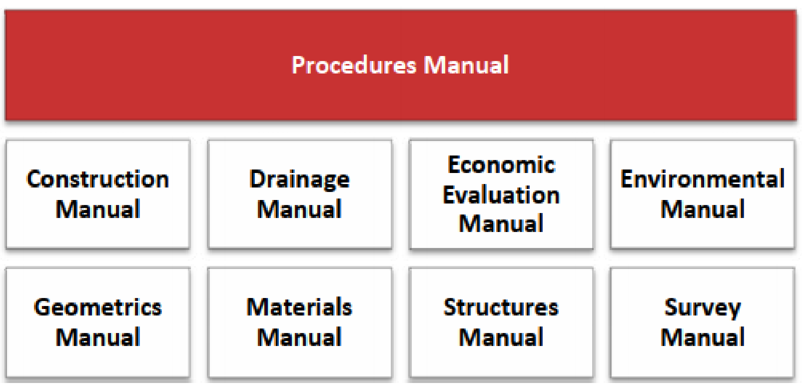
7 Project Engineering

7.1 Introduction

TransNamib has confirmed that they have adopted the suite of Engineering Manuals as published by the Namibian Roads Authority (RA). The purpose of the manuals is to provide a basis for uniformity and to set out minimum standards and requirements. The manuals are to be used in planning, design and administration of projects. There are several references to other international standards within these manuals. All the references are not repeated in this report, but the RA's manuals should be used as a basis for further design stages. The manuals are publicly available at www.ra.org.na.

The requirements of roads do not unilaterally comply with that of railways. The RA manual are summarised in Figure 7-1.

Figure 7-1: Roads Authority Project Standards Manuals (Extract from Manual)



It is also recommended, at the commencement of the detail design stage, that the Client's requirements are re-visited, and the RA Manual requirements adjusted to the Client's specific rail requirements. A workshop session is recommended whereby all the requirements as per the RA manuals are discussed and amended where deemed necessary.

The following is a short overview of the RA manuals:

i) **Procedures Manual:** The Procedures Manual is the controlling document. It describes the duties and responsibilities of consultants contracted for the preparation of designs, tenders for, and supervision of construction by contract.

ii) **Construction Manual:** The Construction Manual outlines the process for the monitoring of construction work with particular reference to activities and the interaction between the various parties involved in the construction work.

iii) **Drainage Manual:** Refer to paragraph 5.2.8 and 7.3.1.1.

iv) **Economic Evaluation Manual:** Guidance regarding the Economic Evaluation of investments. Not deemed relevant to rail projects.

v) **Environmental Manual:** Guidance with regards to environmental impacts.

vi) **Geometrics Manual:** The RA adopted the SANRAL G2 Guidelines for use in Namibia. The RA's manual gives further guidance on issues particular to Namibia as well as information on benchmark values to be used for Namibia.

vii) **Materials Manual:** The purpose of is to set down the standards and norms to be adhered to by Consultants in the execution of materials-related work.

viii) **Structures Manual:** Set out the procedures and criteria which must be applied in the planning and design of bridges and other structures. Not deemed applicable to rail projects.

ix) **Survey Manual:** The purpose is to set out the standards and norms that must be used by those tasked with the execution of survey work. Refer to paragraph 7.4.2.

7.2 Geology and Geotechnical

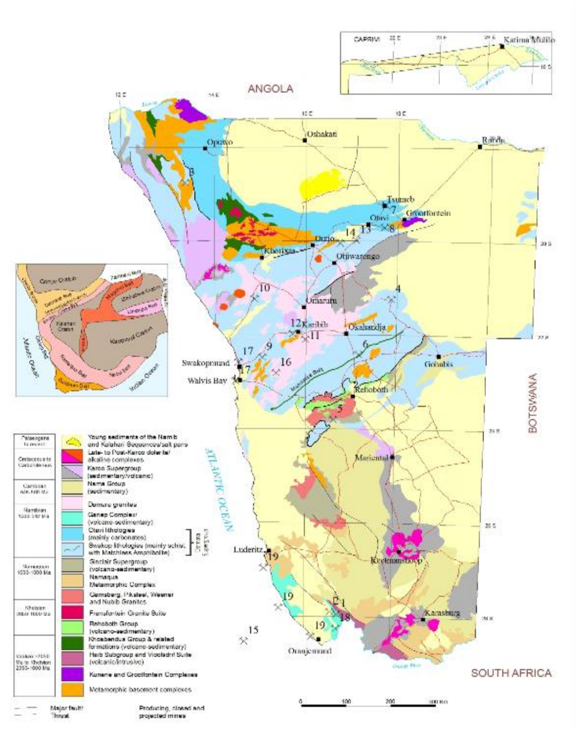
7.2.1 Geology along the Project Alignment

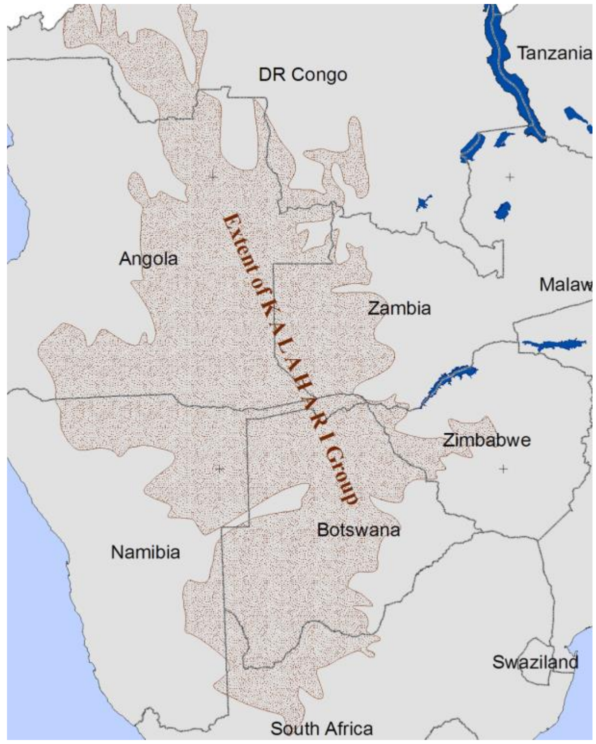
The TZR runs mostly along the B8 road. The project area traverses four regions, Otjozondjupa; Kavango West; Kavango East and Zambezi.

A simplified Geological Map of Namibia is as indicated in Figure 7-2. The entire route of the railway line falls in the Palaeogene to recent age which generally comprises of young sediments of Nambi and Kalahari Sequences. A small portion near Grootfontein falling in Otavi lithologies comprising of mainly carbonates.

The project area is part of the Kalahari Basin, a vast inland depression that formed some 130 – 180 million years ago. Much of the Kalahari consist of sand shaped by wind into dunes.

Figure 7-2: Simplified Geological Map of Namibia



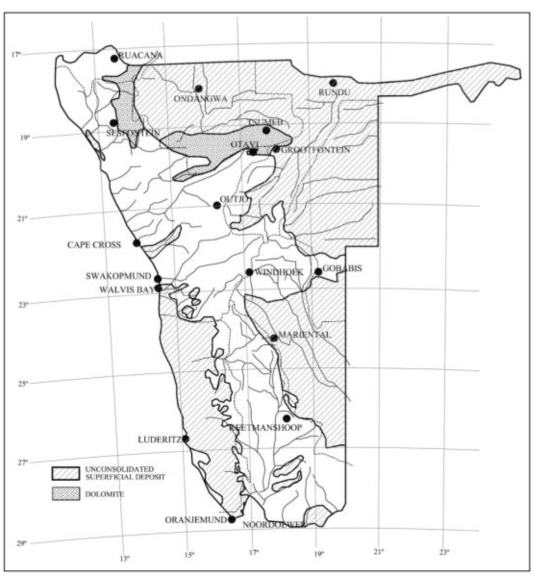


Simplified Geological Map of Namibia (GSN)	Extent of Kalahari group (GSN)

Source: Geological Survey of Namibia

A simplified geological map of Namibia as provided in the Drainage Manual is as below in Figure 7-3.

Figure 7-3: Simplified Geological Map of Namibia (ref: Drainage Manual)



The extent of Kalahari group is indicated in Figure 7-2. The Kalahari Group is characterized by sand overlying up to 300 m of variably cemented sands, clays and gravels. Sediments are flat lying and essentially sandy and not many exposures of rock occur. The Kalahari sand is generally 80 m to 100 m thick and is often cemented into calcrete. Calcrete is a white, hard limestone material, belonging to the pedogenic materials group, which is commonly used as a natural road building material in Namibia. The widespread blanket of windblown sand is fine to medium grained and generally poorly rounded. In places it may pass into loamy calcareous alluvium and calcrete as found along drainage depressions.

The Kalahari Beds were deposited on an erosional landscape known as the “African Surface” into which a deep “Pre-Kalahari Valley” was eroded in the late Cretaceous (from 65 million years ago). Kalahari deposition took place during Tertiary.

Calcrete and Silicrete are commonly found in project area. Silcrete is an indurated soil duricrust (hard layer on or near the surface of soil) formed when surface sand and gravel are cemented by dissolved silica. The formation of silcrete is similar to that of calcrete. Calcretes are the most common duricrust found in the Kalahari basin, with almost all Kalahari Group sediments having undergone some degree of calcretisation in the past.

Calcrete is a sedimentary rock, a hardened deposit of calcium carbonate (calcite). This calcium carbonate cements together other materials, including gravel, sand, clay, and silt. Calcrete and Silicrete are commonly used in road construction.

7.2.1.1 Seismic Activity in Namibia[14]

Table 7-1: Earthquake- Historic data of Namibia

Year	Maximum Magnitude	Total Hits
1980	4.8	1
1983	5.2	4
1992	5.0	1
1997	5.3	1
2005	4.1	1
2006	4.8	1
2008	4.8	1
2009	5.1	1
2010	4.1	1
2012	4.8	1
2018	5.0	1

[14] Earthquakes in Namibia, history, map, tracker

7.2.2 Geotechnical Assessment

Geotechnical assessment for any railway project is necessary for making appropriate design provisions for the following project components:

(1) Railway Formation - Embankment and Cuttings

(2) Foundations of bridges and culverts

(3) Foundations of buildings and workshops

(4) Quarries for sourcing of material – earth, sand, ballast

For construction of a greenfield railway line, the soil for filling the embankment is generally classified as 'good' or 'other-than-good' depending upon its grain size and consistency limits. Broadly speaking, coarse-grained soils come under the category of 'good' soils. Fine-grained soils such as inorganic clay, silts, and clayey soils are grouped under the category of other-than-good soils.

7.2.2.1 Reference Documents

The Consultant has been able to collect the following documents and reports which provide some pertinent insights on the geotechnical characteristics of the project area:

- Investigative Study Report -Investigation for Road Preservation and Rehabilitation of TR8/4: Rundu – Divundu (198.00 km)' by 'Tulipamwe Consulting Engineers'-July 2018.
- Environmental Scoping Report -Investigation for Road Preservation and Rehabilitation of TR8/6: Kongola -Katima Mulilo by 'Enviro Management Consultants'-2018 (which also includes Drainage Report – Lund Consulting Engineers).
- Draft Study Report -Investigation for Road Preservation and Rehabilitation of TR8/6: Kongola -Katima Mulilo by 'Enviro Management Consultants'-February 2019.
- Material report for the feasibility study report for rehabilitation of TR 8/2 and TR8/3: Taranaki via Mururani gate to Rundu (170.00 km)- September 2019 by 'Consulting Engineers And Project managers (Pty) Ltd'.
- Groundwater Investigations in the Eastern Caprivi Region Main Hydrogeological Report-April 2005.

The Consultant has studied the above listed reports in detail and based on the information provided, the preliminary geotechnical assessment of the project area is summarized in the following section.

7.2.2.2 Grootfontein to Rundu Section

7.2.2.2.1 Specific Reference Document for this Section

1) Material report for the feasibility study report for rehabilitation of TR 8/2 and TR8/3: Taranaki via Mururani gate to Rundu (170.00 km)- September 2019 by 'Consulting Engineers And Project managers (Pty) Ltd'.

7.2.2.2.2 Details Provided in Reference Document

The reference document provides summary of results of the tests conducted on this section. These are summarised as under:

(A) Dynamic Cone Penetration (DCP) tests were done along the centre of the road between Taranaki and Rundu in two sections as shown below:

- On Section 1 – Taranaki- Mururani (DCP tests were conducted)
- On Section 2 – Mururani - Rundu (DCP tests were conducted)

The summary of the test results is shown in Table 7-2:

Section 1 – Taranaki- Mururani

Table 7-2: DCP Test Results from Taranaki to Mururani Section

DCP at Chainage	CBR at 150 mm	CBR at 300 mm	CBR at 450 mm	CBR at 600 mm	CBR at 750 mm	CBR at 950 mm
79+00	500	230	140	298	78	52
81+00	79	412	184	75	45	84
83+00	500	294	184	94	75	58
84+00	152	87	41	90	107	57
85+00	500	119	141	108	401	100
87+00	500	224	106	183	125	90
89+00	187	69	116	108	62	73
91+00	172	103	35	68	75	52
93+00	265	291	240	99	101	83
95+00	500	273	260	70	89	57
97+00	500	117	107	230	106	62
99+00	147	82	46	131	181	73
101+00	145	108	70	285	85	75
103+00	500	182	167	201	70	90
105+00	288	175	99	390	185	45
107+00	441	304	55	42	400	90
109+00	500	300	115	131	114	25
111+00	362	284	46	35	68	57
113+00	261	288	90	42	131	116
115+00	214	160	97	164	120	140
117+00	215	157	203	104	89	140
119+00	406	90	77	83	38	158
126+00	197	75	58	100	94	29
127+00	218	163	94	79	112	43

Section 2 – Mururani - Rundu

Table 7-3: DCP Test Results from Mururani to Rundu Section

DCP at Chainage	CBR at 150 mm	CBR at 300 mm	CBR at 450 mm	CBR at 600 mm	CBR at 750 mm	CBR at 950 mm
2+00	350	260	60	61	62	60
4+00	400	500	142	156	84	164
6+00	150	60	20	75	60	60
8+00	500	252	59	87	154	92
10+00	60	75	65	54	45	50
12+00	500	241	124	51	48	65
14+00	500	184	259	68	34	59
16+00	104	155	58	213	85	134
18+00	98	70	153	212	306	89
20+00	91	115	52	136	196	87
22+00	458	158	145	58	61	54
24+00	179	93	47	23	66	50
26+00	155	66	82	470	222	86
28+00	254	74	49	59	187	50
30+00	116	85	65	201	140	72
32+00	79	70	96	51	53	58
34+00	179	171	118	119	52	112
36+00	178	68	500	137	168	31
38+00	119	174	149	500	288	32
40+00	500	214	56	82	48	32
42+00	119	174	149	500	288	110
44+00	500	58	61	93	156	75
46+00	191	253	132	136	139	91
48+00	500	500	500	500	500	500
50+00	386	424	500	500	500	500
52+00	18	500	500	500	500	500
54+00	424	372	161	118	86	119
56+00	280	174	132	74	30	29
58+00	500	85	94	162	208	59
60+00	500	124	58	62	132	84
62+00	300	35	300	45	121	59
64+00	250	87	85	74	54	84
66+00	424	500	104	80	81	34
68+00	335	408	85	145	120	85
70+00	39	143	31	24	13	32
72+00	500	130	54	141	42	58
74+00	238	404	358	107	76	83
76+00	222	294	96	325	48	75
78+00	202	199	204	228	106	130
80+00	104	72	74	84	79	38
82+00	119	74	49	86	113	112

TECHNOFIN CONSULTANTS

DCP at Chainage	CBR at 150 mm	CBR at 300 mm	CBR at 450 mm	CBR at 600 mm	CBR at 750 mm	CBR at 950 mm
84+00	152	119	41	83	57	50
86+00	179	173	103	175	171	200
88+00	200	132	71	65	58	73
90+00	127	90	85	87	67	72
92+00	136	86	91	75	84	74
94+00	500	215	141	85	47	53
96+00	104	70	41	108	88	73
98+00	219	86	149	77	65	36
100+00	424	202	132	128	53	84
102+00	193	107	78	111	90	77
104+00	173	128	96	73	61	93
106+00	329	230	167	84	75	44
108+00	150	74	87	104	91	33
110+00	21	153	146	251	97	38
112+00	258	75	81	42	148	87
114+00	171	58	58	49	44	90
116+00	269	88	65	83	87	49
118+00	225	118	75	49	81	41
120+00	500	109	106	59	38	74
122+00	500	381	45	73	51	89
124+00	391	163	247	97	143	54
126+00	108	72	88	179	253	40

(B) Borrow Pit Investigations: In the road study, seven existing borrow pits were identified along the road route. The samples from the seven borrow pits were sourced for conducting geotechnical tests. The location of these borrow pit is given in Table 7-4 below.

Table 7-4: Borrow Pit locations for Grootfontein to Rundu Section

#	Borrow Pit Location	Location Village	Nearest proposed Railway Chainage (Approx.) (Km)	Road Number	Road Chainage
1	Mavanze	Mavanze	257.00	TR8/3	126
2	Erago	Erago	201.00	TR8/3	48
3	Ncobe	Ncobe		TR8/3	70
4	Katyinakatyi	Katyinakatyi	247.00	TR8/3	110
5	Mururani	Mururani	133.00	TR8/3	10
6	Namcom	Geduildoerdery Farm	-	TR8/2	82
7	Taranaki	Taranaki	-	TR8/2	98

Following tests were conducted on the samples obtained from these borrow pits:

- Maximum Dry Density and Optimum moisture Content

- California Bearing Ratio of untreated soils and gravels
- Sieve Analysis
- Atterberg limits

These tests were conducted during August -September 2019. Following is the summary of test results:

Table 7-5: Borrow Pit Test Results

Sample No.	Location	Offset (km)	Chainage	Road Name	Material Description	Sieve Analysis Percent Passing Sieve Size										Grading Modulus	Mdd (kg/m³)	O.M.C (%)	CBR @ % Mod AASHTO					Atterburgs				Type of material
						63.0	53.0	37.5	26.5	19.0	13.2	4.75	2.0	0.425	0.075				100	98	95	93	90	LL	PL	PI	LS	
BR19/114	Mavanze	2	126+00	TR8/3	White Calcrete gravel	100	86	65	61	57	51	42	39	36	0.7	2.25	1948	8.9	75	65	51	36	21	23.6	16.0	7.6	2.1	G5
BR19/113	Erago	2.8	78+00	TR8/3	White Calcrete gravel	100	82	68	58	54	47	38	34	27	1.6	2.38	1778	13.5	171	155	133	105	73	23.7	16.8	6.9	2.1	G5
BR19/117	Ncobe	1.5	59+00	TR8/3	White Calcrete gravel	100	85	73	66	58	54	45	44	30	2.3	2.24	1765	13.5	58	39	22	15	6	44.7	35.8	8.9	4.4	G7
BR19/112	Katyinakatyi	5.8	48+00	TR8/3	White Calcrete gravel	100	92	77	68	60	50	39	34	27	1.2	2.38	1379	16.4	30	27	22	19	14	27.8	23.4	4.4	1.4	G7
BR19/115	Mururani	0.3	12+00	TR8/3	White Calcrete gravel	100	87	75	62	58	49	40	36	26	1.5	2.37	1927	11.2	157	137	112	94	73	23.9	18.2	5.7	1.7	G5
BR19/116	Namcon	0.05	98+00	TR8/2	White Calcrete gravel	100	80	69	60	50	41	30	24	18	0.5	2.58	1749	14.4	104	83	60	53	44	37.8	21.6	16.2	5.6	G6
BR19/111	Taranaki	0.7	81+000	TR8/2	White Calcrete gravel	100	82	67	59	48	43	30	23	14	0.7	2.62	1626	15.3	66	53	37	33	27	37.8	17.9	19.9	8.3	G8

7.2.2.2.3 Brief Interpretation of Details and Recommendations about Formation and Foundations

The borrow pit test results were further analysed to study their soil classification by working out Cu (Uniformity Coefficient) and Cc (Coefficient of Curvature). The Uniformity Coefficient (Cu) and the Coefficient of Curvature (Cc) are the measures of soil gradation and particle size distribution. These coefficients help to classify the soil in terms of its gradation such as 'well graded' or 'poorly graded'.

Table 7-6: Test Results of Borrow Pit Samples

#	Borrow pit	Sieve Analysis - % passing Sieve size										Max. dry	Cu	D30	Cc
	Location	63	53	37.5	26.5	19	13.2	4.75	2	0.425	0.075	Density	D60/ D10		D30^2/ (D10*D60)
												(kg /m3)			
1	Maranze	100	86	65	61	57	51	42	39	36	0.7	1948	158.48	0.43	0.04
2	Erago	100	82	63	58	54	47	38	34	27	1.6	1778	167.76	2.00	0.66
3	Ncobe	100	85	73	66	58	54	45	44	30	2.3	1765	110.28	0.43	0.06
4	Katyinakatyi	100	92	77	68	60	50	39	34	27	1.2	1379	97.75	2.00	1.08
5	Murarani	100	87	75	62	58	49	40	36	26	1.5	1927	115.82	2.00	0.90
6	Namcon	100	80	69	60	50	41	30	24	18	0.5	1749	100.00	4.75	3.21
7	Taranaki	100	82	67	59	48	43	30	23	14	0.7	1626	82.88	4.75	2.66

Based on the above analysis, the classification of soil has been done and is given in Table 7-7.

Table 7-7: Soil Classification

#	Borrow pit location	State of Soil	Soil Classification	Remark
1	Maranze	Dense	GM	Less compressible soil, medium plastic in nature
2	Erago	Dense	GW- GM	Less compressible soil, low plastic in nature
3	Ncobe	Dense	GM	Medium compressible soil, medium plastic in nature
4	Katyinakatyi	Loose	GW- GM	Less compressible soil, low plastic in nature
5	Murarani	Dense	GW- GM	Less compressible soil, low plastic in nature
6	Namcon	Dense	GW	Medium compressible soil, medium plastic in nature
7	Taranaki	Medium	GW	Medium compressible soil, highly plastic in nature

From the above it could be concluded that for major portion on Grootfontein to Rundu section the natural soil is generally well graded coarse soil with some portions having low plasticity. The soils have also exhibited good maximum dry density values and high California Bearing Ratio (CBR) values.

Soils with less than 5% particles finer than 75 microns are appropriate as a 'fill' material for Railway projects. These soils are considered excellent material for Railway embankments even for top structural layers.

The material properties for earthwork have been given in Table 1 of Spoornet S 410 'Specification for Earthwork'. Based on these specifications, the material obtained along the route is considered to be a good material for Railway embankment construction.

7.2.2.3 Rundu to Divundu Section

7.2.2.3.1 Specific Reference Document For This Section

(1) Investigative Study Report -Investigation for Road Preservation and Rehabilitation of TR8/4: Rundu – Divundu (198 km)' by 'Tulipamwe Consulting Engineers'-July 2018.

7.2.2.3.2 Details Provided in Reference Document

The Report has indicated the following:

Based on the As-Built data for the original construction of the road on this section over the period from October 1986 to December 1994, the material for the various pavement layers were sampled from borrow pits established at regular intervals along the road. The material sourced from the borrow pits was mostly calcrete and silcrete gravel, used for the base and sub-base. These or similar sources, which are largely located on tribal land, are still being utilized for constructing base patches as part of routine maintenance of the road on this section.

Calcrete is used in construction worldwide. In many areas, calcrete is also used for road construction, either as a surfacing material or, more commonly, as a base material. It is one of the most common road materials used in Southern Africa. Calcrete is widely used as a base material when it is locally available and cheap.

7.2.2.3.3 Brief Interpretation of Details and Recommendations about Formation and Foundations

The Kalahari is characterized by sand overlying up to 300m of variably cemented sands, clays and gravels. Sediments are flat lying and essentially sandy and not many exposures of rock occur. The Kalahari sand is generally 80m to 100m thick and is often cemented into calcrete. Calcrete is a white, hard limestone material, belonging to the pedogenic materials group, which is commonly used as a natural road building material in Namibia.

Considering that the section between Rundu and Divundu has shown soils being mostly calcrete and silcrete gravel, used for the base and sub-base, these soils would also be good material for embankment fill material.

7.2.2.4 Divundu to Katima Mulilo Section

7.2.2.4.1 Specific Reference Document for This Section

(1) Environmental Scoping Report -Investigation for Road Preservation and Rehabilitation of TR8/6: Kongola -Katima Mulilo by 'Enviro Management Consultants'-2018 (which also includes Drainage Report – Lund Consulting Engineers.

(2) Draft Study Report -Investigation for Road Preservation and Rehabilitation of TR8/6: Kongola -Katima Mulilo by 'Enviro Management Consultants'-February 2019.

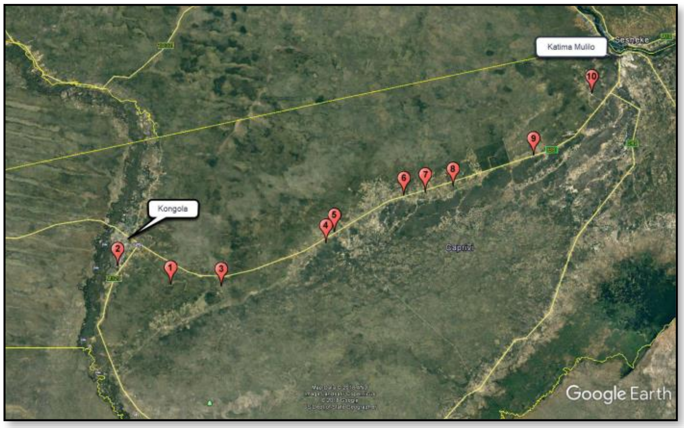
(3) Groundwater Investigations in the Eastern Caprivi Region Main Hydrogeological Report-April 2005.

7.2.2.4.2 Details Provided in Reference Document

The details provided in the report at reference 3 above are briefly presented here as it relates to geotechnical conditions of the section between Kongola and Katima Mulilo:

(A) The report states that, during 1997-98, VKE consortium had identified 38 borrow pits and tests of soil samples from these pits were carried out as part of design of road T0806 during 1997/98. Most of the borrow pits had yielded suitable material for sub-base, selected and fill layers for the initial construction of T0806. These borrow pits were visually inspected by the project team which conducted the study in 2019 and identified 10 borrow pits for conducting investigations to establish use of the material for rehabilitation of the road between Kongola- Katima Mulilo. The location of these 10 borrow pits along the road is shown in the google map image in Figure 7-4.

Figure 7-4: Borrow Pits Locations along the Kongola-Katima Mulilo Road



The tests conducted on the soil samples from these 10 borrow pits is summarised Table 7-8.

Table 7-8: Summary of Borrow Pits Investigation Results

No.	Chainage (km)	Distance from CL (km)	Direction	PI			GM			CBR (%)		Material Class (TRH 14)
					Range			Range		Avg. @ 95% MOD AASHTO	Avg. @ 98% MOD AASHTO	
				Avg	Min	Max	Avg	Min	Max			
1	14.1	3.2	RHS	5	4	5	0.93	0.89	0.96	29	32	G7
2	0 (Choi Village)	6	RHS	7	SP	12	2.60	2.53	2.66	36	49	G6
3	23.2	2	RHS	2	SP	6	1.28	0.9	1.76	30	57	G6
4	45.4	0.6	RHS	7	6	13	1.97	1.33	2.52	35	43	G6
5	47.8	0.08	LHS	11	9	12	1.39	1.13	1.63	24	28	G7-G9
6	63	0.05	LHS	8	7	8	1.04	0.97	1.11	13	22	G9
7	67.8	0.85	RHS	SP	SP	SP	0.98	0.97	0.98	19	30	G7
8	72.4	1.2	RHS	9	6	11	1.27	1.11	1.43	31	44	G7
9	89.1	0.05	LHS	7	SP	9	1.24	0.99	1.63	10	13	G9
10	106.6	3	LHS	8	6	10	2.12	1.98	2.27	38	49	G6

The field work under this project comprised of:

- Conduct DCP tests at 1km intervals and at each test pit
- Excavate test pits to a minimum depth of 800 mm
- Measure in-situ density and moisture content of each layer using a nuclear gauge
- Profiling of the test pits
- Sampling of individual layers for laboratory testing

The material samples were subjected to the following laboratory tests:

- Indicator tests: Grading analysis, Atterberg limits, i.e., PI, LL & LS
- MDD (Maximum Dry Density)
- OMC (Optimum Moisture Content)

- CBR (California Bearing Ratio)

The pavement materials investigations were undertaken by Omamanya Laboratory Services Pty (Ltd) during November and December 2017.

The details of investigation of the material for road section gives a good insight into the material available along the TZR and its suitability for the fill material and for structural layers for the railway embankment. The tests also give an idea of the foundations which can be provided at cross drainage structures (Bridges).

Results of Pit Tests: The fill material as per the 17 pit tests conducted along the route is summarised as under:

"The material used for fill can generally be described as silty sand with scattered Calcrete nodules, which is the in-situ material. The CBR @ 100% of modified AASHTO density is more than 31% with the material classification ranging from G5 to G8. The quality of the materials is considered good for the purpose of fill. There are no grading requirements for fill material."

DCP Tests Results: DCP's were done at 1 km intervals along T0806, alternating between the outer wheel tracks of the east- and westbound lanes. A total of 99 DCP tests were done. The DCP tests were carried out in accordance with THM 6, Standard Method 6.

Predicted DCP layer strengths according to the traffic classes heavy, medium and light traffic (Heavy: 0.8-12 million E80 per lane; Medium: 0.2 – 0.8 Million E80 per lane and Light: less than 0.2 million E80 per lane). Heavy traffic capacity is highlighted green which indicates the layer is in good condition. A sample DCP layer strength has been shown in Table 7-9.

Table 7-9: DCP Layer Strength Summary (sample)

km	Base	Subbase	Selected	Fill
Uniform Section 1 (17.98 km to 22.25 km)				
18	L	M	M	H
19	L	M	M	H
20	L	M	M	H
21	M	M	M	H
22	M	M	H	H
Uniform Section 2 (22.25 km to 40.25 km)				
23	M	M	H	H
24	M	H	M	H
25	L	M	M	H
26	L	M	M	H
27	M	M	M	H
28	L	M	M	H

Against 116 DCP tests conducted, all the tests have shown nearly all readings in the in-situ subgrade / fill layer are heavy traffic ratings indicating that this layer is in good condition and provides firm support for the pavement. Thus, the fill material has not posed any problems on

the route. For the TZR, fill material utilised along the route from local borrow areas would not be an issue.

7.2.2.4.3 Brief Interpretation of details and recommendations about Formation and Foundations

The test results obtained have shown that all the fill material falls in the material classification from G 5 -G8. The CBR @ 100% of modified AASHTO density is more than 31%. The quality of the materials is considered good for the purpose of fill for the Railway embankments and can also be used for structural layers of railway embankment. The foundations of cross drainage structures would also not pose any problems and majority of these structures can be provided with open foundations. At major bridge locations, detailed geotechnical investigation will have to be done to establish the type of foundations to be adopted during detail design stage.

7.2.3 Summary Of Geotechnical Assessment of the Project Area

Geological and geotechnical data has been gathered from prior ground investigations for road projects in the vicinity of the project as follows:

- material tests carried out on the samples taken from pits.
- past data on investigations carried out on the samples sourced from the pits along the final route.
- Dynamic cone penetrometer tests result along the road route as has been detailed above.

It is concluded that no major challenges are likely to be encountered in constructing the railway embankment fill material including structural layers.

The quality of the materials is generally considered good for the purpose of fill for railway embankments. The foundations of cross drainage structures would also not pose any major problems and the majority of these structures can be provided with open foundations.

At major bridges, detail geotechnical investigation will have to be done to establish the type of foundations, at the detail design stage.

7.3 Hydrology and Hydraulics

Engineering hydrology is the science of water resource engineering which deals with the study of occurrence, distribution, movement and the properties of water on the earth or beneath the earth surface or in the atmosphere. It is a comparatively new science.

The engineering hydrology primarily deals with estimation of water resources and study the components of the hydrological cycle like precipitation, runoff, transpiration, and their interactions.

The project area between Grootfontein to Katima Mulilo is extremely flat so much so that the topographical maps do not show many contours of this area except some stretch at Grootfontein. Although this area receives relatively high rainfall in the Namibian context, the topography is such that catchment areas in the conventional sense do not predominate, although (isolated) localised drainage lines do feature.

In terms of rail design, conventional hydrological analyses are based on:

→ The identification of catchment areas where stream flow lines cross a rail alignment. Once catchment areas have been identified, the necessary catchment area characteristics are determined, from which the runoff can be calculated for a defined return period. Drainage structures has been provided in the rail embankment (culverts, bridges etc.), sized according to the calculated runoff.

→ From the research study and documents available, it has evident that no major water courses are present along the route and drainage structures mainly act as balancing structures.

7.3.1 Flood Estimation for Railway Projects in Namibia

7.3.1.1 Road Drainage Manual

As far as hydrology and drainage is concerned, TransNamib has not developed any specific manual / code for the same. However, inspired by the first Road Drainage Manual (RDM) developed in South Africa in 1981, the former Department of Transport in Namibia adapted sections of the Road Drainage Manual and published its own "Drainage Manual" under the auspices of the Ministry of Works, Transport and Communication, Government of the Republic of Namibia in 1993. Later, the manual was updated in the year 2014 and is now known as Road 'Drainage Manual 2014'. TransNamib has accepted the Drainage Manual 2014 as one of the many Road Manuals suitable for use on railway projects too.

The manual is a good source of theoretical and practical insights in dealing with the hydrological assessments for linear transport corridors. Railway projects bear much similarity with road projects in terms of engineering hydrology (rainfall, catchments, runoff, discharge, etc.).

Furthermore, the TZR is proposed to run concurrently with the major arterial roads (in the same transport corridors). The proposed rail alignment runs along B8 road.

7.3.2 Key Hydrological Terminology

Following are some of the frequently used hydrological terminology:

→ **High Flood Level** - The maximum water level reached at a given point during the flood.

→ **Peak Discharge** – The maximum flow rate during the flood.

→ **Maximum flow velocity (Vmax)** - The maximum calculated flow velocity associated with a given flow rate.

→ **Flood volume** - The volume of water that is released from a catchment, responding to a given storm event and catchment characteristics.

- → **Flood duration** - The period of time during which the discharge does not drop below a given limit.
- → **Time of concentration (Tc)** - This is a measure of the catchment response time. This is the time for the surface runoff from the hydraulically most remote part of the catchment area to reach the road crossing point.

Peak discharge is the key parameter in the determination of the sizing of the drainage structure and the backwater effect associated with the structure. The peak discharge is directly related to the characteristics of the storm event and response of the contributing catchment area.

With the peak discharge having been determined, the high-flood level (flood line) and associated flow velocities may be determined by means of hydraulic calculations (uniform or gradually varied flow relationships).

7.3.2.1 Run Off

During a rainstorm, part of the water on the catchment may be prevented from reaching the catchment exit, while some runoff may be delayed enroute. Losses in the volume resulting from precipitation arise from infiltration, evaporation, storage in surface depressions and interception by vegetal cover. The excess precipitation travels by the hydraulically shortest route to the catchment exit.

The run-off that is generated within a catchment through precipitation depends on the:

(1) Characteristics of the storm event (type, intensity, duration).

(2) The response characteristics of the catchment (permeability, slope, area, soil type); and

(3) The influence of soil moisture conditions temporal storage on the run-off (storage volumes).

(4) Developmental influences (urbanization, forestry, agriculture).

7.3.2.2 Storm characteristics

Identifying storm types is important when reviewing the duration, distribution and intensity of rainfall.

Namibia receives most of its rainfall from convection processes, such as unstable showers and thunderstorms, which are the result of the convective rising and subsequent condensation of water vapour in warm air pockets heated by the surface of the earth. Most floods from small catchments are the result of convection thunderstorms, which generally yield high intensity - short duration rainfall.

Figure 7-5: Convection Storm Developing

7.3.2.3 Drainage Basin

The area of the drainage basin above a given point on a stream is a major contributing factor to the amount of flow past that point. For given conditions, the peak flow at the proposed site is approximately proportional to the drainage area.

The shape of a basin affects the peak discharge. Long, narrow basins generally give lower peak discharges than pear-shaped basins. The slope of the basin is a major factor in the calculation of the time of concentration of a basin. Steep slopes tend to result in shorter times of concentration and flatter slopes tend to increase the time of concentration. The mean elevation of a drainage basin is an important characteristic affecting runoff.

Higher elevation basins can receive a significant amount of precipitation as snow. A basin orientation with respect to the direction of storm movement can affect peak discharge. Storms moving upstream tend to produce lower peaks than those moving downstream.

7.3.2.4 Return period

As per the road Drainage Manual of Namibia, the table below reflects the Cabinet approved standard flood frequencies for various road drainage structures. The calculated flood with a return period of 20 years (frequency = 1 in 20 years) is used as the basis for defining the design return period.

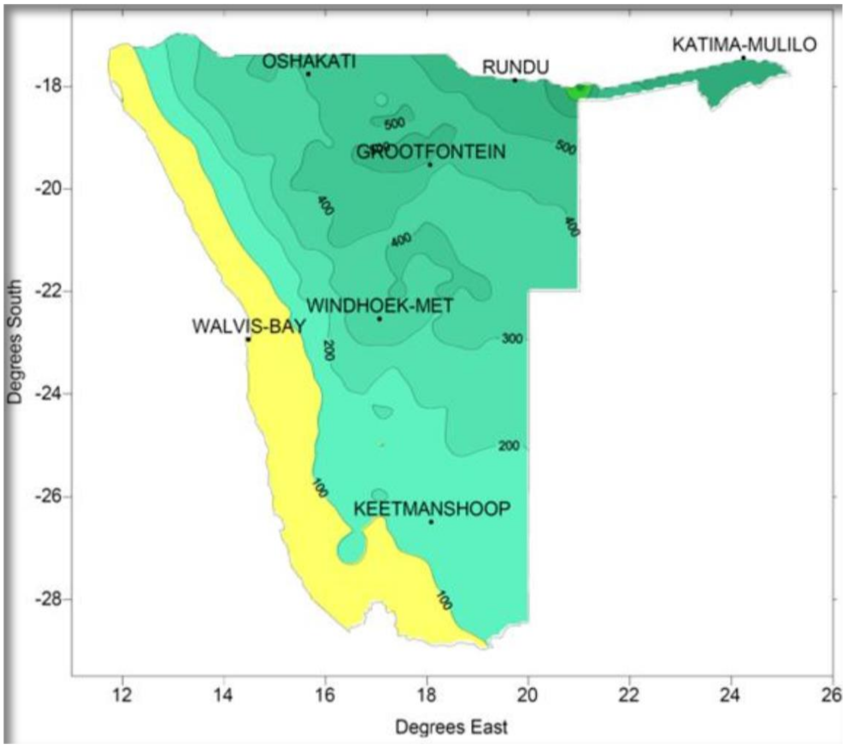
Table 7-10: Basic Design Return periods

1:20 year peak discharge (m3 /s)	Design return period (Years)			
	District road (DR)	Gravel main road (MR)	Surfaced main and trunk road (TR)	Freeway
0 to 20	1:5	1:10	1:15	1:20
20 to 150	1:10	1:15	1:25	1:50
More than 150	1:15	1:25	1:50	1:100

7.3.2.5 Mean Annual Precipitation

Mean annual precipitation has a significant influence on the depth of the precipitation for particular storm duration and return period, and on the peak flood discharge. Mean annual precipitation for a particular location on the project has been interpreted from the figure 3.2 provided in the road Drainage Manual 2014 (Figure 7-6 below).

Figure 7-6: Isohyetal Map of Namibia (Ref: Fig 3.2 of Drainage Manual)



Namibia is located in the Subtropical High-Pressure Zone in between the Inter- Tropical Convergence Zone which straddles the equator to the north and the Temperate Zone which covers the part of the globe to the south. Quasi-stationary cells of high pressure dominate this broad area of the Subtropical High-Pressure Zone and two of these cells, the Botswana Anticyclone and the South Atlantic Cyclone, are what make Namibia's climate so dry.

The Botswana Anticyclone, which is prominent in winter, feeds dry air over Namibia and obstructs the flow of moist air in from the Inter-Tropical Convergence Zone to the north. This gives rise to clear skies and warm to hot temperatures and this cell is the original cause of the Kalahari Desert and the surrounding arid and semi-arid areas.

Rainfall in Namibia generally increases in a north-easterly direction and the Project Area, located in the northeastern parts of Namibia, is also one of the wettest areas in the country. Rainfall in the Project Area ranges between 550-600 mm per year. Overall, the northeastern parts of Namibia experience about 45-50 rainfall days, that is days with 1 mm of rainfall or more per year, expectantly the highest in the country. Like most of Namibia, the majority of rainfall occurs in the summer months, with the peak between December and March. Given the rough rainfall range of 550-660 mm in the Project Area, a mean annual precipitation (MAP) value of 600 mm was selected to represent the Project Area.[15]

[15] Investigative Study Report Investigation for Road Preservation and Rehabilitation of TR8/4: Rundu – Divundu

TECHNOFIN CONSULTANTS

7.3.3 Basic Meteorological Data on Project Route[16]

7.3.3.1 Temperature

- **Grootfontein-Rundu:** Average annual temperatures are 20-22 ˚C.
- **Rundu-Divundu:** Average annual temperatures are 20-22 ˚C.
- **Divundu-Katima Mulilo:** Average annual temperatures are 20-22 ˚C.

7.3.3.2 Rainfall

- **Grootfontein-Rundu:** Average annual rainfall increases steadily from Grootfontein north-westwards, from 500-550 mm at Grootfontein to 550-600 mm at Rundu. Part of the wettest zones in Namibia.
- **Rundu-Divundu:** Average annual rainfall is 550mm, mostly as summer thunderstorms.
- **Divundu-Katima Mulilo:** Average annual rainfall is 550mm, increasing gradually towards Katima Mulilo, where it is more than 600mm. Flooding is prevalent towards Katima Mulilo in the rainy season.

7.3.4 Different Flood Calculation Methods

There is no method in hydrological engineering which can precisely predict the exact amount and intensity of the rainfall in any assigned future period. The expected flood and its consequent damages can only be judged and approximated. Hence, while deciding / designing hydraulic structures the discretion and the judgement of the design engineer becomes very important.

Various methods have been used for estimating floods. Some of them are based on characteristics of the drainage basin, other are based on the theory of probability by using previously known flood data and still others are based on the study of the rainfall and the runoff.

The proven and most used methods are[17]:

⇒ Statistical methods.

⇒ Deterministic methods (Rational, Alternative Rational and SCS); and

⇒ Empirical methods (Large-Area Design Flood Procedure, Empirical Flood Zone Method, Regional Maximum Flood Method and Empirical Determination Formula).

These methods are briefly introduced below:

7.3.4.1 Statistical Methods

Statistical methods involve the use of historical data to determine the flood for a given return period. Their use is thus limited to catchments for which suitable flood records are available, or

[16] Namibia - Weather forecast: Detailed weather conditions and forecast, long range monthly forecast, and climate data | Weather Atlas (weather-atlas.com)
[17] Road Drainage Manual 2014

for which records from adjacent catchments are comparable and may be used. Where accurate flow records, covering a long period are available, statistical methods are very useful to determine flood peaks for different return periods. The method lends itself to extrapolation of data to determine flood magnitudes for longer return periods.

7.3.4.2 Rational Method

The Rational method is based on a simplified representation of the law of conservation of mass. Rainfall intensity is an important input in the calculations.

7.3.4.3 SCS method

The SCS method was developed by the United States Soil Conservation Service (SCS) for use on small agricultural catchments. It has since been improved and extended for use on much larger catchments and has been used since 1962 as an alternative to the Rational Method in Republic of South Africa. ***This method has been adopted for hydrological assessment for Trans-Zambezi railway extension project.***

7.3.4.4 Empirical methods

Empirical methods are based on the analyses of historical data and/or the results of other methods. Empirical methods are suited to check the order of magnitude of the results obtained by means of the other methods.

On applicability of the methods, the Drainage Manual stipulates the following:

Figure 7-7: Applicability of Various Hydrological Calculations Method

<table>
<tr><th colspan="2">Method</th><th>Input data</th><th>Recommended maximum area (km²)</th><th>Return period of floods that could be determined (years)</th></tr>
<tr><td colspan="2">Statistical method</td><td>Historical flood peak records</td><td>No limitation (larger areas)</td><td>2 – 200 (depending on the record length)</td></tr>
<tr><td rowspan="3">Deterministic methods</td><td>Rational</td><td rowspan="2">Catchment area, watercourse length, average slope, catchment characteristics, rainfall intensity</td><td>< 15</td><td>2 – 100, PMF</td></tr>
<tr><td>Alternative Rational</td><td>No limitation</td><td>2 – 200, PMF</td></tr>
<tr><td>SCS</td><td>SCS curve number, design rainfall depth, retention</td><td>< 25</td><td>2 – 100</td></tr>
<tr><td rowspan="4">Empirical methods</td><td>Large-Area Design Flood Procedure</td><td rowspan="4">Catchment area, watercourse length, distance to catchment centroid, slope, mean annual rainfall, veld types or regions</td><td rowspan="4">No limitation (larger areas)</td><td rowspan="4">10 – 200, RMF</td></tr>
<tr><td>Empirical Flood Zone Method</td></tr>
<tr><td>Regional Maximum Flood Method</td></tr>
<tr><td>Empirical Determination Formula: Namibia - Department of Transport</td></tr>
</table>

7.3.5 Route Hydrology

There are two recent study documents which deal quite in details on the hydrological aspects of the project area:

TECHNOFIN CONSULTANTS

(1) Namibia Roads Authority's 'Consultancy services for the investigation for road preservation and rehabilitation of T0806 from Kongola to Katima Mulilo in the Zambezi Region of Namibia', conducted from 2017 to 2019.

(2) Namibia Roads Authority's 'Investigation for Road Preservation and Rehabilitation of TR8/4: Rundu – Divundu', conducted in 2016.

'The permeability of the area, as well as the flat topography, causes large volumes of water to be absorbed into the soil structure. Runoff is considerably reduced due to the latter. With reference to the catchment area determination, the project area is subject to large sandy and flat areas that required substantial terrain depression filling in order for catchment areas to be compiled by means of software algorithms. During analyses where depression filling was done to only 1m depth, almost no continuous water courses were generated by the software, further substantiating the fact that conventional runoff calculations cannot be applied successfully for the area, without high-detail topographic and soil structure surveys.

With reference to the Feasibility Study for Trans-Caprivi Highway, (VKE, 1992), the report confirms the above findings and also recommends that the existing culverts and their flood history should be used as primary guidance and that conventional runoff formulae should not be used as baseline for culvert design and/or evaluation in the area.'[18]

In the above referred second study too 'Due to the flat topography of the project Area, catchment areas could not be identified from the DEM data for most drainage points. In addition, some drainage points were identified from the DEM data although it is clear from satellite imagery that drainage does not occur at these locations.'[19]

Due to the flat topography of the project area, identification of the catchment areas could from the Digital Terrain Modelling sourced through SRTM data by Global Mapper was found to be unfeasible. Also, many times the data indicating a particular catchment and stream is not collaborated by satellite imageries. Considering that detailed topographic and engineering studies will be done at the detailed design stage of the project, for the purpose of this study, the hydrological assessment done in the two above referred studies is a good basis for railway bridges too.

Consequently, except for two major rivers, which are described in the section below, the bridge opening on the rest of the TZR extension route is based on the cross drainages already provided on the existing adjacent highway. The railway waterway openings will generally be marginally larger than that provided on the roads.

[18] Namibia Roads Authority 'Consultancy services for the investigation for road preservation and rehabilitation of T0806 from Kongola to Katima Mulilo in the Zambezi Region of Namibia'

[19] Namibia Roads Authority's 'Investigation for Road Preservation and Rehabilitation of TR8/4: Rundu – Divundu'

7.3.6 Overview of River Systems on the Proposed Route[20]

Namibia is one of the driest countries in Africa, is bordered by two deserts, the Kalahari on the east and the Namib on the west and relies heavily on ephemeral river systems for the sustenance of rural and urban centres.

Typical of the arid environment, the country is characterised by high rainfall variability and long periods of droughts. The country is also the most arid country south of the Sahara, with only ephemeral rivers in its interior as perennial rivers only occur along the northern and southern borders of the country. Ephemeral rivers that flow to the northern and eastern part of the country, flow largely towards regions with high rainfall, while those that flow southward and westwards, largely traverse the arid and hyper arid regions, with rainfall varying from 0-100 mm per year (Jacobson et al., 1995).

7.3.7 Perennial Rivers

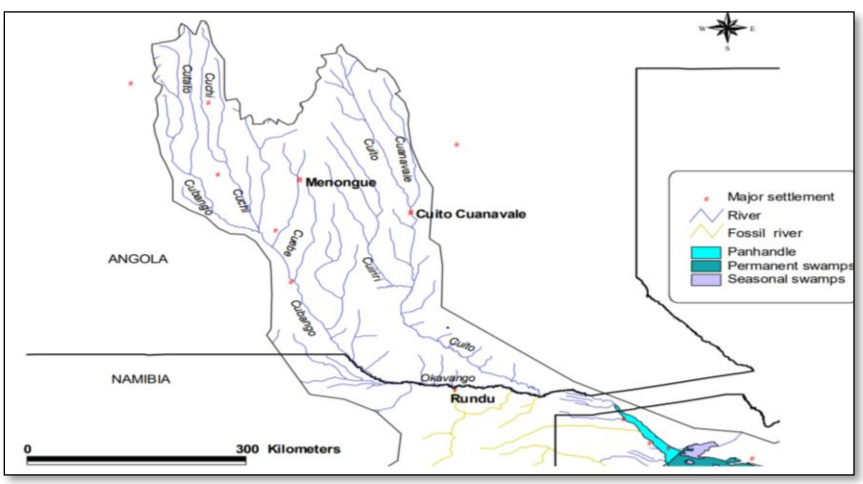
The perennial rivers that are encountered by the TZR extension in the East Kavango and Zambezi Regions – namely the Okavango and Kwando Rivers – are lifelines for the people and wildlife.

7.3.7.1 Okavango River[21]

The two main rivers, the Cubango and Cuito, originate in Angola and flow to the south, where they become the border between Angola and Namibia. After flowing together, they become the Okavango River that enters the Caprivi Strip in Namibia about 50 km further downstream.

After entering Botswana, the Okavango River flows into the Okavango Delta, a large swamp area. A spillway exists from this area to the Chobe River in the Zambezi basin in periods of high floods.

Figure 7-8: Upper Okavango River Basin[22]

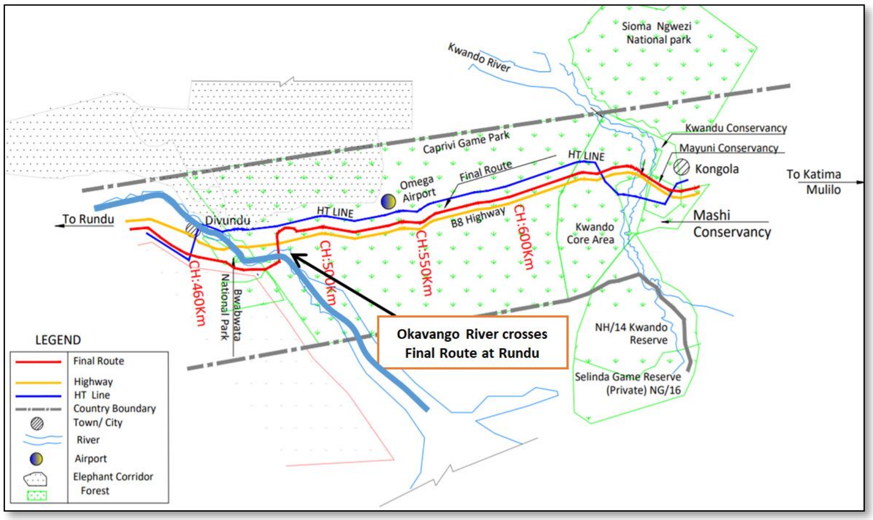


[20] (PDF) Ephemeral River systems and their ecosystem provisions to the local populations: A review of the Huab and Ugab Rivers, Namibia (researchgate.net)
[21] The Okavango basin (fao.org)
[22] Cubango-Okavango River Basin Water Audit (CORBWA) Project Synthesis Report

The Omatako tributary in Namibia is an ephemeral river, flowing north-east to enter the Cubango River at the border between Angola and Namibia.

Okavango river crosses the TZR extension route near Divundu at KM: 470.941 as indicated in the figure below:

Figure 7-9: Okavango River Crossing



The railway alignment after bypassing Divundu, crosses Okavango river & B8 highway at KM: 470.941 & KM:471.430 respectively. A bridge of 3 X 50.5 m size has been provided on the highway.The railway bridge's configuration is proposed as 6 X 30 + 2 X 20. As comparared to road bridge, one additional span on either end of the waterway is being proposed as pathways to facilitate potential unhindered wildlife movement in the area.

Table 7-11: Catchment Area of Okavango River[23]

Catchment area	River ending in /contributing to	Area in km2
Okavango	Okavango Delta	13 644,787

7.3.7.2 Kwando River[24]

The Kwando river is a river in south-central Africa flowing through Angola and Namibia's Caprivi Strip, into the Linyanti Swamp on the northern border of Botswana. Downstream Linyanti Swamp the river is called the Linyanti River, and further east the Chobe River, before it flows into the Zambezi River.

The Kwando rises in the central plateau of Angola on the slopes of Mount Tembo, thence flowing southeast along the Zambian border. Along this reach it flows in a maze of channels in a swampy corridor 5–10 km wide. As with all rivers in south-central Africa its flow varies

[23] Study of Mapping the Major Catchments of Namibia by B. J. Strohbach
[24] The Kwando River | Namibia | Botswana (namibweb.com)

TECHNOFIN CONSULTANTS

enormously between the rainy season when it floods and may be several kilometers wide, and the dry season when it may disappear into marshes.

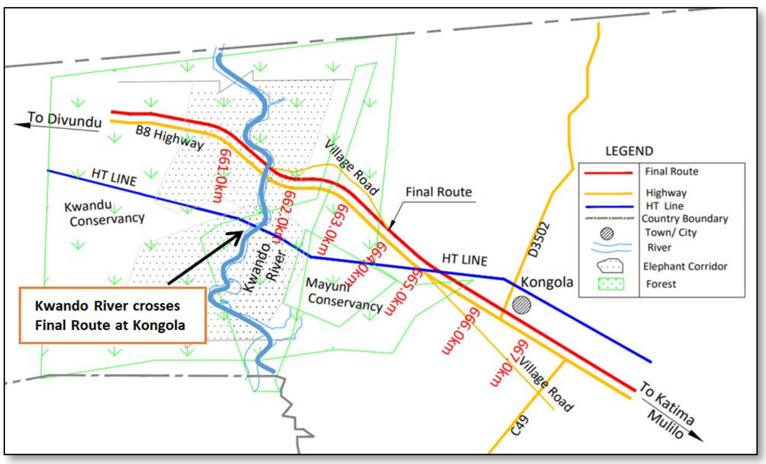
The Kwando continues in its marshy channel across the neck of the Caprivi Strip of Namibia and then forms the border between Namibia and Botswana as it continues southeast.

Table 7-12: Catchment area of Kwando[25]

Catchment area	River ending in /contributing to	Area in km2
Kwando	Okavango Delta	6 846,593

Kwando river crosses the TZR extension route near Kongola at KM: 661.485 as indicated in the figure below:

Figure 7-10: Kwando River Crossing



The railway alignment runs parallel to B8 Highway on this stretch. A overall length of the bridge of 51.00 m has been provided on the highway. The railway bridge's configuration is proposed as 4 X 30.0 m Steel Girders. As comparared to road bridge, one additional span on either end of the waterway of 30 m length each is being proposed as pathways to facilitate potential unhindered wildlife movement in the area.

7.3.8 Spanning arrangement for the Proposed 'Cross Drainage' Bridges

The complete list with spanning arrangement for each of Cross Drainage Bridges proposed on the TZR extension, based on the cross drainages already provided on the existing adjacent highway, are as per Appendix -3 – Major/Minor/Important Bridge List.

7.4 Engineering Survey Parameters

As mentioned TransNamib has confirmed that they have adopted the RA's manuals for Engineering purposes. The objective of this section is to provide a brief overview of the

[25] Study of Mapping the Major Catchments of Namibia by B. J. Strohbach

parameters required for completing detailed engineering surveys as part of the next phase of the project.

7.4.1 Materials Manual (Geotechnical Surveys)

The Roads Authority's Materials Manual sets standard and norms to be adhered to in the execution of materials-related work. The Materials Manual of the RA sets out the geotechnical work to be carried out at the detail design stage. This work includes centreline soil survey, prospecting for road/ rail building materials, sampling of materials from borrows- pits and quarries, testing of materials proposed for use during construction, evaluation of test results, subgrade stability assessments, and all other relevant investigations and work relating to pavement design and geotechnical matters.

7.4.1.1 Centreline Materials Survey

The properties of the soil in the bulk earthworks shall comply to Spoornet's specification no. S410. If the natural soils are unsuitable sub-ballast may be stabilised. The structural layers for a 20-t axle load are depicted in Figure 7-11.

Figure 7-11: Structural Layers for 20t Axle Loading

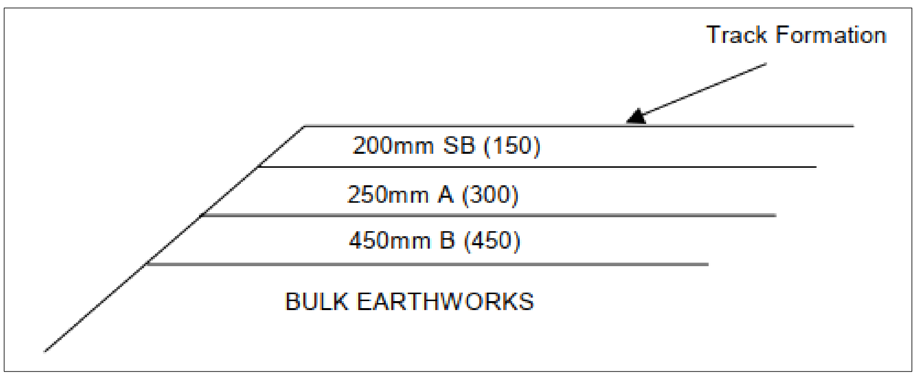


Figure 7-12: Structural Layers for 20t Axle Loading

Note: Dimensions in brackets apply when sub-ballast and special sub-ballast layers are stabilised.

The general material requirements are listed below.

Table 7-13: Railway Earthwork Requirements

	PI	CBR Strength	Material Classification (TRH 4)
Special Sub-Ballast	3-10	60	G4-G5
Sub-Ballast	3-10	30	G5
A	<12	20	G6-G7
B	<17	10	G8
Bulk earthworks	<25	5	G9-G10

The purpose of the centreline materials survey is to:

i) establish the strength of the in-situ materials that will be available for construction of the lower earthwork layers (bulk earthworks).

ii) determine the usage of the in-situ material and extent of imported or borrow materials to be used.

iii) identify problems with bulk cut and fills.

A centreline survey is only applicable when a route has been finalised. The following is a general scope of the centreline survey required:

i) Dig pits on railway centreline. Test pits each 200m is recommended as a start but would prove to be impractical over the length of this project. The 200m spacing should be revised and is subject to Engineering judgement.

ii) Describe horizons encountered.

iii) Sample at least half of the pits dug of each separate layer of material encountered for sampling.

iv) Indicator tests performed for each sample (i.e., screen analysis, % passing the 0,075mm sieve and Atterberg constants).

v) A minimum of 5 CBR tests on representative samples of each material type (with a minimum of 5 x CBR tests per 2km).

vi) Cuts should be inspected where sampling is precluded, to give an indication of the material which may be encountered.

vii) Fills that exceed 1m shall be inspected at 200 m intervals and sampled if necessary.

viii) The frequency of testing and depth of testing should be reviewed after the horizontal and vertical alignments have been fixed.

7.4.1.2 General Borrow Pit Requirements

Material for bulk earthworks is generally readily available within the free-haul distance. Borrow pits for selected fill material (fill material above bulk earthworks) should preferably be spaced no further than 3-5 km apart and they should be properly tested beforehand. A minimum of 9 test holes and 4 CBR tests should be conducted per borrow pit.

Indicator samples shall be taken of each soil type encountered in every test hole. A CBR sample shall be taken of each soil type encountered but with a minimum of 1 CBR sample per material horizon for every 3 test holes dug. CBR tests shall be carried out on samples representative of each material type selected for a specific use, with a minimum as indicated above.

SB and SSB materials borrow pits shall a minimum of 12 test holes per borrow pit with similar testing regime.

The suitability of mechanical stabilisation with binders should be tested with indicators testing on the material and binder and CBR and indicator testing on the mixture.

Additional Initial Consumption of Stabiliser (ICS), Indirect Tensile Strength (ITS) and UCS is required for chemical stabilisation with cement or lime.

Tests shall be carried out to determine the presence of deleterious salts in all borrow material to be used for Sub ballast.

The above is indicative and should be used as a guideline. The onus shall remain with the contractor to verify final quality and quantity of material. Material may be sourced from elsewhere.

Environmental Impact Assessments (EIAs) will be required for each borrow pit which will stipulate that borrow pits should be managed in a safe manner and rehabilitated afterwards. Land compensation also applies to borrow pit areas.

7.4.1.3 Base Borrow Pits/ Quarries

Crushed rock sources should be closer than 20km and natural materials do not exceed 10km. Solid rock quarries shall core drill on a 50m grid. One out of three cores shall be crushed, screened and tested. The hardness and durability of the aggregate and base material in all sources proposed for use in base shall be proved by means of the 10% FACT (Fine Aggregate Crushing Test) and/or the Durability Mill Index (Texas Ball Mill) test. These are specified in Community of Land Transport Officials (COLTO) and include wet and dry testing for durability.

If the available material in a borrow pit requires crushing and screening, samples must be made up to simulate the anticipated end product.

7.4.1.4 Bridge and Large Culvert Structures

The founding conditions of major concrete and load bearing structures, such a bridges and large culverts, will require additional geotechnical investigation. Apart from the centreline survey, these areas should undergo extensive geotechnical testing that could include rotary core drilling. The purpose of the testing should be to assess the nature of the underlying soils, site geology, excavation conditions, material utilisation potential and founding conditions.

7.4.1.5 Recording & Reporting of Materials Investigation

All the test results obtained as a result of the investigations into centreline materials, quarries and borrow pits shall be recorded. The RA has specific recording sheets, and the suitability thereof is to be clarified during the detail design stage.

At the detailed design stage, prior to finalisation of the project specifications, a report on the materials investigation shall be submitted to the Client for approval. This report shall contain all centreline materials survey and borrow pit information. The minimum requirements for the reports are set out in the RA Materials Manual.

7.4.2 Survey Manual (Topographic Survey)

The survey work consists of three phases namely: i) Basic Survey, ii) Digital Terrain Model (DTM) Survey and iii) the Topographical Detail Survey.

7.4.2.1 Basic Survey

The purpose is to provide a backbone of permanently marked and accurately fixed survey stations for future use in staking and revision surveys. The manual sets out the nature of each permanent survey station in detail and should be spaced not further than 800m apart. Two other stations should be visible from each station (inter-visibility).

Horizontal control shall be based on the official national spatial reference network on the appropriate coordinate system and shall be determined by Global Navigation Satellite System (GNSS) survey methods only. The final horizontal coordinates of permanent survey stations shall be given to 2 decimals of a metre.

Vertical control (elevations) shall be based on the national geodetic benchmark wherever possible. The elevation of any benchmark to be used in a survey shall be verified from at least one other benchmark. The elevations of the permanent survey stations shall be determined by digital spirit levelling only and shall be measured twice by forward and reverse levelling. All spirit levelling of permanent survey stations shall, in addition to forward and reverse levelling, be checked independently by GNSS levels. Final elevations of permanent survey stations shall be given to 3 decimals of a metre.

One hard and one digital copy of the following survey records must be submitted to the Client on completion of the basic survey.

7.4.2.2 Cadastral Phase

This phase covers the collection of all data defining the cadastral boundaries of all properties in respect of which deeds of tenure are registered in the Deeds Registries, excluding short term leases and the interior boundaries of separate mining titles which together constitute single mining properties, but including all farms, subdivisions, small holdings, township lots, servitudes, etc. falling within the strip to be surveyed.

The primary source of cadastral information shall be the offices of the Surveyor-General and the Mining Commissioner from which copies of diagrams are to be obtained.

Cadastral data shall be prepared on the relevant coordinate system.

Many of the older diagrams are inaccurate, and it may be impossible to arrive at reliable positions from diagram data alone. In such cases the field survey of a certain number of beacons shall be done to provide sufficient control, but this may entail extensive surveys far afield from the area concerned to achieve reliability. The extent and scope of such surveys, especially within communal lands should be determined during the detailed design phase.

7.4.2.3 Digital Mapping and Terrain Modelling

Detailed DTMs are often preceded by strip digital imagery/ photogrammetric surveys as the alignment is in the process of being finalised. This could include digital image acquisition, photography, ground surveys to verify geo-referenced images, contour or DTM acquisition, cadastral compilation, digital mapping. The necessity of the above would have to be determined as part of the detail design phase.

The objective of the DTM is to arrive at comprehensive topographical survey from which accurate horizontal and vertical alignments can be derived. The setting-out will then only take place immediately prior to construction.

The DTM will also be used to accurately quantify volumes during the design and construction. The DTM survey should also provide a backbone of permanently marked and accurately fixed survey stations for future use in staking and surveying.

A detailed DTM survey typically consists of:

i) a basic survey establishing a horizontal and vertical survey network of permanent survey stations, and the supply of related records shall be included in the Basic Survey.

ii) a DTM survey which includes all the survey work required for the production of the DTM.

iii) A topographical detail survey that must be surveyed within the strip that will have a bearing on the proposed horizontal and vertical alignments.

iv) The tolerances indicated below (Table 7-14) shall dictate the survey method to be used.

Table 7-14: DTM tolerances

FEATURE	HORIZONTAL	VERTICAL
Edge and centre of surfacing, shoulder break points, tops of cuts and toes of fills lines and drains	100mm	25mm
Kerbs, culverts, bridges, manholes	50mm	25mm
Gravel roads	100mm	50mm
Other topographical details	100mm	100mm
General spot shot for DTM	-	100mm

The survey deliverables are a detailed survey report, coordinate list, CAD drawing file and DTM file as specified in the survey manual.

7.4.2.4 Bridge and Local Site Surveys

The purpose is to provide topographical details to enable the design of a river crossing (large bridges and culverts) which will require hydraulic characteristics of the river/ stream. These surveys should be linked to the overall rail alignment survey.

Generally, an area 100m upstream, downstream and from each bank should be surveyed.

Special features that may affect the run-off of a river or stream, such as dams, weirs, rapids, falls etc., shall be investigated and reported on.

7.4.3 Compensation Survey

The rail will pass through a substantial portion of communal land. The inhabitants are to be compensated for disturbance. The RA manuals does not specifically specify the time and extent of how the compensations should be dealt with. The MoWT has published a guideline on land acquisition and compensation that can be used as a guideline.

Experience has shown that the extent of the compensation should be identified and included in the surveys as soon as the alignment of the rail is fixed. Compensation items include informal and formal dwellings, fencing, fruit trees, cultivated land etc. These items should be surveyed, and the details of the owners should be captured as well.

Typically, the cost estimate of the compensation is included in the contractor's Bill of Quantities as a provisional sum and the contractor is tasked with the timely compensation of the inhabitants.

The MoWT has recently required to do the compensation directly and not via the contractor. This approach is not recommended as any delays from the MoWT will directly implicate the contractor and could result in major delay costs to be carried by the MoWT.

It is recommended that the compensation procedure should be clarified with the MoWT during the detail design phase.

8 Structures

8.1 Introduction

This chapter covers the preliminary assessment for structures - bridges, culverts, eco crossings.

8.2 Bridge Classification

Bridge might be classified based upon purpose, site condition, construction material, loading standard and spans.

For this project, bridges have been classified based on its 'Opening' i.e., 'Total Span' (see Table 8-1).

Table 8-1: Bridge Classification

#	Classification	Crossing Detail	Linear Opening / Span
1	Important Bridge	River Crossing (Okavango & Kwando River)	50 m and above
2	Major Bridge	Other major water bodies and cross drainage excluding Okavango & Kwando river	6 m to 50 m
3	Minor Bridge	Minor Water bodies, Canals, Balancing Culverts	Up to 6 m
4	Road Under Bridge (RUB)	Road crossing below the railway	
5	Road Over Bridge (ROB)	Road crossing above the railway	

8.3 Bridge Summary

Based on the study of structures and 'openings' provided on the adjacent B8 road corridor as well as preliminary hydrological studies, following is the summary of proposed bridges and culverts on the alignment at this feasibility stage (Table 8-2 and Table 8-3).

Table 8-2: Summary of Proposed Bridges on Final Route

#	Description	Qty.
1	Minor Bridge (Culverts)	358
2	Major Bridge	7
3	Important Bridge	2

Table 8-3: Summary of Road Bridges (ROB/RUB) and Level Crossings

#	Description	Qty.
1	ROB (Road over Bridge)	7
2	RUB (Road Under Bridge)	70
3	Level Crossing	37

A detailed **Major/Minor Bridge List** is as per Appendix -3 – Major/Minor/Important Bridge List to this report.

A detailed **ROB/RUB/Level Crossing List** is as per Appendix -4- ROB/RUB/Level Crossing to this report.

8.3.1 Important Bridges – River Crossing

On rivers, a relatively long span bridge needs to be arranged so as to avoid interfering with the flow of the river and to prevent the risk of scouring. Detailed geotechnical investigations must be carried out to determine the quality of the bearing soil or rock strata, whether grouting is needed to fill voids, and to select an installation method (i.e., drilling through rock or boulders vs. driving piles through soft material) at each abutment and pier location.

Table 8-4 summarizes the spans which are proposed for river crossings at Okavango & Kwando river:

Table 8-4: Proposed Linear Waterway for Important River crossings

#	Chainage (m)	Type	Linear Waterway	River Name
1	470.941	Steel Girder	6X30.0 m + 2 X 20.0 m	Okavango
2	661.485	Steel Girder	4 X 30 m	Kwando

Figure 8-1 provides a typical General Arrangement Drawing (GAD) for steel girders on important bridges. Steel girders will be prefabricated in workshop and will be launched at site.

Figure 8-1: Typical GAD of 1 X 30 m Steel Girder for Important Bridges

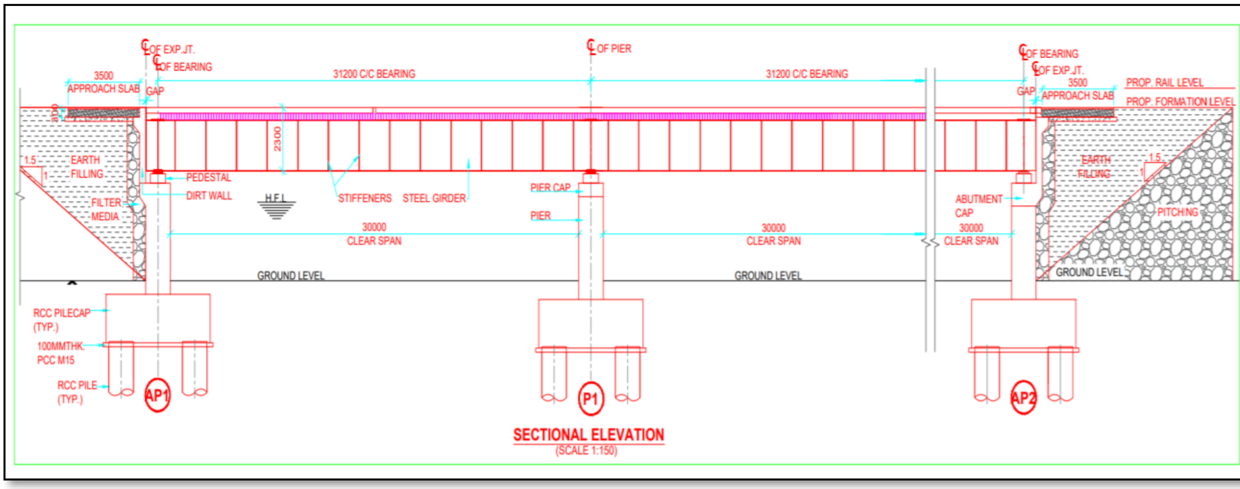
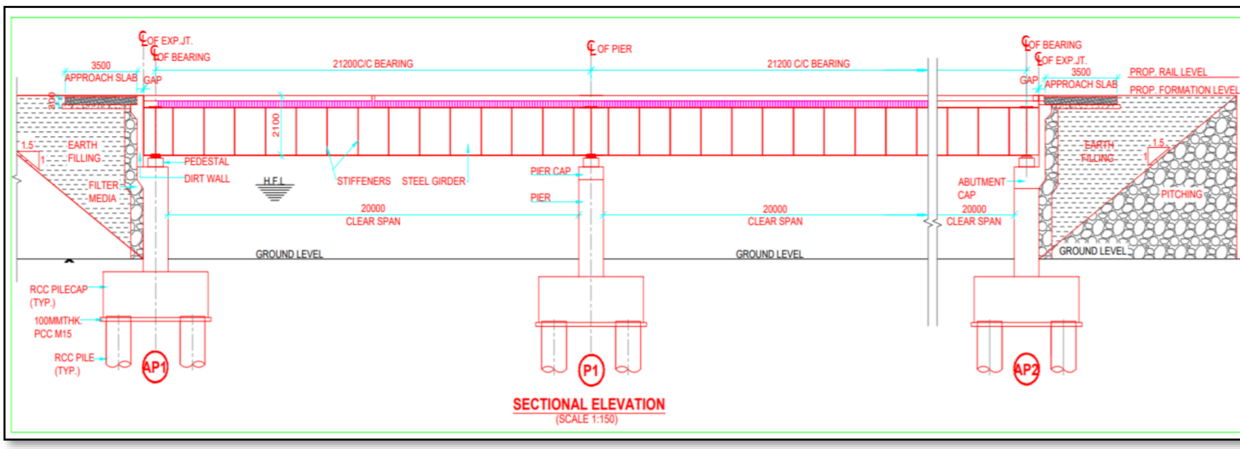


Figure 8-2: Typical GAD of 1 X 20 m Steel Girder for Important Bridges



8.3.2 Major Bridges

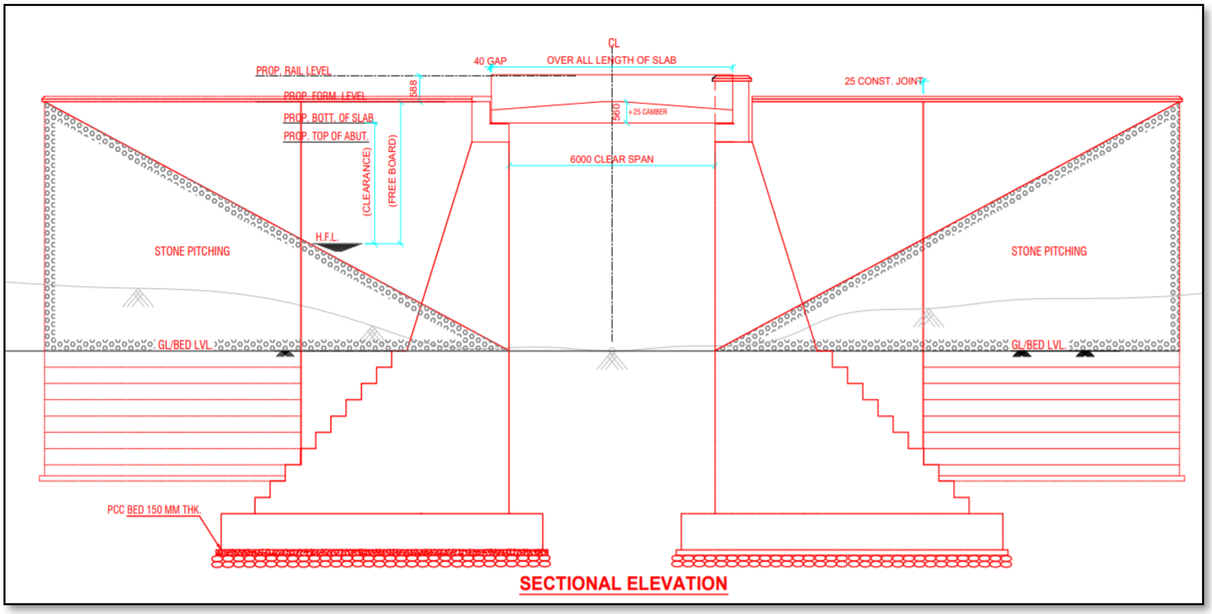
Following are the proposed Major Bridges on Trans Zambezi railway extension line:

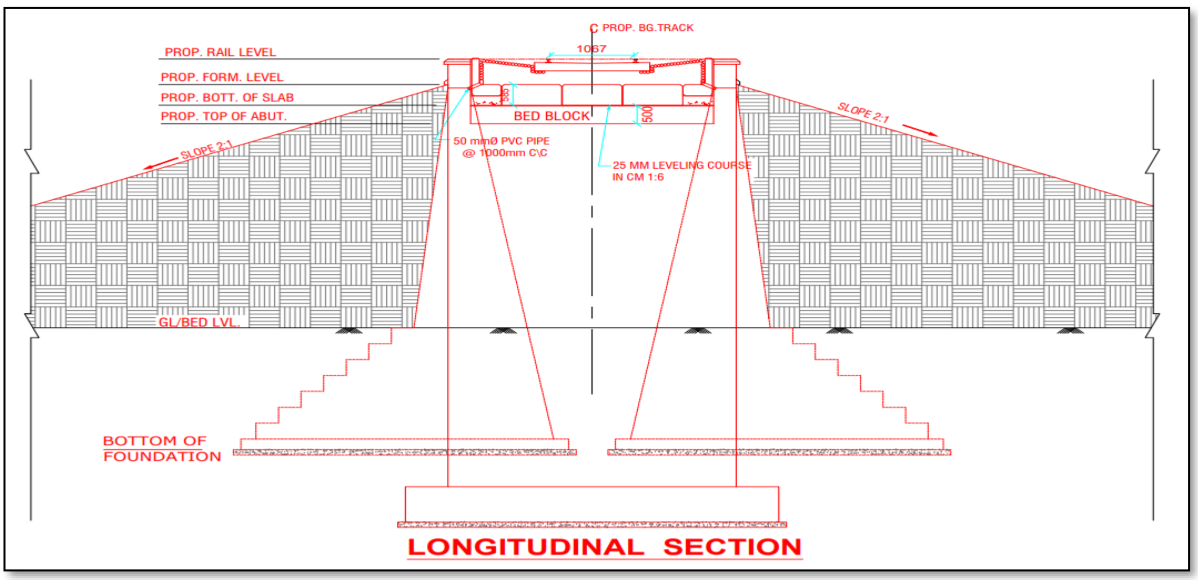
Table 8-5: Proposed Linear Waterway for Major Bridges

#	Chainage (km)	Type	Linear Waterway	Location
1	11.900	PSC Slab	2 X 6.00 m	Near Grootfontein
2	15.142	PSC Slab	2 X 6.00 m	Near Grootfontein
3	15.489	PSC Slab	2 X 6.00 m	Near Grootfontein
4	37.100	Steel Girder	1 X 30.0 m	Kokasib River
5	259.345	PSC Slab	2 X 6.00 m	Ndonga River near Rundu
6	284.980	PSC Slab	2 X 6.00 m	Near Kambowo
7	360.000	PSC Slab	2 X 6.00 m	Omatako River near Mashare

TECHNOFIN CONSULTANTS

Figure 8-3: Typical GAD of 1 X 6 PSC Slab for Major Bridges





8.3.3 Minor Bridges

Also categorized as 'Culverts', Minor Bridges are provided to ensure adequate localized 'Cross Drainage' mostly as 'Balancing Culverts'. There generally is no defined drainage channel passing through a minor bridge.

The dimensions/quantities of Minor Bridges / Culverts to be used on the projects are summarized in Table 8-6. This is followed by a typical drawing for box culverts on minor bridges (see Figure 8-4 to Figure 8-7). Box culverts offer superior strength and easy installation.

Table 8-6: Proposed Linear Waterway for Minor Bridges

#	Type	Linear Waterway	Total Bridges (#)
1	Pipe Culvert	1 X 0.75 m	52
2	Reinforced Cement Concrete (RCC) Box	1 X 2.0 m	297
3	RCC Box	1 X 4.0 m	8
4	RCC Box	1 X 6.0 m	1

Figure 8-4: Typical GAD of 1 X 2 Box Culvert for Minor Bridge

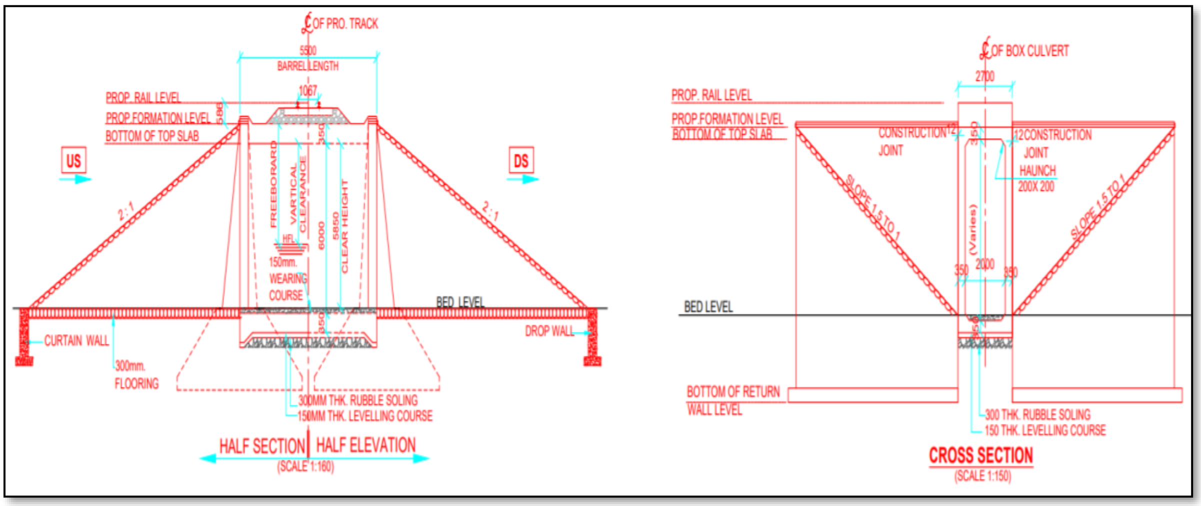


Figure 8-5: Typical GAD of 1 X 4 Box Culvert for Minor Bridge

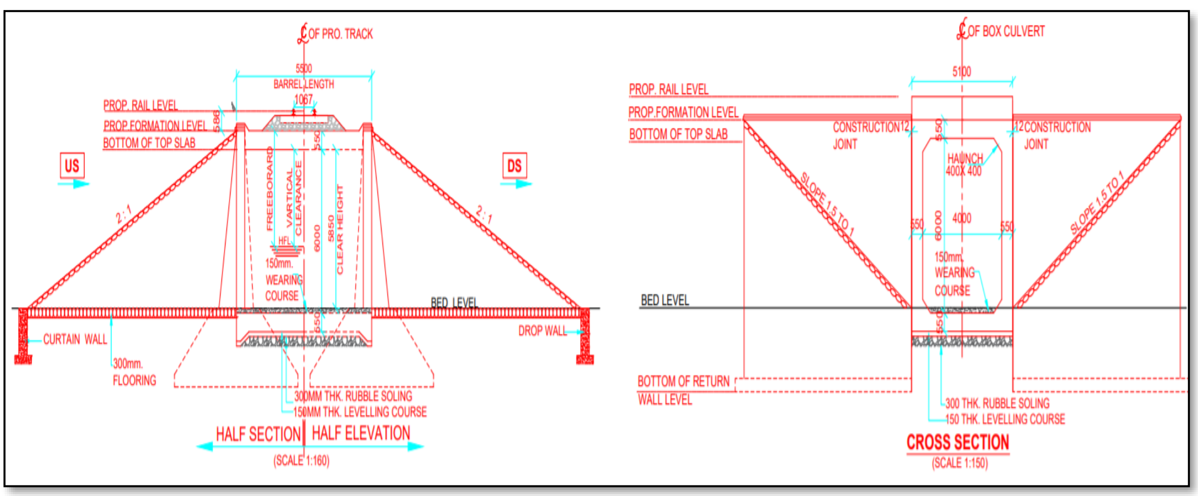


Figure 8-6: Typical GAD of 1 X 6 Box Culvert for Minor Bridge

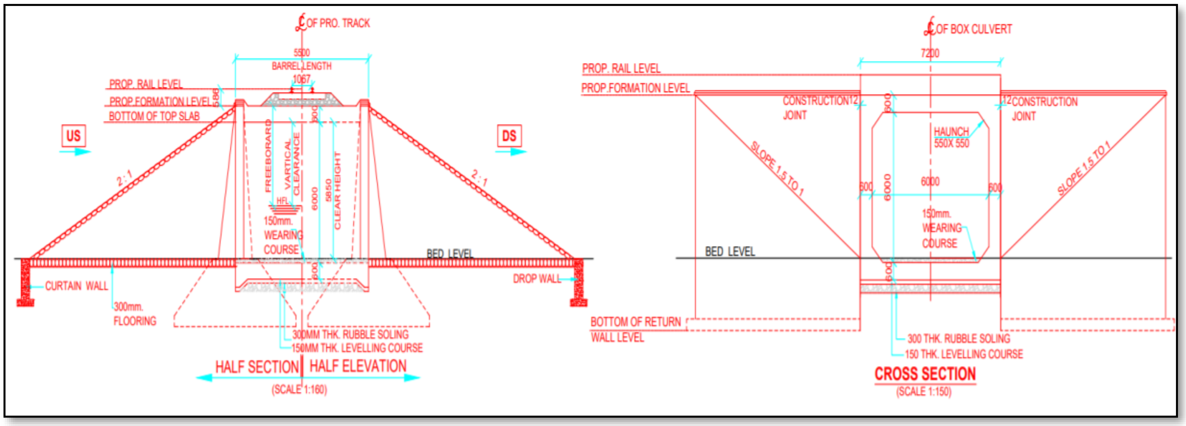
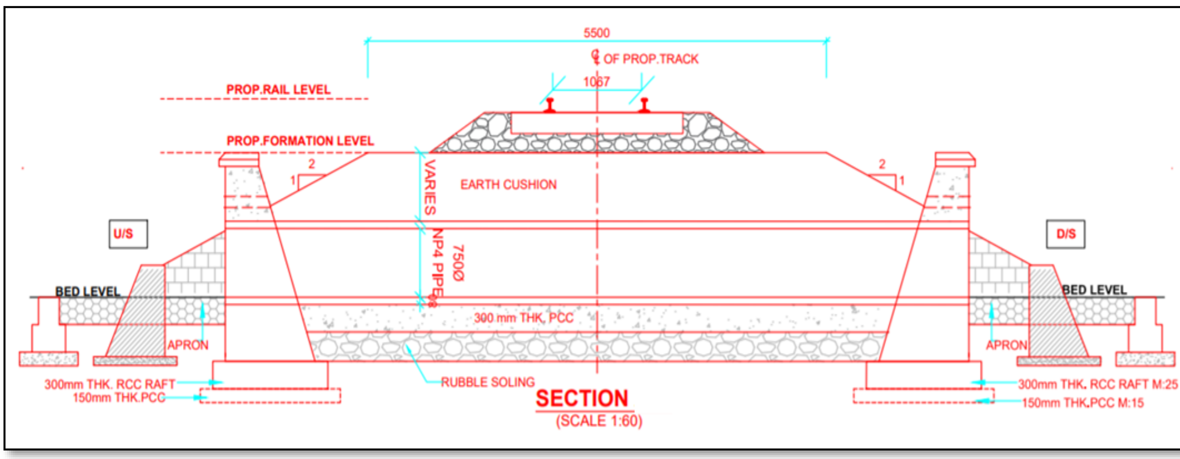


Figure 8-7: Typical GAD of Pipe Culvert



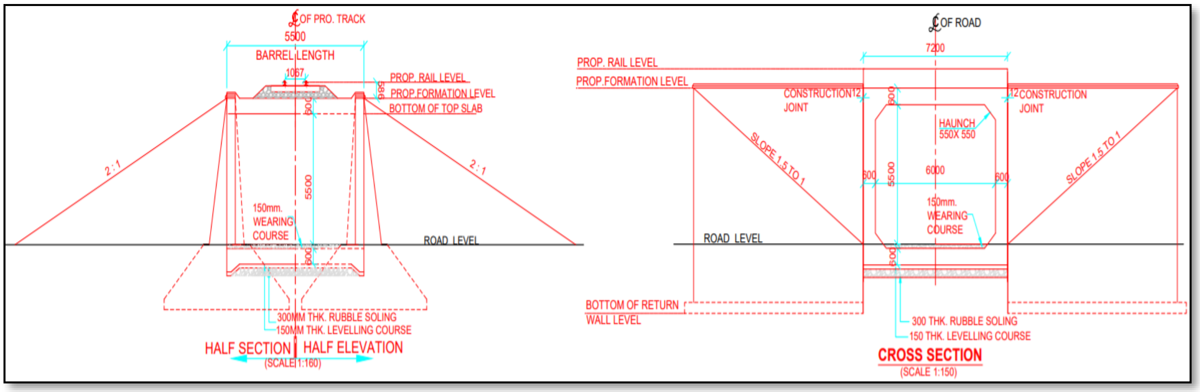
8.3.4 Road Under Bridge (RUB)

Road under bridges (RUB) are constructed where the road traffic is substantial to justify a 'Grade Separated' rail-road crossing. Road alignment crosses 'under' the Railway alignment. An RUB is the most suitable structure where the space is limited for the approaches specifically in urban areas. The vertical clearance may be further reduced depending on type of road and vehicles used in that area. RUBs are proposed on a total of 70 major road crossings along proposed railway alignment (see Table 8-7 followed by Figure 8-8 for a typical GAD of a RCC box for road under bridges).

Table 8-7: Proposed spanning arrangement for Road Under Bridges

#	Type	Span (m)	Total Bridges (#)
1	RCC Box	1 X 6.00 m	70

Figure 8-8: Typical GAD of RCC Box for Road Under Bridges



8.3.5 Road Over Bridge (ROB)

A Road over bridge (ROB) is constructed where the road traffic is substantial to justify a 'Grade Separated' rail-road crossing and where the road alignment crosses 'above' the railway alignment. ROBs are usually constructed where enough space is available for the approaches.

The requirement of vertical clearance for a railway is more than that for a road. Thus, a longer approach length is required in case of ROBs. Due to increased approach length, the cost of providing a ROB is high. ROBs are proposed at seven road crossings along proposed railway alignment (see Table 8-8).

Table 8-8: Proposed spanning arrangement for Road Over Bridges

#	Chainage (m)	Type	Span (m)	Location
1	9.430	PSC Slab	1 X 12.00 m	Near Grootfontein
2	47.900	PSC Slab	1 X 12.00 m	-
3	50.660	PSC Slab	1 X 12.00 m	-
4	111.061	PSC Slab	1 X 12.00 m	Near Henta
5	122.735	PSC Slab	1 X 12.00 m	Near Mururani
6	354.000	PSC Slab	1 X 12.00 m	Near Nyondo
7	365.600	PSC Slab	1 X 12.00 m	Near Ndiyona

Figure 8-9 and Figure 8-10 provide a typical GAD and picture of a ROB, respectively.

Figure 8-9: Typical GAD of PSC Slab for Road Over Bridges

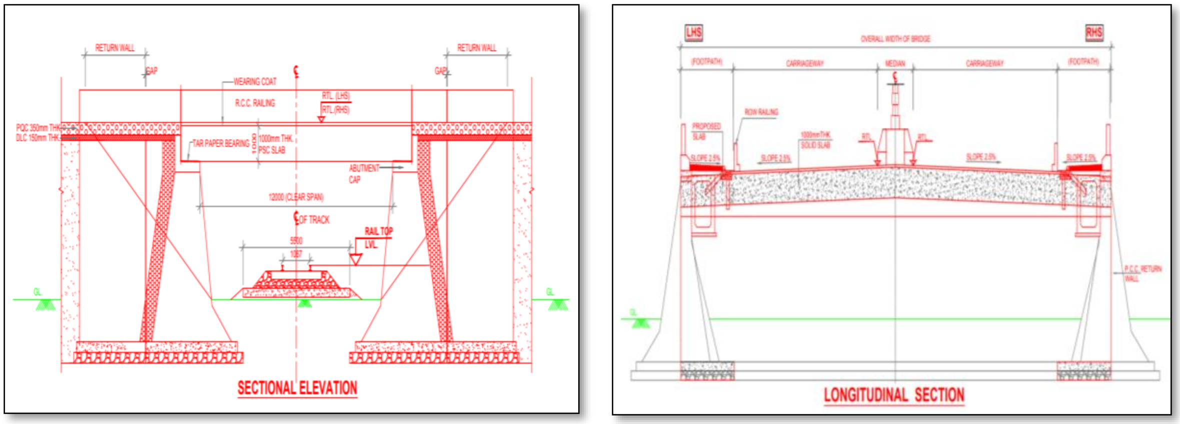


Figure 8-10: Road over Bridge

8.3.6 Eco Crossings

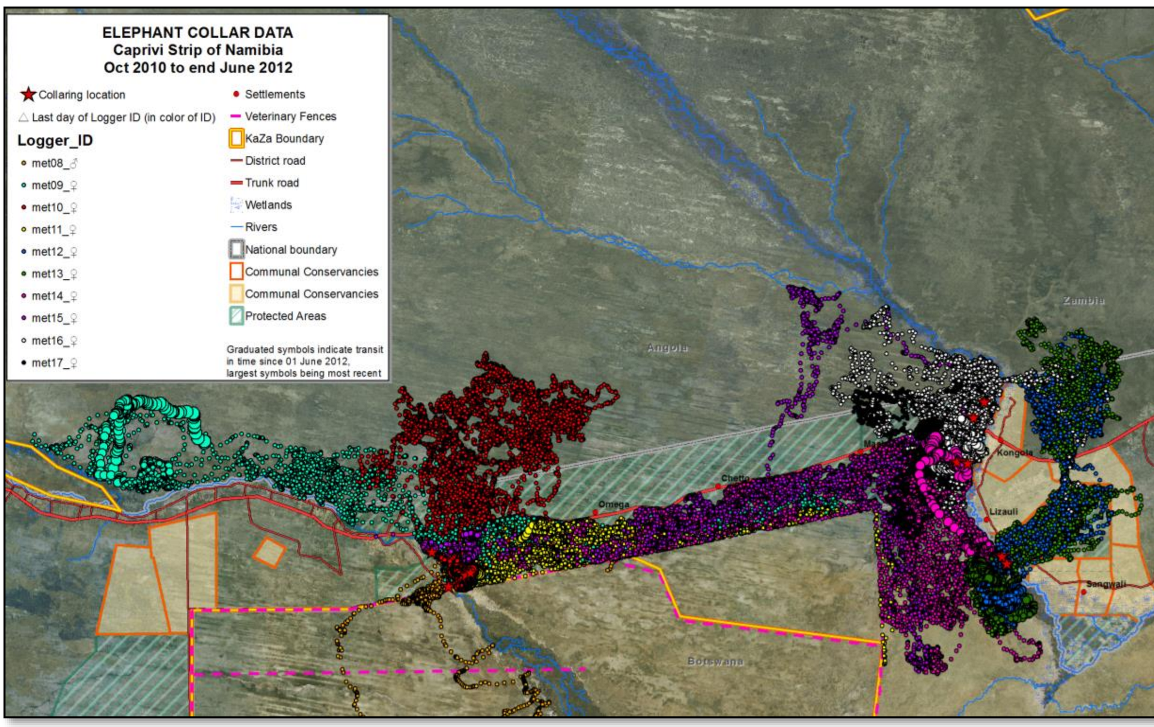
Figure 8-11: Eco Crossing

Eco crossings are structures that allow animals to cross human-made barriers safely. Eco crossings may include underpasses, wildlife tunnels, viaducts, and overpasses or green bridges (mainly for large or herd-type animals), amphibian tunnels, fish ladders, canopy bridges (especially for monkeys and squirrels), tunnels and culverts (for small mammals such as otters, hedgehogs, and badgers); and green roofs (for butterflies and birds).

Wildlife crossings are a practice in habitat conservation, allowing connections or reconnections between habitats, combating habitat fragmentation. They also assist in avoiding collisions between vehicles and animals, which in addition to killing or injuring wildlife may cause injury to humans and property damage.

As per the 'Sear Report- Strategic Environmental Assessment For Development Of Namibia Into A Logistics Hub Along The Walvis Bay-Ndola-Lubumbashi Development Corridor- September 2019', the Figure 8-12 below displays elephant collar data in the East Kavango and Zambezi Regions. Dots of different colours represent 10 individuals. Note the movements of the purple and yellow individuals, which clearly did not move northwards over the main Trans-Zambezi Highway through Bwabwata National Park, even though there is no physical barrier along the road. Their movements along the southern edge of this Park were constrained by the Veterinary Fence. Other individuals show their preference for staying close to the rivers.

Figure 8-12 Elephant collar data in the East Kavango and Zambezi Regions[26]



The final TZR Extension route traverses environmentally sensitive area from Divundu to Kongola where animals, generally Elephants, could cross the existing B8 highway and the proposed TZR railway corridor. To facilitate unhindered movement of elephants, 'Eco Crossings' have been proposed as follows:

Table 8-9 Eco Crossings along the Final Route

#	Chainage (From –To)	#
1	From km 464.000 to 526.000 at every 10 km	7
2	From km 562.000 to 567.000 at every 10 km	1

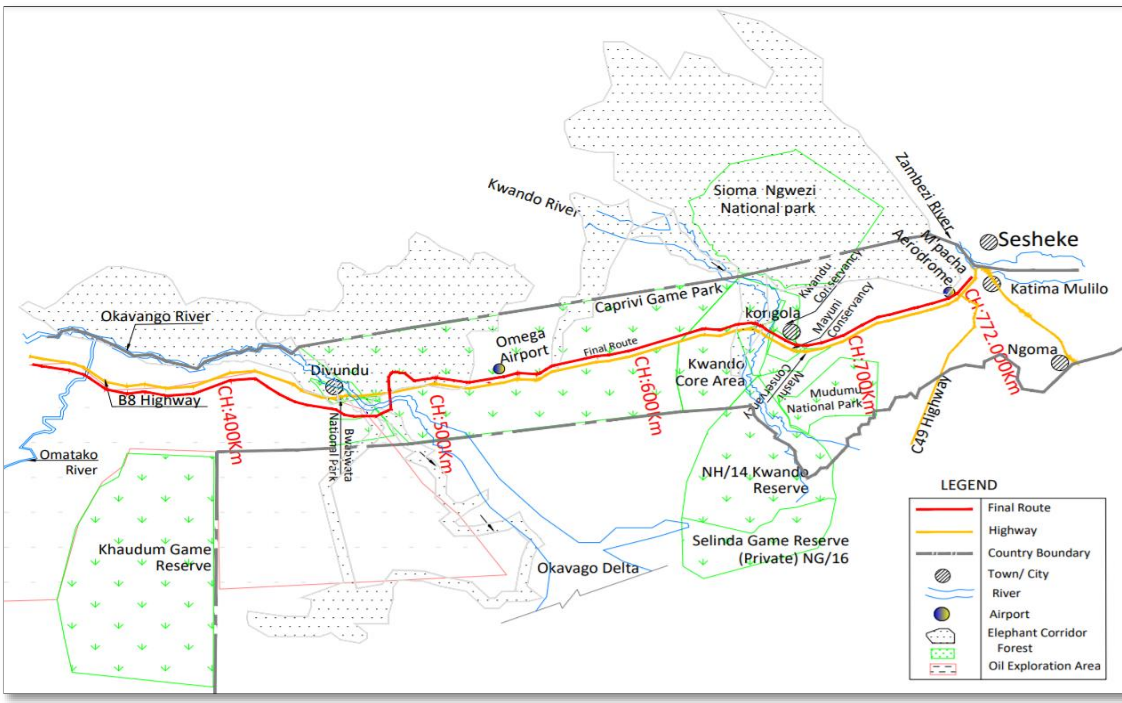
[26] Sea Report- Strategic Environmental Assessment for Development of Namibia into A Logistics Hub Along The Walvis Bay-Ndola-Lubumbashi Development Corridor- September 2019

3	From km 615.000 to 663.000 at every 10 km	5
4	From km 693.000 to 702.000 at every 10 km	1
	Total Eco Crossings (#)	**14**

The rationale of an eco- crossing is to create a continuous natural surface on a bridge type structure to enable wild and domestic animals to safely cross a railway line or road without conflict.

Also, adequate 'Fencing' has been proposed to protect animal transgression on both sides of railway corridor on this stretch.

Figure 8-13 Eco Corridor along the Final Route



9 Stations

9.1 Introduction

A railway stations forms integral part of the railway infrastructure, and it is where traffic is booked and managed and/or where train operations are managed.

9.2 Station Identification

Trans Zambezi Railway (TZR) Extension is being designed primarily as a 'Freight' railway. If it is not a freight/ goods origin-destination point, the purpose of a Railway Station on a freight line is for railway operational management. Based on the anticipated traffic, TZR is going to be a 'Single' line railway on which trains in both the directions will run. For running of multiple bi-directional trains over a long stretch, trains need to 'cross' one another and also 'overtake/ bypass' other trains. Railway stations are the locations where crossings/ bypassing is made possible.

In railway parlance, the section of a railway line between two adjacent stations is called a 'Block Section'. For safety reasons not more than one train can occupy a block section at any point of time. Consequently, no other train can be in the same block section from either side till the time the first train clears a block section. 'Line Capacity' is the maximum number of trains which can potentially run on a railway section over a 24-hour period. Longer a train occupies a block section, lesser the number of trains which can operate in a day thus limiting the line capacity. The other important consideration for line capacity is the 'Operational Speed'. Therefore, the stations on a freight railway need to be spaced out optimally so as to achieve the operational and traffic requirements of a railway line.

Apart from the line capacity consideration, the identification of individual station location also depends on numerous other factors such as topography, nearby city/ town, approachability, access to utilities, safety, etc.

For TZR, for the given design speed, the design endeavour was to identify station locations at a spacing of approximately 25 km or so.

9.3 Station Design Approach

9.3.1 Selection of Site for a Railway Station

The following factors are considered when selecting a site for a railway station:

- **Spacing:** Distance from adjacent station
- **Adequate land:** There should be adequate land available for the station building, not only for the proposed line but also for any future expansion on both sides of the station.
- **Level area with good drainage:** The proposed site should preferably be on a fairly level ground with good drainage arrangements.
- **Alignment:** The station site should preferably have a straight alignment so that various signals are clearly visible. The proximity of the station site to a curve presents several operational problems.

- **Easy accessibility:** The station site should be easily accessible for station staff.
- **Facilities:** The site selected for the station should have sufficient facilities (water and power supply, sewerage) for staff to perform their functions which is mainly booking and managing traffic.
- **Visibility:** The environment around the site selected for a station should be such that them exists clear and improved visibility for the drivers of trains.

9.3.2 Identification of Station Locations on Final Route

The stations' locations on the route were selected based on the following:

- Best able to fulfil operational and commercial purposes
- Generally, on straight and flat terrain
- As close as possible to city centres
- Land availability for present needs and possible future expansion

9.4 Stations On TZR

Following is the comprehensive list of stations proposed on TZR extension (Table 9-1):

Table 9-1: Station Locations on Final Route

#	Name of Proposed Station	From: KM	To: KM	Distance Between Stations(km)	Ruling Gradient between Stations	Gradient at Station
1	Grootfontein	0.000	1.000			1 in 800
				22.000	1 in 170	
2	Berg Aukas	22.000	23.000			1 in 400
				29.200	1 in 170	
3	Crossing Station	51.200	52.200			1 in 400
				21.300	1 in 200	
4	Crossing Station	72.500	73.500			1 in 800
				28.000	1 in 200	
5	Henta	100.500	101.500			1 in 800
				24.500	1 in 200	
6	Mururani	125.000	126.000			1 in 400
				26.000	1 in 300	
7	Crossing Station	151.000	152.000			1 in 400
				26.000	1 in 170	
8	Crossing Station	177.000	178.000			Level
				27.000	1 in 200	
9	Kuseka	204.000	205.000			Level

#	Name of Proposed Station	From: KM	To: KM	Distance Between Stations(km)	Ruling Gradient between Stations	Gradient at Station
				28.000	1 in 300	
10	Nkutu	232.000	233.000			1 in 400
				17.000	1 in 200	
11	Crossing Station	249.000	250.000			1 in 400
				14.000	1 in 200	
12	Rundu	263.000	264.000			1 in 400
				20.000	1 in 200	
13	Kambowo	283.000	284.000			1 in 400
				17.000	1 in 200	
14	Kaiango	300.000	301.000			1 in 800
				28.000	1 in 200	
15	Mabushe	328.000	329.000			1 in 400
				19.000	1 in 200	
16	Nyondo	347.000	348.000			Level
				17.000	1 in 200	
17	Nadiyona	364.000	365.000			1 in 1000
				16.000	1 in 200	
18	Kayaru	380.000	381.000			1 in 600
				21.000	1 in 170	
19	Crossing Station	401.000	402.000			Level
				28.000	1 in 300	
20	Shinyemba	429.000	430.000			1 in 800
				21.000	1 in 200	
21	Kake	450.000	451.000			1 in 800
				17.000	1 in 200	
22	Divundu	467.000	468.000			1 in 1200
				18.000	1 in 170	
23	Crossing Station	485.000	486.000			Level
				17.000	1 in 800	
24	Crossing Station	502.000	503.000			1 in 800
				24.000	1 in 400	
25	Omega	526.000	527.000			1 in 400
				27.000	1 in 200	
26	Crossing Station	553.000	554.000			Level
				26.000	1 in 400	
27	Crossing Station	579.000	580.000			1 in 800
				24.000	1 in 200	
28	Omega III	603.000	604.000			1 in 800

#	Name of Proposed Station	From: KM	To: KM	Distance Between Stations(km)	Ruling Gradient between Stations	Gradient at Station
				29.000	1 in 200	
29	Crossing Station	632.000	633.000			Level
				30.900	1 in 300	
30	Kongola	662.900	663.900			1 in 400
				23.600	1 in 170	
31	Crossing Station	686.500	687.500			Level
				22.500	1 in 1000	
32	Sibbinda	709.000	710.000			Level
				24.000	1 in 300	
33	Sachinga	733.000	734.000			Level
				25.000	1 in 200	
34	Mpacha	758.000	759.000			1 in 400
				13.000	1 in 200	
35	Katima Mulilo	771.000	772.000			Level

9.4.1 Major Stations

Table 9-2 lists the 'major stations' on the final route. Major stations are those that are near cities, towns and villages and which could be later used for freight and passenger bookings.

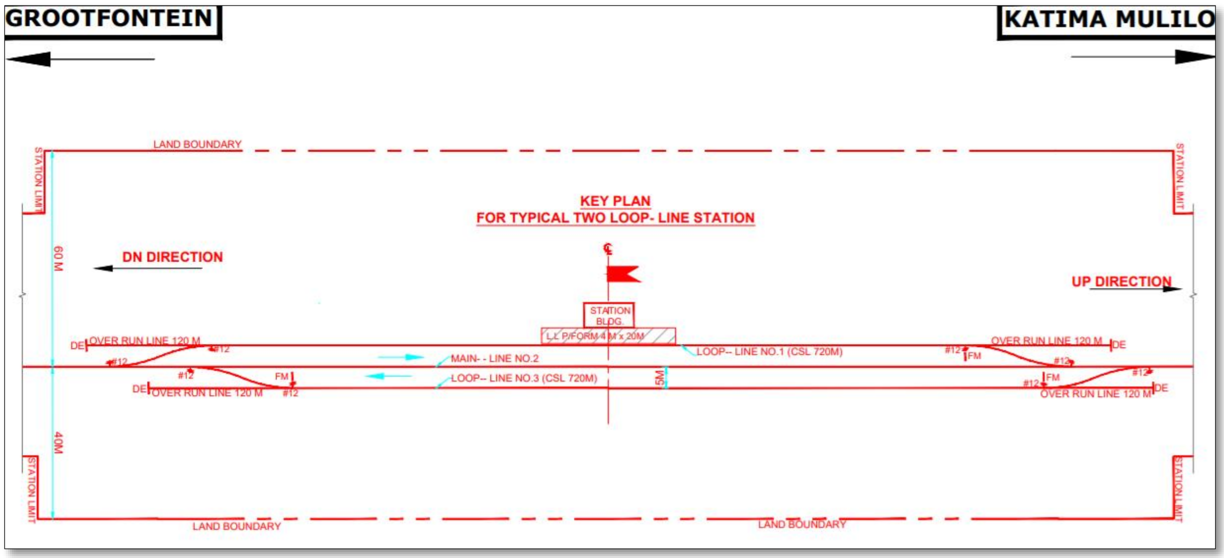
Table 9-2: Distance Between a Major Station and the Closest City, Town or Village

#	Name of Major Station	Approx. Distance from main city center (in km)
1	Grootfontein	2.00
2	Rundu	1.50
3	Divundu	6.50
4	Kongola	2.50
5	Katima Mulilo	4.00

9.5 Typical Station Layouts

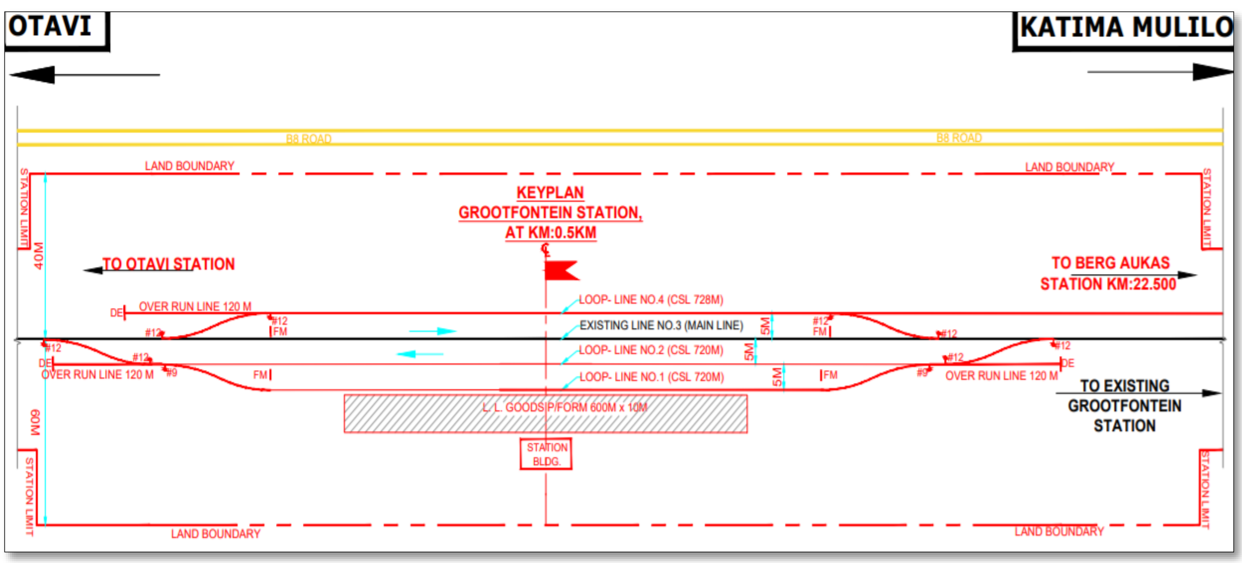
Except for major stations, the typical layout of all other stations shall be as indicated in the figure below:

Figure 9-1: Typical Layout for Other Stations- Two Loop Lines



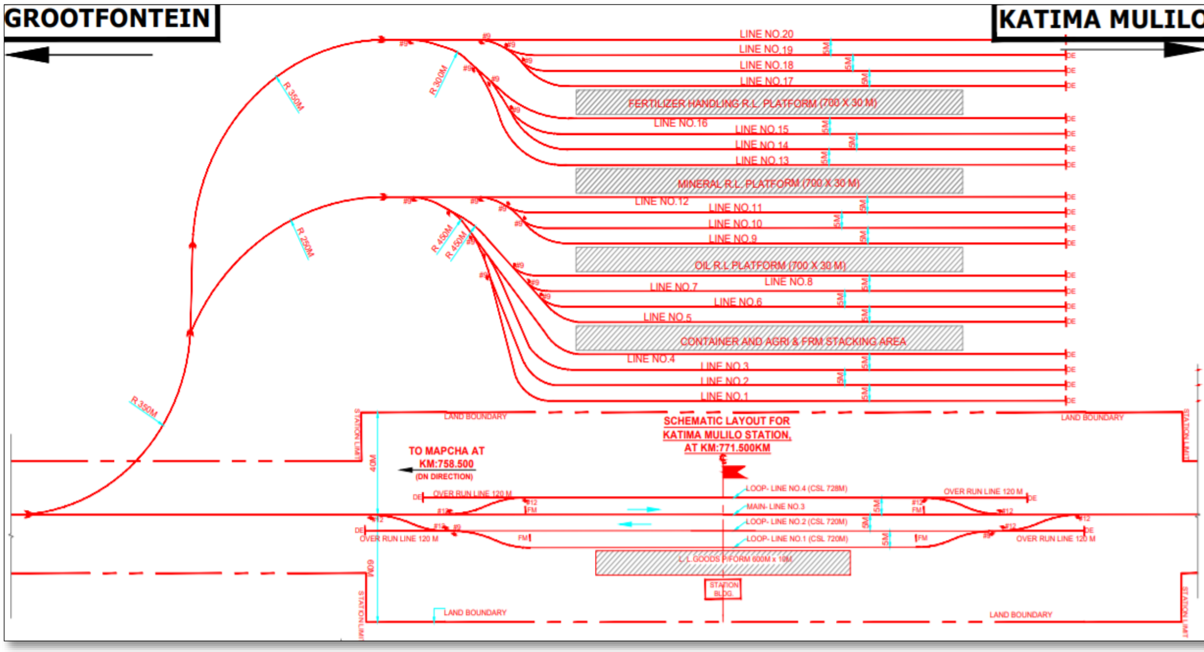
The layout for Grootfontein station is as follows:

Figure 9-2: Layout for Grootfontein Station



Katima Mulilo will be a 'Terminal' station till the time seamless connectivity to Zambian railway is established through a new railway bridge over Zambezi river. As such, the Katima Mulilo station apart from serving the operational objectives would also become a 'temporary' major transhipment hub for all commodities. The detailing will need to be done at the Detailed Design stage, however, the potential layout of Katima Mulilo could be as follows:

Figure 9-3: Potential Layout of Katima Mulilo Station



The Key Plans for all the major stations have been provided in Volume III of this Report.

9.6 Design Guidelines for External Works at Stations

Constructing train stations will include some external civil works such as parking areas, sewer drainage sewer drainage and water reticulation. SANS (South Africa National Standards 1200) is a set of standardized specifications for civil engineering construction and is recommended.

SANS was adopted for use in Namibia following its independence. Considering Namibia's historic relations with South Africa, these standards have been used in Namibia as far back as the 1960s.

SANS 1200 consists of the following documents:

- SANS 1200 A 1986 Section A: General
- SANS 1200 AA 1986 Section AA: General (small works)
- SANS 1200 AB 1986 Section AB: Engineer's office
- SANS 1200 AD 1986 Section AD: General (Small dams)
- SANS 1200 AH 1986 Section AH: General (structural)
- SANS 1200 C 1980 Section C: Site clearance
- SANS 1200 D 1988 Section D: Earthworks
- SANS 1200 DA 1988 Section DA: Earthworks (small works)

- SANS 1200 DB 1989 Section DB: Earthworks (pipe trenches)
- SANS 1200 DE 1984 Section DE: Small earth dams
- SANS 1200 DK 1996 Section DK: Gabions and pitching
- SANS 1200 DM 1981 Section DM: Earthworks (roads, subgrade)
- SANS 1200 DN 1982 Section DN: Earthworks (railway sidings)
- SANS 1200 F 1983 Section F: Piling
- SANS 1200 G 1982 Section G: Concrete (structural)
- SANS 1200 GA 1982 Section GA: Concrete (small works)
- SANS 1200 GB 1984 Section GB: Concrete (ordinary buildings)
- SANS 1200 GE 1984 Section GE: Precast concrete (structural)
- SANS 1200 GF 1984 Section GF: Prestressed concrete
- SANS 1200 H 1990 Section H: Structural steelwork
- SANS 1200 HA 1990 Section HA: Structural steelwork (sundry items)
- SANS 1200 HB 1985 Section HB: Cladding and sheeting
- SANS 1200 HC 1988 Section HC: Corrosion protection of structural steelwork
- SANS 1200 HE 1983 Section HE: Structural aluminium work
- SANS 1200 L 1983 Section L: Medium pressure pipelines
- SANS 1200 LB 1983 Section LB: Bedding (pipes)
- SANS 1200 LC 1981 Section LC: Cable ducts
- SANS 1200 LD 1982 Section LD: Sewers
- SANS 1200 LE 1982 Section LE: Stormwater drainage
- SANS 1200 LF 1983 Section LF: Erf connections (water)
- SANS 1200 LG 1983 Section LG: Pipe jacking
- SANS 1200 M 1996 Section M: Roads (general)
- SANS 1200 ME 1981 Section ME: Subbase
- SANS 1200 MF 1981 Section MF: Base
- SANS 1200 MFL 1996 Section MFL: Base (light pavement structures)
- SANS 1200 MG 1996 Section MG: Bituminous surface treatment
- SANS 1200 MH 1996 Section MH: Asphalt base and surfacing
- SANS 1200 MJ 1984 Section MJ: Segmented paving
- SANS 1200 MK 1983 Section MK: Kerbing and channelling
- SANS 1200 MM 1984 Section MM: Ancillary roadworks
- SANS 1200 NB 1981 Section NB: Railway sidings (trackwork)

In addition, the Concrete Manufacturers Association of South Africa (CMA) publishes leading industry guides and standards in close cooperation with the South African Bureau of Standards. The CMA published five paving manuals covering design aspects, specifications, installation, site management and laying and training. These manuals can be used for further guidance.

9.7 Project Drawings

As part of the 'Feasibility' stage preliminary engineering design work undertaken by the Consultant for the project, following set of drawings have been developed at this Final Report stage which are enclosed as **Volume III** of this Report.

Table 9-3: List of Engineering Drawings

Sr. No.	Drawing Name	Sheet Size	No.
A	**Key Plan (Overall)**	A2	1
B	**Key Plan (Longitudinal Section Profile)**	A2	1
C	**Plan and Longitudinal Section**		
	Plan and Longitudinal Section at every 25 Km interval	A4	31
D	**Typical Cross Sections of filling & cutting for Single Track**	A4	1
E	**Key Plan of Track Layout**		
	Key Plan of Track Layout for Grootfontein Station	A4	1
	Key Plan of Track Layout for Rundu Station	A4	1
	Key Plan of Track Layout for Divundu Station	A4	1
	Key Plan of Track Layout for Kongola Station	A4	1
	Schematic Track Layout for Katima Mulilo Station	A4	1
	Key Plan of Track Layout for Two Loop Line Station	A4	1

10 Signal and Telecommunications

10.1 Introduction

This chapter covers the system for working for Signalling and Telecommunications (S&T). S&T are essential to a railway line as they manage the safe and speedy movement of trains.

10.2 Design Challenge For Railway Signal &Telecom

The following factors have major impact on the design for the signaling and telecommunications systems for a railway:

- → Operations plan and project requirements namely freight traffic forecasts and centralized operations
- → Railway track and alignment: number of stations and level crossings, geographical conditions and topography of the railway corridor
- → Safety of operations of freight trains in line with the forecast traffic mix and telecommunications services considered between railway stations and control center
- → Robustness and durability related to the installation of electronic systems in isolated and non-protected areas in terms of asset security, theft and vandalism
- → Availability of reliable electrical power along the line, operational and maintenance constraints related to the operation of autonomous power supply and air conditioning for electronic systems in isolated areas

10.3 Railway Signalling

The objective of a signaling and train control system is to ensure safe and efficient running of trains while addressing the operational requirements of the railway in terms of line capacity and train speeds.

10.3.1 Signalling Terminology

- **Signalling System:**

Running a safe train operation requires that every train must have authority to occupy the main track before it can begin moving. A signalling system has several interconnected equipment's designed to perform these operations without conflicts.

Figure 10-1: Interlocking

- **Interlocking:**

Is an arrangement of signal apparatuses that prevent conflicting movements through an arrangement of tracks such as junctions or crossings. An interlocking is designed so that it is impossible to give *clear* signals to trains unless the route to be used is proved to be safe.

- **Absolute Block System of train working**

'Absolute block' refers to a system where the track is considered to consist of a series of sections, such that when one train is occupying a section of track (the block section), no other train is allowed to enter that section.

This is the most widely used system for ordinary train routes. A station or signal box controls a block section in one direction (from its rear), and no train may enter that block in that direction without permission from that signal box (the station or signal box is said to accept or receive the train). When a train has been accepted, no other trains can be accepted on that block section until it has left that block section.

The two signal boxes at either end of the block section have to tightly coordinate their actions, especially in the case of block sections that allow bidirectional movement on a single line. The permission to enter the block may be implicit in the aspects of signals governing access to the block.

- **Block instruments:**

Block instruments control the coordinated movement of trains on the block section; the block instruments of the two stations or signal boxes at either end of the block section are electrically interconnected for this purpose.

In areas with track circuits, block working may be accomplished without block instruments by using the information from the track circuit to coordinate the aspects of signals using electric or electronic circuitry. In automatic signalling areas, block working is handled by the track circuits connected to the signalling system such that the movement of the trains controls the signals. Block working can be done with axle counters too.

- **Signals:**

These are provided at approach of the stations to guide the train to follow the instructions through the signal aspects.

- **Point Machines**

Point machines are used for operation of Points to set the route. These are devices for changing the setting of the points depending on the route set. The point machines can be operated remotely**.**

- **Connected communication and power system**

The hardware e.g., signals, point machines, track circuits, axle counters are connected through power and communication cables and related software.

- **Electrically operated interlocking**

Electrically operating interlocking such as Panel interlocking (PI), used in most medium-sized stations in which the points and signals are worked by individual switches that control the or Route Relay interlocking (RRI) used in large and busy stations that have to handle high volumes of train movements. In this, an entire route through the station can be selected and all the associated points and signals along the route can be set at once by a switch for receiving, holding, blocking, or dispatching trains.

10.3.2 Basic Signaling Rules

Regardless of whether the mechanisms are controlled manually or by electronic circuits, and whether they are operated mechanically or electrically, all interlocking schemes usually enforce several or all of the following rules:

- No signal can be pulled off unless corresponding points are set correctly.
- Facing points are locked to the corresponding route when a signal is pulled off.
- Signals for conflicting movements cannot be pulled off simultaneously.
- Points for conflicting routes cannot be set simultaneously.
- Trailing points are locked to the rear when a signal is pulled off.
- Distant, warners, repeaters, etc. cannot be pulled off unless the corresponding stop signals are pulled off.
- Gate stop signals cannot be pulled off unless level-crossing gates are blocked to road traffic.

10.3.3 Electronic Interlocking System (EI)

The signalling system for the entire route would follow the system which suits the local conditions, level of sophistication, system of operation, availability of spares and servicing during operation, failure management, cost, manpower requirement and other aspects. However, whatever the system – it has to be failed safe and must have a very high level of reliability. It should follow the RAMS concept (Reliability, Accessibility, Maintainability and Safety).

The era of interlocking started with mechanical lever frames. As the size of yards and train movements increased, the size of lever frames also increased. These lever frames not only increased in size occupying more space but also required intensive maintenance. With the advent of Electro-mechanical relays, these lever frames gave way to relay interlocking based installations. This development resulted in relatively faster operation, fail safety in operation and reduced size of buildings required for housing of interlocking installations. With further increase in traffic and expansion of railway network, large number of Route Relay Interlocking and Panel Interlocking installations were commissioned.

Route Relay Interlocking (RRI) and Panel Interlocking installations use Electro- mechanical relays requiring complex wiring and Inter-connections. The wiring diagrams for such installations run into hundreds of sheets. Individual relays, wiring and interconnections along with thousands of soldered joints are required to be physically examined and certified. Therefore, the advantages of relay based interlocking installations are being nullified.

With the development of modern fault tolerant and fail safety techniques, electronics and particularly microprocessors have found acceptance in the area of railway Signalling world over. Railways in advanced countries of Europe, North America & Australia have gone for large scale introduction of microprocessor-based EI. This system occupies considerably less space, consumes less power, is more reliable and is easy to install and maintain. Also, initial commissioning and changes due to yard re-modelling can be carried out in negligible time requiring skeleton manpower for traffic management during the blocks.

EI is a computer based electronic interlocking system, used for controlling points, signals, level crossing gates etc., through a centralized control panel or through a visual display unit, like existing relay based/ mechanical interlocking systems. (Microprocessor or Micro controllers are used in EI's.)

EI is the most modern and 'State Of Art' technology in Railway Signalling and is recommended for the TZR considering the traffic potential and the number of trains which are anticipated to run on the route.

EI has several advantages in comparison to PI and RRI as under:

- System can be tested at factory level using simulation panels.
- Modular in design and easy for maintenance, thus requiring less staff.
- Expertise of hardware and software is not much needed for maintaining the equipment at initial stage.
- Requires a smaller number of relays - vital EI replaces interlocking circuits Thus less space required for signal equipment room (Relay rooms).
- Less power supply as compared with existing PI/ RRI's. Less failures, less wiring, less soldering, less complexity in the circuit.
- Enables usage of optical fiber cable (with Object Controller) which reduces requirement of Copper cables, their cost & maintenance.
- Remote operation of signals, points, and level crossings controls is feasible.
- Is compatible with Centralized Traffic Control.
- All EI's are designed and manufactured as per the international safety standards particularly European standards.
- Standard of safety and reliability is higher as compared to Panel Interlocking or Route Relay Interlocking systems.

- Datalogger / Event logger is an integral part of EI.
- Has Self-diagnostic in feature - easy for rectification of failures and reduces failure duration.

EI are solid state, where the wired networks of relays are replaced by software logic running on special-purpose control hardware. The fact that the logic is implemented by software rather than hard-wired circuitry greatly facilitates the ability to make modifications when needed by reprogramming rather than rewiring. In many implementations this vital logic is stored as firmware that cannot be easily altered to both resist unsafe modification and meet regulatory safety testing requirements.

All over the world, for over 20 years, computer-based interlocking is used to renew old station equipment or for new stations. All the big signalling companies produce and install computer-based interlocking. **Computer interlocking does not follow common specifications, so every vendor uses a proprietary design** which, in general, has different modularity from other vendors.

When interlocking should be used for small stations, some signalling companies propose a centralised interlocking system controlling all gears in the yard. In such cases, multi core signalling cable is required to be laid throughout the yard.

Bigger yards are operated with distributed architecture. In this case, small EI systems are installed at each signalling location comprising of one or two points track circuits and connected signals. This distributed EI system is known as Object Controller (OC).

These OCs are connected to the central Interlocking system through fibre optic cable. Costly signalling copper cables are required only from OC to equipment such as points, signals, track and level crossings. This avoids costly signalling cable throughout the yard. All the stations of a section can further be connected using the backbone communication network. This system is more economical than having single equipment, requires fewer staff and has the advantage of giving the performance of fail-safe Centralised Traffic Control.

10.3.4 Point Operation

The Turnouts proposed to be used on Trans-Zambezi will comprise of 'Secant' design on concrete sleepers with elastic fastenings and fully curved flexible point blade manufactured from 51 kg/m rail (switch blades fit undercut to the stock rail). Rest of the rails in the turnouts would be of 48 kg/m rail of grade R350 LHT (head hardened). The crossing assembly would be made up of 'Rail-bound Frog' with a manganese casting insert. Entire Turnout would be welded with Exothermic welding. The turnout will also have features of motor operated points. The point operation will be through suitably designed electric point machine having clamp lock type of full compliment. A clamp lock that clamps together the closed switch against the stock rail achieves the locking of the switch. For the working of clamp lock, the throw bar of points machine is provided with a stroke for opening and closing of the switch tightly for locking of closed switch. The signalling system is designed in such a way that route once set provides for the closing and locking of the points for the selected route for safe movement of the train being received or despatched through motor operated points which gets movement signals through the set of relays.

10.3.5 Track Vacancy Detection

For the purpose of track vacancy detection, two systems are used: **Track Circuits or Axle Counting.**

Generally, track circuits are based on a phase relay working at 50 Hz or 25 Hz For Trans Zambezi, where electrical traction is not projected, both types of relays (European type at 50 Hz or Asian working at 25 Hz) can be used though would require a dedicated power source.

Digital axle counter field unit / counting device is the track side electronic assembly that energise the axle detectors for detecting the passing wheels determining the direction of movement and keeping the counting of wheels. It transmits the count and health information to the central evaluator at regular intervals. Based on the information detected, central evaluator determines status of track section whether clear or occupied.

Recently, different European signalling companies have designed an Axle Counting System which has a centralised equipment module that can control all the track section of the stations known as Multi section Digital Axle Counter. Block working with the adjacent stations can also be controlled through Block Proving Axle Counter.

This new way of detecting vacancy of the track has the advantage of being immune to electrical interference, it does not require insulated joints on the rail and guarantees detection of the track circuits (secondary in the station), which could be rusty due to lack of use, and not guarantee detection from track relays. The multi section digital axle counter can be widely deployed for simultaneous monitoring of following track section in a station or yard area.

10.4 Railway Telecommunications System

The objectives of a telecommunications system consist in providing the necessary means to ensure efficient, reliable and continuous operations of the railway both through voice communications and data exchanges.

In order to ensure this, the telecommunication system must provide the following basic functions:

- Voice communication between the railway control center and trains.
- Voice communication between stations and between the railway control center and stations.
- Data transmission between railway signalling facilities installed along the line and the railway control center.

The following technologies could be considered to design the telecommunication for the railway:

- Fiber optic backbone or microwave links connecting different railway locations (stations and bungalows) and the railway control center.

- Transmission network equipment, such as Synchronous Digital Hierarchy (SDH) or IP/Ethernet to backhaul voice and data communications between these railway locations.
- Fixed telephony at stations and at specific locations such as signals and switches.
- Radio communications such as Very High Frequency (VHF) or cellular for track-to-train voice communications.

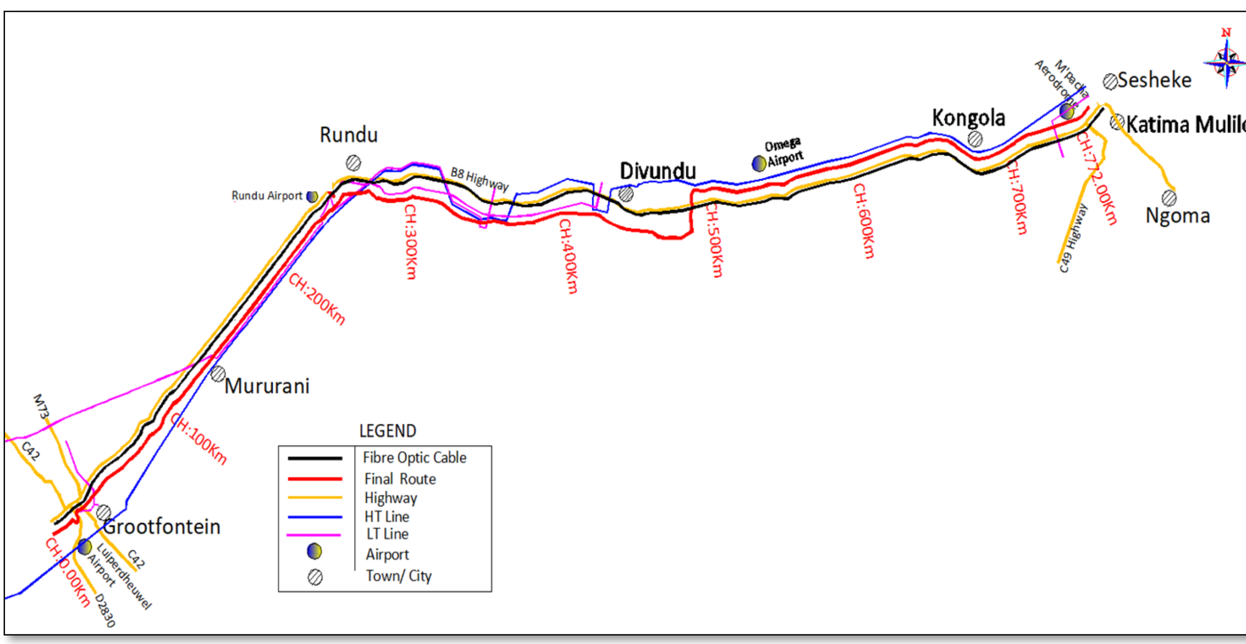
Of course, communication cannot only be by radio but also an efficient network using fibre optics.

A railway network operation must rely on an efficient and complete range of information: voice, data services, Integrated Services Digital Network (ISDN)services, video, and signalling safe data. All stations along the TZR must be connected with a central dispatcher and between stations, signal data and block information should be exchanged in an efficient and reliable system.

The communication method used in optic fibre is Pulse code modulation which uses regeneration instead of amplification. In the case of amplification, signals as well as noises are amplified. But in case of regeneration, at each repeating stations the noise is completely eliminated, and useful date is regenerated.

In conclusion, Trans-Zambezi Railway extension must utilise the optical cable of Telecom Namibia on the stretches were its optical cable runs close to the Railway alignment and install long distance communication network laying optical cables along the railway line on other stretches. (*Refer to Figure 10-2).*

Figure 10-2: Fibre Optic Cable of Telecom Namibia along the Final Route



For establishing voice communication between various work site and level crossing gates, a separate quad cable is recommended to be laid along the track to avoid installation of Synchronous Transport Module (STM) at mid-section point where reliable source of electric power and service buildings to house STM cannot be ensured. This quad can be used for block working axle counters and different safety gadgets like hot axle detectors, flood detectors etc.

The media used for transmitting and receiving signalling and communication data are required to be fail safe and failure free. The optic fibre cable is susceptible for breakage during excavation work. To prevent the failure due to breakage the latest tread is to lay two cables one on each side of the track. In case one cable is cut, the data communication will not be affected.

11 Railway Operations

11.1 Introduction

The 'Operations' of Railway system are governed by:

- National Laws.
- General Rules for Railway operation /Standard Code of Operating Rules / General Code of Operating Rules.
- Subsidiary Rules for Operations.
- Station Working Rules; and
- Asset Maintenance requirements for safe operations

The above documents lay the legal and executive authority for operations of a railway network/system. Rules and regulations are laid down to ensure safety of railway operations. Railway infrastructure and rolling stock must satisfy the requirements of public safety in terms of their construction, at the time of commissioning and in terms of their operation.

The train operations in the Trans-Zambezi Railway Extension have been planned with an overall objective of movement of trains from Katima Mulilo to Walvis Bay and for trains which will run through, regionally, once the railway connectivity is established between Zambia and Namibia.

In this section of the Report, three scenarios have been examined with respect to traffic projections, assessment of number of train movements and assessment of number of rolling stock required for the Trans- Zambezi Railway.

The operational details, phase wise train numbers, rolling stock requirement, railway maintenance and other related train operational issues of the Trans -Zambezi Railway extension for each scenario have also been examined in detail.

11.2 Railway Operations -General

The railway operations and train movements across any railway network depends on large number of factors. Important ones are as under:

Traffic Demand

- Freight (and Passenger) Traffic

Rolling Stock

- Capacity
- Configuration

Railway Infrastructure

- Railway Civil infrastructure
- Infrastructure Design Parameters
- Single Line and/or Double line sections

- Station Details- Chainages, Distance between Stations
- Gradients and Curvatures
- Yard layout and Design
- Signal and Telecom System

Railway Maintenance

- Rolling Stock Maintenance Facilities and Locations
- Track and Signal Maintenance
- Terminal Maintenance Facilities

Train Operations

- Train service design for passenger operation
- Train service design for freight operation
- Train timetabling (where applicable)
- Freight train operation
- Rolling stock management

For the Trans-Zambezi Railway extension only Freight movement has been considered at this stage.

11.3 Traffic Demand and Forecast

The traffic demand and forecast has been covered in detail in **'Travel Demand Model Report – Vol II.** (Transport Volume Estimation) prepared by the Consultant as part of the '*Feasibility Study for the Trans-Zambezi Railway Extension Grootfontein – Rundu – Katima Mulilo* this study'. This report describes, in detail, freight traffic assessment for the Trans-Zambezi Railway line. The study considered 13 scenarios for assessment of traffic.

The table and figure that follow summarize the scenarios that were carried forward.

Table 11-1: Scenario Descriptions used for Railway Operation Study

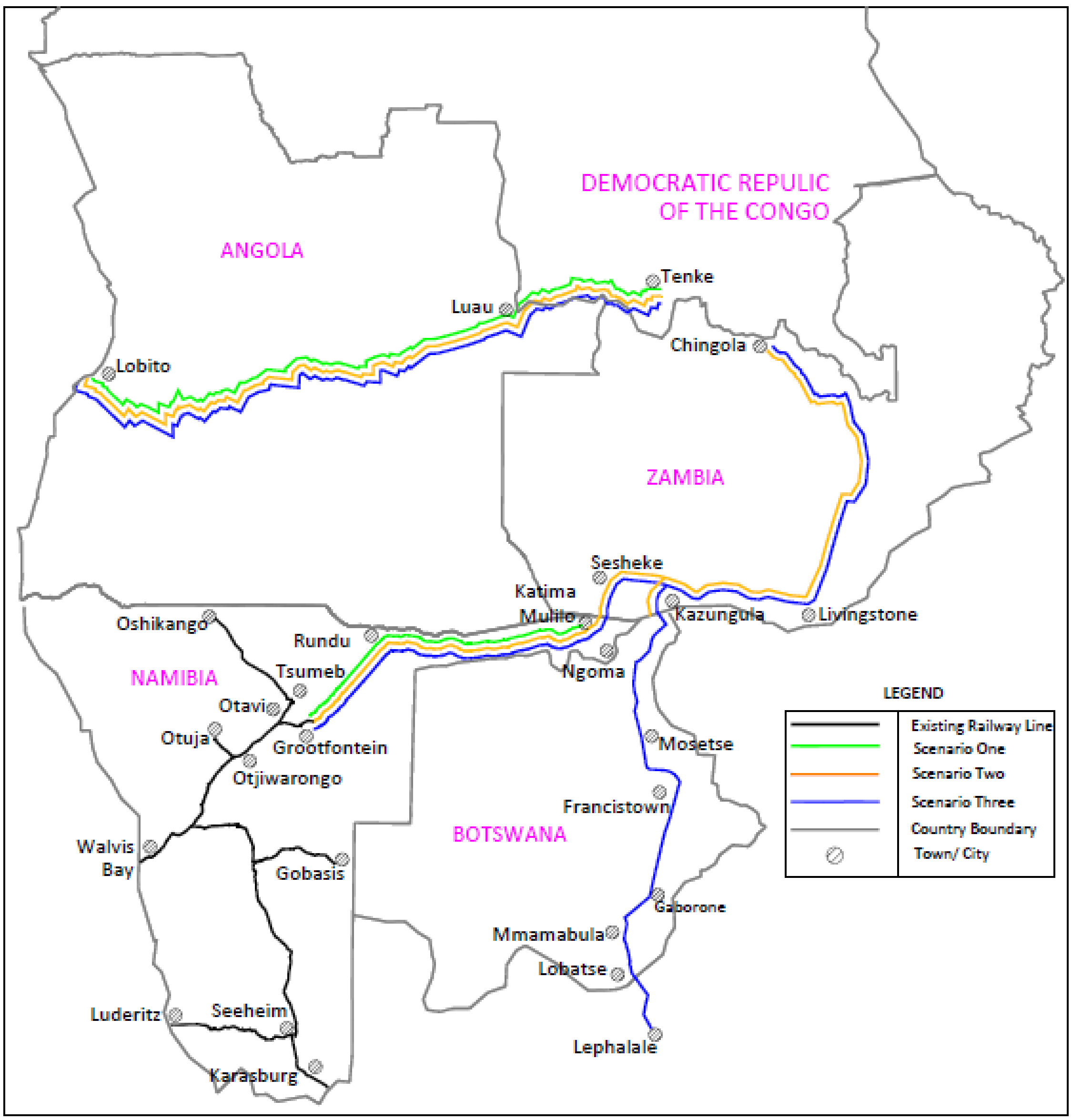
Updated Scenario #	Trans-Zambezi Rail is built	Benguela Line (including extension from Luau to Dilolo/Tenke) is successfully tendered	Zambia's existing network from Livingstone to Chingola is rehabilitated	Zambia East/West line from Sesheke to Livingstone via Kazungula is built	Botswana North/South Line (Kazungula to Lephalale) is built
Primary Funding Responsibility	Namibia	Angola	Zambia	Zambia	Botswana
1	Included	Included	Not Included	Not Included	Not Included
2	Included	Included	Included	Included	Not Included

TECHNOFIN CONSULTANTS

Updated Scenario #	Trans-Zambezi Rail is built	Benguela Line (including extension from Luau to Dilolo/Tenke) is successfully tendered	Zambia's existing network from Livingstone to Chingola is rehabilitated	Zambia East/West line from Sesheke to Livingstone via Kazungula is built	Botswana North/South Line (Kazungula to Lephalale) is built
3	Included	Included	Included	Included	Included

These are indicated through the map as under:

Figure 11-1: All Scenario Map for Railway Operation Study



TECHNOFIN CONSULTANTS

1. **Scenario 1 -** Grootfontein to Katima Mulilo
2. **Scenario 2 -** Grootfontein, Katima Mulilo, Sesheke, Kazungula, Livingstone, Chingola (*note that Livingstone to Chingola section is Zambia's existing rail network)*
3. **Scenario 3 -** Grootfontein, Katima Mulilo, Sesheke, Kazungula, Livingstone, Chingola AND Kazungula, Mosetse, Francistown, Gaborone, Mmamabula, Lobatse, Lephalale *(note that Francistown to Lobatse is Botswana's existing network)*

11.4 Traffic Projections

11.4.1 Traffic Projections – Tonnage:

Year wise projected freight traffic from the year 2027 to the year 2069 for the above three scenarios are summarised as under:

1. **Scenario -1**

Table 11-2: Projected traffic between Grootfontein and Katima Mulilo (in tonnes per Year)

#	Year	From Grootfontein to Katima Mulilo (tonnes per year)	From Katima Mulilo to Grootfontein (tonns per year)
1	2027	680,316	714,771
2	2031	2,617,763	2,664,835
3	2041	3,875,164	3,672,685
4	2051	5,751,690	5,032,397
5	2061	8,588,683	6,784,596
6	2066	10,543,123	7,925,757
7	2069	11,939,011	8,715,939

Table 11-3: Projected traffic for Rundu and Divundu (in tonnes per Year)

#	Year	From Grootfontein to Rundu (tonnes per year)	From Divundu to Grootfontein (tonnes per year)
1	2027	8	1,360
2	2031	32	4,971
3	2041	47	6,271
4	2051	70	7,921
5	2061	103	10,033
6	2066	126	11,389
7	2069	141	12,323

2. Scenario – 2

Table 11-4: Projected traffic between Grootfontein and Katima Mulilo (in tonnes per Year)

#	Year	From Grootfontein to Katima Mulilo (tonnes per year)	From Katima Mulilo to Grootfontein (tonnes per year)
1	2027	1,475,231	1,264,559
2	2031	5,686,409	4,757,788
3	2041	8,475,296	6,741,155
4	2051	12,668,279	9,441,079
5	2061	19,044,518	12,937,134
6	2066	23,446,332	15,226,769
7	2069	26,593,289	16,816,490

Table 11-5: Projected traffic for Rundu and Divundu (In tonnes per Year)

#	Year	From Grootfontein to Rundu (tonnes per year)	From Divundu to Grootfontein (tonnes per year)
1	2027	8	1,360
2	2031	32	4,971
3	2041	47	6,271
4	2051	70	7,921
5	2061	103	10,033
6	2066	126	11,389
7	2069	141	12,323

3. Scenario – 3

Table 11-6: Projected traffic between Grootfontein and Katima Mulilo (in tonnes per Year)

#	year	From Grootfontein to Katima Mulilo (tonnes per year)	From Katima Mulilo to Grootfontein (tonnes per year)
1	2027	1,270,684	1,179,831
2	2031	4,895,575	4,417,265
3	2041	7,285,459	6,172,471
4	2051	10,873,496	8,552,491
5	2061	16,323,150	11,628,199
6	2066	20,083,165	13,636,389
7	2069	22,770,502	15,028,594

Table 11-7: Projected traffic for Rundu and Divundu (in tonnes per Year)

#	year	From Grootfontein to Rundu (tonnes per year)	From Divundu to Grootfontein (tonnes per year)
1	2027	8	1,360

#	year	From Grootfontein to Rundu (tonnes per year)	From Divundu to Grootfontein (tonnes per year)
2	2031	32	4,971
3	2041	47	6,271
4	2051	70	7,921
5	2061	103	10,033
6	2066	126	11,389
7	2069	141	12,323

11.4.2 Traffic Projections – Wagon Wise:

The potential traffic in terms of weight (tonnes per annum) when converted to equivalent railway wagon loads indicates the traffic volume as follows[27]:

1. Scenario- 1

Table 11-8: Scenario 1 – Traffic Projections-Wagon Wise

#	Year	From	To	Open Wagons	Covered Wagons	Flat Wagons	Tank Wagons
1	2027	Grootfontein	Katima Mulilo	133,238	131,774	337,242	78,062
	2027	Katima Mulilo	Grootfontein	167,230	172,787	341,826	32,929
	2027	Grootfontein	Rundu	0	0	28	0
	2027	Divundu	Grootfontein	0	0	4,534	0
2	2031	Grootfontein	Katima Mulilo	613,181	611,541	1,120,031	273,010
	2031	Katima Mulilo	Grootfontein	1,028,511	472,195	1,033,992	130,136
	2031	Grootfontein	Rundu	0	0	32	0
	2031	Divundu	Grootfontein	0	0	4,971	0
3	2041	Grootfontein	Katima Mulilo	912,543	910,307	1,649,482	402,831
	2041	Katima Mulilo	Grootfontein	1,430,486	645,266	1,417,343	179,590
	2041	Grootfontein	Rundu	0	0	47	0
	2041	Divundu	Grootfontein	0	0	6,271	0
4	2051	Grootfontein	Katima Mulilo	1,362,134	1,359,122	2,434,629	595,804
	2051	Katima Mulilo	Grootfontein	1,975,016	877,818	1,933,213	246,351
	2051	Grootfontein	Rundu	0	0	70	0
	2051	Divundu	Grootfontein	0	0	7,921	0
5	2061	Grootfontein	Katima Mulilo	2,045,342	2,041,295	3,615,453	886,594
	2061	Katima Mulilo	Grootfontein	2,678,662	1,176,675	2,596,842	332,417
	2061	Grootfontein	Rundu	0	0	103	0
	2061	Divundu	Grootfontein	0	0	10,033	0
6	2066	Grootfontein	Katima Mulilo	2,517,019	2,512,299	4,427,157	1,086,648

[27] Wagon details are in the sections that follow in this Report

#	Year	From	To	Open Wagons	Covered Wagons	Flat Wagons	Tank Wagons
	2066	Katima Mulilo	Grootfontein	3,137,339	1,371,139	3,028,803	388,477
	2066	Grootfontein	Rundu	0	0	126	0
	2066	Divundu	Grootfontein	0	0	11,389	0
7	2069	Grootfontein	Katima Mulilo	2,854,253	2,849,066	5,006,258	1,229,433
	2069	Katima Mulilo	Grootfontein	3,455,060	1,505,743	3,327,839	427,297
	2069	Grootfontein	Rundu	0	0	141	0
	2069	Divundu	Grootfontein	0	0	12,323	0

2. Scenario- 2

Table 11-9: Scenario 2 – Traffic projections-Wagon Wise

#	Year	From	To	Open Wagons	Covered Wagons	Flat Wagons	Tank Wagons
1	2027	Grootfontein	Katima Mulilo	331,967	330,503	655,208	157,554
	2027	Katima Mulilo	Grootfontein	414,634	255,255	534,252	60,418
	2027	Grootfontein	Rundu	0	0	28	0
	2027	Divundu	Grootfontein	0	0	4,534	0
2	2031	Grootfontein	Katima Mulilo	1,380,342	1,378,702	2,347,489	579,875
	2031	Katima Mulilo	Grootfontein	1,970,340	786,138	1,766,526	234,784
	2031	Grootfontein	Rundu	0	0	32	0
	2031	Divundu	Grootfontein	0	0	4,971	0
3	2041	Grootfontein	Katima Mulilo	2,062,576	2,060,340	3,489,535	862,844
	2041	Katima Mulilo	Grootfontein	2,811,298	1,105,536	2,491,307	333,014
	2041	Grootfontein	Rundu	0	0	47	0
	2041	Divundu	Grootfontein	0	0	6,271	0
4	2051	Grootfontein	Katima Mulilo	3,091,282	3,088,269	5,201,265	1,287,463
	2051	Katima Mulilo	Grootfontein	3,958,923	1,539,120	3,476,251	466,785
	2051	Grootfontein	Rundu	0	0	70	0
	2051	Divundu	Grootfontein	0	0	7,921	0
5	2061	Grootfontein	Katima Mulilo	4,659,301	4,655,253	7,797,787	1,932,177
	2061	Katima Mulilo	Grootfontein	5,447,304	2,099,556	4,750,230	640,044
	2061	Grootfontein	Rundu	0	0	103	0
	2061	Divundu	Grootfontein	0	0	10,033	0
6	2066	Grootfontein	Katima Mulilo	5,742,821	5,738,101	9,588,441	2,376,969
	2066	Katima Mulilo	Grootfontein	6,422,794	2,466,290	5,584,157	753,527
	2066	Grootfontein	Rundu	0	0	126	0
	2066	Divundu	Grootfontein	0	0	11,389	0
7	2069	Grootfontein	Katima Mulilo	6,517,823	6,512,636	10,867,970	2,694,860
	2069	Katima Mulilo	Grootfontein	7,100,308	2,720,826	6,163,032	832,324
	2069	Grootfontein	Rundu	0	0	141	0
	2069	Divundu	Grootfontein	0	0	12,323	0

3. Scenario- 3

Table 11-10: Scenario 3 – Traffic projections-Wagon Wise

#	Year	From	To	Open Wagons	Covered Wagons	Flat Wagons	Tank Wagons
1	2027	Grootfontein	Katima Mulilo	280,830	279,366	573,389	137,099
	2027	Katima Mulilo	Grootfontein	376,507	242,545	504,597	56,182
	2027	Grootfontein	Rundu	0	0	28	0
	2027	Divundu	Grootfontein	0	0	4,534	0
2	2031	Grootfontein	Katima Mulilo	1,182,634	1,180,994	2,031,156	500,791
	2031	Katima Mulilo	Grootfontein	1,817,105	735,060	1,647,343	217,758
	2031	Grootfontein	Rundu	0	0	32	0
	2031	Divundu	Grootfontein	0	0	4,971	0
3	2041	Grootfontein	Katima Mulilo	1,765,117	1,762,881	3,013,600	743,861
	2041	Katima Mulilo	Grootfontein	2,555,390	1,020,234	2,292,268	304,580
	2041	Grootfontein	Rundu	0	0	47	0
	2041	Divundu	Grootfontein	0	0	6,271	0
4	2051	Grootfontein	Katima Mulilo	2,642,586	2,639,574	4,483,352	1,107,985
	2051	Katima Mulilo	Grootfontein	3,559,058	1,405,832	3,165,246	422,355
	2051	Grootfontein	Rundu	0	0	70	0
	2051	Divundu	Grootfontein	0	0	7,921	0
5	2061	Grootfontein	Katima Mulilo	3,978,959	3,974,911	6,709,240	1,660,040
	2061	Katima Mulilo	Grootfontein	4,858,283	1,903,216	4,292,103	574,597
	2061	Grootfontein	Rundu	0	0	103	0
	2061	Divundu	Grootfontein	0	0	10,033	0
6	2066	Grootfontein	Katima Mulilo	4,902,030	4,897,309	8,243,174	2,040,652
	2066	Katima Mulilo	Grootfontein	5,707,123	2,227,733	5,027,524	674,008
	2066	Grootfontein	Rundu	0	0	126	0
	2066	Divundu	Grootfontein	0	0	11,389	0
7	2069	Grootfontein	Katima Mulilo	5,562,126	5,556,939	9,338,855	2,312,582
	2069	Katima Mulilo	Grootfontein	6,295,755	2,452,641	5,537,268	742,929
	2069	Grootfontein	Rundu	0	0	141	0
	2069	Divundu	Grootfontein	0	0	12,323	0

11.5 Rolling stock features

The summary of Rolling Stock features for Trans-Zambezi Railway is as follows:

11.5.1 Wagons Features

There is requirement of four types of wagons to transport the potential freight traffic. The basic features of proposed wagons which can give optimised output are as under:

Table 11-11: Basic Wagon features

#	Type of wagons	A/L(t)	Tare weight(t)	Pay load(t)	Gross load	Pay to tare ratio	Wagon length over coupler(m)	Commodities which can be loaded
1	Open	18.5	20	54	74	2.7	10.89	Iron ore, Minerals
2	Covered	18.5	23	51	74	2.22	14.45	Bagged commodities like food grains, fertilizers, cement etc.
3	Flat	18.5	19	55	74	2.89	13.16	ISO containers
4	Tank	18.5	25	49	74	1.96	12.42	Petroleum products

Other features of wagons:

a. Bogie type wagons
b. Structural steel welded construction
c. Three piece all coil spring, cast steel bogie
d. Cartridge tapered roller bearings
e. Graduated/ direct release air brake system as prevalent in system,
f. Composition brake block
g. Brake linkage with slack adjuster
h. Coupler assembly will be as per the railway system requirement. Its working capacity should be commensurate for 50 wagon composition.
i. Suspension and damping suitable to maximum speed of 80 kmph in loaded/empty condition.

11.5.2 Locomotive Features

Presently Namibian railway system is using 2000 HP diesel locomotive. It is further understood that TransNamib is in a process of acquiring 2250 horsepower diesel locomotive on lease. For working of Trans Zambezi railway system, there can be following options.

1. To continue with 2 X 2250 horsepower diesel locomotive. It is best option in initial stage as connecting railway systems (Grootfontein- Walvis Bay and Zambian Railway) might not be able to upgrade to 18.5 t axle load uniformly. If required in future, 3 X 2250 horsepower diesel locomotive can be used to meet requirement of running time and line capacity.
2. If connecting railway permit use of 4000 HP diesel locomotive on their system from initial stage, this type of locomotive will be a better option. The advantages are:

a. Lower running time, higher utilisation and higher train handling per day

TECHNOFIN CONSULTANTS

b. For smaller loads one 4000 HP Loco can be used as single loco. For higher load of 50 wagons of 18.5t axle load only two locomotives can work the train even in 1 in 66 gradient of connecting railway system.

c. It will provide better fuel efficiency, hence economical.

11.6 Freight Train Configuration

The trains on the Trans Zambezi railway network can potentially have following different configurations:

1. 40 wagon train with 2 X 2250 HP locomotive plus one brake/guard van
2. 40 wagon train with 2 X 4000 HP locomotive plus one brake/guard van

The Brake / Guard Vans can be avoided by using end of train telemetry, if railway working rules permit. To increase the average operating speed and line capacity multiple locomotives (up to three) can also be used.

11.7 Infrastructure for Operations

11.7.1 Ruling Gradient for TZR

The 'Ruling Gradient' has been covered in detail under Para 4.5.2.1 of this report. A ruling gradient of 1 in 170 has been adopted for the entire section from Grootfontein to Katima Mulilo.

Following is the Chainage wise length of steepest gradient i.e., 1 in 170:

Table 11-12: Chainage wise length of steepest gradient

#	Chainage (km)		Gradient (1 in 170)		Distance (km)
	From	To	Rise	Fall	
1	1.500	2.500	170		1.00
2	3.900	6.500		170	2.60
3	9.700	22.000		170	12.30
4	23.200	38.000		170	14.80
5	39.100	44.500		170	5.40
6	152.300	154.300		170	2.00
7	381.100	382.000		170	9.00
8	474.600	476.600	170		2.00
9	663.900	667.100	170		3.20
			Total Length (in km)		**44.20**

The total length of steepest grade (Ruling Gradient) i.e., 1 in 170 is only around 44.20 Km i.e., about 5.7 % of the total route length.

11.7.2 Stations

The table below gives the station locations with chainages, distance between stations, ruling gradient of block sections, gradient in station yard. It will be observed that all block sections have gradient not steeper than 1 in 170. The entire length of TZR has been provided with 35 stations.

Table 11-13: TZR Station Details and Distances between stations

#	Name of Proposed Station	From: KM	To: KM	Distance Between Stations (km)	Ruling Gradient between Stations	Gradient at Station
1	Grootfontein	0.000	1.000			1 in 800
				22.000	1 in 170	
2	Berg Aukas	22.000	23.000			1 in 400
				29.200	1 in 170	
3	Crossing Station	51.200	52.200			1 in 400
				21.300	1 in 200	
4	Crossing Station	72.500	73.500			1 in 800
				28.000	1 in 200	
5	Henta	100.500	101.500			1 in 800
				24.500	1 in 200	
6	Mururani	125.000	126.000			1 in 400
				26.000	1 in 300	
7	Crossing Station	151.000	152.000			1 in 400
				26.000	1 in 170	
8	Crossing Station	177.000	178.000			Level
				27.000	1 in 200	
9	Kuseka	204.000	205.000			Level
				28.000	1 in 300	
10	Nkutu	232.000	233.000			1 in 400
				17.000	1 in 200	
11	Crossing Station	249.000	250.000			1 in 400
				14.000	1 in 200	
12	Rundu	263.000	264.000			1 in 400
				20.000	1 in 200	
13	Kambowo	283.000	284.000			1 in 400
				17.000	1 in 200	
14	Kaiango	300.000	301.000			1 in 800
				28.000	1 in 200	
15	Mabushe	328.000	329.000			1 in 400
				19.000	1 in 200	
16	Nyondo	347.000	348.000			Level
				17.000	1 in 200	
17	Nadiyona	364.000	365.000			1 in 1000
				16.000	1 in 200	

#	Name of Proposed Station	From: KM	To: KM	Distance Between Stations (km)	Ruling Gradient between Stations	Gradient at Station
18	Kayaru	380.000	381.000			1 in 600
				21.000	1 in 170	
19	Crossing Station	401.000	402.000			Level
				28.000	1 in 300	
20	Shinyemba	429.000	430.000			1 in 800
				21.000	1 in 200	
21	Kake	450.000	451.000			1 in 800
				17.000	1 in 200	
22	Divundu	467.000	468.000			1 in 1200
				18.000	1 in 170	
23	Crossing Station	485.000	486.000			Level
				17.000	1 in 800	
24	Crossing Station	502.000	503.000			1 in 800
				24.000	1 in 400	
25	Omega	526.000	527.000			1 in 400
				27.000	1 in 200	
26	Crossing Station	553.000	554.000			Level
				26.000	1 in 400	
27	Crossing Station	579.000	580.000			1 in 800
				24.000	1 in 200	
28	Omega III	603.000	604.000			1 in 800
				29.000	1 in 200	
29	Crossing Station	632.000	633.000			Level
				30.900	1 in 300	
30	Kongola	662.900	663.900			1 in 400
				23.600	1 in 170	
31	Crossing Station	686.500	687.500			Level
				22.500	1 in 1000	
32	Sibbinda	709.000	710.000			Level
				24.000	1 in 300	
33	Sachinga	733.000	734.000			Level
				25.000	1 in 200	
34	Mpacha	758.000	759.000			1 in 400
				13.000	1 in 200	
35	Katima Mulilo	771.000	772.000			Level

11.7.3 Station yard layouts

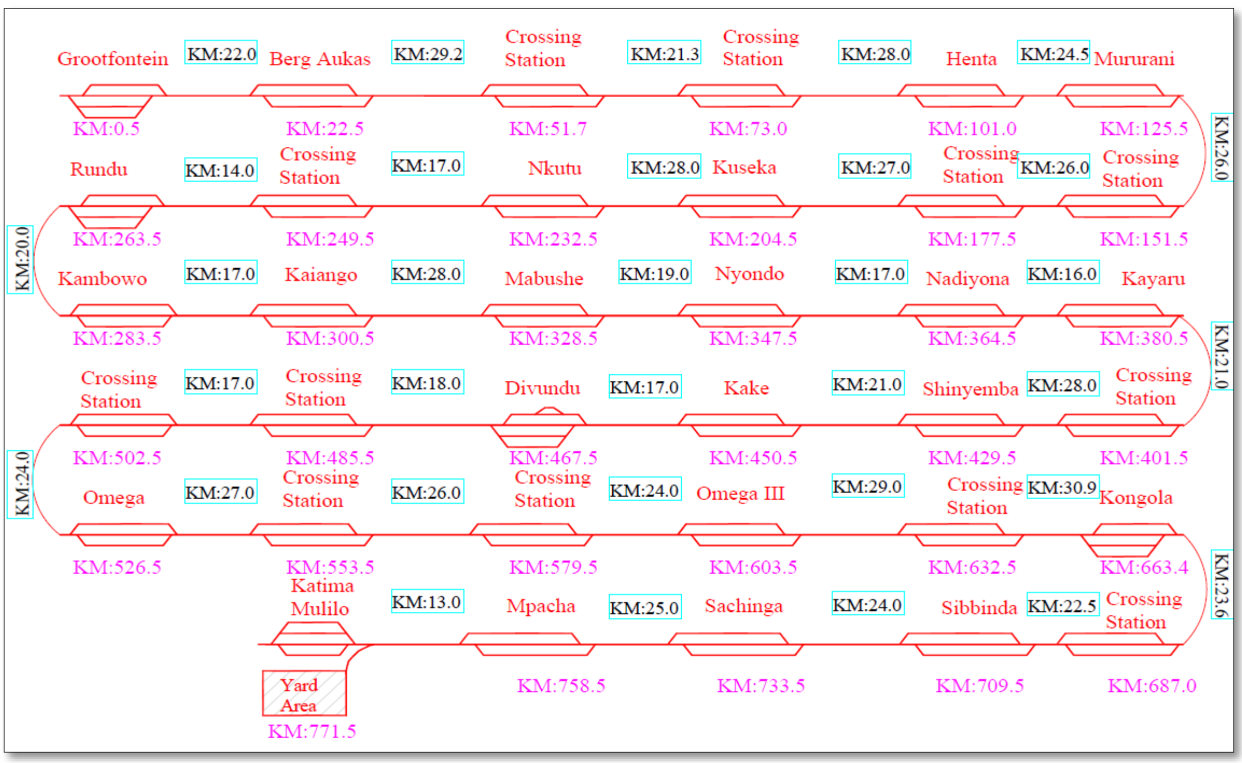
The basic track layouts at stations, transit and terminals, play an important role in train operations. The general functions performed at a freight station are:

- Trains stop for loading/unloading.
- Trains stop for crossing and/or overtaking.
- Trains stop for shunting and reassembling.
- Trains stop for inspections and to attend to the rolling stock in case 'Trouble Shooting' is necessary

The layouts for station on TZR have been designed with connections from main lines for crossing and overtaking. The stations would be easily approachable for maintenance activities.

The yards on the entire section have very simple layouts. The yard layouts have been designed to consider the train movements for freight movement only. The miniature pictorial depiction of proposed 35 stations and inter-distances are as indicated in the figure below:

Figure 11-2: Miniature Station Yard layouts & Distance Between the Stations



11.8 Assessment of Number of Daily Trains

Based on the preliminary designs developed for the new railway infrastructure, block section lengths, grades in block sections, ruling gradient and other design features, following basic design data has been considered for planning of train operations on the Trans-Zambezi Railway:

- Cape gauge with maximum speed of 80 kmph for freight trains.
- Maximum speed at turnouts as 30 kmph initially which can be increased to 40 kmph at a later stage.
- Route length of 772.00 km permitted with maximum axle load of 18.5 ton.
- 35 stations with train crossing facilities.
- The loop / siding lengths at station - 720.00 m.
- Maxima inters station distance 30.90 km which can be reduced to 22.00 km, if required at a later stage to increase the 'line capacity'.
- Ruling gradient as 1 in 170.
- The Trans-Zambezi Railway extension will be provided with colour light signalling with interlocking.
- Train operation and control will be by absolute block section system with authority to proceed controlled by colour light signals.
- There will be one crew changing station at Divundu. Facilities such as locomotive fuelling facility, sick locomotive/wagon attention facility and accident relief train will also be provided at Divundu.
- No wagon loading/ unloading along the route except for small traffic at Divundu/ Rundu. Loading unloading will only be done at Katima Mulilo.
- 24-hour rail operations.

The Trans-Zambezi Railway will primarily be freight operation system. The potential traffic is largely 'through' traffic between two stations i.e., Grootfontein and Katima Mulilo which are located at extreme end of the TZR. Some minor traffic is anticipated from Rundu and Divundu.

The train operation will be on single line with diesel traction. Presently, Namibian Railway system uses diesel traction with 2000 HP locomotives and are planning to introduce 2250 HP diesel locomotives. The trailing load is limited to maximum 40 wagons for vacuum braked wagons. The wagons in use are having axle load of 16.5 ton. Both vacuum brake and air brake rolling stock are being used.

The presently available and new rolling stock will continue to carry traffic on Trans Zambezi extension as well as adjoining sections too. There cannot be any captive rolling stock for TZR Extension as both loading and unloading terminals are located outside of the proposed extension in the adjoining railway system. Hence, wagon payload and train load will be governed by axle load of 16.5 ton till all railway infrastructures between loading and unloading points is upgraded to 18.5-ton axle load.

11.8.1 Projected Number of Trains

Based on traffic projections in tons and wagons per train, the year wise projected number of trains for 40 wagon train configuration has been assessed. The traffic to and from Divundu and Rundu is less than a wagon per day even in the year 2069. Such traffic can be met by attaching an extra wagon in any trough train.

11.8.2 For 40 wagon train of different types of wagons

Table 11-14 provides the projected number of trains with 40 wagon configuration of different types of wagons for the three scenarios.

Table 11-14: Projected number of trains with 40 wagon composition

SCENARIO 1 for 40 Wagon Train							
Train - 40 wagon							
			Year				
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	0.4	2.6	3.6	5.0	6.8	8.0	8.8
Covered	0.5	1.6	2.4	3.7	5.5	6.7	7.7
Flat	0.9	2.8	4.1	6.1	9.0	11.0	12.5
Tank	0.2	0.8	1.1	1.7	2.5	3.0	3.4
Total	2.0	7.8	11.3	16.4	23.8	28.8	32.3
SCENARIO 2 for 40 wagon Train							
TRAINS 40 WAGON			Year				
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	1.1	5.0	7.1	10.0	13.8	16.3	18.0
Covered	0.9	3.7	5.5	8.3	12.5	15.4	17.5
Flat	1.6	5.8	8.7	13.0	19.4	23.9	27.1
Tank	0.4	1.6	2.4	3.6	5.4	6.6	7.5
Total	4.0	16.2	23.8	34.9	51.1	62.2	70.1
SCENARIO 3 for 40 wagon Train							
TRAIN 40 WAGON			Year				
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	1.0	4.6	6.5	9.0	12.3	14.5	16.0
Covered	0.8	3.2	4.7	7.1	10.7	13.2	14.9
Flat	1.4	5.1	7.5	11.2	16.7	20.5	23.3
Tank	0.4	1.4	2.1	3.1	4.6	3.5	6.5
Total	3.5	14.2	20.8	30.4	44.4	51.7	60.6

11.8.3 Assessment of Operating Speed and Running Time of Trains

An assessment of average operating speed and running times of trains on the TZR has been carried out. For assessment of average speed and running time of trains on TZR, following factors have been considered:

- Maximum speed as 80 kmph
- Effect of gradients
- Train crossing time at station and numbers of crossings in the system
- Acceleration and braking time
- Track maintenance time/speed restrictions
- Crew changing and fueling/sanding
- Incidental like unplanned reduction of speed
- Time for interchange formalities at Katima Mulilo and Grootfontein
- Air braked 18.5t axle load wagons having roller bearings
- Speed at turn out as 30 kmph

Considering the above, the indicative average operating speeds and total running time on TZR extension are as indicated in the Table 11-15 below.

Table 11-15: Indicative Average Speeds and Total Running Time on TZR

#	Trailing load	Locomotive	Gradient	No. of crossing	Average speed	Total running time	Remarks
1	40 wagons loaded	2* 2250 hp	UP	4	50 kmph	15.30 hrs	As number of train increase, the number of crossings will increase, and total running time will also increase.
2	40 wagons loaded	2* 2250 hp	Dn	4	55 kmph	14.20 hrs	
3	40 wagons empty	2*2250 hp	UP/Dn	4	60 kmph	13.30 hrs	
4	40 wagons loaded	2*4000 hp	UP	4	58 kmph	13.20 hrs	
5	40 wagons loaded	2*4000 hp	Dn	4	62 kmph	12.25 hrs	
6	40 wagons empty	2*4000 hp	UP/Dn	4	64 kmph	12.00 hrs.	

It needs to be noted that the above values have been derived through theoretical simulation based on high level assumptions. The numbers are for general guidance only. Speed trials will need to be done on the 'prototype' i.e., on project completion to arrive at actual values.

11.8.4 Line Capacity

After consideration of various factors, the 'high level' calculations of maximum trains per day, which can be run on Trans Zambezi railway extension is given in table below:

Table 11-16: Train Running Capacity of TZR with various train Composition

Train composition	Number of trains
2*2250 HP loco plus 40 wagons of 18.5 t	25
2*4000 HP loco plus 40 wagons of 18.5 t	42

11.9 Notes On Enhancement Of Line Capacity

1. Block sections which limit traffic movement can be provided with Intermediate Block Signalling (IBS) system with axle counter to increase train running capacity and meet train operations requirements.
2. Line capacity can also be increased by reducing the inter station distances or by provision of second line for about 52 km from Grootfontein.
3. The loop lengths of 720 m can accommodate additional attachments of locomotive in train composition which will decrease the running time and consequently will result in increasing the line capacity. With 3 X 4000 HP locomotive, the effect of gradients becomes negligible, and train can run on maximum allowable speed. The acceleration timings also get reduced considerably.
4. In future, wagons having high pay load to tare weight ratio such as stainless-steel body wagons, frameless tank wagons and wagons with reduced weight by using high quality castings for bogie can be used so that pay load per train get increased and number of trains required get reduced. The new 'state of art' wagons could enhance the pay load capacity by 7-8% thus reducing the requirement of trains accordingly. Energy consumption also get reduced considerably.
5. Speed at turn out can be increased to 40 kmph by using curved thick web switches which would result in an overall higher operating speed.

11.10 Railway Rolling Stock Assessment

11.10.1 Assessment of Freight Wagons

For assessment of Freight Wagons, the following has been considered:

1. Axle load of 18.5t
2. Pay load according to type of wagon
3. Average speed of trains over Trans- Zambezi Railway Extension as 55 kmph.
4. Average Operating Speed of trains on routes other than Trans Zambezi Railway Extension (viz. Grootfontein- Walvis Bay and routes in Zambia/ Botswana) - 50 kmph
5. Terminal detention for loading/unloading, customs and train examination, 3 days at each end when train/rake is running loaded in both directions.

TECHNOFIN CONSULTANTS

6. Terminal detention for loading/unloading, custom and train examination, 3 days at one end and 1 day at the other end when train/rake is running loaded in one direction only.
7. A 4%-time allowance for maintenance and servicing of wagons.
8. Route lengths considered as under:

Table 11-17: Rail Distances in km

Route /Section	Rail Distances in km
Walvis Bay, Namibia – Grootfontein, Namibia	620.00
Grootfontein, Namibia - Katima Mulilo, Namibia	772.00
Katima Mulilo, Namibia - Chingola, Zambia	1096.00

Based on above, the requirement of freight wagons works out as follows:

Table 11-18: Wagon Requirement by Scenario

Scenario 1							
	Year						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	40	264	361	487	639	735	801
Covered	44	154	236	362	559	697	795
Flat	2	28	73	158	321	440	528
Tank	24	81	121	182	274	338	384
Total	110	527	791	1,189	1,793	2,210	2,508
Scenario 2							
	Year						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	98	483	679	937	1,245	1,441	1,575
Covered	26	201	324	526	867	1,110	1,286
Flat	39	183	314	543	959	1260	1,480
Tank	35	177	266	400	607	750	853
Total	198	1,044	1,583	2,406	3,678	4,561	5,194
Scenario 3							
	Year						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	91	456	629	857	1,129	1302	1,420
Covered	13	152	252	419	703	906	1,053
Flat	22	121	227	415	761	1,012	1,196
Tank	42	151	227	342	518	641	729
Total	168	880	1,335	2,033	3,111	3,861	4,398

11.10.2 Locomotive Requirement

Locomotive requirements have been assessed considering two locomotives for each train as well as using a mix of 2,250 and 4,000 horsepower locomotives. For all maintenance schedule and servicing, a 10%-time allowance has been considered for locomotives. Terminal detention i.e., waiting time for trains and shunting/placement has been considered about 5 hours at each end.

Table 11-19: Locomotive Requirement by Scenario

Scenario 1							
40 WAGON TRAIN	**Year**						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	3	12	12	17	20	26	28
Covered	3	6	9	12	17	20	26
Flat	6	12	14	20	28	34	37
Tank	3	6	6	6	9	12	12
Total	15	36	41	55	74	92	103
Scenario 2							
40 WAGON TRAIN	**Year**						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	3	14	20	28	39	45	50
Covered	3	11	16	23	35	43	49
Flat	6	17	25	37	54	66	75
Tank	2	6	7	11	16	19	22
Total	14	48	68	99	144	173	196
Scenario 3							
40 WAGON TRAIN	**Year**						
Wagon	2027	2031	2041	2051	2061	2066	2069
Open	3	14	19	26	34	40	45
Covered	3	9	14	20	30	37	42
Flat	5	14	21	31	47	57	65
Tank	2	5	6	9	14	11	19
Total	13	42	60	86	125	145	171

11.11 Train Operations - Other Requirements

11.11.1 Accident Relief Trains

For proper and prompt response to deal with accidents, though avoidable but inevitable, there would be a need for provision of Accident Relief Trains (ART) to provide relief and to restore the railway traffic in the quickest time. To take care of this, a special train set need to be provided at a strategic location for prompt availability throughout the route. For the TZR extension Divundu would be the recommended location. The staff for ART at Divundu would also take care of enroute emergency detachment of sick wagons, fueling/sanding and troubleshooting of locomotives.

Accident Relief Train will comprise of:

a. 120 tonne diesel rail cranes
b. 5 coaches for relief train (2 for tool van, 2 for material / other equipment, 1 for staff)
c. 2 wagons for track material

11.11.2 Provision of Crew Changing and Crew Resting Facilities

It is recommended to designate Divundu as an intermediate crew changing point. Appropriate resting facilities for crew will be provided at Divundu. Also, similar facilities might also be provided at Katima Mulilo and Grootfontein based on overall crew planning from Walvis Bay to Zambian railway network.

11.11.3 Loco Fuelling and sanding Location

Intermediate Loco fuelling facility is recommended at Divundu. Fueling point at Grootfontein and Katima Mulilo would also be necessary.

12 Railway Asset Maintenance and Workshops

12.1 Introduction

The Trans-Zambezi Railway will be on Diesel traction. The Rolling Stock comprises of Locomotives, Freight Wagons, maintenance and emergency Response Vehicles as well as Construction, Monitoring and Inspection vehicles. The fixed assets comprise of track, structures, signal and telecom, electrical installations, utilities and building.

Apart from locomotives, per the traffic requirements, four types of freight wagons will operate on the system. In order to properly maintain the locomotives and freight wagons, proper 'Workshop' infrastructure is necessary. Considering operational requirements, availability of skilled manpower, geographic location and the fact that Trans-Zambezi Railway Extension falls on one side of the Namibian Railway system, a considered view needs to be taken for development of new workshop facilities in phased manner at an appropriate location along the railway route from Katima Mulilo – Walvis Bay for locomotives and wagons separately.

The workshop can also take care of all the maintenance activates of track machines and Signal and Telcom systems maintenance.

12.2 Standards and Codes

The Workshop standards will primarily conform to AREMA and AAR standards, as applicable. Other international standards and Namibia Building standards, would also be the guiding factor.

12.3 Workshop Infrastructure – Planning and Workload

12.3.1 Rolling Stock Maintenance Workload

An assessment of Rolling stock requirement has been carried out in the previous section of this report based for the potential traffic from the year 2027 to year 2069 for locomotives and wagons (of different types). The summary of rolling stock assessment for **Scenario 2 –** for completed network Grootfontein, Katima Mulilo, Sesheke, Kazungula, Livingstone, Chingola (*note that Livingstone to Chingola section is Zambia's existing rail network)*:

Table 12-1: Summary of Requirement of Rolling stock assessed for **50 Kmph** speeds for Scenario Two

Rolling Stock	Year						
	2027	2031	2041	2051	2061	2066	2069
Locomotive	14	48	68	99	144	173	196
Wagon	198	1,044	1,583	2,406	3,678	4,561	5,194

12.4 Development Diesel Locomotive Maintenance Workshop

Typically, a diesel Locomotive maintenance workshop is able to take care of about 100 locomotives. Considering the incremental requirement of rolling stock, it is recommended to develop a Diesel Locomotive maintenance workshop initially for about 70 locomotives to take care of the locomotives by the year 2041, with provision of expanding the facility up to 100

TECHNOFIN CONSULTANTS

locomotives by the year 2051. Decision about still further expansion could be made at that stage.

This workshop should be located at a place which minimizes redundant movement of rolling stock for maintenance, and it should not become a constraint in smooth train operations.

It is recommended that the Locomotive Workshop be located close to Walvis Bay for few of the key reasons as follows:

- → Walvis Bay is the Railway Terminus for Trans Zambezi railway line.
- → It would be easier to find and settle skilled personnel for the Workshop here.
- → Suitable vendors and engineering ancillary units would be easy to find and establish.

12.4.1 Maintenance of Locomotives

The 'Scheduled' maintenance of locomotives depends on the make of the locomotive and the maintenance schedule laid down by the manufacturer. The manufacturer's recommended schedule of maintenance has to be strictly adhered to.

The maintenance of locomotive encompasses the following elements:

12.4.1.1 Trip Inspection

- Fuelling.
- Topping-up of all fluids and traction sand.
- Mechanical and electrical visual inspection.
- Functional test of traction and braking.
- Driving cab cleaning.
- Addressing issues/defects reported by the locomotive driver.
- Addressing issues reported by the scanner that will be located on the yard incoming track.
- Preventative Maintenance.
- Performing mechanical and electrical scheduled inspections

12.4.1.2 Curative Maintenance (Repairs)

In this, overhaul and replacement of the major components of diesel engine turbo compressor, main generator, auxiliaries, air compressors, traction motors, wheel sets, bogies, radiators, cooling fans, dynamic brake grids are undertaken along with repair or replacement of minor components.

The 'typical' maintenance schedules of diesel locomotives are as indicated below, though it may vary from manufacturer to manufacturer:

TECHNOFIN CONSULTANTS

Table 12-2: Typical Maintenance Schedule for Diesel Locomotives

Maintenance Schedules	Major Activity of Maintenance
Fuel Stop	Checking Fuel system, Lube oil system, General cleaning and checking
45 Days	Checking of battery, main generator, lube oil filter/TSC filter element, change lubrication
90 Days	Air filter, TSC diffuser, battery, engine component attention,
Six months	Change of engine oil, attention to exhaust system, Radiator, hand brake
One year	Cylinder head, injector, air compressor, electrical cabinet, dynamic brake, small motors
Two years	Cooling system, air compressor, control circuit
Three years	Replacement of cylinder assembly, injectors, main bearing, air compressor values, TM rectifier
Four years	Replacement of dynamic brake, blower, TSC attention, governor replacement
Six years	Air compressor, pumps, oil value, main generator bearing, engine liner, linkages replacement/reconditioning
Nine years	Replacement of crank shaft dampers
Twelve years	Replacement of engine, main generators

Typical detailed schedule is as under:

Table 12-3: Maintenance Workload of Diesel locomotives can be worked with schedule indicated

#	Type of Maintenance Schedules to be done	Arising Date	Schedule
1	Fuel Stop	On Every Trip @ 5/6 days	a
2	45 Days	D+45 days	b
3	90 Days	D+90 days	c
4	Six months	D+180 days	d
5	One year	D+1 year $	e
6	Two years	D+2 years@	f
7	Three years	D+3 years*	g
8	Four years	D+4 years@	h
9	Six years	D+6 years	i
10	Nine years	D+9 years	j
11	Twelve years	D+12 years	k

@$* to be combined with other schedules

Note: D is date of commissioning

a – every trip, other than # 2, 3, 4 (approximately 58 attentions per Loco per year) b – Every year (approximately 4 maintenance attentions per loco per year after combining with schedule at # 3 and 4)

c – Every year (approximately 2 maintenance attentions per loco per year after combining with schedule at # 4)

d – Every year (approximately 2 maintenance attentions per loco per year)

e - First year, 5th year, 7th year, 11th year

f – 2nd year, 8th year

g - 3rd year, 9th year

h – 4th year, 10th year

I – 6th year

J – 9th year

K – 12th year

12.4.2 Locomotive Maintenance Workshop – Major work Areas

Following are major Indicative requirement in the workshop:

- Locomotive Fuelling and Servicing Facilities
- Light Maintenance Area
- Heavy Maintenance Area
- The bogie and Traction Motor Shop Area
- Locomotive overhaul will be in this area, where major components such as the diesel engine, the main alternator and bogies will be replaced. This area will be used primarily for the execution of the locomotive overhaul work.
- Other Facilities around the Locomotive Workshop

The following facilities for locomotive maintenance will also be built around the main building:

→ Locomotive Washing Facility

→ Locomotive Diagnostic Station

→ Fuel and Oil Storage Area (Tank Farm)

→ Fuel Delivery Station

12.5 Development of Wagon Maintenance Workshop

As per the assessment made in this report, by the year 2051, 2406 wagons of different types might be required. By year 2069, the number of wagons requiring maintenance will increase to 5194.

Different types of wagons requiring maintenance by the year 2051 and 2069 are as under:

Table 12-4: Type of wagons by year 2051 and 2069 requiring maintenance

Type of Wagon	By year 2051	By year 2069
Open	937 (39%)	1575 (30.3%)
Covered	526(22%)	1286 (24.7%)
Flat	543 (22.5%)	1480 (28.5%)
Tank	400 (16.5%)	853(16.5%)
Total	**2406**	**5194**

Wagon workshop will have the capacity to deal with corrective maintenance (Trouble Shooting), preventive maintenance, routine overhaul and periodic overhaul for all types of the wagons. Consequently, the workshop would need to be equipped to deal with open, covered, flat and tank wagons all at once.

12.5.1 Maintenance of Wagons

The maintenance requirement of wagons will be governed by several factors and will largely depend on the original equipment manufacturers requirement and the specifications and design adopted for these wagons. The running and operating conditions will also play an important role.

A preliminary assessment of workload for wagon maintenance workshop is as indicated in the table below:

Table 12-5: Wagon Maintenance Assessment

Schedule of Maintenance	No. of wagons (till Yr. 2051)	Workload	No. of wagons (till Yr. 2069)	Workload (wagons per month)
Routine Overhaul (ROH) @ 3 years	2,406	About 67 wagons per month	5,194	145 wagons per month
Periodic Overhaul (POH) @ 6 years		About 34 wagons every month		About 72 wagons per month
Wheel Replacement @ 3 years		2 -3 wagons per day		4 -5 wagons per day
Wagon repairs Non scheduled (accidental)		3 to 4 wagons per month		6 to 7 wagons per month

Apart from the above, following workload has been assessed for 'Non-Workshop' repair of wagons i.e., in 'Sick lines' or 'Loop Lines' at stations:

Table 12-6: 'Non-Workshop' Wagon Repair

Day to day Repair of Wagons in Sick Lines				
Schedule Of Maintenance	**Total No. of wagons in service (till Yr. 2051)**	**Workload**	**Total No. of wagons in service (till Yr. 2069)**	**Workload**
Troubleshooting and repairs which cannot be attended in train formation @ 1%	2,406	24 wagons per day	5,194	52 wagons per day

Additionally, 'Non-Scheduled' Maintenance such as Wheel Turning/Replacement is generally done at every 80,000 km of running.

12.5.2 Wagon Maintenance Workshop- Major Work Areas

Following are major section in a Wagon workshop:

→ Wagon Shop

→ Wheel Shop

→ Bogie Shop

During initial periods the wagon maintenance will be very limited. The workload during the initial period will be generally limited to replacement of defective wheels. Most of the wheelsets removed for defects will be reprofiled and reapplied to other wagons. Wheel replacement will be done on the drop table located on track .

A light repair area where light repairs, mostly repair work identified during trip inspections will be performed. The duration of wagon visits in this area will generally range from two hours to eight hours.

A heavy repair area where heavy repair work to the wagon body, wagon structure, couplers, draft gears and bogies will be performed will also be earmarked. The duration of visits will generally extend from eight hours to five days. Some wreck repairs may require longer shop time; A bogie repair area where bogies will be assembled in preparation for their application to wagons.

The wagon workshop will share with the locomotive workshop several small auxiliary shops located in the central area of the building.

12.6 Stabling Track Requirements in Workshops

Stabling Lines: Each workshop track will provide sufficient space at the incoming and outgoing ends of the workshop for parking number of rolling stock as per the workload of the workshop so that there is no congestion and movement restrictions within the workshop which will affect the efficiency.

The number of stabling lines and shunting lines will be provided based on the daily workload including emergency requirements.

12.7 Workshop Provision for TZR Extension

Thought the exact workshop requirements can only be worked at the Detailed Design Stage, out once the Rolling Stock identifications have been done, based on the preliminary assessment for the completed TZR and corresponding maintenance efforts necessary for the system to function efficiently, the Consultants has kept following provisions on the project estimates:

(1) Loco, Wagon, Workshops and Signaling, Electrical and Track Depot Workshop of about 6000 sqm.

(2) A lump Sum provision for Procurement and Installation of Workshop machinaries, Tools and Plants.

12.8 Maintenance of Railway 'Fixed' Assets

The railway assets in form of fixed assets needs to be maintained to provide efficient services without major breakdown and accident. Following are the assets in 'Fixed' category which would be required to be maintained regularly as per standard norms and schedule:

- Railway Track
- Bridges
- Other Civil Structures
- Signal and Telecom assets
- Electrical assets

12.8.1 Track Maintenance

Railway Track, being the most important asset of a railway system, needs to be intensively maintained regularly. In modern times, 'Manual' maintenance of track, particularly 'heavy' concrete sleeper track, has become non-feasible. The modern system is to adopt mechanized track maintenance with 'On-Track' heavy duty track machines as well as lighter 'Off Track' machinery and equipment.

The table below indicates typical track machinery and its function:

Table 12-7: Track Machines Assessment

Track Machine	Function/ Utility
Large - On Track Machines	
• **Continuous Action Tamping Machine (CSM)**	Mechanised maintenance of concrete sleeper track is done through large on-track tamping machines. A CSM performs the functions of tamping, lifting as well as straightening of

Track Machine	Function/ Utility
	the track. Continuous sequence of operations of CSM enables very high performances. On Concrete sleepers, the frequency of tamping is generally once in two years or passage of 100 Gross Million Tonnes of traffic whichever is earlier. For TZR it is recommended to procure one CSM initially and second machine after 15 years based on the traffic.
Dynamic Track Stabilizer (DTS)	During maintenance operations such as tamping, lifting, slewing, deep screening etc., the lateral resistance of track gets reduced which rebuilds gradually with passage of trains. This consolidation can also be achieved faster and more effectively by causing "controlled settlement" of track by means of a Dynamic Track Stabilizer. Generally, this machine is utilized along with CSM and Ballast Cleaning Machines (BCM). For TZR initially one machine is considered sufficient, later on second DTS can be procured along with procurement of second CSM.
• **Multi Purpose Tamper (MPT)**	These tamping machines are utilised to attend soft spots and Turnouts. For TZR Initially two such machines can be procured which can be further augmented to three as maintenance workload increases.
Ballast Handling Machine	
• **Ballast Cleaning Machine (BCM)**	The function of ballast cleaning machine is to carry out cleaning of ballast by removing muck, thereby improving drainage of track and elasticity of the ballast bed. The machine excavates and picks up ballast by means of cutter chain and carries it to a set of vibrating screens where muck is separated and thrown out by a chute and clean ballast is transferred back to the track. The requirement of this machine of TZR would be after about 10 years of operation.
• **Shoulder Ballast Cleaning Machine (SBCM)**	The machine is used for cleaning of shoulder ballast to improve the drainage of track. One such machine would be required after five years which can be later augmented by one more after ten years of operation.
• **Ballast regulator Machine (BRM)**	This is required to keep the ballast profile as per standard. These machines have their main application in ballast transfer, spreading and profiling operations. Two such machines will be required. These machines will need to be

TECHNOFIN CONSULTANTS

Track Machine	Function/ Utility
	procured at the time of commissioning of the project.
Special Purpose Machines	
• **Mobile Flash Butt Welding Plant**	This machine welds rails. Since all the major work of welding would have been done as part of track construction these would be required only when large scale track renewal is due.
• **Rail Grinding Machine**	The need for such machines is to correct the rail profile by adopted rail grinding as a maintenance activity, generally, for high axle load territory. May not be required of TZR.
• **Utility Track Vehicle.**	A track utility vehicle is to attend to very specialised track maintenance activity, which is fully equipped with small machines. One such vehicle needs to be procured at the time of commissioning of the project.
• **Rail cum Road Vehicle**	These vehicles are utilised for track maintenance activity to transport men and material and have the capability to run on track as well on road. These are utilised for track sections which have fully mechanised system of maintenance. These vehicles can reach spot of track maintenance quickly and attend to defects like rail fracture, turnout attention, long welded rail attention etc. Three such vehicles would be required for TZR which needs to be procured at the time of commissioning of the project.
• **Rail borne Maintenance Vehicle**	These are required on section where road connectivity is not good.
• **Track Measurement Vehicle/equipment**	These are used to assessing the track geometric conditions and to record the various track parameters so that directed maintenance of track can be planned. One such vehicle would be required for TZR. Existing measurement vehicles could also be utilised for this purpose.
Small Machines	
• **Exothermic Rail Welding Equipment**	These are used for exothermic welding of rails. On a section of 772 route km, eight sets of such equipment would be required which need to procure at the time of

Track Machine	Function/ Utility
	commissioning of the project
• **Rail Profile grinder**	These are required for profile grinding of the rail joints after exothermic rail welding. This is part of Exothermic welding set. One machine is required for each such set.
• **Rail hydraulic weld trimmer Machine**	These are required for removing the hot metal after exothermic welding of rail joints. This is part of Exothermic welding set. One machine is required for each such set.
• **Rail Cutting Machines**	Are required to cut rails wherever required. Eight such machines will be required. Need to be procured at the time of commissioning of the project.
• **Rail Drilling Machine**	Is required for drilling holes in rails, if required, for joining rail by fish plates. Eight such machines would be required. Need to be procured at the time of commissioning of the project.
• **Hydraulic Rail tensors**	These are required for destressing of rails. Eight sets of tensors would be required. Need to be procured at the time of commissioning of the project.
• **Lifting Jacks**	These are required as a routine maintenance of track and are used for several operations e.g., sleeper replacement, turnout insertion, destressing of rail track etc. Around 100 number of such jacks would be required for the entire section of 772 route km. Need to be procured at the time of commissioning of the project.
• **Other machines**	As necessary

The costs of procurement of the above listed track construction and maintenance machines are included in the overall railway construction costs and railway operations and maintenance, depending on the specific utility of each.

12.8.2 Bridges & Other Structures

If the design of bridges is robust, the requirement of maintenance is low. However, from 'safety perspective, intensive inspection, cleaning, marking, painting and greasing of bridges is necessary.

Routine upkeep and maintenance of other structures is done as per local building regulations.

12.8.3 S&T, Electrical Assets

Routine as well as 'Emergency' repairs become necessary for these assets. Regular and trained staff is necessary. Provision of fully staffed and equipped mobile units with assigned 'beat' length is a generally adopted maintenance strategy.

13 Bill of Quantities & Cost Estimates

13.1 Introduction

While preparing and presenting the cost estimates, various expense heads have been grouped as follows:

- **Permanent Way- Material:**

→ Supplying Rails
→ Supplying of PSC line sleepers
→ Point & Crossings
→ Fittings
→ Supply of Hard Stone Ballast

- **Permanent Way Linking**
- **Formation:**

→ Earthwork in Formation
→ Side Drains & Fencing

- **Structures:**

→ Major & Minor Bridges, Level Crossing, ROB, RUB
→ Miscellaneous (Retaining Walls, Eco Crossing, etc.)
→ Service Buildings incl. Head Office + High Level/Low Level Platform + Station Infrastructure

- **Land Acquisition and Resettlement Cost**
- **Workshop, T&P and Electrical**
- **Signal & Telecommunication**
- **Access Roads**
- **Preliminary Expenses**
- **Contingencies and Miscellaneous Costs**
- **General Charges, Design and Project Management**

13.2 Permanent Way Material

The TZR extension railway costs are for single line railway track. The rail track items include Rails, Sleepers (Ties), Fittings, Turnouts, Ballast, etc.

13.2.1 Rail

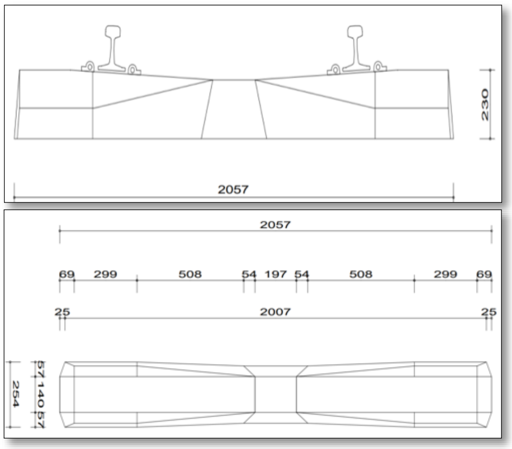
Rails for the project will be imported. Likely source could be manufacturers and suppliers in South Africa, India, China and Europe. The price considered in the cost estimates for rail includes loading /unloading and transportation charges of rail from Walvis Bay port to project site.

13.2.2 Sleepers (Ties)

Pre-stressed 'Mono Block' Concrete Sleepers have been considered for this project at **1429 numbers/ km length** of the track.

The PSC sleepers will be manufactured locally for the project. One of the concrete sleeper manufacturing units is functional at Tsumeb, the capacity of which can be expanded for the project. Further, for a greenfield project spread over about 772 km, establishing at least one more manufacturing plant of appropriate capacity at Rundu/ Divundu will be advisable from logistics consideration.

Figure 13-1: P2 Concrete Sleeper



13.2.3 Track Fittings (Fastenings and Fixtures)

Fastenings are fittings which are used to secure rails with sleepers. Fastenings should provide a firm grip and high toehold on the rail and prevent any longitudinal movement or lateral displacement of the rail.

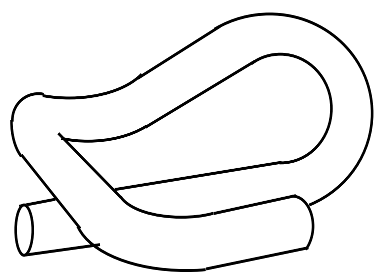
For the Mono Block Concrete Sleepers, Elastic type fastening system are provided such as or equivalent to Pandrol, Vossloh, etc.

Pandrol Clip

The Pandrol clip is an elastic type of fastener which applies a load to the base of rail to keep it held against the sleeper. The load is developed through the flexure of the clip which is shown in the figure.

Four 'Pandrol' clips, are installed on each sleeper. They are inserted into a lug pressed onto the sleepers.
Anti-vandal Pandrol clips (or similar) are recommended.

Figure 13-2: Pandrol Clip



13.2.4 Rail Joints

Though the route is proposed to be Continuous Welded Rails (CWR), practically, during construction stage and later too, many rails are likely to be jointed. We have calculated the requirement of fittings for rail joints considering that Loop lines (Sidings) will not be welded.

Fishplates are steel pieces used to join the rails together. When the rail is laid as jointed track, fishplates assure the correct lateral alignment of the gauge side of the joined rail ends, and the correct horizontal alignment of the tops of the rails.

With the help of nuts and bolts, two fishplates (one on each side of the rail) ensure that the two rail ends are correctly joined.

Fishplate bolt holes have a slightly larger diameter than the bolt. The hole spacing is the same as the rail end hole spacing.

An ideal rail joint should be able to perform the following functions:

- It should hold the rail ends in the correct position, in both horizontal and vertical planes.
- It should provide elasticity equal to that of the rail.
- It should allow the free expansion and contraction of the rail.
- It should be easy to maintain.
- The cost of maintenance should be minimal.
- It should permit the easy replacement of any single rail in the track.

As the contact surfaces wear under traffic, it should permit the adjustments needed to retain vertical and horizontal alignment.

13.2.5 Point & Crossings (Turnouts)

The railway yards are proposed to have all the Turnouts on Main Running line designed for 1 in 12 turnout whereas Turnouts on Passing Loops and Sidings have been considered for 1 in 9 turnout. Turnouts will be on PSC sleeper layout.

The turnout sets will need to be imported in Namibia for this project. However, sleepers for turnouts can be designed and manufactured in the concrete sleeper manufacturing plants proposed for the project.

13.2.6 Ballast

Ballast with a depth of 200 mm is to be laid on the track bed to support the sleepers and rails. The ballast is to be laid on a well-compacted sub-ballast formation.

As per our preliminary assessment, good quality ballast quarries are readily available in the project area.

13.3 Formation (Earthworks)

The estimates for Formation include earthwork for embankments and cuttings which includes preparation of grades and sub-grades, retaining structures, earth strengthening, side drainage, fencing, etc.

In cuttings, side slopes of 1:1.5 have been considered with intermediate benches at 6.0m intervals wherever required. Width of berms have been considered as 1.5 m each.

In fills, side slopes of 1:1.5 with benches at 6.0-m vertical intervals have been considered. Slope protection and turfing costs have been included in cutting & filling quantity.

Earth obtained from ‘Cutting’ will be utilized for ‘Filling’ in the nearby stretches, where-ever practical. Earth for other stretches will be procured from ‘Private’ quarries all along the route. The unit cost of earth in the project estimate includes the cost of procurement, leads, lifts, watering, compaction, complete.

13.4 Structures

Structures include Major & Minor Bridges, Road Over Bridges (ROBs), Road Under Bridges (RUBs), Level Crossings, Service Buildings, High Level and Low-Level Platform, Station Infrastructure.

Bridge costs consist of cost of foundations, sub-structures and super-structures including piles, abutments, piers, bearings, slabs and girder.

Major & Minor Bridges: Bridges have been classified as:

- Minor Bridges/ Culverts – Total Linear Waterway lengths below 6 m
- Major Bridges – Total Linear Waterway lengths more than 6 to 50 m
- Important Bridges- Total Linear Waterway lengths above 50 m

13.5 Land

Land requirement for the new railway route and related infrastructure has been assessed on the basis of a minimum land corridor width of 50 m and additional land for all station yards along with Katima Mulilo yard Area. Wider widths, wherever necessary, on the stretches of high embankments and deep cuttings has been considered.

The land width in station areas has been considered at 100 m. The land at Katima Mulilo yard has been considered 700 m wide over a stretch of about 2.0 km to take care of the multi-commodity logistics transhipment hub that would be required if the TZR is not further connected into Zambia by rail.

13.6 Workshop, T&P and Electrical

Preliminary assessment for Workshop infrastructure has been made as per Section 12.7 of this report. Lump sum provision for Tool and Plants has been made.

The electrical costs considered are for General Electrical requirements at stations, control stations, administration buildings, signaling and systems.

13.7 Signal & Telecommunication

As detailed in Section 10 of this report, Electronic Interlocking and Colour Light Signaling is recommended for the new TZR extension. Appropriate provisions have been made in the project Cost Estimates for the same.

13.8 Access Roads

For the TZR extension a total of 35 stations have been proposed. The stations will need to be provided appropriate 'Access Roads' from the nearest main roads. In our preliminary assessment, we have estimated an average requirement of about 172 m access road at each station. Appropriate cost estimates have been made for this.

13.9 Preliminary Expenses

Project Development is a critical activity for successful implementation of a mega project like this. Expenses need to be incurred on development of a comprehensive 'Perspective Project Development Plan', development and approval of Environmental and Social Impact Assessment (ESIA) and Resettlement Action Plan (RAP), Capacity Development and Project Procurement. These all fall under 'Preliminary' project stage.

We have earmarked 2% markup on the Project Infrastructure Costs on this head.

13.10 Contingencies and Miscellaneous Costs

Mega projects like this are developed and implemented 'once in a generation' in a nation's history. The project development and implementation take long time to happen. There are many 'Known Unknowns' as well as 'Unknown Unknowns'. The best of 'Feasibility Studies', 'Front End Engineering Designs' and Cost Estimates would still not be able to capture 'exactly' all the cost elements.

We have kept a provision of 4% for Project Contingencies and Miscellaneous Costs.

13.11 General Charges, Design and Project Management

For such a megaproject, it is typical for the project proponent (in this case, MoWT) to engage a consultant for the procurement, construction and operational phases of the project. Such engagement not only ensures smooth project delivery, but also develops the in-house capacity of the proponent to manage the current project and implement similar future projects.

Further, Project Management Consultant (PMC) will need to be engaged to effectively plan and monitor as well as to manage the 'Quality'.

Provision of 5% as markup on the Project Infrastructure Costs has been provided in Project Estimates for General Charges, Design and Project Management.

13.12 Unit Rates

The rates of various items have been assessed on the basis of:

v. Known comparable costs of Railway and Highway projects in Namibia

vi. Comparable costs of recent regional railway projects in Africa

vii. The Consultants own library and database

viii. Cost of Land: Rates obtained from online property agencies. The Compensation Policy Guidelines for Communal Land was used to estimate the cost in the communal areas.

ix. Assessed market rates in Namibia

13.13 Key Project Quantities

Following are the 'Key' project quantities:

Table 13-1: Key Project Quantities

#	Key Features	Quantity
i	Route Length (km)	772.00
ii	Track Length (km)	873.00
iii	Earthwork- Filling (million m3)	39.00
iv	Earthwork- Cutting (million m3)	8.00
v	Sub Ballast Layer (million m3)	2.00
vi	Ballast (million m3)	2.00
vii	Land (ha)	4,186.00

13.14 Project Cost Estimates

Based upon extensive studies, reconnaissance, stakeholders' interactions, and preliminary designs of the project, we have estimated the Project Cost for the Trans-Zambezi extension line as **US$ 2,267 million.**

Here is the summary of Project Cost Estimates:

Table 13-2: Summary of Project Cost Estimate

#	Description of Work		Total Cost (In Mn. US$)
A	**Permanent Way Material**		**375**
B	**Permanent Way Linking**		**71**
	Total of Permanent Way (Material+ Labour) (A) + (B)		**446**
C	**Formation**		**929**
	Total for P-way and Earthwork (A +B + C)		**1,375**
D	**Structures**		**436**
	Total Cost for Civil Works (A+B+C+D)		**1,811**
E	**Land Acquisition & Resettlement Cost**		**35**

TECHNOFIN CONSULTANTS

#	Description of Work		Total Cost (In Mn. US$)
	Total Cost for Civil Works + Land (A+B+C+D+E)		**1,846**
F	**Workshop, T&P and Electrical**		**64**
G	**Signal & Telecommunication**		**128**
H	**Access Roads**		**5**
I	**Total Cost of Infrastructure (A+B+C+D+E+F+G+H)**		**2,043**
J	**Preliminary Expenses**	2%	41
K	**Contingencies and Misc.**	4%	82
L	**General Charges, Design and Project Management**	5%	102
	TOTAL COST OF PROJECT (I+J+K+L) (Rounded)		**2,267**
	Route Identification		**Final Route**
	Route Length (km)		**772.00**
	Track Length (km)		**872.93**
1	Per Route km (Million US$)		**2.94**
2	Per Track km (Million US$)		**2.60**

Note: *At Katima Mulilo, cost of basic civil infrastructure has been included viz. earthwork, track, low level platforms for 4 different terminals (Mineral, Oil, Food grain/ Fertilizer and Containers) but cost of development of actual terminals will be borne by separate terminal developers/ operators.*

The preliminary 'Feasibility' stage detailed **Cost Estimates** of the project are attached as Appendix -5 - Detailed Cost Estimate to this Report.

14 Next Steps & Schedule

14.1 Introduction

From the assessments made in Vol I. and Vol II. of this assignment, it is clear that this project is viable from a technical, environmental, legal, financial and ecnomic standpoint and should move forward.

To move forward, certain 'next steps' are required to ensure that the TZR is successfully developed. These steps are described in this section.

14.2 Extension of Study Mandate

The key conclusion of the assignment is that the proposed 772 km Greenfield line is viable from a technical, environmental, legal, financial, and economic standpoint and should move forward. To realize an interconnected regional railway, it is noteworthy that the Greenfield 'Trans Zambezi Extension Railway Line' should connect to Zambia's and Botswana's rail network, thereby providing direct access to regional railway traffic to the Walvis Bay Port.

Furthermore, the line's traffic potential hinges entirely on its ability to attract regional traffic to and from Walvis Bay Port. To realize this potential, apart from direct regional connectivity; minimising transport costs, eliminating inter-modal transhipments and reducing transit time are critical.

With the above context, there are two major areas which need to be investigated and studied further to correctly assess the line's potential in the current national and regional context, namely (i) 'Seamless Inter-Operability with Namibia's Current Railway Network' and (ii) 'Potential Regional Connectivity Through Botswana'.

There was a broad agreement within the stakeholders during the 'Workshop' on taking up these studies.

On the request of the Ministry, M R Technofin has submitted a task and effort schedule as well as a project timeline for two separate studies. Both studies would be an extension to the current study and would commence on submision of this Final Feasibility Report. On completion of the two 'sub-studies', an updated Final Feasibility Report will be submitted to MoWT.

14.2.1 Seamless Inter-Operability with Namibia's Current Railway Network

Discussions on rail operations and rolling stock requirements in Volume I of the feasibility report have assumed that the current railway line between Walvis Bay and Grootfontein will be upgraded to meet the recommended design specifications of the TZR (namely the 18.5 ton/axle load).

The Trans-Zambezi's commercial potential hinges on seamless train movement between the proposed 'Greenfield' line (Grootfontein- Katima Mulilo) and Namibia's current network between Grootfontein and Walvis Bay. It is noted that with significant freight potential coming from regional transit traffic, through connectivity to and from the Walvis Bay port is immensely important.

Interoperability Issues with the Current Network

Key questions that a 'operational and infrastructure planning' study should address are:

1. Can freight traffic move fluidly between the proposed line and the current network?

2. What are the current operational and infrastructure issues on the existing network and how can they be addressed?

3. If funding paucity is an issue and the Walvis Bay – Grootfontein section cannot be fully upgraded, what are alternative low-cost measures?

4. Can the Walvis Bay – Grootfontein section meet forecasted traffic in 10-, 20-, 30-years? What upgrades would be required to meet traffic down the line?

The Consultant's current scope of work does not include any engineering or operational study of the existing railway network. Furthermore, our findings assume that the existing network between Grootfontein and Walvis Bay would be upgraded to a standard that would allow for seamless movement between the proposed line and the current network.

More specifically, the existing Grootfontein – Walvis Bay railway section has a capacity of 16.5 ton/axle-load and sectional design speeds varying between 50 kmph and 80 kmph. We have assumed that this section would be fit for a 18.5 ton/axle-load and to a design speed of 80 kmph for freight, matching with the proposed Trans-Zambezi railway extension.

The ground realities are that the gradients and curvatures on the existing Grootfontein – Walvis Bay section are areas of concern with gradients much steaper and curves much sharper than what are proposed on the Trans-Zambezi Extension Line.

Furthermore, existing station layouts and inter-distances need to be assessed and modified/upgraded accordingly to increase the 'Line Capacity' of the existing Walvis Bay – Grootfontein section to match the proposed TZR.

The existing 'Railway Workshop' infrastructure also needs to be reviewed to ensure that the augmented workshop is able to cater to the much higher demands of rolling stock maintenance (Locomotive, Wagons, Track Machines, etc.) of the expanded Trans Zambezi Railway network.

A mismatch between existing and new railway section would result in an inefficient transport network with unreliable service standards requiring more trains and rolling stock to meet the regional traffic requirements. Other inter-operability issues would also be at play such as 'train bunching' at Grootfontein.

The remit of this study does not include studying how traffic to and from the TZR will interact with Namibia's current rail network. However, this does need to be studied in greater detail to minimize interoperability issues between the proposed line and the current line between Walvis Bay and Grootfontein.

The Consultant has offered its expertise and services as an extension of the present mandate for such study.

14.2.2 Last Mile Connectivity - Potential Regional Connectivity Through Botswana

Though the current assignment is regional in nature, the remit of the current scope of work is limited to looking at a railway line that is within Namibia's borders up to Katima Mulilo. Practically, the proposed line would have to be extended past Katima Mulilo into Zambia or Botswana to establish 'through freight' to eliminate inter-modal transhipments and minimize transit times. The issue is complex, but of great importance if a future rail-based network is to be developed to best effect.

Based on intelligence gathered by the Consultant, it is understood that Botswana and Zambia are currently working bilaterally and are in the final stages of tendering a feasibility study for:

(1) 367 km railway line from Mosetse (Botswana) to Kazungula (Zambia) via the Kazungula Bridge (the bridge was completed in 2021)

(2) 56 km railway line from Mmamabula (Botswana) to Lephalale (South Africa)

In view of this development, the Consultant has found that connecting the proposed line from Katima Mulilo into Botswana via Ngoma (Namibia) is a 'potential' option apart from direct connectivity to Zambia through Katima Mulilo- Shesheke. From Ngoma, the line would traverse Northwest Botswana, connect with the proposed Mosetse – Kazungula line and ultimately connect with Kazungula Bridge (and eventually, Livingstone, Zambia).

As expected, both the financial returns of the TZR and economic returns to Namibia are much higher under a case where the Trans-Zambezi is further extended into Zambia or Botswana relative to confining the project to within the country's borders

Additionally, Zambia and Botswana recently completed the Kazungula Bridge and have formed a national partnership towards connecting the two countries by rail through this bridge. Namibia must become part of this partnership. The proposed TZR will see its full potential if it is co-developed with Zambia and Botswana and their ongoing joint railway developments.

Traffic Certainty

Traffic certainty drives the viability of a railway project and synchronizing the TZR with neighbouring railway developments will enhance this certainty. In-turn, this will feed back to the financing potential and 'tenderability' of the TZR's development and operations.

Immediate next steps would include forming a tri-patriate agreement with Zambia and Botswana so that all three countries' railway developments are synchronized and so that there is a uniform inter-operability framework and operational procedures.

The Consultant has offered its expertise and services to study the potential regional connectivity through Botswana as an extension of the present mandate for such studies.

14.3 Immediate Project Activities following this Study

Implementing large infrastructure projects is a complex activity with many actors and activities contributing to successfully realizing these projects. This is particularly true for (Greenfield) railway projects, such as the proposed TZR.

Railway development requires the integration of *horizontal* elements such as truck, bridges and roadways and *vertical* elements such as stations, yards, and maintenance facilities necessitates a comprehensive set of design and construction services not typically found in other large projects.

Given the complexity of implementing large scale railway infrastructure projects, a rubust project plan at the initial stages becomes a requirement for successful implementation. And indeed, with the MoWT currently carrying out a feasibility study for the TZR, this requirement is alread being addressed by the Client.

14.3.1 Front-end Planning

Robust "Front-end Planning" involves meticulously planning the development of the TZR and Figure 14-1 summarizes key activities that are required by stage (project development, implementation and capacity building) for successful implementation.

Figure 14-1: Overarching Project Planning Activities by Stage

Project Development		Implementation – Financing, Construction and Procurement				Capacity Building
Project Development	**Inter country network**	**Financing for Construction**	**Private Operator**	**Procurement for Implementation**	**Testing & Commissioning**	**MoWT/ TransNamib**
Feasibility Study	Agreement with Zambia / Botswana	Selection of financing model – Multilateral, Bilateral, EPC+F	Developing PPP framework and contract agreement	Packaging of contracts – Civil, Track, S&T	Confirm infrastructure is safe and fit for use	Capacity Building – Trainings etc.
ESIA Studies	Developing inter operability framework & ops SOPs	Selection of specific financing	Define minimum performance standards	Design (FEED) and Preparation of Tender documents	Infrastructure and equipment integration	Reorient towards network mgmt and regulatory oversight
Preparation of Detailed Project Report including designs		Cross-Subsidization studies (e.g., developing SEZs)	Select and Onboard Operator	Selection of Contractors	Rollingstock to meet performance standards	Integration of marine and surface transport

Front-end Planning is critical and includes uncovering project uknowns and uncertainties (and how to address them) as the project is developed and implemented. This allows the Client to develop a structured approach to project execution and to make informed decisions on how best to allocate its resources during execution.

Practically, Front-end Planning also affords the Client to identify and mitigate issues such as right-of-way concerns, utility adjustments, environmental hazards, permitting requirements, etc.

In addition, Front-end Planning should be used to poll all major project stakeholders as to their assessment of the completeness of the process and to address their concerns in order to ensure 'stakeholder buy-in' to the project.

The overarching benefits of Front-end Planning are as follows:

1. Reduce design and construction costs
2. Improve cost and schedule predictability
3. Increase the likelihood of meeting the owner's (in this case, GoG) goals of the project

As per Figure 14-1, the MoWT is currently in the 'feasibility' stage in the Front-end Planning process. Activities following feasibility are discussed below and assume that the Client has taken a decision to move forward with the project into the next stage.

Please note that some of the activities or 'next steps' below are based on the findings from the Vol. II Report (Project Feasibility). Those activities are also placed here though for further context of these activities, Vol II. should be read.

14.3.2 Detailed Environmental and Social Impact Assessment

Section 5 of Vol II. describes, in detail, the next steps required towards completing the full Environmental and Social Impact assessment in compliance with:

1. Local environmental management legislation (Environmental Management Act (2007) and Regulations (2012)).

2. International lending requirements for environmental assessment (IFC – Performance Standards for Environmental and Social Sustainability/World Bank Group – Environmental and Social Standards (ESS)).

The TZR traverses both culturally and environmentally sensitive areas and to ensure their preservation, control measures need to be spelt out and made mandatory for the contractor and the operation and maintenance team to ensure the project brings mostly benefits to Namibia and does not bring the affected society and its environment into an environmental deficit.

Therefore, an immediate next step is to also start conducting the full environmental and social impacassessment and to acquire the necessary approvals from the local environmental authority.

14.3.3 Selecting the Financing Model and Securing Funding Sources

The magnitude of investments are detailed Section 13 of this Report with an overall project size of about US$2.26 billion. This is in addition to the possible expenditures required to complete upgrading the line between Walvis Bay and Grootfontein.

Furthermore, as discussed in Section 3 of Vol II, the most suitable structure involves the government developing the TZR and providing it to a private operator (or operators) under a concession/open access regime. In other words, investments in railway infrastructure would rest with the government.

As such, selecting the financing model and securing funding sources should commence immediately after the feasibility stage is complete with possible funding sources including multi-lateral loans and grants, bilateral (country-to-country) loans and internal funding (government bursury).

Secondary funding sources should also be studied as a means for cross-subsidizing the line's development and operations. For example, Special Economic Zones could be developed at strategic locations under a Landlord model whereby the State leases land to private developers.

Private developers would responsible for developing the land into an economic zone for industrial activities such as agricultural processing, refining copper, or other key strategic activities for Namibia. In term, land lease payments to the State could be used to cross-subsidize the TZR.

14.3.4 Open Access

The 2018 Namibia Transport Policy initiates the concept of 'open access' with respect to rail operations in Namibia and Section 3 (Financial Assessment) of Vol II. confirms that the TZR be structured under an open access regime where the state provides the railway infrastructure and a private operator (or operators) provide railway operations and maintenance services. Practically, open access needs to also apply to the current network so that there are fluid rail operations beyond Grootfontein.

Open access would require amending the National Transport Services Holding Company Act, 1998 and putting into effect, new legislation. Provisions for detailed anti-competitive measures on rail operators will be required (e.g., a licensing system, operating and safety regulations and accident investigations which can be housed with TransNamib as discussed above).

As required, the Competition Act would also have to be amended to ensure there is greater detail and clarity on anti-competitive issues specific to the rail sector. The skillset of the Competition Commission may also have to be enhanced to meet the related specific requirements of Namibia's rail sector.

The Consultant virtually attended the Southern African Rail Association's (SARA) annual conference, and it was noted that there was a push for 'open access' in rail operation. Different forms of open access have transpired, with the standard definition not just limited to train operations but also subletting rolling stock to operators.

From the Zambia field mission, it was also learned that even TAZARA has opened its line to open access operators, creating competition on its own line. One aspect that transpired is on what basis are open access operators charged for using the rail infrastructure. It seems that there is scope to develop a harmonised pricing policy.

14.3.5 Develop PPP Framework and Procure a Private Operator (or Operators)

Shifting over to an open access regime where private operators are engaged to provide railway operations will require developing a PPP framework for procuring a private operator (or operators).

We recommend that a Transaction Advisor is engaged to work with MoWT on these activities. The overall objective of a transaction advisor would be to:

1. Develop the PPP framework for engaging a private operator and on this basis:

   A. Define minimum performance standards and develop tender documents

   B. Prepare the concession/open access agreement defining the government's and private operator's role and responsibilities

   C. Oversee the tender administration and advise MoWT on related matters

   D. Evaluate tender submissions including bidders' proposed specifications for rolling stock

   E. negotiate with the preferred bidder

The above activities should be conducted in accordance with Namibia's PPP Act. Ideally, the operator should also be procured before construction contracts are tendered as input from the operator will be critical on technical specifications will be critical.

14.3.6 Project Packaging and Detailed Design - Front-End Engineering (FEED)

Following feasibility, we recommend that the Client package the construction based on its core components (track, civil and structures, and signal & telecommunications) and to accordingly prepare Detailed Designs till the stage of Front-end Engineering for the same.

The focus of FEED should be to:

1. Environmental Impact Assessment
2. Field surveys, investigations and detailed alignment designs.
3. Provide detailed bill of quantities and cost estimates (a key reference point for the tendering stage).
4. Technical specifications
5. Detailed construction execution schedule

FEED should also be required for upgrading the current Walvis Bay – Grootfontein section where required.

The specifications, bill of quantities and cost estimates for FEED vary between +-15% and provide a sound basis for tendering as follows:

A. Removes uncertainty in bidders' financial proposals thereby removing 'risk pricing' (i.e., overpricing due to unknowns).

B. Allows for bids to be compared during evaluations giving greater confidence in final bid selection.

C. Provides a more authentic and accurate 'reference price' or 'shadow bid price' giving the Client leverage to negotiate better pricing when finalizing the contract.

In our experience, EPC or Item Rate contracts can also be tendered but issues such as non-comparable bids and cost overruns can arise. Putting resources towards FEED now can save multiples of the original FEED cost as the project progresses to construction.

14.3.7 Prepare Tender Documents and Select Contractors

With FEED complete, the next step would be to prepare tender documents for the various construction packages towards selecting contractors to construct the TZR.

14.3.8 Capacity Development

Constructing the proposed TZR offers the government/MoWT a unique opportunity to build its knowledge and skillset in effectively procuring and managing such infrastructure. Such examples of areas for potential capacity building include:

1. Railway safety and regulations
2. Infrastructure project appraisal, planning and management (from a public sector lens)
3. Railway infrastructure and rolling stock technical specification scoping, review and tendering
4. International Federation of Consulting Engineers (FIDIC) contracting management and supervision
5. Climate risk and infrastructure vulnerability
6. Railway infrastructure and rollingstock maintenance planning and oversight

As part of the Front-end Planning and as a means to ensure that the MoWT is effectively armed with the necessary tools to procure and manage such a large infrastructure project, we suggest that a 'capacity needs assessment' be conducted specific to railway development and to procure technical assistance towards fulfilling and capacity needs. We note that in recent times, other African countries such as Uganda have conducted such activities in order to enhance their ability to procure and manage railways.

14.3.9 Levelling Namibia's Land Transport Playing Field

Freight in Namibia predominantly moves by road. Some of the reasons for this can be attributed to a general dissatisfaction with rail services however, road transport pricing also plays a role. A key finding of this assignment is that the playing field between road and rail transport needs to be levelled in Namibia so that where it makes economic sense (e.g., over long distances), freight is shifted from road to rail.

The 2018 Namibian Transport Policy concisely states:

In promoting intermodalism the Government intends to level playing fields and eliminate constraints or disincentives resulting in inefficiencies, including the use of inappropriate modes. A key driver of reducing costs of transport is capacity utilisation. As such, a goal of infrastructure and modal planning will be to optimise capacity utilisation and to achieve a level of integration between modes.

The pricing dynamics and service levels between road and rail transport need to be studied in detail and where required, reforms should ensure a level playing field. As purported in the Transport Policy, reforms should rebalance total surface transport capacity towards rail and promote the integration of rail and road transport (as opposed to these two modes competing).

Namibia's Competition Commission enforces the Competition Act and has a role in leveling the playing field. As required, the Commission should be staffed with the necessary expertise not only to maintain a level playing field but to also ensure that open rail access is operated in a competitive environment (discussed below).

The policy also identifies 'Customer and Public Satisfaction' as a key performance indicator when monitoring and evaluating the performance of the policy's implementation. Given the current sentiments of rail, monitoring satisfaction – especially in an open access regime – is critical.

14.3.10 Defining TransNamib's Role

Section 6 (Legal and Regulatory Assessment) of Vol. II has identified certain legal shortcomings of TransNamib's functions, namely the self-regulating nature of the entity[28]. In addition, research and consultations for this assignment have also highlighted the operating and commercial-oriented shortcomings of TransNamib.

As the country moves towards commercially oriented railway operations with private sector participation, there are certainly opportunities to refocus TransNamib's role in Namibia's rail sector.

TransNamib

TransNamib is housed with Namibia's railway heritage and institutional memory and on this basis alone, there is a real opportunity to redefine TransNamib's role in Namibia's railway development and operations.

For example, while operations may be completely migrated to the private sector, TransNamib can be redefined as a Railway Authority charged with addressing operator licensing, open

[28] See 2018 Namibia Transport Policy

access and safety regulations and accident investigations. TransNamib can also oversee the 'Transport Investment Fund' as discussed in Section 3 of Vol II.

As the Railway Authority, TransNamib should be completely independent from rail infrastructure ownership and operations. Furthermore, its financial sustainability should not be tied to licensing fees to remove any 'conflict of interest' between railway operations and regulations.

14.3.11 Full View of the Logistics Chain (from Vol. II)

The proposed TZR is only one 'hard initiative' in improving Namibia's overall logistics chains towards becoming a premier logistics hub. The interface between land and maritime transport also needs to be considered. Specifically, the infrastructure and services at the Port of Walvis Bay need to be positioned to meet the traffic handled by the TZR.

In other words, the cost effectiveness of ports play an important role in choosing export route options. Logistics companies look holistically, and it is not beneficial if the TZR results in significant benefits to companies while port costs and delays completely negates these benefits.

To this end, we understand that Namport is developing a ports masterplan. This masterplan should consider the infrastructure and/or service requirements that may be required now and, in the future, to handle the traffic generated by the TZR.

14.4 Implementation Schedule

It is the Consultant's view that the TZR can be developed and made operational by the first quarter of 2027. Figure 14-2 provides an 'implementation schedule' for the activities mentioned in the previous section through to construction completion.

Figure 14-2: Project Implementation Schedule

Activity #	Implementation Activity	Responsibility	Duration (Months)	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	Aug-23	Feb-24	Aug-24	Feb-25	Aug-25	Feb-26	Aug-26	Mar-27
				Pre-Construction Period												Construction Period									
1	Resolve Interoperability Issues between the TZR and the existing Walvis Bay Section	MoWT	3																						
2	Resolve pricing dynamics and other issues between rail and road transport removing any advantages to road	MoWT, Competition Commission	5																						
3	Implement Tri-Patriate Railway Development Agreement with Zambia and Botswana	Governments of Namibia, Zambia and Botswana	7																						
4	Restructure TransNamib as a railway authority charged with operator licensing, open access and safety regulations and accident investigations	MoWT, TransNamib	8																						
5	Amend legislation to allow for open access to private rail operators	MoWT, Cabinet, Parliament, Attorney General	12																						
6	Prepare the environmental and social impact assessment and conclude land acquisition/resettlement	MoWT	10																						
7	Prepare FEED for TZR (and existing sections where required)	MoWT	7																						
8	Secure funding for the TZR	MoWT, MoF, Transport Advisory Board	12																						
9	Procure Contractor to Construct the TZR	MoWT	12																						
10	Procure a Private Operator (or Operators)	MoWT / MoF	12																						
11	Construct the TZR	MoWT/Contractor	48																						
12	MoWT Capacity Development	MoWT	Throughout and designed at specific milestone points																						
13	Integrate TZR traffic into NamPort's future port expansion plans	MoWT / NamPort	Throughout TZR (pre)construction and operations																						

15 Appendices

15.1 Appendix -1- Geometrical Features-Gradient

Table 15-1: List of Gradients

#	Chainage (km)		Gradient (1 in n)		Distance (km)	Cumulative Distance (km)
	From	To	Rise	Fall		
1	0.000	1.500		800	1.500	1.500
2	1.500	2.500	170		1.000	2.500
3	2.500	3.900		185	1.400	3.900
4	3.900	6.500		170	2.600	6.500
5	6.500	9.700	180		3.200	9.700
6	9.700	22.000		170	12.300	22.000
7	22.000	23.200		400	1.200	23.200
8	23.200	38.000		170	14.800	38.000
9	38.000	39.100		400	1.100	39.100
10	39.100	44.500		170	5.400	44.500
11	44.500	51.200		200	6.700	51.200
12	51.200	52.100	400		0.900	52.100
13	52.100	53.100	200		1.000	53.100
14	53.100	62.900		800	9.800	62.900
15	62.900	64.000		400	1.100	64.000
16	64.000	73.700		800	9.700	73.700
17	73.700	76.000		400	2.300	76.000
18	76.000	86.300	Level		10.300	86.300
19	86.300	88.500		600	2.200	88.500
20	88.500	90.100	200		1.600	90.100
21	90.100	94.100	Level		4.000	94.100
22	94.100	95.400		200	1.300	95.400
23	95.400	98.900	800		3.500	98.900
24	98.900	100.400	Level		1.500	100.400
25	100.400	101.500		800	1.100	101.500
26	101.500	103.000	Level		1.500	103.000
27	103.000	104.300	500		1.300	104.300
28	104.300	106.600	Level		2.300	106.600
29	106.600	108.500		400	1.900	108.500
30	108.500	115.000	Level		6.500	115.000
31	115.000	115.900	200		0.900	115.900
32	115.900	120.000	Level		4.100	120.000
33	120.000	121.200		200	1.200	121.200
34	121.200	124.500	250		3.300	124.500
35	124.500	129.200		400	4.700	129.200
36	129.200	130.700	300		1.500	130.700
37	130.700	132.600		800	1.900	132.600
38	132.600	137.700	600		5.100	137.700
39	137.700	140.300		500	2.600	140.300
40	140.300	142.100		400	1.800	142.100
41	142.100	144.700	300		2.600	144.700

#	Chainage (km)		Gradient (1 in n)		Distance (km)	Cumulative Distance (km)
	From	To	Rise	Fall		
42	144.700	150.400		500	5.700	150.400
43	150.400	152.300	400		1.900	152.300
44	152.300	154.300		170	2.000	154.300
45	154.300	155.300		500	1.000	155.300
46	155.300	158.000	800		2.700	158.000
47	158.000	163.400	Level		5.400	163.400
48	163.400	165.700		200	2.300	165.700
49	165.700	168.100		400	2.400	168.100
50	168.100	169.300	200		1.200	169.300
51	169.300	170.600		400	1.300	170.600
52	170.600	180.400	Level		9.800	180.400
53	180.400	181.600		200	1.200	181.600
54	181.600	214.700	Level		33.100	214.700
55	214.700	216.900		300	2.200	216.900
56	216.900	224.100	Level		7.200	224.100
57	224.100	230.800		800	6.700	230.800
58	230.800	236.100		400	5.300	236.100
59	236.100	241.300	Level		5.200	241.300
60	241.300	244.100		200	2.800	244.100
61	244.100	248.400	Level		4.300	248.400
62	248.400	255.100		400	6.700	255.100
63	255.100	258.600		200	3.500	258.600
64	258.600	260.700	Level		2.100	260.700
65	260.700	262.700	200		2.000	262.700
66	262.700	264.300	400		1.600	264.300
67	264.300	265.700	200		1.400	265.700
68	265.700	274.100		1200	8.400	274.100
69	274.100	276.500		200	2.400	276.500
70	276.500	280.300		800	3.800	280.300
71	280.300	282.700	1200		2.400	282.700
72	282.700	284.200		400	1.500	284.200
73	284.200	285.400	200		1.200	285.400
74	285.400	286.500	Level		1.100	286.500
75	286.500	288.000	200		1.500	288.000
76	288.000	292.900	800		4.900	292.900
77	292.900	295.200	Level		2.300	295.200
78	295.200	296.900		400	1.700	296.900
79	296.900	298.000	1000		1.100	298.000
80	298.000	299.300	Level		1.300	299.300
81	299.300	301.200	800		1.900	301.200
82	301.200	302.100	Level		0.900	302.100
83	302.100	308.900		700	6.800	308.900
84	308.900	312.400		400	3.500	312.400
85	312.400	317.800	400		5.400	317.800
86	317.800	319.100		200	1.300	319.100
87	319.100	327.200	Level		8.100	327.200
88	327.200	330.700		400	3.500	330.700

#	Chainage (km)		Gradient (1 in n)		Distance (km)	Cumulative Distance (km)
	From	To	Rise	Fall		
89	330.700	336.200	Level		5.500	336.200
90	336.200	338.900		200	2.700	338.900
91	338.900	339.700	Level		0.800	339.700
92	339.700	340.500	200		0.800	340.500
93	340.500	341.500	Level		1.000	341.500
94	341.500	343.100	200		1.600	343.100
95	343.100	349.600	Level		6.500	349.600
96	349.600	350.600		200	1.000	350.600
97	350.600	357.400	800		6.800	357.400
98	357.400	360.300		500	2.900	360.300
99	360.300	362.300	300		2.000	362.300
100	362.300	365.100		1000	2.800	365.100
101	365.100	366.200	200		1.100	366.200
102	366.200	368.700		300	2.500	368.700
103	368.700	370.000	Level		1.300	370.000
104	370.000	373.000	200		3.000	373.000
105	373.000	379.100		400	6.100	379.100
106	379.100	381.100	600		2.000	381.100
107	381.100	382.000		170	0.900	382.000
108	382.000	384.900	300		2.900	384.900
109	384.900	388.300		500	3.400	388.300
110	388.300	389.700	Level		1.400	389.700
111	389.700	392.900	300		3.200	392.900
112	392.900	393.800	Level		0.900	393.800
113	393.800	395.600		200	1.800	395.600
114	395.600	397.800	600		2.200	397.800
115	397.800	399.300		400	1.500	399.300
116	399.300	402.400	Level		3.100	402.400
117	402.400	408.100		300	5.700	408.100
118	408.100	410.600	300		2.500	410.600
119	410.600	413.500		1000	2.900	413.500
120	413.500	422.700	Level		9.200	422.700
121	422.700	425.000	400		2.300	425.000
122	425.000	430.300		800	5.300	430.300
123	430.300	433.500		300	3.200	433.500
124	433.500	434.400	200		0.900	434.400
125	434.400	448.000	Level		13.600	448.000
126	448.000	448.900	800		0.900	448.900
127	448.900	457.400		800	8.500	457.400
128	457.400	459.000	Level		1.600	459.000
129	459.000	463.800		200	4.800	463.800
130	463.800	465.900	1200		2.100	465.900
131	465.900	470.900		800	5.000	470.900
132	470.900	472.400	Level		1.500	472.400
133	472.400	474.600	500		2.200	474.600
134	474.600	476.600	170		2.000	476.600
135	476.600	479.200	400		2.600	479.200

#	Chainage (km)		Gradient (1 in n)		Distance (km)	Cumulative Distance (km)
	From	To	Rise	Fall		
136	479.200	495.800	Level		16.600	495.800
137	495.800	504.500		800	8.700	504.500
138	504.500	506.200	800		1.700	506.200
139	506.200	510.200	Level		4.000	510.200
140	510.200	515.100		1200	4.900	515.100
141	515.100	521.400	Level		6.300	521.400
142	521.400	525.500	800		4.100	525.500
143	525.500	527.200		400	1.700	527.200
144	527.200	528.800		200	1.600	528.800
145	528.800	533.500	Level		4.700	533.500
146	533.500	535.100	1000		1.600	535.100
147	535.100	539.900	Level		4.800	539.900
148	539.900	542.400		400	2.500	542.400
149	542.400	561.600	Level		19.200	561.600
150	561.600	570.300		800	8.700	570.300
151	570.300	572.200	400		1.900	572.200
152	572.200	580.100		800	7.900	580.100
153	580.100	582.400	300		2.300	582.400
154	582.400	585.700		800	3.300	585.700
155	585.700	592.300	1800		6.600	592.300
156	592.300	593.300		200	1.000	593.300
157	593.300	596.800	800		3.500	596.800
158	596.800	598.100		200	1.300	598.100
159	598.100	599.400	800		1.300	599.400
160	599.400	600.900		400	1.500	600.900
161	600.900	604.400	800		3.500	604.400
162	604.400	609.700		1000	5.300	609.700
163	609.700	611.500	800		1.800	611.500
164	611.500	617.700		700	6.200	617.700
165	617.700	621.300	800		3.600	621.300
166	621.300	622.500		200	1.200	622.500
167	622.500	624.100	800		1.600	624.100
168	624.100	640.400	Level		16.300	640.400
169	640.400	643.600		300	3.200	643.600
170	643.600	645.300	Level		1.700	645.300
171	645.300	648.000	300		2.700	648.000
172	648.000	651.300		400	3.300	651.300
173	651.300	654.300	500		3.000	654.300
174	654.300	657.800		800	3.500	657.800
175	657.800	660.200		300	2.400	660.200
176	660.200	661.700	Level		1.500	661.700
177	661.700	663.900		400	2.200	663.900
178	663.900	667.100	170		3.200	667.100
179	667.100	670.300	Level		3.200	670.300
180	670.300	672.400		1200	2.100	672.400
181	672.400	675.700	400		3.300	675.700
182	675.700	677.800		200	2.100	677.800

#	Chainage (km)		Gradient (1 in n)		Distance (km)	Cumulative Distance (km)
	From	To	Rise	Fall		
183	677.800	686.300		800	8.500	686.300
184	686.300	691.300	Level		5.000	691.300
185	691.300	696.200		1000	4.900	696.200
186	696.200	713.400	Level		17.200	713.400
187	713.400	720.600		800	7.200	720.600
188	720.600	722.600	300		2.000	722.600
189	722.600	728.500	Level		5.900	728.500
190	728.500	731.900	800		3.400	731.900
191	731.900	734.500	Level		2.600	734.500
192	734.500	736.100		800	1.600	736.100
193	736.100	740.000	Level		3.900	740.000
194	740.000	742.100		200	2.100	742.100
195	742.100	755.700	Level		13.600	755.700
196	755.700	759.200		400	3.500	759.200
197	759.200	762.200	800		3.000	762.200
198	762.200	764.500		1000	2.300	764.500
199	764.500	765.400	200		0.900	765.400
200	765.400	772.000	Level		6.600	772.000

15.2 Appendix -2 – Geometrical Features- Curves

Table 15-2: Curvature Details of Final Route

#	Start Chainage(m)	End Chainage(m)	Length(m)	Degree of Curvature by Arc	Radius(m)
1	2775.04	2837.83	62.797	5.83	300
2	2989.19	3434.87	445.675	5.83	300
3	3552.21	4737.01	1184.795	2.92	600
4	5289.3	6123.5	834.206	2.06	850
5	7100.9	7396.33	295.424	1.75	1,000
6	8292.51	9246.14	953.629	2.06	850
7	10356.76	10474.57	117.817	0.88	2,000
8	11646.57	12219.66	573.086	1.46	1,200
9	18244.04	18293.71	49.67	1.75	1,000
10	18441.45	18472.51	31.068	1.75	1,000
11	19013.41	19059.58	46.169	1.75	1,000
12	19338.72	19458.67	119.948	1.75	1,000
13	19689.61	19752.81	63.21	1.75	1,000
14	20035.45	20151.56	116.113	1.75	1,000
15	20363.33	20420.07	56.743	1.75	1,000
16	20580.38	20617.12	36.738	1.75	1,000
17	20860.99	20906.83	45.843	2.5	700
18	21147.92	21154.76	6.84	2.5	700

#	Start Chainage(m)	End Chainage(m)	Length(m)	Degree of Curvature by Arc	Radius(m)
19	21366.55	21415.23	48.679	1.75	1,000
20	29259.62	29409.59	149.975	1.75	1,000
21	29542.71	29588.67	45.962	1.75	1,000
22	37261.02	37288.14	27.122	1.75	1,000
23	39790.99	39953.98	162.983	1.75	1,000
24	48618.12	48728.34	110.212	1.75	1,000
25	50371.85	50576.65	204.802	2.5	700
26	56666.87	56691.92	25.044	1.75	1,000
27	59859.02	59870.32	11.295	1.75	1,000
28	62469.47	62613.06	143.587	1.75	1,000
29	65799.03	65801.98	2.946	1.75	1,000
30	71560.56	72031.11	470.547	1.46	1,200
31	74545.89	75454.26	908.366	1.82	960
32	77563.84	77673.2	109.356	1.75	1,000
33	81921.84	82218.03	296.195	1.75	1,000
34	82352.02	82480.34	128.32	2.92	600
35	82734.22	82775.01	40.797	1.75	1,000
36	86422.77	86650.46	227.688	1.75	1,000
37	89660.38	89678.17	17.788	0.7	2,500
38	98906.16	98947.18	41.025	1.75	1,000
39	99117.47	99288.23	170.759	1.75	1,000
40	102483.9	102653.5	169.652	1.75	1,000
41	103675.7	104085.4	409.746	1.75	1,000
42	113270.1	113272.5	2.392	1.75	1,000
43	117786.5	117800.5	14.008	1.75	1,000
44	130452.2	130936	483.728	1.75	1,000
45	131387	131711.5	324.546	1.75	1,000
46	132280.9	132895.7	614.83	1.46	1,200
47	134229	134519.6	290.67	1.75	1,000
48	140061.3	140077.5	16.182	1.17	1,500
49	153725.3	153733.2	7.971	1.46	1,200
50	160560.7	160562.3	1.547	1.46	1,200
51	170113.8	170563.9	450.176	1.75	1,000
52	170959.7	171420.7	461.016	1.75	1,000
53	173545.2	174061.7	516.478	2.06	850
54	174211.4	174731.2	519.784	2.06	850
55	200518.2	200527.6	9.441	1.46	1,200
56	205417.5	205443.4	25.824	1.46	1,200
57	214758.3	214776.8	18.59	1.17	1,500
58	218577.7	218882.8	305.058	1.75	1,000

#	Start Chainage(m)	End Chainage(m)	Length(m)	Degree of Curvature by Arc	Radius(m)
59	219580.4	219893.3	312.897	1.75	1,000
60	220892.7	221071.4	178.725	1.75	1,000
61	222285.5	222472.6	187.117	1.75	1,000
62	223229	223238.2	9.193	1.46	1,200
63	230761.7	230769.5	7.804	0.58	3,000
64	236283.8	236511.4	227.647	1.75	1,000
65	242847.8	242862.1	14.279	2.33	750
66	242978.9	243062.9	84.073	2.06	850
67	244621.9	244879.3	257.36	1.75	1,000
68	246183.4	246681.3	497.888	1.75	1,000
69	248540.3	248721.1	180.841	1.75	1,000
70	253900.3	253965.2	64.993	1.75	1,000
71	254137.9	254201.3	63.46	1.75	1,000
72	256446.3	256984.7	538.429	0.88	2,000
73	258834.3	259518.9	684.582	1.75	1,000
74	260325	260485.6	160.571	1.75	1,000
75	261750.4	262090.9	340.467	1.75	1,000
76	264315.5	265099.8	784.272	1.75	1,000
77	267778.2	269115.1	1336.882	1.17	1,500
78	270248.2	270275.9	27.679	0.88	2,000
79	279653.5	279867	213.511	1.75	1,000
80	281218.9	281328	109.081	1.75	1,000
81	282121.2	282166.5	45.252	1.75	1,000
82	285311.3	285530.6	219.271	1.46	1,200
83	286186.5	286394.1	207.515	1.75	1,000
84	291632.5	291950.9	318.418	1.75	1,000
85	300019	300322	303.069	2.06	850
86	306996.9	307199.5	202.622	1.75	1,000
87	308069.9	308292.3	222.345	2.06	850
88	313576.9	313624.4	47.467	1.75	1,000
89	319001.7	319009.7	8.013	1.46	1,200
90	331218.9	331334.5	115.581	1.75	1,000
91	337337.7	337575.2	237.44	1.75	1,000
92	340639	340640.9	1.856	0.88	2,000
93	348756.8	349069.3	312.565	1.75	1,000
94	350626.2	350740.5	114.38	1.75	1,000
95	351060	351119.3	59.318	1.75	1,000
96	360432.2	360738.8	306.564	1.75	1,000
97	368382.3	368486	103.698	1.75	1,000
98	368733	368903.3	170.318	1.46	1,200

#	Start Chainage(m)	End Chainage(m)	Length(m)	Degree of Curvature by Arc	Radius(m)
99	378302.8	378565.8	263.017	1.75	1,000
100	378865	378894.1	29.129	0.88	2,000
101	390874.3	391126.7	252.455	1.75	1,000
102	408481.5	408569.6	88.128	1.75	1,000
103	409675.4	409811.2	135.738	1.46	1,200
104	419840.1	419992.8	152.708	1.75	1,000
105	420879.3	421051.8	172.429	1.75	1,000
106	438825.7	439143.7	317.991	0.88	2,000
107	439359.8	439482.6	122.832	1.75	1,000
108	443486.1	443585.3	99.136	1.75	1,000
109	443942.5	444024.7	82.221	2.06	850
110	452818.8	453090.6	271.74	1.17	1,500
111	457213.3	457299.8	86.588	1.75	1,000
112	462204.8	462306.6	101.828	1.75	1,000
113	464001.5	464639.8	638.365	1.75	1,000
114	465345	465932.8	587.803	1.75	1,000
115	466172	466690.6	518.519	1.75	1,000
116	468981	470542.7	1561.645	1.46	1,200
117	472092.1	473956.9	1864.84	1.94	900
118	475092.9	475655.3	562.334	1.75	1,000
119	488097.3	488151.3	54.018	1.75	1,000
120	508775.4	508947.1	171.706	0.88	2,000
121	509268.4	509284.4	16.028	1.75	1,000
122	509588.7	509773.9	185.185	0.88	2,000
123	510334.8	510366	31.249	1.75	1,000
124	523774.3	525116.8	1342.537	0.44	4,000
125	540992.2	541090.5	98.279	1.17	1,500
126	546916.6	547024.6	108.025	0.88	2,000
127	547368.9	547392.8	23.981	1.75	1,000
128	547746	547758.3	12.329	1.75	1,000
129	548063.7	548115.2	51.509	1.75	1,000
130	555444.9	555759.2	314.25	0.7	2,500
131	556198.1	556284.1	85.981	1.46	1,200
132	556759	556903	144.06	1.17	1,500
133	557380	557649.2	269.169	0.88	2,000
134	558027.9	558058	30.049	1.75	1,000
135	558567.3	558609.4	42.116	0.88	2,000
136	561289.5	561318	28.432	1.17	1,500
137	563996.4	565416.4	1420.035	0.39	4,500
138	584958.8	585003.5	44.717	1.46	1,200

#	Start Chainage(m)	End Chainage(m)	Length(m)	Degree of Curvature by Arc	Radius(m)
139	585404.4	585407.3	2.827	1.75	1,000
140	590347	590405.5	58.5	1.75	1,000
141	599672.5	599739.5	67.024	1.46	1,200
142	634923.6	636060.7	1137.148	0.44	4,000
143	636547.6	636603.3	55.656	1.75	1,000
144	642312.3	642925.7	613.404	0.58	3,000
145	643323.2	643387.8	64.613	1.75	1,000
146	643860.3	644077.8	217.494	0.7	2,500
147	651066.7	651869.8	803.066	0.5	3,500
148	657318.5	658237.9	919.311	0.7	2,500
149	658998.1	659156.9	158.716	1.75	1,000
150	659704.2	660315.3	611.097	1.75	1,000
151	661370.4	661905.8	535.423	2.06	850
152	662281.7	662977.5	695.84	1.75	1,000
153	664848.9	664989.4	140.49	1.75	1,000
154	675359.6	675453.8	94.276	1.17	1,500
155	679635.8	680568.7	932.899	0.44	4,000
156	681001.4	681169.3	167.931	1.17	1,500
157	685345.8	685725.6	379.731	0.88	2,000
158	686427.2	686472.3	45.156	1.46	1,200
159	692487.4	692521.8	34.47	0.88	2,000
160	693029.7	693149.9	120.235	1.17	1,500
161	702876.5	703421.1	544.629	0.58	3,000
162	713536.5	713559.2	22.691	1.17	1,500
163	721624.5	722146.2	521.686	0.88	2,000
164	726708.5	726715.5	7	1.75	1,000
165	738849.1	738857.9	8.818	1.46	1,200
166	740425.5	740428	2.496	1.75	1,000
167	746857.5	746947.7	90.198	0.88	2,000
168	754698.8	754776.8	78.047	1.75	1,000
169	755068.2	755100.1	31.886	1.75	1,000
170	759379.7	759582.3	202.608	1.46	1,200
171	759926.1	759982.4	56.299	1.75	1,000

15.3 Appendix -3 – Major/Minor/Important Bridge List

Table 15-3: List of Proposed Major Bridges

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)	Remark
1	11.900	PSC Slab	2	6	Near Grootfontein
2	15.142	PSC Slab	2	6	Near Grootfontein
3	15.489	PSC Slab	2	6	Near Grootfontein
4	37.100	Steel Girder	1	30	Kokasib River
5	259.345	PSC Slab	2	6	Ndonga River
6	284.980	PSC Slab	2	6	Near Kambowo
7	360.000	PSC Slab	2	6	Omatako River

Table 15-4: List of Proposed Minor Bridges

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
1	13.005	RCC Box	1	2
2	13.010	RCC Box	1	2
3	13.015	RCC Box	1	2
4	14.270	RCC Box	1	2
5	16.517	PSC Slab	1	6
6	17.500	RCC Box	1	2
7	19.200	RCC Box	1	2
8	39.000	RCC Box	1	2
9	39.580	RCC Box	1	2
10	39.620	RCC Box	1	2
11	39.820	RCC Box	1	2
12	40.420	RCC Pipe	1	0.75
13	41.200	RCC Pipe	1	0.75
14	41.810	RCC Box	1	2
15	42.390	RCC Box	1	2
16	42.710	RCC Box	1	2
17	43.155	RCC Box	1	2
18	43.365	RCC Box	1	2
19	44.103	RCC Box	1	2
20	45.750	RCC Pipe	1	0.75
21	46.194	RCC Pipe	1	0.75
22	53.000	RCC Pipe	1	0.75
23	53.370	RCC Pipe	1	0.75
24	53.860	RCC Pipe	1	0.75
25	54.250	RCC Pipe	1	0.75
26	54.405	RCC Box	1	2
27	54.670	RCC Box	1	2
28	54.860	RCC Pipe	1	0.75
29	55.240	RCC Box	1	2

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
30	55.460	RCC Box	1	2
31	55.630	RCC Box	1	2
32	55.765	RCC Box	1	2
33	56.170	RCC Box	1	2
34	56.355	RCC Pipe	1	0.75
35	56.630	RCC Box	1	2
36	56.730	RCC Box	1	2
37	57.000	RCC Box	1	2
38	57.085	RCC Box	1	2
39	57.385	RCC Pipe	1	0.75
40	57.775	RCC Pipe	1	0.75
41	58.250	RCC Pipe	1	0.75
42	58.605	RCC Box	1	2
43	58.770	RCC Box	1	2
44	58.885	RCC Box	1	2
45	59.160	RCC Box	1	2
46	59.430	RCC Box	1	2
47	59.690	RCC Box	1	2
48	60.150	RCC Box	1	2
49	60.330	RCC Box	1	2
50	60.520	RCC Box	1	2
51	60.600	RCC Box	1	2
52	60.666	RCC Box	1	2
53	60.772	RCC Box	1	2
54	60.912	RCC Box	1	2
55	61.220	RCC Box	1	2
56	61.350	RCC Box	1	2
57	61.685	RCC Pipe	1	0.75
58	62.210	RCC Box	1	2
59	62.530	RCC Box	1	2
60	62.782	RCC Box	1	2
61	62.885	RCC Box	1	2
62	63.000	RCC Box	1	2
63	63.015	RCC Box	1	2
64	63.540	RCC Box	1	2
65	63.740	RCC Box	1	2
66	64.000	RCC Box	1	2
67	64.190	RCC Box	1	2
68	64.590	RCC Box	1	2
69	65.000	RCC Box	1	2
70	66.000	RCC Box	1	2
71	66.500	RCC Box	1	2

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
72	67.080	RCC Box	1	2
73	67.640	RCC Box	1	2
74	68.090	RCC Box	1	2
75	68.350	RCC Box	1	2
76	68.500	RCC Box	1	2
77	68.730	RCC Box	1	2
78	71.190	RCC Box	1	2
79	71.580	RCC Box	1	2
80	73.120	RCC Box	1	2
81	73.490	RCC Box	1	2
82	74.100	RCC Box	1	2
83	74.350	RCC Box	1	2
84	74.480	RCC Box	1	2
85	74.580	RCC Box	1	2
86	74.730	RCC Box	1	2
87	75.203	RCC Box	1	2
88	75.315	RCC Box	1	2
89	75.530	RCC Box	1	2
90	75.675	RCC Box	1	2
91	75.730	RCC Box	1	2
92	75.785	RCC Box	1	2
93	75.830	RCC Box	1	2
94	76.550	RCC Pipe	1	0.75
95	76.935	RCC Box	1	2
96	77.170	RCC Box	1	2
97	77.850	RCC Box	1	2
98	78.120	RCC Box	1	2
99	79.680	RCC Box	1	2
100	80.050	RCC Box	1	2
101	80.500	RCC Box	1	2
102	80.870	RCC Box	1	2
103	81.200	RCC Box	1	2
104	81.700	RCC Box	1	2
105	82.000	RCC Box	1	2
106	83.057	RCC Box	1	2
107	83.600	RCC Box	1	2
108	84.180	RCC Box	1	2
109	85.540	RCC Box	1	2
110	86.180	RCC Box	1	2
111	86.280	RCC Box	1	2
112	86.450	RCC Pipe	1	0.75
113	86.800	RCC Box	1	2

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
114	86.950	RCC Box	1	2
115	87.430	RCC Box	1	2
116	88.700	RCC Box	1	2
117	89.010	RCC Box	1	2
118	89.320	RCC Box	1	2
119	89.650	RCC Pipe	1	0.75
120	90.250	RCC Box	1	2
121	90.400	RCC Box	1	2
122	90.740	RCC Box	1	2
123	92.000	RCC Box	1	2
124	92.300	RCC Box	1	2
125	92.900	RCC Pipe	1	0.75
126	93.150	RCC Box	1	2
127	93.400	RCC Box	1	2
128	93.540	RCC Box	1	2
129	93.730	RCC Box	1	2
130	94.720	RCC Box	1	2
131	95.050	RCC Box	1	2
132	95.250	RCC Box	1	2
133	96.550	RCC Pipe	1	0.75
134	97.140	RCC Box	1	2
135	97.520	RCC Box	1	2
136	97.620	RCC Box	1	2
137	97.865	RCC Box	1	2
138	98.100	RCC Box	1	2
139	98.465	RCC Box	1	2
140	99.820	RCC Box	1	2
141	100.420	RCC Box	1	2
142	100.720	RCC Box	1	2
143	101.220	RCC Box	1	2
144	102.580	RCC Box	1	2
145	102.590	RCC Box	1	2
146	103.310	RCC Box	1	2
147	103.530	RCC Pipe	1	0.75
148	104.210	RCC Pipe	1	0.75
149	105.500	RCC Box	1	2
150	105.550	RCC Box	1	2
151	105.900	RCC Box	1	2
152	106.550	RCC Box	1	2
153	107.250	RCC Box	1	2
154	107.600	RCC Box	1	2
155	109.550	RCC Pipe	1	0.75

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
156	109.830	RCC Box	1	2
157	111.300	RCC Pipe	1	0.75
158	111.360	RCC Box	1	2
159	111.840	RCC Box	1	2
160	114.040	RCC Box	1	2
161	114.240	RCC Box	1	2
162	114.430	RCC Box	1	2
163	114.435	RCC Box	1	2
164	114.540	RCC Box	1	2
165	114.880	RCC Box	1	2
166	116.140	RCC Box	1	2
167	116.440	RCC Box	1	2
168	116.655	RCC Box	1	2
169	119.000	RCC Box	1	2
170	119.200	RCC Box	1	2
171	119.420	RCC Box	1	2
172	119.735	RCC Box	1	2
173	121.320	RCC Box	1	2
174	121.720	RCC Box	1	2
175	122.000	RCC Box	1	2
176	122.220	RCC Box	1	2
177	123.430	RCC Box	1	2
178	123.600	RCC Box	1	2
179	123.800	RCC Box	1	2
180	124.440	RCC Box	1	2
181	124.650	RCC Box	1	2
182	124.840	RCC Box	1	2
183	126.130	RCC Box	1	2
184	126.820	RCC Box	1	2
185	134.800	RCC Box	1	2
186	135.090	RCC Box	1	2
187	135.420	RCC Pipe	1	0.75
188	136.600	RCC Box	1	2
189	137.700	RCC Box	1	2
190	138.900	RCC Box	1	2
191	139.190	RCC Box	1	2
192	139.550	RCC Box	1	2
193	142.900	RCC Box	1	2
194	144.330	RCC Box	1	2
195	147.900	RCC Box	1	2
196	148.670	RCC Box	1	2
197	149.130	RCC Box	1	2

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
198	152.120	RCC Box	1	2
199	155.140	RCC Pipe	1	0.75
200	156.660	RCC Box	1	2
201	157.220	RCC Box	1	2
202	157.600	RCC Box	1	2
203	158.980	RCC Box	1	2
204	160.195	RCC Box	1	2
205	185.640	RCC Pipe	1	0.75
206	186.220	RCC Pipe	1	0.75
207	186.600	RCC Pipe	1	0.75
208	187.150	RCC Pipe	1	0.75
209	201.630	RCC Box	1	2
210	205.545	RCC Box	1	2
211	211.220	RCC Box	1	2
212	212.500	RCC Box	1	2
213	217.700	RCC Pipe	1	0.75
214	226.300	RCC Box	1	2
215	227.905	RCC Box	1	2
216	230.900	RCC Box	1	2
217	236.940	RCC Pipe	1	0.75
218	248.635	RCC Box	1	2
219	251.855	RCC Pipe	1	0.75
220	258.920	RCC Box	1	2
221	259.700	RCC Box	1	2
222	260.500	RCC Box	1	2
223	265.300	RCC Box	1	2
224	265.600	RCC Box	1	2
225	266.300	RCC Box	1	2
226	284.850	RCC Box	1	2
227	301.850	RCC Pipe	1	0.75
228	311.710	RCC Box	1	2
229	311.980	RCC Box	1	4
230	339.000	RCC Box	1	2
231	339.300	RCC Box	1	2
232	339.520	RCC Box	1	4
233	350.293	RCC Box	1	2
234	350.300	RCC Box	1	2
235	364.020	RCC Box	1	4
236	368.090	RCC Box	1	2
237	371.020	RCC Box	1	2
238	373.605	RCC Box	1	2
239	373.990	RCC Box	1	2

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
240	374.000	RCC Box	1	2
241	376.500	RCC Box	1	2
242	377.980	RCC Box	1	2
243	381.590	RCC Box	1	4
244	381.600	RCC Box	1	2
245	381.800	RCC Box	1	2
246	385.000	RCC Box	1	2
247	385.230	RCC Box	1	2
248	385.440	RCC Box	1	2
249	397.460	RCC Box	1	2
250	400.355	RCC Box	1	2
251	400.580	RCC Box	1	2
252	401.580	RCC Box	1	2
253	402.790	RCC Box	1	2
254	402.885	RCC Box	1	2
255	403.000	RCC Box	1	2
256	404.000	RCC Box	1	2
257	405.775	RCC Box	1	2
258	405.880	RCC Box	1	2
259	417.020	RCC Box	1	2
260	418.930	RCC Box	1	2
261	419.020	RCC Pipe	1	0.75
262	440.640	RCC Box	1	2
263	441.030	RCC Box	1	4
264	443.170	RCC Pipe	1	0.75
265	443.360	RCC Pipe	1	0.75
266	445.750	RCC Pipe	1	0.75
267	449.990	RCC Box	1	2
268	450.100	RCC Pipe	1	0.75
269	451.000	RCC Pipe	1	0.75
270	452.000	RCC Pipe	1	0.75
271	455.000	RCC Pipe	1	0.75
272	462.600	RCC Box	1	2
273	463.200	RCC Box	1	2
274	468.000	RCC Box	1	2
275	471.230	RCC Box	1	2
276	472.745	RCC Box	1	2
277	475.600	RCC Box	1	2
278	484.175	RCC Box	1	2
279	484.360	RCC Box	1	2
280	492.000	RCC Pipe	1	0.75
281	492.480	RCC Pipe	1	0.75

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
282	523.505	RCC Box	1	2
283	524.220	RCC Box	1	2
284	526.600	RCC Box	1	2
285	527.240	RCC Box	1	2
286	527.670	RCC Box	1	2
287	541.250	RCC Box	1	2
288	546.120	RCC Box	1	2
289	546.250	RCC Box	1	2
290	548.830	RCC Pipe	1	0.75
291	559.100	RCC Box	1	2
292	559.300	RCC Box	1	2
293	561.042	RCC Box	1	2
294	563.215	RCC Box	1	2
295	565.000	RCC Box	1	2
296	567.535	RCC Pipe	1	0.75
297	574.535	RCC Box	1	2
298	574.720	RCC Box	1	2
299	579.640	RCC Box	1	2
300	579.800	RCC Pipe	1	0.75
301	582.620	RCC Box	1	2
302	582.800	RCC Box	1	2
303	584.510	RCC Box	1	2
304	612.835	RCC Box	1	2
305	617.835	RCC Box	1	2
306	644.200	RCC Box	1	2
307	649.855	RCC Box	1	2
308	650.380	RCC Box	1	2
309	656.345	RCC Box	1	2
310	657.235	RCC Box	1	2
311	657.465	RCC Box	1	2
312	657.612	RCC Box	1	2
313	658.000	RCC Pipe	1	0.75
314	658.200	RCC Box	1	2
315	660.530	RCC Box	1	4
316	660.560	RCC Box	1	2
317	661.085	RCC Box	1	2
318	661.395	RCC Box	1	2
319	661.878	RCC Box	1	2
320	662.075	RCC Box	1	2
321	662.135	RCC Box	1	4
322	662.560	RCC Box	1	2
323	662.830	RCC Box	1	2

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
324	662.870	RCC Box	1	2
325	663.255	RCC Box	1	2
326	663.775	RCC Box	1	2
327	664.580	RCC Box	1	2
328	664.880	RCC Box	1	2
329	665.000	RCC Box	1	2
330	665.200	RCC Box	1	2
331	681.220	RCC Box	1	2
332	686.520	RCC Pipe	1	0.75
333	694.460	RCC Box	1	2
334	700.590	RCC Pipe	1	0.75
335	704.310	RCC Box	1	2
336	704.820	RCC Box	1	2
337	709.390	RCC Pipe	1	0.75
338	710.580	RCC Box	1	2
339	714.280	RCC Box	1	2
340	718.100	RCC Box	1	2
341	719.920	RCC Box	1	2
342	722.080	RCC Box	1	2
343	723.600	RCC Box	1	2
344	725.550	RCC Pipe	1	0.75
345	727.370	RCC Box	1	4
346	733.300	RCC Box	1	2
347	741.040	RCC Box	1	2
348	741.115	RCC Box	1	2
349	746.440	RCC Box	1	2
350	749.645	RCC Box	1	2
351	750.920	RCC Box	1	2
352	752.560	RCC Box	1	2
353	756.500	RCC Box	1	2
354	757.300	RCC Box	1	2
355	761.160	RCC Pipe	1	0.75
356	764.040	RCC Box	1	2
357	767.400	RCC Box	1	2
358	771.920	RCC Box	1	2

Table 15-5: List of Proposed Important Bridges

#	Proposed Chainage (km)	Proposed Structure	Spanning Arrangement (number X span)	Remark
1	470.941	Steel Girder	6 X 30 m + 2 X 20 m	Okavango River
2	661.485	Steel Girder	4 X 30 m	Kwando River

15.4 Appendix -4- ROB/RUB/Level Crossing

Table 15-6: List of Proposed Road Over Bridges (ROBs)

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
1	9.430	PSC Slab	1	12
2	47.900	PSC Slab	1	12
3	50.660	PSC Slab	1	12
4	111.061	PSC Slab	1	12
5	122.735	PSC Slab	1	12
6	354.000	PSC Slab	1	12
7	365.600	PSC Slab	1	12

Table 15-7: List of Proposed Road Under Bridges (RUBs)

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
1	4.545	RCC Box	1	6
2	4.700	RCC Box	1	6
3	13.630	RCC Box	1	6
4	15.600	RCC Box	1	6
5	17.330	RCC Box	1	6
6	19.250	RCC Box	1	6
7	19.306	RCC Box	1	6
8	21.305	RCC Box	1	6
9	21.420	RCC Box	1	6
10	31.820	RCC Box	1	6
11	42.535	RCC Box	1	6
12	43.170	RCC Box	1	6
13	67.355	RCC Box	1	6
14	70.310	RCC Box	1	6
15	90.090	RCC Box	1	6
16	94.000	RCC Box	1	6
17	106.325	RCC Box	1	6
18	107.615	RCC Box	1	6
19	116.260	RCC Box	1	6
20	128.210	RCC Box	1	6
21	131.270	RCC Box	1	6
22	132.450	RCC Box	1	6
23	132.530	RCC Box	1	6
24	163.200	RCC Box	1	6
25	193.170	RCC Box	1	6
26	195.310	RCC Box	1	6
27	196.430	RCC Box	1	6
28	259.190	RCC Box	1	6
29	267.000	RCC Box	1	6
30	267.520	RCC Box	1	6
31	269.131	RCC Box	1	6
32	270.131	RCC Box	1	6
33	307.140	RCC Box	1	6
34	325.000	RCC Box	1	6
35	339.170	RCC Box	1	6

#	Proposed Chainage (km)	Proposed Structure	#	Span (m)
36	359.220	RCC Box	1	6
37	366.600	RCC Box	1	6
38	374.375	RCC Box	1	6
39	374.500	RCC Box	1	6
40	397.500	RCC Box	1	6
41	397.761	RCC Box	1	6
42	424.670	RCC Box	1	6
43	424.800	RCC Box	1	6
44	470.400	RCC Box	1	6
45	470.800	RCC Box	1	6
46	471.440	RCC Box	1	6
47	471.870	RCC Box	1	6
48	474.230	RCC Box	1	6
49	534.608	RCC Box	1	6
50	535.000	RCC Box	1	6
51	535.550	RCC Box	1	6
52	539.717	RCC Box	1	6
53	539.900	RCC Box	1	6
54	545.900	RCC Box	1	6
55	546.000	RCC Box	1	6
56	573.770	RCC Box	1	6
57	574.000	RCC Box	1	6
58	613.030	RCC Box	1	6
59	657.113	RCC Box	1	6
60	659.524	RCC Box	1	6
61	660.524	RCC Box	1	6
62	664.876	RCC Box	1	6
63	666.650	RCC Box	1	6
64	682.190	RCC Box	1	6
65	712.160	RCC Box	1	6
66	713.000	RCC Box	1	6
67	727.656	RCC Box	1	6
68	750.534	RCC Box	1	6
69	752.649	RCC Box	1	6
70	756.410	RCC Box	1	6

Table 15-8: List of Proposed LC

#	Chainage (m)	Description
1	4.575	LC
2	55.660	LC
3	61.935	LC
4	62.965	LC
5	182.382	LC
6	188.108	LC
7	219.755	LC
8	231.710	LC

9	237.000	LC
10	245.800	LC
11	262.800	LC
12	280.700	LC
13	281.225	LC
14	296.680	LC
15	320.475	LC
16	362.725	LC
17	407.230	LC
18	410.610	LC
19	438.238	LC
20	447.090	LC
21	510.190	LC
22	549.000	LC
23	606.086	LC
24	628.645	LC
25	670.537	LC
26	672.856	LC
27	673.367	LC
28	708.094	LC
29	711.000	LC
30	717.090	LC
31	720.560	LC
32	761.410	LC
33	761.723	LC
34	765.723	LC
35	765.776	LC
36	767.211	LC
37	767.919	LC

15.5 Appendix -5 - Detailed Cost Estimate

15.5.1 Main Summary of Trans-Zambezi Railway Final Route Estimate

Table 15-9: Main Summary of Trans-Zambezi Railway Final Route Estimate

#	Description of Work	Total Cost (In Mn. US$)
A	**Permanent Way Material**	**375**
B	**Permanent Way Linking**	**71**
	Total of Permanent Way (Material+ Labour) (A) + (B)	**446**
C	**Formation**	**929**
	Total for P-way and Earthwork (A +B + C)	**1,375**
D	**Structures**	**436**
	Total Cost for Civil Works (A+B+C+D)	**1,811**
E	**Land Acquisition & Resettlement Cost**	35
	Total Cost for Civil Works + Land (A+B+C+D+E)	**1,846**
F	**Workshop, T&P and Electrical**	64

#	Description of Work		Total Cost (In Mn. US$)
G	**Signal & Telecommunication**		128
H	Access Roads		5
I	**Total Cost of Infrastructure (A+B+C+D+E+F+G+H)**		**2,042**
J	**Preliminary Expenses**	2%	41
K	**Contingencies and Misc.**	4%	82
L	**General Charges, Design and Project Management**	5%	102
	TOTAL COST OF PROJECT (I+J+K+L) (Rounded)		**2,267**
	Route Identification		**Final Route**
	Route Length (km)		**772.00**
	Track Length (km)		**872.93**
1	Per Route km (Million US$)		**2.94**
2	Per Track km (Million US$)		**2.60**

Note: *At Katima, cost of basic infra has been included viz. earthwork, track, low level platforms for 4 different terminals (Mineral, Oil, Food grain/ Fertilizer and Containers) but cost of development of actual terminals will be borne by separate terminal developers/ operators.*

15.5.2 Estimate of Permanent Way (including Katima Mulilo Yard)

Table 15-10: Estimate of Permanent Way

#	Description of Work	Unit	Quantity	Rate (In US$)	Amount (In US$)
	Rails				
1	Procurement and Supply of 48 **Kg Rails**. Item includes shipping and transportation of Rail to Depot/ Site with all leads & lifts	MT	89,667	1,657	148,578,219
	Sleepers		-		-
2	Manufacture / Supply of **PSC Sleepers for 48 Kg rails (Ordinary Sleepers)** including transportation of material to Depot/ Site with all leads & lifts	#	1,309,790	65	85,136,350
	Point & Crossings				
3	Supply Points & Crossing for 48 Kg Rails, 1 in 9 including leading, loading, unloading and stacking at site along with PSC Sleepers for 48 Kg rails **complete set for 1 in 9 Fan Shaped turnou**ts. - **Turnout 48 kg, 1:9 Rail bound, P2 Concrete sleepers, Secant EXW SA**	Per set	42	86,907	3,650,094
4	Supply Points & Crossing for 48 Kg Rails, 1 in 12 including leading, loading, unloading and stacking at site along with PSC Sleepers for **1 in 12 Fan Shaped turnouts. - Turnout 48 kg, 1:12 Rail bound, P2 Concrete sleepers, Secant EXW SA**	Per set	281	94,065	26,432,265
	Fittings		-		-
5	Supply of **Fish plate for 48 Kg rails** with Nuts and Bolts	Pairs	12,690	193	2,449,170
6	Supply of **Fish bolts & Nuts for 48 Kg rail. joints.**	#	76,140	5.0	380,700
7	Supply of **fastenings** for 48Kg PSC sleeper with 48 Kg rails		-		
a	Supply of **Grooved Rubber Sole Plates 6mm thick** to suit 48 kg PSC sleeper	#	2,750,559	1.5	4,125,839
b	Supply of **GFN Liners** for 48 Kg rail on 48 Kg PSC sleepers	#	5,512,400	1.1	6,063,640

#	Description of Work	Unit	Quantity	Rate (In US$)	Amount (In US$)
c	Supply of **Elastic Rail clips (ERC)** flat toe to suit 48 kg PSC sleeper	#	5,512,400	3.0	16,537,200
d	Supply of **Elastic Rail clips (ERC) 'J' type** to suit 48 kg PSC sleeper	#	76,140	3.7	281,718
	Ballast Supply				-
8	Supply and Delivery (at site) of **Hard stone Ballast of 40-65 mm size**, clean angular, hard and durable track ballast	Cum	1,205,600	58	69,924,800
	Ballast Work		-		-
9	**Picking of stone ballast** from ballast depots, leading, **spreading** uniformly on formation as to achieve standard profile	Cum	1,205,600	9	10,850,400
10	Rolling of the Ballast carpet	RMT	872,926	1	872,926
	Total cost of Permanent Way Material (A)				**375,283,321**
#	**DESCRIPTION OF WORK**	**UNIT**			
	Track Linking and Other Works				
11	**Handling, assembling, linking and laying of Railway Track with 48 Kg Rails** of all lengths on Mono block PRC sleepers on straight, curves, bridges and level crossings etc. including cutting & drilling of holes in rails wherever required & fixing fish plated joint fittings, fixing all standard fittings and fastenings by 'Mechanized' process. The Track Panels shall be made at 'Centralized' depots and carried on the site by special vehicles on rail/ road.	Track Km.	873	19,036	16,617,020

TECHNOFIN CONSULTANTS

#	Description of Work	Unit	Quantity	Rate (In US$)	Amount (In US$)
12	**Assembling, laying and linking of CG 48 kg, points and crossings 1 in 9** LH/RH with Combination GFN Liners & all fittings and fastenings, curved switches with CMS crossing on 48 Kg. PSC sleeper fan shaped layout	#	42	20,500	861,000
13	**Assembling, laying and linking of CG 48 kg, points and crossings 1 in 12 LH/RH** with Combination GFN Liners & all fittings and fastenings, curved switches with CMS crossing on 48 Kg. PSC sleeper fan shaped layout	#	281	23,429	6,583,549
14	**Welding of rail joints of 48 kg rail** with short pre heat, **Thermit Welding (SKV)** process or Flash Butt Welding Process	#	152,763	223	34,066,149
15	**Drilling of holes** 32mm/ 28mm/ 26.5mm dia.in 48 Kg rails at site wherever necessary to proper alignment and chamfering with contractors' labours, tools and plants with all leads, lifts, and track crossings complete as directed by Engineer-In-Charge.	#	76,140	2	152,280
16	**Cutting of 48 Kg** rails in main track/yard or cess, with abrasive rail cutter to proper square, truly vertical with contractor's labours, tools and plants with all lead's lifts, track crossings complete as directed by Engineer-In-Charge.	#	15,228	5	76,140
17	Fabricating, erecting and fixing in position snag dead end	#	160	4,393	702,880
18	**Fabrication, Supply, Transportation & Fixing of various sign boards v**iz. Speed indicators, "STOP"/DANGER (Caution) Sign Boards, etc.	#	1,010	279	281,790
19	Supplying & Casting and fixing RCC, Curve, Gradient, Kilometre, Fouling mark post and Bridge tablets, etc.	#	1,010	249	251,490
20	**Tamping of ballast**		-		-

#	Description of Work	Unit	Quantity	Rate (In US$)	Amount (In US$)
a	First round	RMT	873,000	2	1,746,000
b	Second round	RMT	873,000	2	1,746,000
C	Third round	RMT	873,000	1	873,000
21	**Tamping of newly laid turnouts/points and crossing**		-		-
a	First round	Each	323	528	170,544
b	Second round	Each	323	440	142,120
c	Third round	Each	323	440	142,120
22	Transportation of rails, sleepers within project area, wherever required from Stores to any location of project area.	MT	476,056	13	6,188,728
	Total cost of Permanent Way Execution (B)				**70,600,810**
	Grand Total (Schedule-A +Schedule-B)				**445,884,131**

15.5.3 Estimate of Earthwork in Formation

Table 15-11: Estimate of Earthwork in Formation

#	Description of Work	Unit	Quantity	Rate (In US$)	Amount (In US$)
1	Earthwork in **Filling in embankment** to proper profile, levels, slopes, grade and camber with contractor's own earth excavated from approved borrow areas. (Royalty if any shall be paid by Contractor)	cum	38,596,961	16	617,551,378

#	Description of Work	Unit	Quantity	Rate (In US$)	Amount (In US$)
2	**Earthwork in Cutting** in formation, side drains, level crossing approaches, platforms, catch water drains, diversion & finishing to required dimension and slopes to obtain a neat appearance to standard profile inclusive of all labour, machine & materials and removing & leading all cut spoils either to make spoil dumps beyond 10m from cutting edge or for filling in embankment with all leads, lifts, ascent, descent, loading, unloading, all taxes/royalty, clearance of site and all incidental charges, bailing & pumping out water, if required, etc.				-
2(a)	In all conditions and classifications of soil except Rock	cum	7,108,446	12	85,301,353
2 (b)	Soft rock not requiring blasting in all conditions	cum	888,556	38	33,765,119
2 (c)	In rock and very hard rock	cum	888,556	60	53,313,346
3	Supplying Sub ballast layer including spreading, watering, Compaction in layers	cum	1,043,488	24	25,043,702
4	Turfing / planting, including all lead & lift and watering as required until properly rooted	sqm	8,374,368	2	16,748,736
5	Leading cut spoil				-
5(a)	Upto 1 KM	cum	1,421,689	6	8,530,136
5(b)	Upto 5 KM	cum	1,421,689	6	8,530,136
6	Extra for compaction of cut spoil	cum	2,843,378	9	25,590,406
Total Amount (In US$)					**874,374,312**

15.5.4 Estimate of Side Drains and Fencing

Table 15-12: Estimate of Side Drains and Fencing

#	Qty. (km)	Both Side Length (m)	Total Drain Length (m)	Unit Rate (In US$ per m)	Total Cost (In US $)
1	221.2	442,400	221,200*	180	39,906,913

***Note:** *Considered drain length along both side of alignment in cutting excluding cross drainage structure, river spans, etc.)*

15.5.5 Summary of Estimate of Major, Important & Minor Bridges, Eco Crossing, ROBs, RUBs

Table 15-13: Summary of Estimate of Major, Important & Minor Bridges, Eco Crossing, ROBs, RUBs

#	Description	Unit	Quantity	Rate (In US$)	Amount (In US$)
1	**River/Cross Drainage Bridges**				
i	Minor Bridges (upto 6 m)	sqm	9,666	4,174	40,345,884
ii	Major Bridges (> 6 to upto 50 m)	sqm	622	5,492	3,417,122
iii	Important Bridges (More than 50 m)	sqm	2,074	10,983	22,778,742
2	**Road bridges**				
i	Road Over Bridges	sqm	2,450	5,766	14,126,700
ii	Road Under Bridges	sqm	42,000	4,382	184,044,000
3	**Road Crossing (At Grade Crossings)**	sqm	10,360	2,417	25,040,120
4	**Eco Crossing**	sqm	23,100	5,492	126,865,200
5	**Miscellaneous, Retaining wall**	lumpsum			5,795,051
				Total Amount (In US$)	**422,412,819**

15.5.6 Estimate of Service Building, Weigh Bridge Room, Low Level Platform including Katima Mulilo Yard

Table 15-14: Estimate of Service Building, Weigh Bridge Room, Low Level Platform

ESTIMATE OF SERVICE BUILDING, WEIGH BRIDGE ROOM, PLATFORM (LOW/HIGH LEVEL)					
#	**Description of Work**	**Unit**	**Quantity**	**Rate (In US$)**	**Amount (In US$)**
1	Construction of buildings which includes office, commercial staff rooms, Carriage and Wagon storeroom, Crew rest room, Cabins and Toilet block	sqm	1,800	586	1,054,800
2	Centralized Control Office	sqm	1,500	586	879,000
3	Weigh-Bridge Room	sqm	125	205	25,625
4	Trans-Zambezi Railway HO - Rundu	sqm	5,000	586	2,930,000
5	Platform Low Level	sqm	54,000	123	6,642,000
6	Foot Over Bridges	sqm	330	5,858	1,933,140
				Total Amount (In US$)	**13,464,565**

15.5.7 Estimate of Signal and Telecommunication

Table 15-15: Estimate of Signal and Telecommunication

#	Description of Work	Unit	Quantity	Rate (In US$)	Amount (In US$)
1	Installation of complete signaling and telecommunication systems including Signal posts, Cabling, Track circuiting, etc.	Stations	35	3,660,715	128,125,025
				Total Amount (In US$)	**128,125,025**

15.5.9 Estimate of Electrical (General Supply)

Table 15-16: Estimate of Electrical (General Supply)

#	Description of Work	Unit	Quantity	Rate (In US$)	Amount (In US$)
1	Electrification of Service Building, Electronic Weigh Bridge, cabins, electrification of office complex, etc.	Stations	35	146,429	5,125,015
				Total Amount (In US$)	**5,125,015**

15.5.10 Estimate of Workshop and Mechanical Engineering

Table 15-17: Estimate of Workshop and Mechanical Engineering

#	Description of Work	Unit	Quantity	Rate (In US$)	Amount (In US$)
					Total
1	Loco, Wagon, Workshops and Signaling, Electrical and Track Depot Workshop	sqm	6000	8,786	52,716,000
2	Procurement and Installation Machinery Equipment’s & Plants Tools etc.	Lumpsum		5,857,143	5,857,143
				Total Amount (In US$)	**58,573,143**

15.5.11 Estimate of Land

Table 15-18: Estimate of Land

Total Cost (N$) = (A)+(B)	NAD $	Area as per Corridor (50 m)	Area required as per L-section (Ha)	Total Cost (NAD $)
Final Route	478,000,000.00	3860.00	4081.00	505,293,057*
Additional for Katima Mulilo Yard	478,000,000.00	3860.00	105.00	13,002,591*

*On pro-rata basis

15.6 Appendix 6 – Gauge Convertibility & Electrical Traction

As stated in Section 4 of this Report, in 2007, the Africa Union resolved that 'Standard Gauge' (SG) should be adopted for the construction of new railway lines in order to promote interoperability on the continent. Member countries were encouraged to consider standard gauge corridors when studying and developing new lines.

The Namibian rail network stretches from the South (South African border) to the Northern part of the country (Angolan border) and from the middle of the country to its coast and harbour towns. The gauge in all the neighbouring countries i.e., Angola, Zambia, Botswana, Zimbabwe, Democratic Republic of Congo (DRC) and South Africa, is 'Cape Gauge'.

The stated objective of the proposed Trans Zambezi Railway (TZR) extension corridor is to link the Walvis Bay Port in Namibia to its hinterland as well as to provide efficient port access to adjoining land locked countries of Zambia, Botswana, DRC, and Zimbabwe.

A railway line already exists connecting Walvis Bay to Grootfontein station. The TZR will be an extension of the exiting Walvis Bay- Grootfontein corridor, which is in Cape Gauge. Change of gauge at Grootfontein will either make 'transhipment' of goods necessary at Grootfontein or necessitate huge investments in change of gauge for the railway section between Walvis Bay and Grootfontein. Both the options are unviable. Furthermore, the purpose of the Trans Zambezi railway extension is connecting Namibia (Walvis Bay port) to neighbouring countries, all of which have Cape Gauge on their railways.

Considering all the above, the gauge for the TZR has been adopted as 'Cape Gauge' for the present.

On the request of MoWT and AfDB, this section of the report deals with 'high level' recommendations related to potential future 'Gauge Conversion' to Standard Gauge (SG) and assessment of cost implications, presuming that at some point of time in distant future the whole of regional railway network does gets converted to Standard Gauge necessitating TZR too to convert.

For working out approximate cost difference for a Cape gauge and Standard Gauge the Consultant has adopted the American Railway Engineering Maintenance of Way Association's (AREMA) standards for SG.

15.6.1 Land Requirement

For a fixed land corridor of 50 m, there would not be too much impact on land requirement for SG on most of the TZR stretch. However, as stated in the subsequent section of this report, SG standards does stipulate flatter side slopes as well as about 10% higher formation width, which would make additional land acquisition necessary on stretches of high banks and deep cuttings.

As a high-level assessment, an increase in land requirement by 1.55% would translate into an increase in land cost by US$ 0.45 million (2021 prices).

15.6.2 Embankment

Additional earthwork on the 'berms' of existing formations of Cape Gauge will need to be done for conversion to SG.

- **Formation Width in Filling**: In case of standard gauge, the required formation width would be 6.1 m as compared to 5.5 m of Cape Gauge.
- **Formation Width in Cutting:** In case of SG this would be 7.3 m against 6.7 m.
- **Side slopes**: The AREMA considers a slope of 2H: 1V while the Cape Gauge standard is as per Transnet Manual is 1.5H: 1V.
- **Sub ballast:** Increase in quantity due to increase in formation width.

Due to the above reasons, the increase in earthwork quantities due to SG are summarized in Table 15-19:

Table 15-19: Increase in Earthwork Quantity Due to Gauge Convertibility

Item	Percentage increase in Quantity
Earthwork - Filling	23.50%
Earthwork - Cutting	4.86%
Sub-ballast Layer	38.38%

The percentage increase in quantity would translate to an additional cost of about US$ 170 million (2021 prices).

15.6.3 Rail

For conversion to Standard gauge, we have presumed that same 48 kg/m /57kg/m rail will continue to be used on the converted track. Hence, no additional cost for rail procurement has been considered.

15.6.4 Concrete Sleepers

The design of concrete sleepers would change to accommodate a wider gauge in case of Standard gauge. The length of Cape gauge concrete sleeper is 2,057 mm while for a standard gauge the length would be 2,600 mm. Complete sleeper renewal (probably with higher sleeper density) will become necessary.

The cost of procurement and replacement of sleepers (at 2021 prices) would be approximately **US$ 96 million**.

15.6.5 Track Fittings

Since the gauge will change and sleepers will be specific to SG, all the rail/ sleepers fittings will need to be replaced.

The cost of procurement and replacement of track/ sleeper fittings (at 2021 prices) would be approximately **US$ 30 million**.

15.6.6 Ballast

Additional ballast will be required due to increase in width of formation of standard gauge. Also, in case of standard gauge a minimum ballast depth of 300 mm is adopted.

The likely financial implications due to this will be approximately **US$ 25 million.**

15.6.7 Turnouts

The loop lengths for station sidings are being kept as 720 m for Cape Gauge track on TZR extension. Same loop lengths will be good enough for Standard Gauge too. However, all the turnouts will need to be replaced with standard layouts of SG track.

Financial cost implications for this are assessed as about **US$ 33 million.**

15.6.8 Bridges

To 'future-proof' the designs for possibly converting the alignment from cape to standard gauge at a future date, we suggest that the substructure of major and important bridges be built to standard gauge specifications with steel superstructure fit for cape gauge now itself. The steel super structure could be changed for standard gauge when required.

Also, Road Over and Road Under bridges should be designed so that they can accommodate wider dimensions necessary for a SG track, apart from potentially higher Axle Load for SG.

Minor bridges and culverts should generally be able to extend to meet with the requirements of SG.

The financial implications @ 25% of the upfront capital cost of the bridges (2021 prices) is approximately **US$ 73 million.**

15.6.9 Track Work for Gauge Conversion

Even though rails are not envisaged to be replaced still completed sleeper renewal turnout renewal and ballast enhancement will need to done for gauge conversion.

Approximate cost for all such track work can be considered as 50% of the cost of the original track linking. Hence, the estimate lumpsum cost for track gauge conversion will be approximately **US$ 36 million.**

15.6.10 Other and Miscellaneous Costs

Apart from the above itemized cost heads, there would be substantial financial implications on repositioning of signalling and electrical systems, workshop modifications, side drians, fencing and modifications to platforms and appurtenances.

Approximate cost for the above items has been considered as 25% of the original cost.

The lump sum assessed cost for all such items is approximately **US$ 65 million.**

15.6.11 Costs for Design and Management Of Conversion

The preliminay expenses, contingencies, design, management and commissioning of gauge conversion of about 772 km will in itself be a huge project. The assessed lump sum cost for the same is approximately US$ 58 milliion (2021 prices).

Hence the assessed total cost of gauge conversion from Cape Gauge to Standard Gauge would be approximately US$ 583 million (2021 prices)

15.6.12 Electric Traction

In the Stakeholders discussions, assessment of the cost of electrification for Electric Traction was enquired about. Our high level assessment of the same is about US$ 0.45 to 0.6 million per track km. This estimate does not include the cost of enabling electrical infrastructure to the corridor such as power plants, substations, and HT/LT lines.