Republic of Zambia
Road Development Agency (RDA)

DATA COLLECTION SURVEY ON TRANSPORT AND INFRASTRUCTURE DEVELOPMENT ALONG NACALA CORRIDOR

FINAL REPORT

March 2019

Japan International Cooperation Agency

Nippon Engineering Consultants Co., Ltd.

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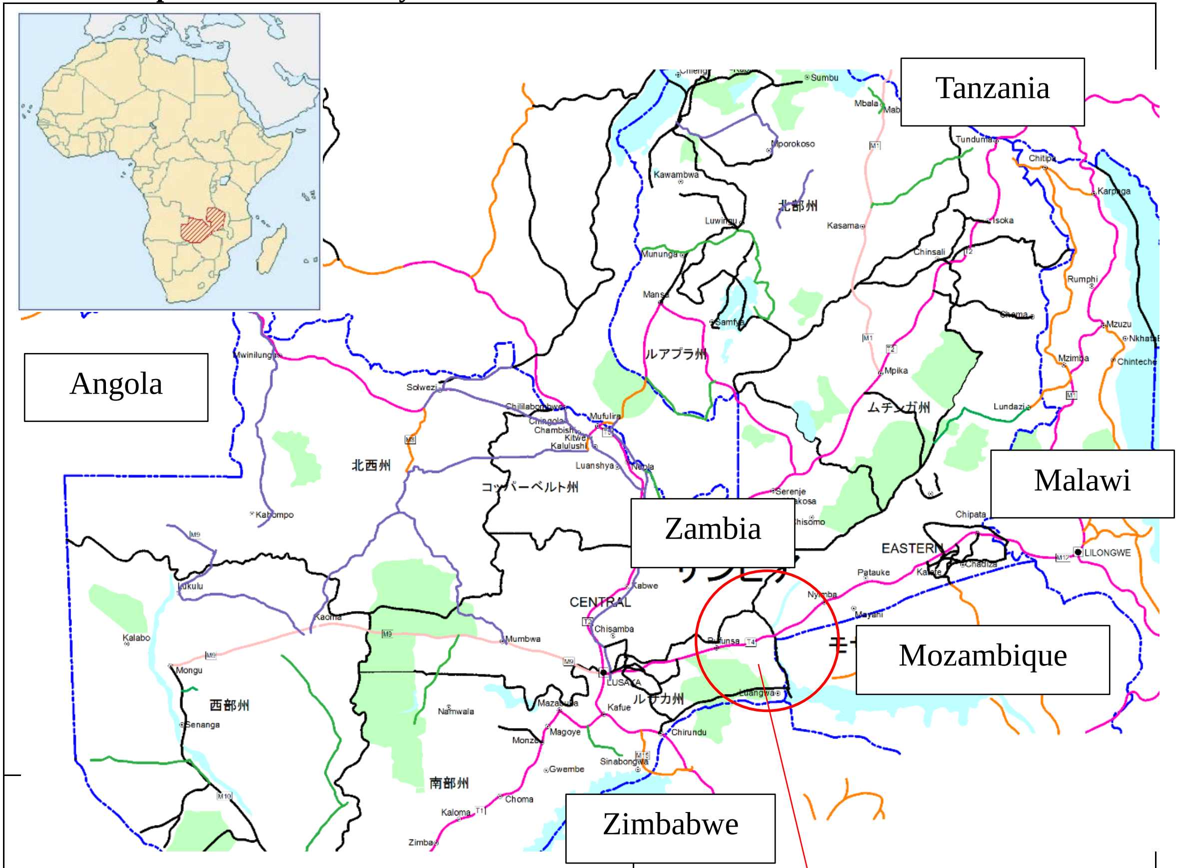
Data Collection Survey on Transport and Infrastructure Development along Nacala Corridor

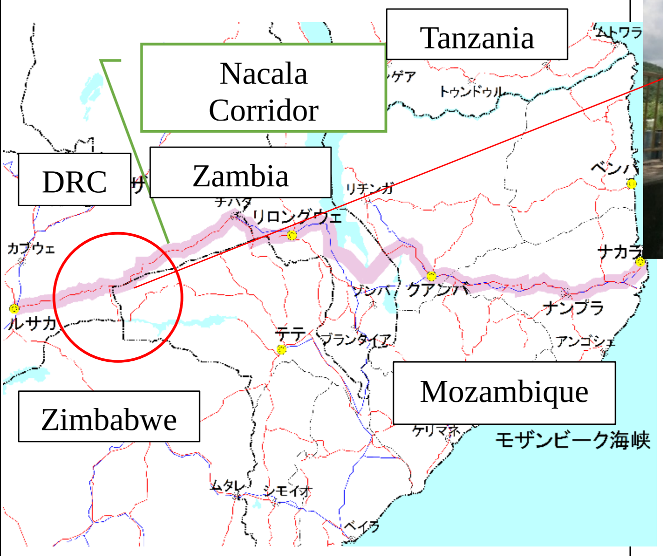
Photos
Location Map of the Areas Surveyed
Abbreviations

Photos

Launching a fixed-wing UAV

Location Map of the Areas Surveyed





Luangwa Bridge

(1) Structure: 3-span continuous steel cable-stayed bridge

(2) Bridge length: L=302m

(3) Span arrangement: 40 + 222 + 40 m

(4) Completion: 1968

(5) Repair history:

1) 1974: Bolt replacement
2) 1981: Bolt replacement, adjustment of cable tension
3) 1998: Addition of floor beams, addition of steel plates to girders, cable replacement, main tower reinforcement, etc.

Abbreviations

Abbreviation	Formal name
7NDP	7 th National Development Plan
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AfDB	African Development Bank
ARAP	Abbreviated Resettlement Action Plan
BM	Bench-Mark
COMESA	Common Market for Eastern and Southern Africa
C/P	Counterpart
DAC	Development Assistance Committee
EIA	Environmental Impact Assessment
EIB	Europe Investment Bank
EU	European Union
F/S	Feasibility Study
GDP	Gross Domestic Product
GPS	Global Positioning System
IDA	International Development Association
IMF	International Monetary Fund
JICA	Japan International Cooperation Agency
LAP	Land Acquisition Plan
MHID	Ministry of Housing and Infrastructure Development
MoTC	Ministry of Transport and Communication
M/P	Master Plan
NRFA	National Road Fund Agency
NTP	National Transportation Plan
ODA	Official Development Assistance
PC	Prestressed Concrete
PCU	Passenger Car Unit
RDA	Road Development Agency (Zambia)
ROW	Right of Way
SADC	Southern African Development Community
SATCC	Southern African Transport and Communications Commission
SPT	Standard Penetration Test
TAZARA	Tanzania Zambia Railway Authority
WB	World Bank
ZDA	Zambia Development Agency
US$	US dollar

UR	Euro
ZAWA	Zambia Wildlife Authority
ZMW	Zambia Kwacha

1. Introduction

1.1 Background of the Survey

Because Zambia is an inland country in Southern Africa, its land logistics network is a lifeline for the nation's economy and multiple international corridors are playing a critical role as the transportation system in the country. One of such international corridors is the Nacala Corridor, which connects Lusaka in Zambia and the Port of Nacala in the Republic of Mozambique through the Republic of Malawi. The Nacala Corridor is a particularly important international corridor for the country's future economic growth, because this road is the geographically shortest route from Zambia to ports on the East Coast, and because it is the only access road that connects Lusaka Province and Eastern Province.

However, these international corridors including the Nacala Corridor were devastated during the civil war in Mozambique. And the delay in transportation infrastructure development since then is partly attributable to the high cost of distribution in Zambia today, which is hampering the growth of the entire industry. In the 7th National Development Plan (2017-2021), the Zambian Government acknowledged that the underdeveloped state of the transportation infrastructure along these international corridors is a bottleneck to the country's economic growth and industrial diversification, posting the improvement of trunk roads (including bridges) along international corridors needed to promote trade inside and outside the country as one of its priority areas.

As part of the transportation infrastructure development along the Nacala Corridor within Zambia, the road in the section between Lusaka and the Luangwa Bridge was improved, funded by the Zambian Government. In addition, the road in the section between the Luangwa Bridge and Mwami, which is on the national border between Zambia and Malawi, was improved with support from the European Union (EU), the European Investment Bank (EIB), and the African Development Bank (AfDB).

The Luangwa Bridge on the Nacala Corridor was built with support from the United Kingdom in 1968. However, the bridge was damaged later due to conflicts among neighboring countries, and it is becoming older in recent years. While having been repaired and reinforced to maintain its function, the bridge is faced with strength and durability problems due to the sharp increase in traffic and the passage of heavy vehicles. For this reason, vehicles passing through the bridge must have a gross vehicle weight of 55ton or less, and they must travel at a speed of 30km/h or less. Moreover, the passage of vehicles over the bridge is restricted so that only one vehicle is allowed to pass the bridge at a time. Because of these restrictions, heavy vehicles with a gross vehicle weight exceeding 55ton for cargo transportation along international corridors in Zambia have no choice but to run on other international corridors than the Nacala Corridor. As the above examples show, the Luangwa Bridge is becoming a bottleneck affecting the function of the Nacala Corridor. In addition, the access road to the bridge on the Lusaka side has a geometric structure not suited for the passage of heavy vehicles. However, improving the structure of this access road is difficult because of the steep terrain in the area.

Given this situation, replacement of this bridge is the most pressing issue with the Nacala Corridor Economic Development, and the Zambian Government recently made a request to Japan for rebuilding the Luangwa Bridge.

1.2 Purpose of this Survey

In order to study the necessity to rebuild the Luangwa Bridge, some basic information such as natural conditions, traffic volume, and possible bridge types must be collected. This task is intended to collect necessary information and identify the issues to be solved concerning the Zambian government's plans for the transportation infrastructure development along the Nacala Corridor and its current status. This task is also aimed at conducting surveys on natural conditions and traffic volume with respect to the Luangwa Bridge that the Zambian Government wants rebuilt and collecting the basic information needed to evaluate the project including a possible bridge type.

The Luangwa Bridge is located approximately 250km east of Lusaka along the Nacala Corridor (called the Great East Road in Zambia), where the corridor intersects with the Luangwa River, the border between Lusaka Province and Eastern Province. The small town on the Lusaka side (called Luangwa Bridge Market) is the only shopping area in the surrounding region.

1.3 Efforts to Shorten On-site Survey Period

This task required that on-site surveys including a boring survey, topographic survey, and traffic volume survey be conducted within as short a time period as one-and-a-half months. Moreover, the on-site survey period fell on the rainy season, and all kinds of efforts were made to shorten the on-site survey period.

The efforts made in this task included: 1) a topographic survey by aerial photogrammetry using an unmanned aerial vehicle (UAV) and 2) the start of a boring survey at the center of the river before the water level began to rise. As a result, the on-site survey period was shortened as expected by the use of UAV-based aerial photogrammetry. On the other hand, the boring survey at the center of the river had to be stopped after drilling down to a depth of about 15m from the ground surface, because the water level suddenly rose due to heavy rain fall in the upstream area. Another boring survey on the right bank failed because the water level rose during drilling. As a last resort, the boring location was moved to higher ground for re-drilling.

This experience made it clear that UAV-based aerial photogrammetry for topographic surveys is quite effective in shortening the on-site survey period, though depending on the measurement precision required. In the season when natural vegetation grew thick, it took a considerable amount of time to select the ground control points on the ground surface. However, by measuring coordinates of the ground control points and taking aerial photographs in parallel, the on-site survey period could be reduced significantly.

Based on the above findings, UAV-based topographic surveys are considered to be an effective method for time and cost savings in the preparatory survey process. At the same time, because the analysis and application of data obtained from UAV-based topographic surveys are extremely easy, it is expected that this survey method will be used extensively in the future.

1.4 Survey Schedule

The on-site survey period for this survey started on January 7, 2019 and ended on February 20, 2019 (45 days). The following shows the work flow of this survey.

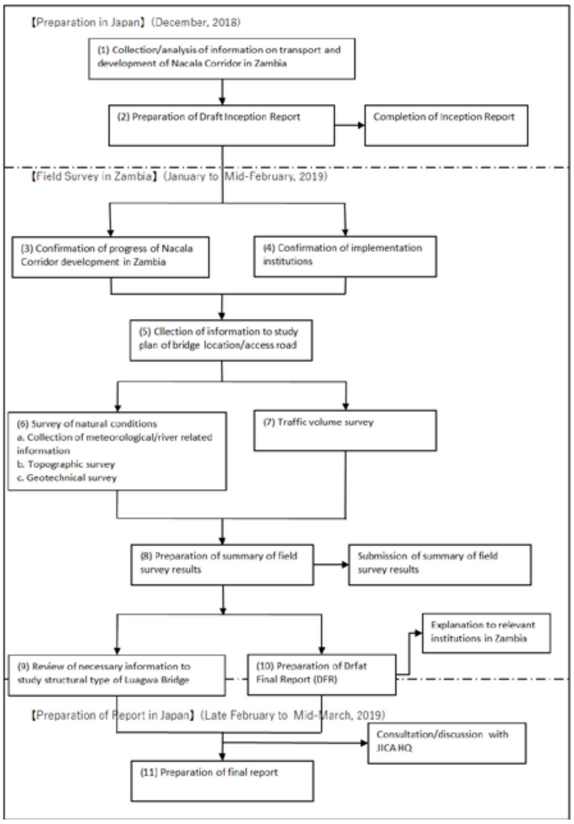


Figure 1.4-1 Work flow

2. Current Status of Transport and Infrastructure Development along Nacala Corridor

Zambia's National Transport Policy (NTP) 2016, a policy for the transportation sector, points out the importance of making the existing domestic transportation system more efficient in the country, which aimed to become a land transportation hub in Southern Africa by leveraging its geographical advantage. To make it happen, Zambia must solve the following major policy challenges.

(1) Realizing smooth coordination and regulation in the transportation and traffic sectors by strengthening of authority for the Ministry of Transport and Communications.
(2) Capacity building in the transportation sector.
(3) The allocation of resources available between different transportation modes so that both carriers and users will be benefitted at the same time.
(4) Realizing reasonable transportation costs.
(5) Realizing appropriate transportation policies and systems that will contribute to sustainable development and poverty reduction.

Zambia has a nationwide road network with a total length of approximately 68,000km, when small-scale roads are included. **Table 2-1** shows the current status of road development by road classification. Zambia depends heavily on road transportation for cargo transportation, because of being an inland country far from the ocean and the limited availability of railway routes. Despite these facts, the country has not constructed and rehabilitated those roads well in the past.

Under these circumstances, Zambia set up a policy to develop road infrastructure as soon as possible in order to support the country's economic growth. Specifically, the country formulated the 1st Road Sector Investment Programme Project (ROADSIP I) in 1998, which was followed by the 2nd Project (ROADSIP II). In September 2012, Zambia launched the Accelerated National Road Construction Programme, whose specific projects were listed in the Link Zambia 8000 Road Project, a nationwide road development project. In the meanwhile, Zambia launched the Pave Zambia 2000 Road Project in September 2011 with the aim to improve paved road ratios throughout the country and to satisfy the needs of road users.

Due to insufficient capacity of the road authorities to maintain the large stock of road network, the Government prioritizes the development of the important road network, called Core Road Network, of 40,554km including trunk roads.

Table 2-1 Current status of road development by road classification

Classification	Responsible Authority	Total length (km)	Percentage of good condition (%)
Trunk road	RDA	3,088	85
Main road	RDA	3,691	
District road	RDA	13,707	
Urban road	LRAs	5,294	49
Primary feeder	LRAs	15,800	12
Secondary feeder	LRAs	10,060	
Tertiary feeder	LRAs	4,424	
Park road	ZAWA	6,607	
Community road	LRAs	5,000	
Total		67,671	

Source: Road Maintenance Strategy 2015-2014, Revised National Transport Policy

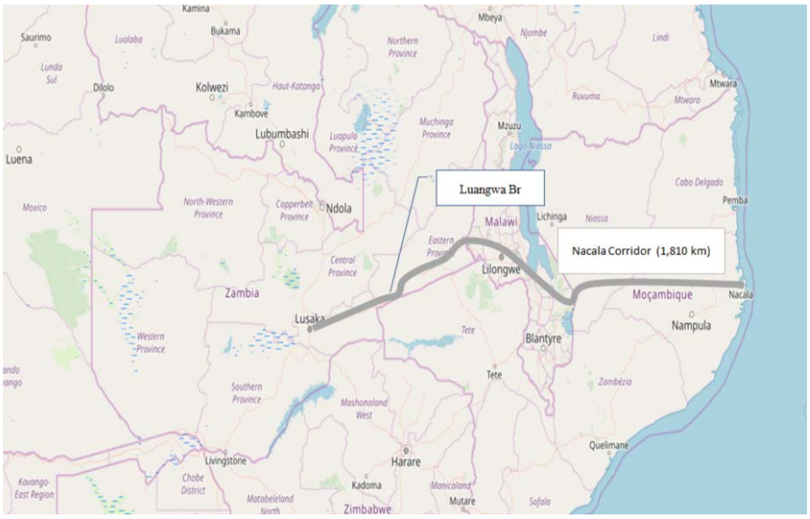


Figure 2-1 Location map of Nacala Corridor

2.1 Importance of Nacala Corridor

Located slightly east of the center of Southern Africa, Lusaka is geographically close to the Port of Nacala. The Port of Nacala is open to the Indian Ocean and is deep enough for large vessels to come in and out. If the corridor directly connecting Lusaka and the Port of Nacala is developed, four international corridors will be effectively converged into Lusaka. These international corridors are the Dar es Salaam Corridor, the Nacala Corridor, and the Beira Corridor in Eastern Africa, and the North-South Corridor connecting Zambia and the Port of Durban in South Africa. If this can be done, Lusaka would be positioned as an important land transportation hub in the vast central area of Southern Africa.

It is expected that the development of the Nacala Corridor would not only provide Zambia with easy access to the Port of Beira and the Port of Nacala in Mozambique, but it would also increase the Nacala Corridor's competitiveness over other international corridors, resulting in decreased prices of imports into Zambia. This would contribute to solving traffic congestion along the North-South Corridor, where traffic volume is increasing. Therefore, the development of the Nacala Corridor is extremely significant for the future growth of Zambia.

In the meanwhile, the Nacala Corridor is the only road connecting Lusaka and Eastern Province, whose poverty ratio is higher than other provinces (70% according to 2015 data). In this light, the development of the Nacala Corridor is essential in driving agricultural and industrial growths in Eastern Province, which is blessed with the fertile land. It is expected that this approach will produce significant effects toward the realization of political measures for domestic economy diversification, which the Zambian government is pushing along.

The railway in the section between the Port of Nacala in Mozambique and Blantyre in Malawi was already repaired. Today, the railway is laid up to Chipata in Zambia, which is located close to the border with Malawi, including the sections that have not yet repaired. If road transportation and railway transportation can be effectively connected to each other in Chipata, the convenience of the Nacala Corridor in land transportation will be enhanced dramatically. If this can be done, the traffic volume along the Nacala Corridor within Zambia is expected to increase significantly in the future. Zambia expects that the capacity of the Nacala Corridor will expand to a level that can absorb the increasing traffic volume along the North-South Corridor, the road connecting Lusaka and the Port of Durban.

The Nacala Corridor leads to both the Nacala Port and Beria Port. Since the latter located at the river mouth, the regular dredge work is needed to remove the sand sediment and the port is not suitable for the large vessels. In contrast, Nacala Port is a deep port without restrictions of usage, and has further growth potential. Therefore, the development of Nacala Port has large latent capabilities for Zambia compared with Beria Port.

In the meanwhile, transportation costs and time for each international corridor in Zambia are compared in the "Final Report of DATA COLLECTION SURVEY ON NACALA CORRIDOR INTEGRATED DEVELOPMENT IN SOUTHERN AFRICA." Because the Nacala Corridor is currently under development, the volume of cargo transportation along this corridor is only less than 10% of that along the North-South Corridor. However, once its development is completed, the Nacala Corridor will start demonstrating its advantages in transportation distance and costs. Therefore, the potential importance of the Nacala Corridor is obvious. The number of days required for cargo transportation from Lusaka to the Port of Nacala, including customs clearance procedures, is slightly larger than cargo transportation from Lusaka to the Port of Durban along the North-South Corridor. However, the advantages of using the Nacala Corridor will be better understood with the increasing traffic volume along the Nacala Corridor. It is therefore obvious that customs clearance procedures will be simplified in the future, which will make the Nacala Corridor still more competitive.

Table 2.1-1 Distance between Lusaka and other major cities in Southern Africa

Country	Port	Transportation mode	Distance (km)	Number of border crossing
Mozambique	Beira	Road	1,054	2
Mozambique	Nacala	Road	1,810	2
Tanzania	Dar es Salaam	Road	1,985	1
		Railway	2,039	1
South Africa	Durban	Road	2,381	2
		Railway	2,638	2

Source: Final Report of DATA COLLECTION SURVEY ON NACALA CORRIDOR INTEGRATED DEVELOPMENT IN SOUTHERN AFRICA

Table 2.1-2 Comparison of transportation costs and time between different corridors from Lusaka

Corridor	Port	Mode	Transportation cost (USD)*1	Transportation time (days)*2
Nacala	Nacala	Road + Railway	2,834	9
Beira	Beira	Road	3,043	10
North-South	Durban	Railway	3,174	9
Dar es Salaam	Dar es Salaam	Railway	3,555	14
Nacala	Nacala	Road	4,184	14
Dar es Salaam	Dar es Salaam	Road	4,842	14
North-South	Durban	Road	4,843	8

*1:20 ft Dry Container *2: Including custom clearance at entry port

Source: Final Report of DATA COLLECTION SURVEY ON NACALA CORRIDOR INTEGRATED DEVELOPMENT IN SOUTHERN AFRICA

Table 2.1-3 Transportation ratio for each corridor in Zambia (2016)

Corridor	Border	Mode			Volume (ton/year)		%
		Road	Railway	Air			
Nacala	Chanida	133,859	0	0	133,859	454,909	4.5
	Mwami	313,179	7,871	0	321,051		
Dar es Salaam	Nakonde	3,038,121	366	0	3,038,487	3,038,487	30.0
North-South /Baira	Chirundu	3,043,193	0	0	3,043,193	4,080,750	40.2
	Kariba	5,748	0	0	5,748		
	Livingstone	130,147	1,171	1	131,774		
	Victoria Falls	106,053	3,080	0	109,133		
	Kazungula	790,898	0	0	790,902		
Lobito	Kasumbalesa	2,138,821	0	0	2,138,821	2,138,821	21.1
Walvis Bay	Katima Mulilo	441,465	0	6	441,472	441,472	4.4
Total		10,141,485	12,488	7	10,141,485	10,141,485	100.0

Source: Final Report of DATA COLLECTION SURVEY ON NACALA CORRIDOR INTEGRATED DEVELOPMENT IN SOUTHERN AFRICA

Table 2.1-4 Transportation ratio for each corridor in Zambia (Export 2016)

Corridor	Border	Mode			Volume (ton/year)		%
		Road	Railway	Air			
Nacala	Chanida	36,351	0	0	36,351	337,694	12.9
	Mwami	293,472	7,871	0	293,472		
Dar es Salaam	Nakonde	224,432	4	0	224,436	224,436	8.6
North-South /Baira	Chirundu	743,349	0	0	743,349	1,157,437	44.2
	Kariba	1,762	0	0	1,762		
	Livingstone	124,099	1,171	2	124,099		
	Victoria Falls	23,871	0	0	23,871		
	Kazungula	263,184	0	0	263,184		
Lobito	Kasumbalesa	744,115	0	0	744,115	744,115	28.4
Walvis Bay	Katima Mulilo	156.546	0	0	156.546	156,546	6.0
Total		2,611,180	9,046	2	2,620,228	2,620,228	100.0

Source: Final Report of DATA COLLECTION SURVEY ON NACALA CORRIDOR INTEGRATED DEVELOPMENT IN SOUTHERN AFRICA

Table 2.1-5 Transportation ratio for each corridor in Zambia (Import 2016)

Corridor	Border	Mode			Volume (ton/year)		%
		Road	Railway	Air			
Nacala	Chanida	91,394	0	0	91,394	105,418	2.5
	Mwami	14,025	0	0	14,025		
Dar es Salaam	Nakonde	1,923,570	106	0	1,923,676	1,923,676	45.7
North-South /Beira	Chirundu	1,378,571	0	0	1,378,571	1,830,240	43.5
	Kariba	3,985	0	0	3,985		
	Livingstone	6,046	0	454	6,500		
	Victoria Falls	75,144	0	0	75,144		
	Kazungula	366,038	0	0	366,038		
Lobito	Kasumbalesa	134,112	0	0	134,112	134,112	3.2
Walvis Bay	Katima Mulilo	215,349	0	0	215,349	215,355	5.1
Total		4,208,232	106	0	4,208,802	4,208,802	100.0

Source: Final Report of DATA COLLECTION SURVEY ON NACALA CORRIDOR INTEGRATED DEVELOPMENT IN SOUTHERN AFRICA

Table 2.1-6 Zambia's major trading partners

Rank	1	2	3	4	5	Others	Total
Import from	South Africa	DR Congo	China	Kuwait	India	-	
Ratio (%)	31	21	14	5	4	25	100
Export to	Switzerland	China	India	South Africa	DR Congo	-	
Ratio (%)	38	15	10	7	5	25	100

Source: Study Team

2.2 Current Status of Nacala Corridor Development

The road development for the Nacala Corridor within Zambia was supported by the EU, the European Investment Bank, and the African Development Bank. The road improvement project was conducted for the section between the Luangwa Bridge and Mwami, which is located near the border with Malawi, with a total length of approximately 360km. The section was divided further into four sections (Luangwa Bridge-Nyimba, Nyimba-Petauke-Sinda, Sinda-Katete-Mutenguleni, and Mutenguleni-Chipata-Mwami). These roads were designed in accordance with the South African Development Community (SADC) Road Design Standards. The road development for the section between Lusaka and the Luangwa Bridge was already completed, funded by the Zambian Government.

In the meanwhile, each donor has not yet decided future support plans for Nacala Corridor development within Zambia.

Table 2.2-1 Current status of Nacala Corridor development

Section	Length	Donor	Completion
Lusaka-Luangwa Br	Approx. 250km	-	2015
Luangwa Br-Nyimba	98.9km	EU/EIB	2018
Nyimba-Petauke-Sinda	114.0km	AfDB	2018
Sinda-Katete-Mutenguleni	95.5km	EU/EIB	2018
Mutenguleni-Chipata-Mwami	50.0km	EU/EIB	2018

Source: Study Team

	
A train of vehicles waiting before the Luangwa Bridge	A view of the road in the section between Lusaka and the Luangwa Bridge
	
Luangwa Bridge Market	Access road to the Luangwa Bridge

Photo 2.2-1 Current status of Nacala Corridor development

2.3 Current Status of Support Provided by Japan and Other Donors

Due to its inadequate infrastructure, the Nacala Corridor and the vicinities have not been developed well despite the potential for development including energy resources such as coal and natural gas and fertile land suited for agriculture. In 2016, Japan formulated the "Master Plan for Nacala Corridor Development" in order to support the development of the corridor and its neighboring areas from the viewpoint of stimulating and growing the whole region in a sustainable and robust manner.

In the past, Japan has supported several projects in Mozambique, including "Urgent Rehabilitation of Nacala Port," "Nacala Port Development Project," and "Improvement of Nacala Port." Japan also has supported the development of trunk roads, including "Montepuez-Lichinga Road Upgrading," "Mandimba-Lichinga Road Upgrading," "Construction of Bridges on the Road between Ile and Cuamba," "Construction of Bridges on National Highway 380," "Nacala Corridor Road Network Upgrading," etc. In addition, Japan has supported various projects in the electric power, agriculture, and social development fields.

In 2018, Japan implemented the "DATA COLLECTION SURVEY ON NACALA CORRIDOR INTEGRATED DEVELOPMENT IN SOUTHERN AFRICA," in which issues, needs, and potential for development in the Nacala Corridor region were analyzed and priority projects including the regional comprehensive development strategies were proposed. In this process, Japan included the replacement of the Luangwa Bridge in the list of the projects that should be promoted in the future.

With respect to the development of the Nacala Corridor within Zambia, the section between the Luangwa Bridge and the border with Malawi was recently upgraded with support from the EU, the European Investment Bank, and the African Development Bank. However, there are no specific plans for additional support programs.

2.4 Effects Expected from Nacala Corridor Development

If the Nacala Corridor is developed well, competition among the international corridors that converge into Lusaka is expected to increase by necessity, resulting in price competition in the transportation sector. This means the reduction in import prices for Zambia, a country that must rely on import for many types of daily commodities. In addition, the development of the Nacala Corridor would enable Zambia to depart from the present state of heavily depending on the South Africa route through the North-South Corridor. This approach is expected to disperse the risk of threatening the security of transportation routes due to unstable political situations in other countries. The increasing competition among international corridors would influence not only transportation costs but also the number of days required for cargo transportation. As a result, it is expected that the time needed for customs clearance procedures will be reduced not just on the Nacala Corridor but also on other international corridors. AfDB is planning to support the development of One-Stop-Boarder-Posts (OSBPs) at borders of Zambia, Malawi and Mozambique. Through these development, shorter customs clearance will be expected to convenience to the improvement of the convenience to use the Nacala Corridor.

At present, the route connecting Livingstone and South Africa through the North-South Corridor is the most important trunk road for Zambia, thanks to the competitiveness among custom brokers, the about custom clearance is realized and this offsets the disadvantages of longer hauling distance and higher transportation costs. For this reason, the traffic volume along this route is increasing at a steady pace, which suggests the need to ease the traffic at some point in the future. Being closer to the Asian region and the Middle East region, where continuous economic growth is expected in the future, the Nacala Corridor has a leading position in complementing the function of the North-South Corridor in the future.

In addition, the Nacala Corridor is the only major road that provides Lusaka and other cities in Zambia with access to Eastern Province. For this reason, the development of the Nacala Corridor is expected to promote not only the development of Eastern Province but also the growth of Malawi, another inland country in Southern Africa.

2.5 Challenges Facing Nacala Corridor Development

There are fewer major cities along the Nacala Corridor within Zambia compared with the North-South Corridor. For this reason, excluding the crop harvest season, the daily use of this corridor by local residents will not increase at a rapid pace in the foreseeable future. In order to demonstrate the full power of the Nacala Corridor, the following measures should be taken in addition to improvements in facilities at the Port of Nacala: 1) shortening the time required for cargo transportation from Lusaka to the Port of Nacala, 2) introducing the effective and systematic connection of road transportation and railroad transportation in Chipata, 3) shortening the time required for customs clearance procedures at national borders, and 4) improving the Luangwa Bridge to lift the traffic restriction through the bridge so that heavy vehicles will be able to pass the existing traffic bottleneck safely and freely, and so that an environment will be created in which the vehicles currently driving along other international corridors will be willing to change their destination.

3. National Development Plans

The 7NDP with a plan period of 2017-2021 aims at efficient national development to realize the nation's target Vision 2030. For this purpose, the previous plan for each sector was changed to a multi-sector plan, which is conducted by taking account of other strategic regional development projects of the southern Africa such as the regional plan of Southern African Development Community (SADC), Agenda 2063 of Africa Union, and the protocol of Common Market for Eastern and Southern Africa (COMESA).

3.1 Current Status of Transport Sector Development in Zambia

In its long-term development plan called Vision 2030, the Zambian Government aimed to become a prosperous middle-income nation by 2030, by departing from the conventional economy that depends heavily on copper resource vulnerable to price fluctuations in the international market such as copper resources, and through the promotion of economic diversification.

As specific development plans to achieve this goal, the Zambian Government formulated the 5th National Development Plan (2006-2010), the 6th National Development Plan (2011-2015), and the revised 6th National Development Plan. However, partly due to insufficient coordination among individual plans, the Zambian Government was unable to produce the expected results. Following the completion of the revised 6th National Development Plan, the Zambian Government formulated the 7th National Development Plan (2017-2021) with the aim to achieve Vision 2030. The major objectives to be achieved in the 7th National Development Plan are summarized below.

(1) Shifting from its excessive dependence on mining to policies aimed to promote economy diversification. Enhancing social protection programs.
(2) Realizing an employment system in which working conditions will be improved by the reduction of non-regular workers.
(3) Developing a system in which incentive mechanisms work properly. Removing disincentives to economic growth. Renewing emphasis on the importance of the agriculture, mining, and tourism sectors for poverty reduction and job creation.
(4) Result-oriented management at the Ministries, Provinces, and other contracting organizations.

Early development of the undeveloped road network is extremely important for economic growth of Zambia. Roads are critical as catalysis to support the promotion of trade, agriculture, tourism, and commerce, shifting from the traditional economy relying on natural resources, for securing employment of the youth

Nacala Corridor is one of the corridors whose development is aimed at by the regional development projects in various regions of Africa. Nacala Corridor is an international corridor in the southern Africa. It is an important economic corridor for Zambia and Malawi, which have no sea, to have industrial development of the regions along the corridor and promote the nation-wide economic growth. On the basis of this idea, the Secretariat of SADC added the development of Nacala road corridor to the regional master plan of 2012-2027. Malawi, Mozambique, and Zambia agreed upon Spatial Development Initiative (SDI) under the support by SADC for joint action on the development of Nacala Corridor.

The revised National Transportation Policy (RNTP) states that Zambia will make utmost efforts to become the hub of both commerce and transportation in the southern Africa region taking advantage of its location in the center of the region. To materialize this goal, Zambian Government will focus on the followings:

1) To support development of economical and environmentally friendly integrated transport infrastructure and delivery system
2) To promote competitiveness among ports by developing transport corridors

In addition, the development of system as well as facilities which enables the handling of freight between road and railway smoothly will be promoted.

The Link Zambia 8000 Road Project, which was formulated in 2012, is intended to achieve the following goals.

- Change Zambia to a country fully linked to its neighboring countries
- Create 24,000 jobs with emphasis on young people
- Promote the growth of the local construction industry
- Contribute to road users for cost and time reductions
- Create nuclei for economic growth along roads

For the development of Nacala Corridor in Zambia, the road from Lusaka to the boarder to Malawi has been developed so far and Luangwa Bridge is the only undeveloped section and needs traffic restriction. Therefore, immediate improvement of the bridge is desired.

4. Implementation system of Zambia

In Zambia, transportation and traffic policies are handled by the Ministry of Transport and Communication (MTC), the Ministry of Works and Supply (MWS), and the Ministry of Housing and Infrastructure Development (MHID). These ministries, together with their subordinate organizations, are involved in transportation infrastructure development in Zambia. **Table 3.1-1** shows each ministry's areas of responsibility.

Table 3.1-1 Areas of responsibility of the ministries involved in the transportation sector

Organization	Responsible policy areas
MTC	Transportation policies, planning, and program formulation
MWS	Operation and maintenance
MHID	Project implementation

The Road Development Agency (RDA) is a government agency that holds jurisdiction over the development of trunk roads throughout Zambia, under the supervision of the Ministry of Housing and Infrastructure Development (MHID). The RDA is headquartered in Lusaka. Figure 4.1-1 shows the organization of the RDA Headquarters at director levels. Each of the Road Maintenance Bureau and the Road Construction Bureau has two sections as their subordinate organizations. In addition to this headquarters, a local office is set up in each province to handle road construction and road maintenance.

In the meanwhile, the Luangwa Bridge over the Luangwa River, the border between Lusaka Province and Eastern Province, is under the jurisdiction of the local office of Lusaka Province and the local office of Eastern Province.

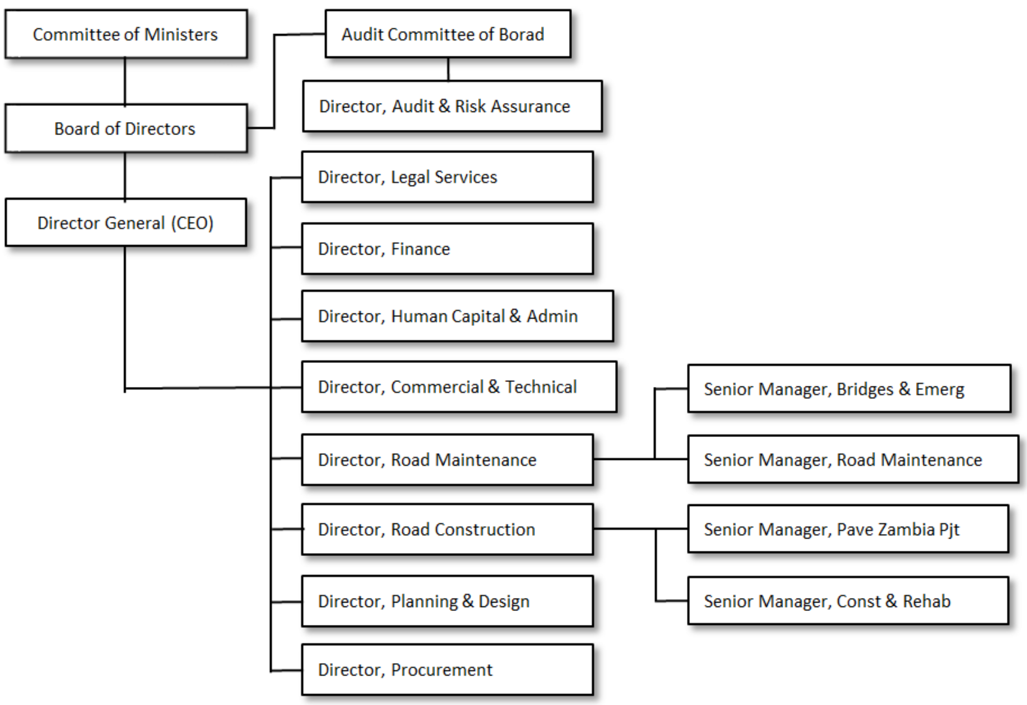


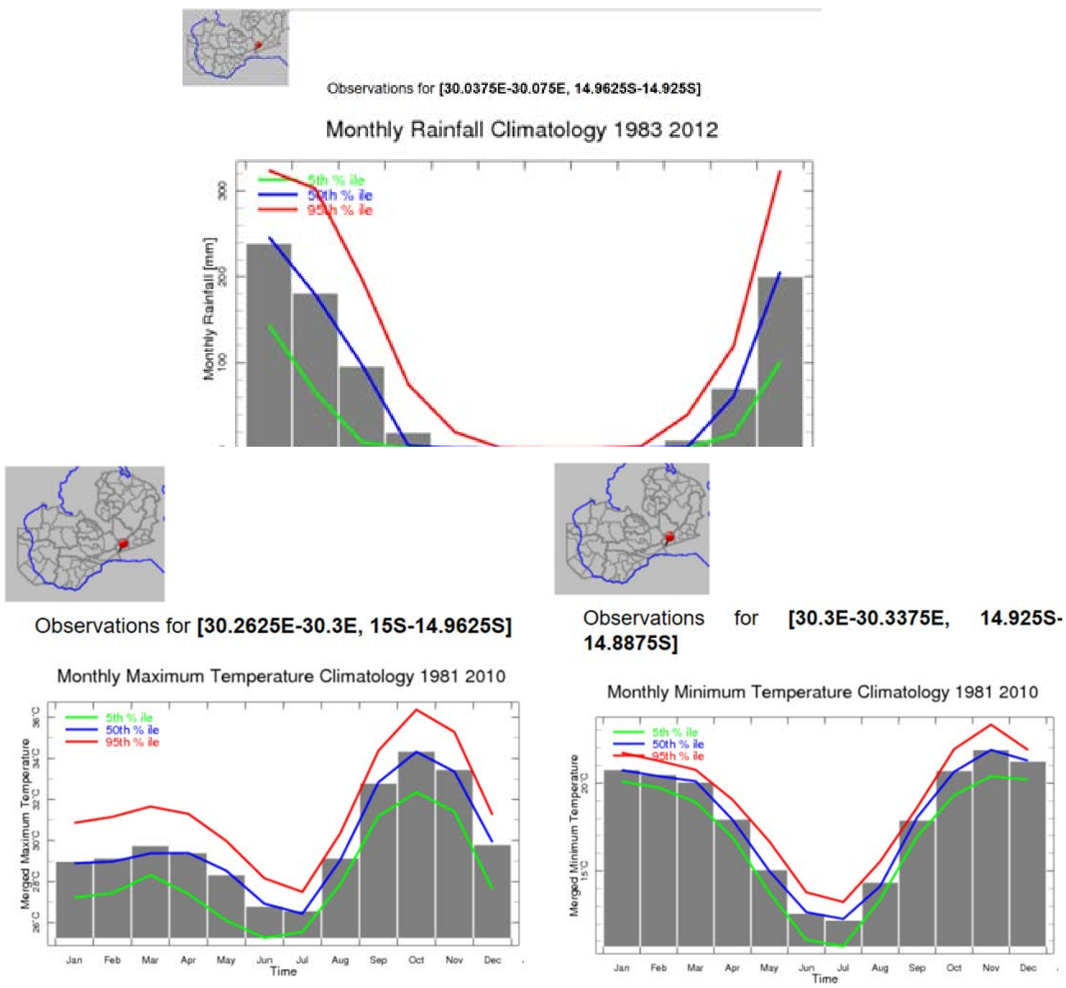
Figure 4-1 Organization chart of RDA Headquarters

5. Basic Information for Rebuilding of Luangwa Bridge

5.1 Natural Conditions

1) Weather

The climate of the region south of the Luangwa Bridge is "hot semi-arid," which is classified into BSh of Koppen-Geiger Climate Classification. There is no meteorological station in the vicinity of the Luangwa Bridge. According to analysis by the Zambia Meteorological Department, the region's annual maximum and minimum temperature are 35ºC in October and 13ºC in July, respectively. The elevation of the area near the Luangwa Bridge is approximately 400m, and the difference in temperature between the bridge area and Lusaka, which is located approximately 250km toward the west at an elevation of 1,150m, is about 4ºC. According to the estimate of the Zambia Meteorological Department, the annual rainfall in the bridge area ranges from 800 to 1,100mm. In this region, rainfall is concentrated in the rainy season that starts at the end of October. About 250mm/month of rainfall is observed between December and February, and rainfall virtually stops in late March. Based on these data, the rainy season is considered to last for five months from November to March in the Luangwa Bridge area. It is safe to say that there is no rainfall in other seasons.



Source: Zambia Meteorological Department, Website, Monthly Climate Analysis

Figure 5.1-1 Rainfall and temperature around Luangwa Bridge

2) River

The Luangwa River is one of the major tributaries of the Zambezi River. The Luangwa River rises in north-east Zambia near the border with Malawi and Tanzania and flows in the southwest direction. Near the Luangwa Bridge, the river changes its course toward the south and meets the Zambezi River. Approximately 2km downstream of the Luangwa Bridge in the south, the Luangwa River serves as the border between Zambia and Mozambique.

At the point where the Luangwa Bridge is located, rocks protrude into the river from both sides, making it the narrowest river width. The river winds gently both upstream and downstream of the Luangwa Bridge, where the river is wider than the narrowest point under the bridge. In the dry season when the river water volume decreases, the width of the water course narrows to approximately 100m, and wide sand riverbed appears in the river on the other side of the undercut slope. According to the data compiled by Technical University of Munich based on its observation between 2002 and 2016, the seasonal water-level variation of the Luangwa River is 5.88m. While the water-level variation between the mean and minimum is 1.62m, the water-level variation between the mean and maximum is 4.27m. This data suggests the possibility that the water level may rise sharply in the rainy season.

At present, water-level observation is not conducted near the Luangwa Bridge. But according to hearings with local residents, the water level has not risen to the girder position of the Luangwa Bridge, and the highest water level they have ever seen is about 5m above the sand riverbed. This suggests that the girder height of the existing Luangwa Bridge was not determined by the maximum water level but for other reasons.

Figure 5.1-2 shows the cross-section of the river measured near the location where a new bridge may be built. Downstream of the existing Luangwa Bridge, the water course of the Luangwa River curves to the left. Because of inertia force applied to the river water, the water speed becomes faster on the right side, and the water course becomes deeper along the right bank. According to the results of measurements in this survey, the deepest riverbed point at the location for a new bridge lies at a depth of about 10m in the river course along the right bank on the Lusaka side. The water speed on the right bank side is fast at about 3.5m/s. The water speeds at points between the river center and the left bank side are slow at around 1.5 to 1.0m/s. Because a rock protrudes into the river on the right bank side immediately upstream of the location for a new bridge, the river's mainstream collides with this rock then changes its course to the left.

In a photograph taken in October 2016 close to the end of the dry season, sand riverbed appeared across about one-third of the river width at the location of the existing Luangwa Bridge on the Lusaka side, and the width of the water course narrowed to approximately 100m at the location for a new bridge. Judging from these data, the cross-section of the Luangwa River changes significantly between the rainy season and the dry season.

Photo 5.1-1 Mainstream alignment of Luangwa River

Photo 5.1-2 Luangwa River in the dry season

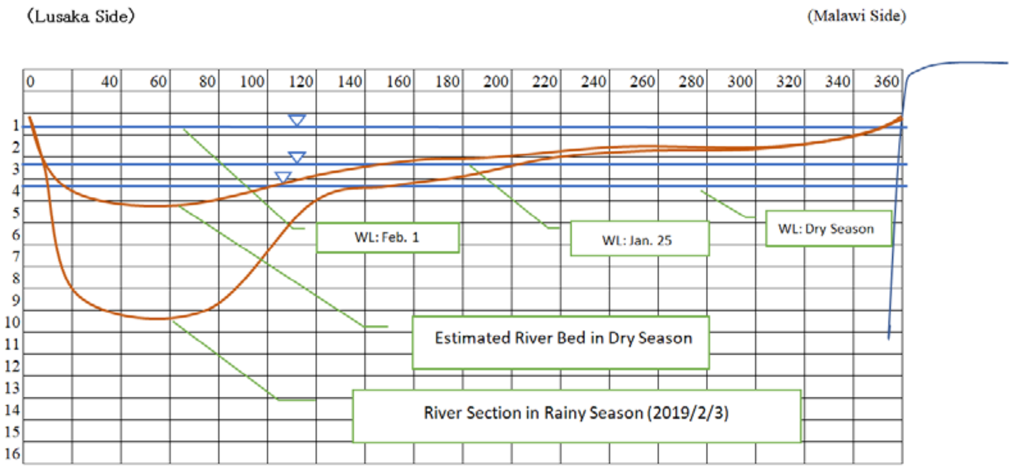


Figure 5.1-2 Cross-section of the river at the location for a new bridge

3) Topography

The area surveyed is located in a relatively flat region called "African Shield" made from the Precambrian basement rocks (more than 570 million years ago) that have been little affected by tectonic events (such as mountain building and faulting), which is thinly covered with weathered surface soil. The shield, also called "craton," is part of the continental lithosphere stabilized after tectonic events in the Precambrian age. Due to weathering and erosion over hundreds of millions of years, "an extremely gentle terrain looking like a shield placed horizontally with the front surface facing upward" was formed in the region. The shield is characterized by the Precambrian basement rocks that sporadically appear above the ground surface.

The area surveyed is located in a gentle valley where the Luangwa River dissected a rift valley in the shield. The Luangwa Bridge is built over the narrow section where the river curves and becomes narrow. There are relatively steep ridges on both sides of the Luangwa Bridge, where some blockish bare rocks are found, with weathering-induced cracks propagating on.

The slope on the right bank side (Lusaka side) downstream of the Luangwa Bridge is undercut by the river, and some portions of the undercut slope are seen collapsed (**Photo 5.1-3)**. Because the access road to the bridge on the right bank side is passing right above the undercut slope, the risk of disturbing road transportation may increase with the growing collapsed slope areas.

If the road alignment needs to be shifted toward the mountain side to improve the safety of the access road to the bridge on the right bank side, large-scale construction of a cut earth slope will be required. Given this complex terrain, it would be difficult to construct such a cut slope while maintaining safe road transportation at the same time.

When a new bridge is built in the future, it is recommended to exclude the section of the undercut slope areas. The recommended location for a new bridge would be approximately 1km downstream of the existing Luangwa Bridge. On the other hand, there is a small-scale river terrace (6 to 8m above the riverbed level) approximately 0.5 to 1.5km downstream of the Luangwa Bridge on the left bank side (Malawi side) **(Photo 5.1-4**). On the river terrace, there are two villages, each of which has 10 to 15 huts (simple houses) and several cornfields (**Photo 5.1-5**).

If a new bridge is built approximately 1km downstream of the existing Luangwa Bridge, it will pass almost the middle point between the two villages. The access from these villages to the road (Nacala Corridor) would become easier than it is today.

Photo 5.1-3 A distant view of the undercut slope on the right bank side (Lusaka side)

Photo 5.1-4 The slope between the riverbed and river terrace on the left bank side (Malawi side)

Photo 5.1-5 The villages on the river terrace on the left bank side (Malawi side)

4) Geology

The study area is located on a shield consisting of Precambrian bedrock (more than 570 million years ago) covered with a thin weathered surface layer. The bedrock is composed of crystalline igneous rocks (e.g. granite, granodiorite) and high-grade metamorphic rocks (e.g. gneiss, schist).

The bedrock exposed here and there along the banks of the Luangwa River in the study area is Precambrian gneiss, a type of high-grade metamorphic rock, and this gneiss is widely distributed in and around the study area. Gneiss is a type of metamorphic rock that has a banded structure formed as highly banded (i.e. characterized by regularly oriented, thin-layered structure) crystalline schist was metamorphically altered and mineral grains grew larger. Gneiss is characterized by indistinctive bands found at places (**Photo 5.1-6**).

Photo 5.1-6 Gneiss outcrop (by the access road on the left-bank side of the Luangwa River)

Slopes in and around the study area have many, irregularly-distributed and finely-fractured outcrops of weathered gneiss and bare rocks that have cracks caused by stress relief induced by excavation **(Photo 5.1-7**). This indicates that the construction of a large cut slope would cause a maintenance problem.

Photo 5.1-7 Gneiss outcrop and fallen rocks along a cut slope (access road on the right-bank side)

In this study, a boring survey was conducted at a total of three locations, namely, on the right and left banks of the Luangwa River and at the center of the riverbed, to investigate the ground conditions, with a view to constructing a new bridge (tentatively called "New Luangwa Bridge") at a planned site about 1 km downstream from the Luangwa Bridge.

The three boreholes were numbered BH-1 (right bank), BH-2 (mid-channel of the river) and BH-3 (left bank). Since, however, the river stage approached the boring site when weathered rocks were found at GL-8.5 to 9.0 m, the boring machine was moved to another point (referred to as borehole BH-1') located about 10 m closer to the mountain to another location (about 2.5 m higher) (**Photo 5.1-8** to **Photo 5.1-11**).

Later, when weathered rocks were encountered at GL-7.5 to 12.0 m at BH-1', the river stage approached the boring site again, and the boring at this point was discontinued because of concern about the safety of the workers (**Photo 5.1-12**and **Photo 5.1-13**).

Photo 5.1-8 Boring survey at BH-1 (right bank)

Photo 5.1-9 Boring survey at BH-1' (right bank)

Photo 5.1-10 Boring survey at BH-2 (mid-channel)

Photo 5.1-11 Boring survey at BH-3 (left bank)

Photo 5.1-13 Cores taken at BH-1' (right bank)

Photo 5.1-12 River stage at BH-1' (right bank)

Figure 5.1-3 shows a geological cross section inferred from the boring survey results. The ground conditions at each survey location are briefly described below.

At BH-1 (right bank), the accumulation of Holocene talus deposits (gravelly silty sand) and present riverbed deposits (fine sand with lenses of rounded gravel 5 to 10 cm in diameter) can be seen at depths between ground surface and GL-6.6 to 7.5 m. Those deposits are underlain by weathered gneiss formed by metamorphism of Precambrian rocks.

At BH-2 (mid-channel), there are present riverbed deposits at depths between ground surface and GL-15.0 m or more, and it can be inferred that those deposits are underlain by weathered Precambrian gneiss (boring at BH-2 was discontinued because the boring site became submerged as the river stage rose rapidly when GL-15.0 m was reached).

At BH-3 (left bank), the accumulation of Holocene terrace deposits (silty to clayey sand) can be seen at depths between ground surface and GL-9.0 m. Those deposits are underlain by weathered gneiss at depths down to GL-20.0 m, and weakly weathered gneiss has been found at depths of 20.0 m or more.

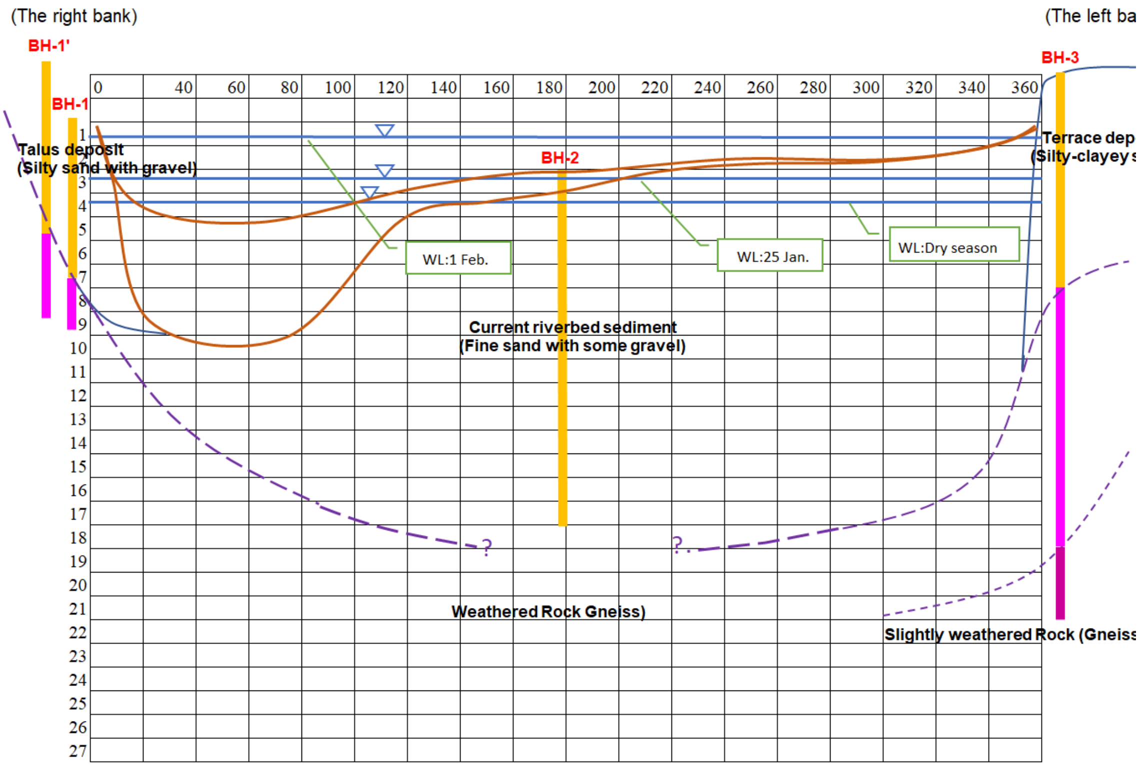


Figure 5.1-3 Geological cross section at the planned bridge site

The present riverbed deposits are gravelly sand layers consisting mainly of fine sand of loose to medium dense. Judging from the groundwater movement in the sand layers, open excavation is likely to result in a collapse of the excavation. Even if the ground at the site is closed with steel sheet piles down to the bedrock (weathered gneiss), excavation is likely to result in boiling because the bedrock is cracky.

The weathered gneiss underlying the present riverbed deposits has many cracks, and weathered regions can be seen along cracks. Since, however, the rock is hard (it can be classified as "cracky hardrock" in the classification system indicated in the Japanese Design Specifications for Highway Bridges), it can be expected to have sufficient bearing capacity to support a spread foundation or a caisson foundation. Because the underlying less weathered gneiss exhibits only slight disintegration (it can be classified as "good hard rock"), it could be used as a stable bearing stratum for an important structure such as a bridge. When, however, it exists at a great depth, it is not suitable for use as a bearing layer for the planned bridge.

Photo 5.1-14 (BH-3) Boring core (fine sand and silty sand, weathered gneiss occurring along cracks at depths of GL-8.5 m or more)

Photo 5.1-15 (BH-3) Boring core (gneiss, cracky hard rock at depths down to GL-20.0 m, hard rock at depths greater than GL-20.0 m)

5.2 Present state of Luangwa Bridge

The existing Luangwa Bridge is a 302-m-long (40 + 222 + 40 m) steel cable-stayed bridge. After the first steel bridge, completed in 1932, was destroyed, the existing Luangwa Bridge was completed in 1968 as the only bridge linking Lusaka and Eastern Province with the assistance of the United Kingdom. Unlike the side spans of other cable-stayed bridges designed today, the side spans of the Luangwa Bridge are so short that the central span of the bridge tends to sag even under the dead load. The concrete deck slab is supported by two slim steel box girders, and the service life of the bridge assumed at the design stage was 75 years. Although details are not known because the design drawings of the Luangwa Bridge no longer exist, it is likely that the design standard applied when the bridge was designed is was BS153 (1958), which was the then-current British Standard, and its partial revisions. This means that the designers did not anticipate frequent application of loads from 50-ton trailers, which are common today.

In the years when the bridge was constructed, it was generally believed, because of the rapid advances in computation theory, that steel box girder construction is economical and makes long-span bridge construction possible. Consequently, in the 1970s and 1980s, many steel bridges were built by using thin steel plates. The steel box girder bridge collapse in 1979 in the United Kingdom, however, resulted in the 1982 revision of the design standard to BS5400 Part 3. In Germany, too, the design standard DIN18806 (1984) and DIN18800 (1991) were revised in the wake of the steel box girder bridge collapse in 1980. Compared with the present design standards, the steel box girder designs in the 1960s tend to be excessively economy-oriented. In those days, experience and knowledge about the fatigue of steel highway road bridges were not necessarily sufficient. In view of these, it can be inferred that the useful life of the Luangwa Bridge, which carries the traffic of heavy vehicles, is by far shorter than expected when the bridge was designed.

According to records, Zimbabwe troops partially destroyed the Luangwa Bridge in 1979. About 20 years later, reinforcing work was carried out in 1997 with the financial aid of Denmark. As a result, all cables were replaced with larger-diameter (65 mm) cables, the steel piers and pylons were reinforced, steel plates were added to the lower flanges of the girders, additional cross beams were installed to the underside of the deck slab, and wind braces were added to connect the abutments and girders so that the sag of the girders was reduced. As a result of the reinforcement work, the central span girders were pulled up about 200 mm.

Even the large-scale rehabilitation and reinforcement work, however, was not enough to make the bridge strong enough to permit free passage of heavy vehicles. At present, therefore, the traffic of heavy vehicles has to be restricted. As a result of the reinforcement work, the bridge now meets the strength requirements for a cable-supported structure under the load conditions involving a single heavy vehicle, but it is likely that damage affecting durability to those parts of the bridge that have not been reinforced since the construction of the bridge, such as welds of the girders, has been accumulating.

Table 5.2-1 Present state of Luangwa Bridge

Bridge type	Three-span continuous steel cable-stayed bridge
Length	L=302 m (40m+222m+40m)
Lane configuration	Two roadway lanes (W = 7.315 m), sidewalk on both sides (W = 1.440 m on each side), Deck slab width W = 10.195 m
Substructure	Abutment: Spread Foundation, Pier: Spread Foundation (estimated)
Tower	Steel box tower, (H=42 m height)
Cable	Arrangement: Harp type, Cable type: Locked coil rope
Deck Floor	Composite reinforcement concrete with steel cross beams
Girder	2 steel box girders(778×1981mm)
Designer	Freeman Fox & Partners
Contractor	Dorman Long (Bridge and Engineering) Ltd.
Design Standard	N/A
Completion	1968
Traffic restriction	Maximum weight 55 tons, vehicle speed 30 km/h, only one vehicle at a time

Source: Study Team

Table 5.2-2 History of Luangwa Bridge

Year	Repair/reinforcement history	Years after completion
1973	Partially repaired.	5
1979	Partially destroyed by Zimbabwe troops.	11
1997	Large-scale rehabilitation and reinforcement were carried out. Girder sag was reduced by 200 mm by replacing all cables with larger-diameters cables, reinforcing steel piers and pylons, adding steel plates to the lower flanges of the girders, adding cross beams to the underside of the deck slab, adding wind braces connecting the abutments and girders and reconcreting abutment vertical bearings.	29
2003-2004	To make up for axial force (tension) loss of the replacement cables newly installed in 1997, the cables were re-tensioned so as to lift up the sagging girders.	35

Source: Study Team

Table 5.2-3 Examples of reinforcements

 Adding the steel sections and stiffeners	 Doubling the number of deck cross beams	 Installing reinforcement plates to cable anchorages
 Installing steel plates to the lower flanges of the girders	 Replacing cables with larger-diameter locked coil ropes	 Reinforcement with concrete anchorage

5.3 Necessity for reconstruction

It is utmost important to recognize the fact that the Luangwa Bridge has no appropriate detour and alternative in Zambia when the replacement of the bridge is considered. The Luangwa River is the largest river along the Nacala Corridor and the Luangwa Bridge is the only bridge crossing the river to link Eastern Province with other part of the country. When the Bridge becomes closed to the traffic, Eastern Province stands isolated and such situation results in a huge loss against both Malawi and Mozambique where the Nacala Corridor passes through.

The upper limit of the weight of a vehicle allowed on the existing bridge is 55 tons, and the speed limit and the number of vehicles allowed at a time on the bridge are 30 km/h and 1, respectively. Therefore, there is sometimes a queue of about 10 vehicles waiting in front of the bridge. Most of the heavy vehicles using the existing bridge are large six-axle trailers weighing about 55 tons. On other international corridors where there is no weight limit, seven-axle and eight-axle trailers weighing more than 55 tons are running, but such vehicles cannot use the Nacala Corridor. The Luangwa Bridge, therefore, is currently a bottleneck to the functioning of the Nacala Corridor and a primary factor hampering the effective use of the cost and time advantages of the Nacala Corridor.

The Luangwa Bridge has been in service after undergoing repairs and reinforcements, but fifty years have already passed since the construction of the bridge. It is certain that fatigue damage to the suspended girders in the central span has been accumulating rapidly because of recent increases in the traffic of heavy vehicles, particularly close-to-weight-limit six-axle large trailers. The original lower flange-web welds are no longer visible because of reinforcements added in subsequent years. Because it is certain that the traffic of heavy vehicles weighing up to 55 tons will continue to increase in the coming years, damage is likely to increase rapidly.

In Japan, the total weight of a large vehicle allowed on public roads is limited to 25 tons. The heavy vehicle traffic on the Luangwa Bridge, therefore, is equivalent to heavy traffic of vehicles weighing 2.2 times more than the largest allowable vehicles in Japan. This indicates that fatigue damage of steel bridge is calculated 10.6 times (the third power of 2.2) greater, and it is equivalent to the damage caused by a traffic of 2,120 heavy vehicles/day (= 200 heavy vehicles/day x 10.6) in Japan where the weight limit of vehicles allowed on public roads is 25 tons. This is equivalent, assuming that the vehicle type on the Luangwa Bridge is the same as that on bridges in Japan, to an average traffic volume of 118 vehicles per hour, or 2 heavy vehicles per minute at daytime. This shows how great the influence of large trailers is under the present conditions.

Another problem is that the Lusaka-side access road of the existing Luangwa Bridge has a horizontal radius of about 80 m. Although the traffic of large trailers will without doubt increase in the coming years, the road is not well structured to accommodate the traffic of such trailers. In fact, a head-on collision accident between large vehicles occurred on that access road, and it is generally recognized as an accident-prone spot. However, improvement of the access road is impossible due to the restriction of the landform and therefore both Luangwa Bridge and the access road are bottle necks for Nacala Corridor.

As a consequence, Luangwa Bridge requires immediate reconstruction along with the development of Nacala Corridor.

6. Traffic Volume

6.1 Present traffic volume

The volume of traffic on the Luangwa Bridge can be estimated from the traffic volume between Lusaka and Chipata because there is no major city in the area along the Nacala Corridor in Zambia. **Figure 6.1-1** which indicates the traffic volume of heavy vehicles on each corridor, shows that the number of equivalent standard axles per year in the direction of maximum traffic of the Nacala Corridor is about 70% of that of the Dar es Salaam Corridor and 50% of the North-South Corridor toward Livingstone. As shown in **Figure 6.1-2**, the most distinctive characteristic is a high percentage of heavy vehicles having an axle weight exceeding the specified limit. According to 2007 heavy vehicle data, traffic volume is smaller than on the Dar es Salaam Corridor, but the percentage of vehicles that have an axle weight exceeding the specified limit is 52.5% and the percentage of vehicles whose axle weights all exceed the specified limit is 28.1%. Both percentages are by far higher than the percentages of other corridors. The passenger car equivalency factors are higher than the average of all corridors and are estimated to be 3.0, 4.0 and 4.6 for large buses, standard trucks and larger trailers, respectively.

The traffic of vehicles heading for Lusaka from the port side such as six-axle large tanker trucks transporting petroleum is heavy, while the volume of traffic of vehicles heading in the opposite direction is said to be smaller. This indicates that after arriving at Lusaka, a significant percentage of large tanker trucks may head for other destinations without returning directly to where they came from and then return to the port through other routes.

According to the result of the traffic volume survey conducted recently, passenger cars account for 53.5% of the vehicles passing the Luangwa Bridge; large buses 10%; and the remainder are mostly six-axle large trailers. **Figure 6.1-4** shows the characteristics of the traffic on the Nacala Corridor. As shown, the percentage of large trailers is lower than on other corridors. On the other hand, the percentage of two-wheel trucks tends to be considerably high. This suggests that large trailers, which represent the primary mode of transportation of goods in Zambia, avoid using the Nacala Corridor where traffic restrictions are imposed. The result of a hearing survey of local residents about the characteristics of traffic volume on the Luangwa Bridge is shown in the table below. According to the survey result, although subjective judgments are not consistent with objective quantitative survey results, local residents tend to have the following impressions: traffic volume does not vary significantly among days of the week; traffic is heavy even at nighttime; large trailers account for most of the traffic; and traffic volume increases significantly during agricultural production periods.

As of the time when the study was conducted, road improvement from Lusaka to the Port of Nacala had not been completed. It can be inferred, therefore, that few vehicles come directly from the Port of Nacala.

Table 6.1-1 Results of hearing survey about traffic volume on Luangwa Bridge

	Question	Answer
1	On which day of the week is traffic the heaviest?	Almost the same.
2	On which day is traffic heavier, Saturday or Sunday?	There is no difference.
3	At what time of the day is traffic heavy?	At 4:00 to 8:00 and at 18:00 to 24:00.
4	Is there little traffic at nighttime	There is a certain amount of traffic at nighttime, too.
5	Do large trailers (trucks) account for most of the traffic?	Exactly.
6	Where do large trailers come from?	They come from the Port of Beira. They do not come from the Port of Nacala.
7	Does traffic volume increases during agricultural production periods?	Yes.
8	To what extent does traffic increase during agricultural production periods	About 100 to 2000 vehicles per day.

Source: Study Team

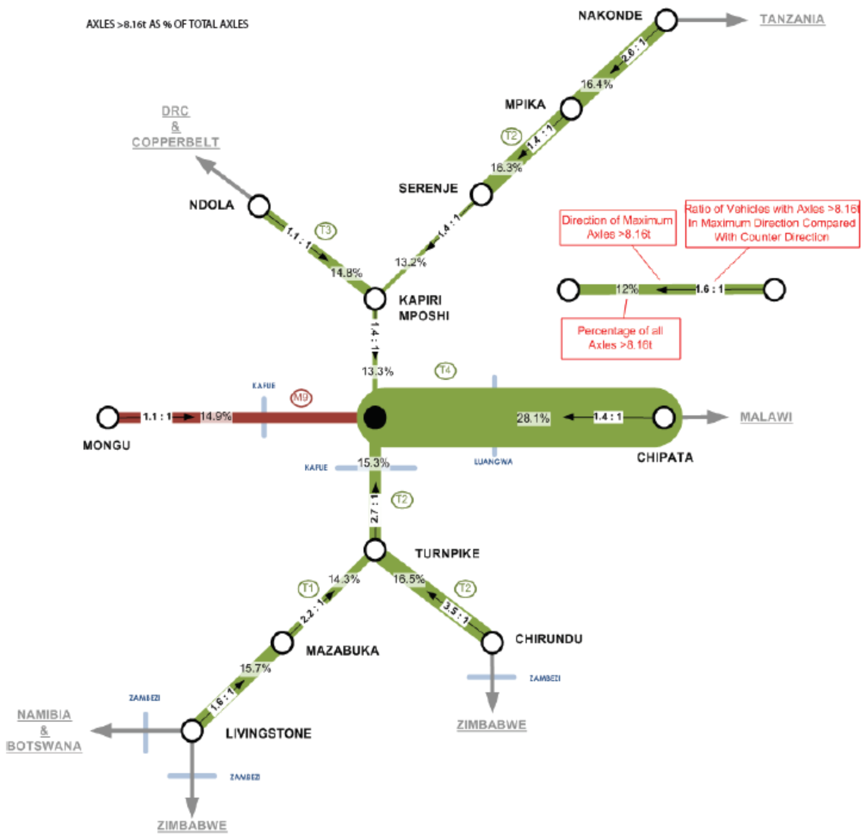


Figure 6.1-1 Road traffic conditions on each corridor

Source: Analysis of Available Axle Loading Data

Figure 6.1-2 Characteristics of traffic on the Nacala Corridor
Source: Analysis of Available Axle Loading Data

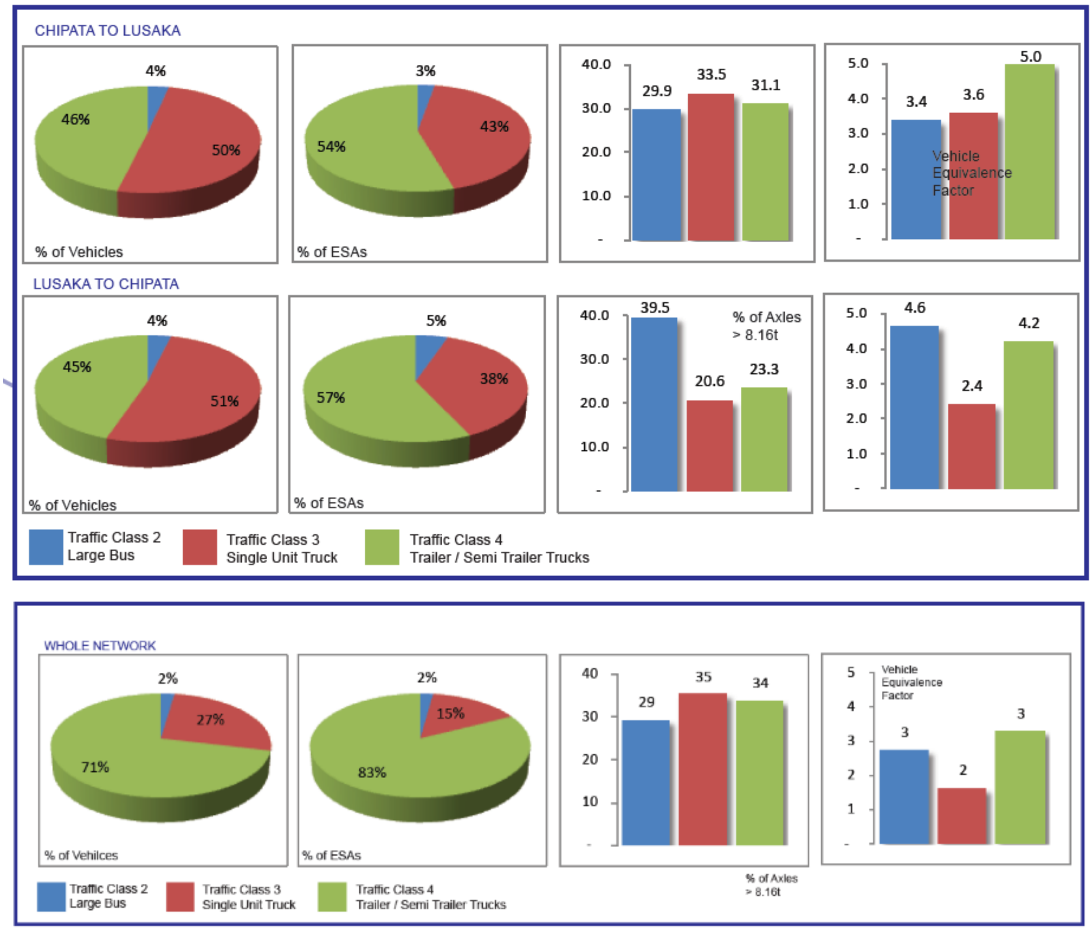


Figure 6.1-3 Characteristics of traffic on the Nacala Corridor

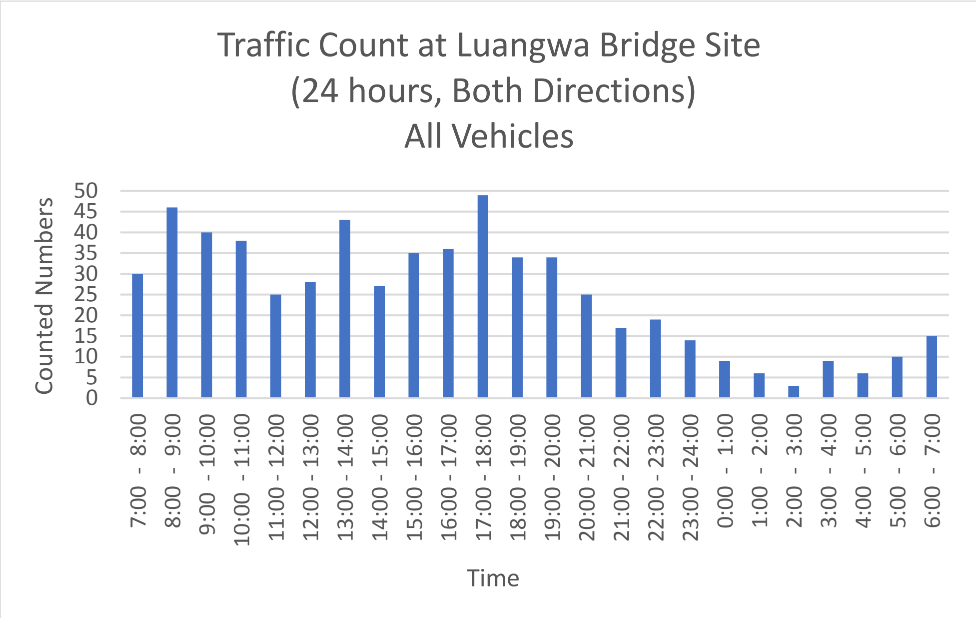
Table 6.1-2 shows the traffic counts taken during a 24-hour period from February 1 to February 2, 2019. The 24-hour traffic count totaled 598 vehicles. Large trailers and large trucks account for about one-third of the total, indicating that the Nacala Corridor is an important transportation route. Large six-axle trailers were the dominant type of vehicle, and they are thought to be the largest vehicle that meet the axle weight requirements and at the same time meet the weight limit (55 tons) requirements.

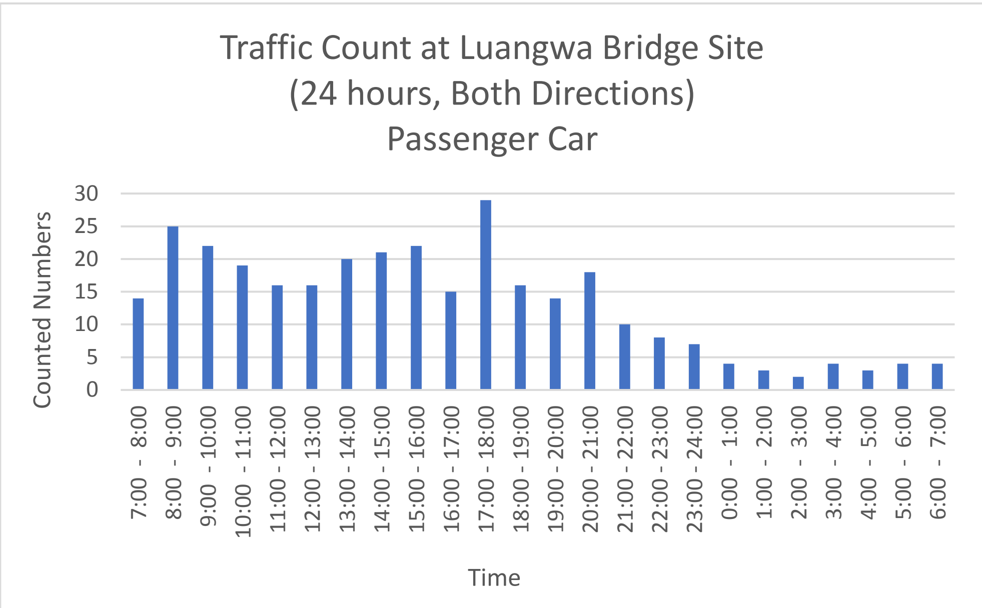
Comparison of traffic counts at different times of the day reveals that traffic counts are high during the 12-hour period from 7:00 to 19:00. Nighttime counts are roughly half of the daytime counts. Passenger car counts decrease significantly at nighttime, while the ratio of decrease in large trailer count is not as high as that of the decrease in passenger car count, and nighttime counts of large trailers are relatively high. Because the survey was conducted during a non-agricultural harvesting period, it is believed that there was little traffic of trucks transporting agricultural products. If the increase is assumed to increase by 15% in terms of PCU, then the daily count will be 1,679 vehicles.

Figure 6.1-6 shows the hourly traffic counts taken during the one hour from 11:00 to 12:00 on the roads to the Chirundu Bridge and Livingstone. It has been found that the transportation of goods relies mainly on large trailers. The traffic count survey confirmed that trailers running on the Nacala Corridor include not only six-axle trailers, which are the dominant type of transportation vehicle on the corridor, but also a significant number of seven-axle and eight-axle trailers, which are more suitable for mass transportation than six-axle trailers. This indicates that the size of trailers used for transportation varies depending on whether traffic restrictions are imposed or not.

Table 6.1-2 Traffic Count for 24 Hours (1 – 2 Feb, 2019)

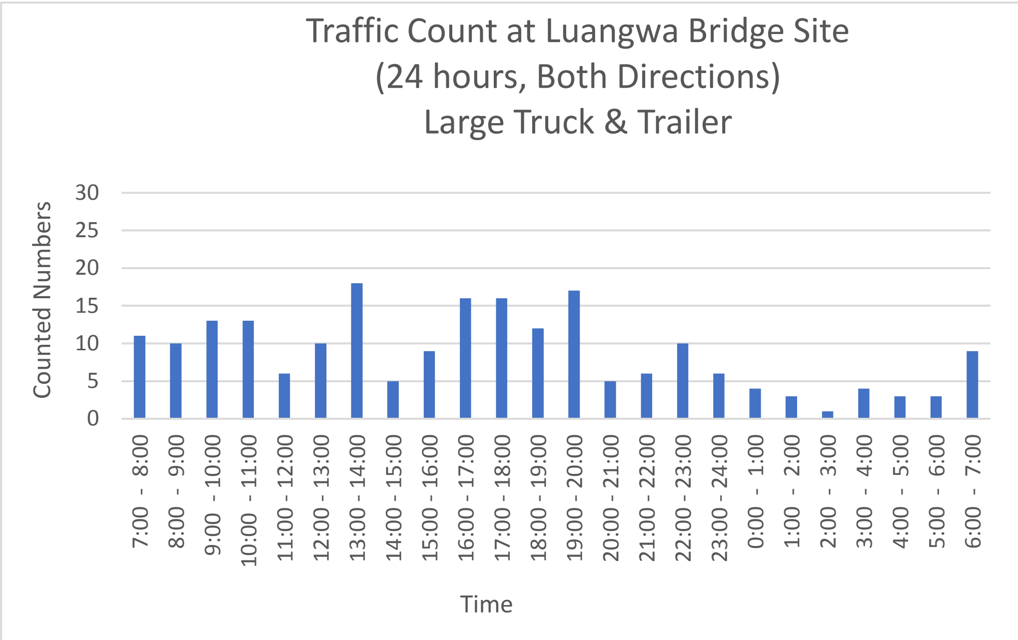
Type	Passenger	Small Truck	Bus	Large Trailer/Truck	Total
Daily Traffic	316	19	53	210	598
Ration (%)	52.8	3.2	8.9	35.1	100.0
Passenger car equivalency factor	1.0	1.0	3.0	4.6	
PCU	316	19	159	966	1,460





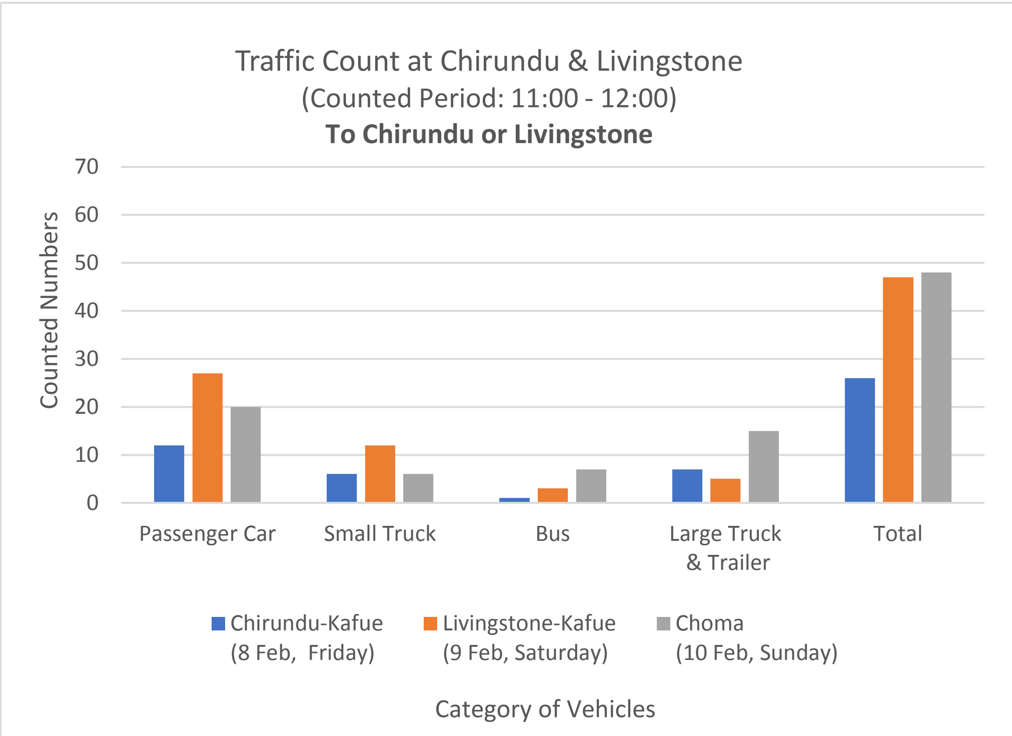
Source: Study Team

Figure 6.1-4 Characteristics of traffic on Luangwa Bridge



Source: Study Team

Figure 6.1-5 Characteristics of traffic on Luangwa Bridge



Source: Study Team

Figure 6.1-6 Characteristics of traffic on the roads to Chirundu Bridge and Livingstone

6.2 Future traffic volume

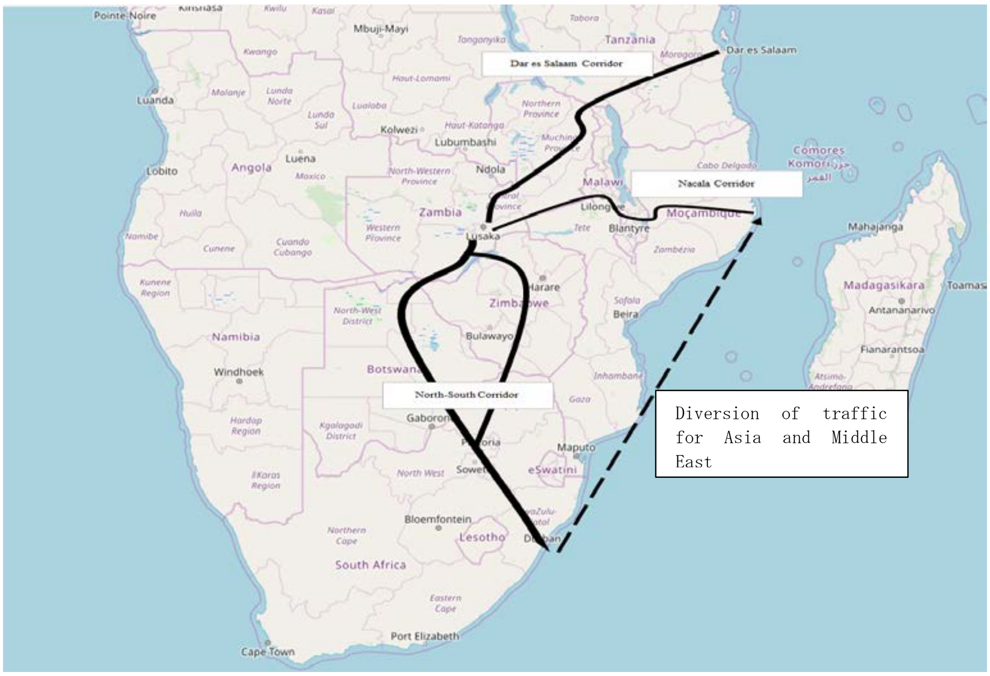
Because this study does not include the estimation of future traffic volume, traffic volume in the coming years on the Nacala Corridor is estimated here from the results of the traffic count study conducted by RDA.

Traffic volume on the Nacala Corridor is greatly affected by the state of corridor development in not only Zambia but also Malawi and Mozambique, where the Port of Nacala is located. Furthermore, as mentioned earlier, traffic volume on the corridor is also affected by railway service availability in Chipata and the time required for cross-border customs clearance.

After the completion of the Luangwa Bridge, there will no longer be a 55-ton weight limit and a one-vehicle-at-a-time restriction so that large trailers can pass the bridge freely. It is also certain that the number of seven-axle trailers, which are rarely seen on the Nacala Corridor at present, will increase on the corridor. Because the new bridge will reduce transportation time, it will attract more vehicles from other corridors so that traffic volume increases sharply.

According to 2015 traffic volume survey results, the large trailer traffic count between Lusaka and Livingstone was 620 to 710 vehicles/day. Considering that the Zambia's trade between China, India and Kuwait shares about 25%, if 15% of the large trailers currently using the north-south corridor leading to the Port of Durban are diverted, then the traffic count of large trailers will increase by 25% from 200 vehicles/day to 250 vehicles/day. Since the trade of Zambia with the Asia and Middle East regions account for about 30% of the total world trade, a more rapid increase can be expected.

At present, the imports transported via the Port of Dar es Salaam accounts for a considerable percentage of the goods transported on the corridor. If, however, the traffic restrictions associated with the Luangwa Bridge are lifted, it is a matter of time before imports via the Port of Nacala increase because of advantages in terms of distance and cost. The traffic of large trailers on the Nacala Corridor, therefore, will further increase.



Source: Study Team

Figure 6.2-1 Traffic diversion to the Port of Nacala

7. Bridge Plan

7.1 Bridge location

Luangwa Bridge is located across the narrowest part of Luangwa River, which is about 1 km along the right bank of the river from the Luangwa Bridge market. Possible locations of a new bridge are shown in **Figure 7.1-1**. Since it is extremely difficult to build an abutment on the left bank of the river due to restriction of the land form, the construction of the new bridge upstream the current bridge is excluded from the possible plans.

The route A is intended to avoid closure of the existing road during the construction. But the construction of the abutment on the left bank is very difficult due to land form. The route B, C and D are intended to shorten the access road in Malawi side and are advantageous because the width is narrow than the route E. However, large excavation work is unavoidable on either right or left bank with steep landform and these routes must compromise that the poor road alignment cannot be improved completely and more importantly the closure of access road is unavoidable during construction. It is necessary to keep the existing road always opened since it is used as only road to enter from Lusaka to the eastern states.

The route E is planned to allow the free passage of the existing road by constructing shorter bypass. The river width and hence the bridge length in the plan E are largest. However, a sand land shows up on the left bank covering more than half of the river width in the dry season. Therefore, the plan E is advantageous from an economic viewpoint because it does not require underwater construction work. The plan allows the current traffic to be completely opened during the construction and the construction of an access road is easy owing to the gentle slope of both banks. This plan also solves a problem of geometrical structure of the road.

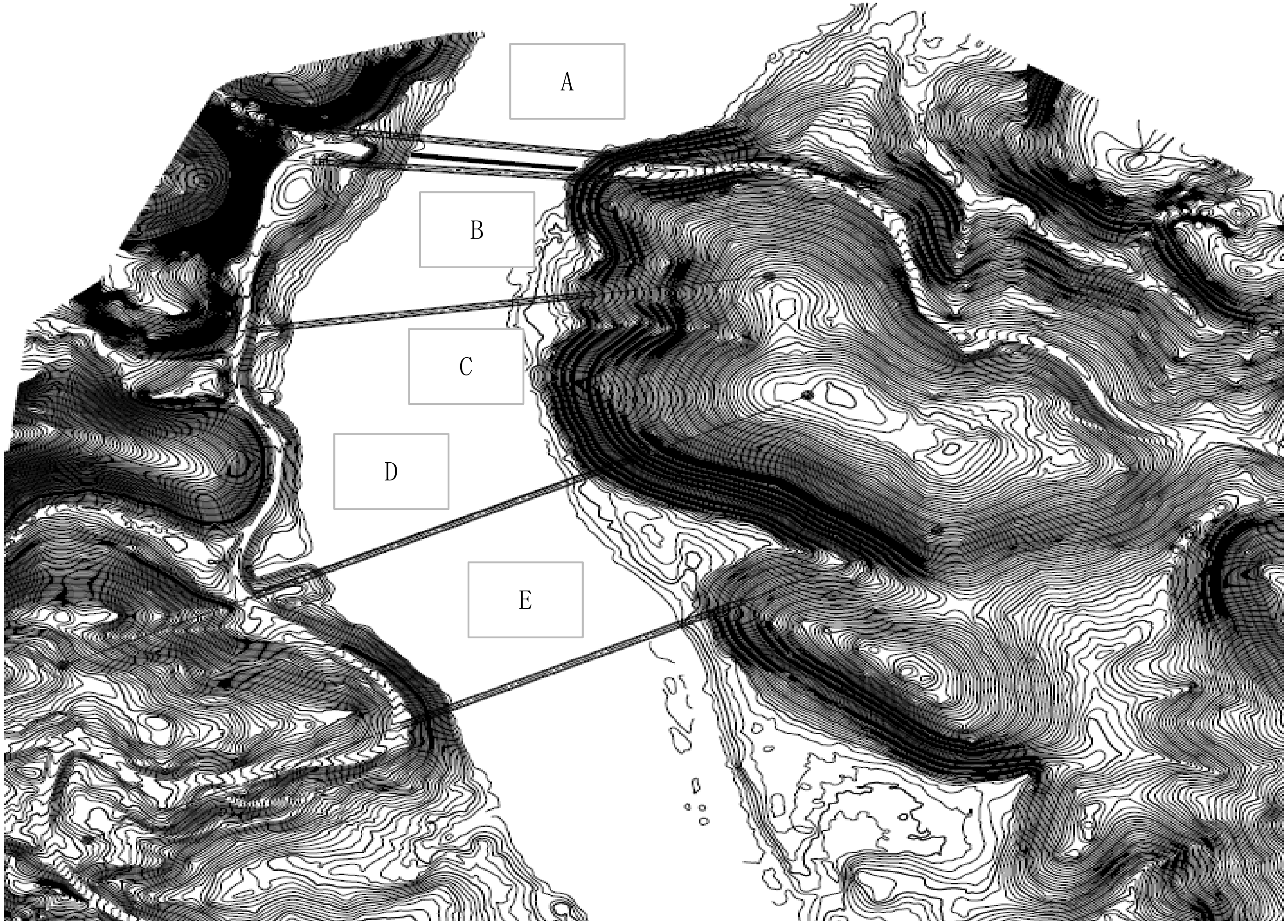


Figure 7.1-1 Comparison of candidate routes

Table 7.1-1 Comparison of candidate routes

Route	A	B	C	D	E
Location	Upstream of existing bridge. Longer bridge is needed than B and construction is difficult in steep slope of right bank.	Downstream of existing bridge. Shorter bridge is applicable but construction of brisge and access road is impossible in steep slopes of both sides.	Downstream of B. Longer bridge is needed. Construction is dfficult especially in steep slope of left bank.	Downstream of B and C.Longer bridge is needed than B and C. Construction is very difficlut in steep slopes of both bank sides.	It does not interfere with existing access road. Bridge length is almost same as C. Construction of bridge and road is easy.
Bridge Length	450～500m	350～400m	450～500m	500m	500m
Waterway in dry season	100m	100m	150m	130m	130m
Max. Span Length	130m	150m	150m	150m	150m
Construction in Water	Not necessary for construction in dry season.	Not necessary for construction in dry season.	Probably necessary	Not necessary for construction in dry season.	Not necessary for construction in dry season.
Access Road	Difficult to construct access road on right bank. Difficult to imrove poor geometry of existing road.	Difficult to construct access road on right and left banks. Difficult to imrove poor geometry of existing road.	Difficult to construct access road on right and left banks. Difficult to imrove poor geometry of existing road.	Difficult to construct access road on right and left banks. Difficult to imrove poor geometry of existing road.	Longer access road is needed but construction is easy.
River Bank Protection	Probably necessary of left bank.	Not necessary	Not necessary	Not necessary	Not necessary
Convenience	Least convenient	Not convenient	Not convenient	Not convenient	Nearest rout to Luangwa Bridge Market.
Geometry of Road	No improvement of existing access road.	Complete imrovement is impossible.	Complete imrovement is impossible.	Complete imrovement is impossible.	Complete improvement is possible.
Influence to Environment	Large earthwork is necessary.	Large earthwork is necessary.	Large earthwork is necessary.	Large earthwork is necessary.	Medium earthwork is necessary.
Resettlement	No need	No need	No need	No need	Several resettlement may be necessary
Existing Road during Construction	Temporary closure is needed.	Temporary closure is needed.	Temporary closure is needed.	Temporary closure is needed.	No closure is necessary.
Technical Evaluation	Not appropriate	Not appropriate	Not appropriate	Not appropriate	Appropriate
Construction Cost	Same as route E	Expensive than route A	Expensive than route A	Expensive than route A	Same as route A
Evaluation	Not appropriate	Not appropriate	Not appropriate	Not appropriate	Appropriate

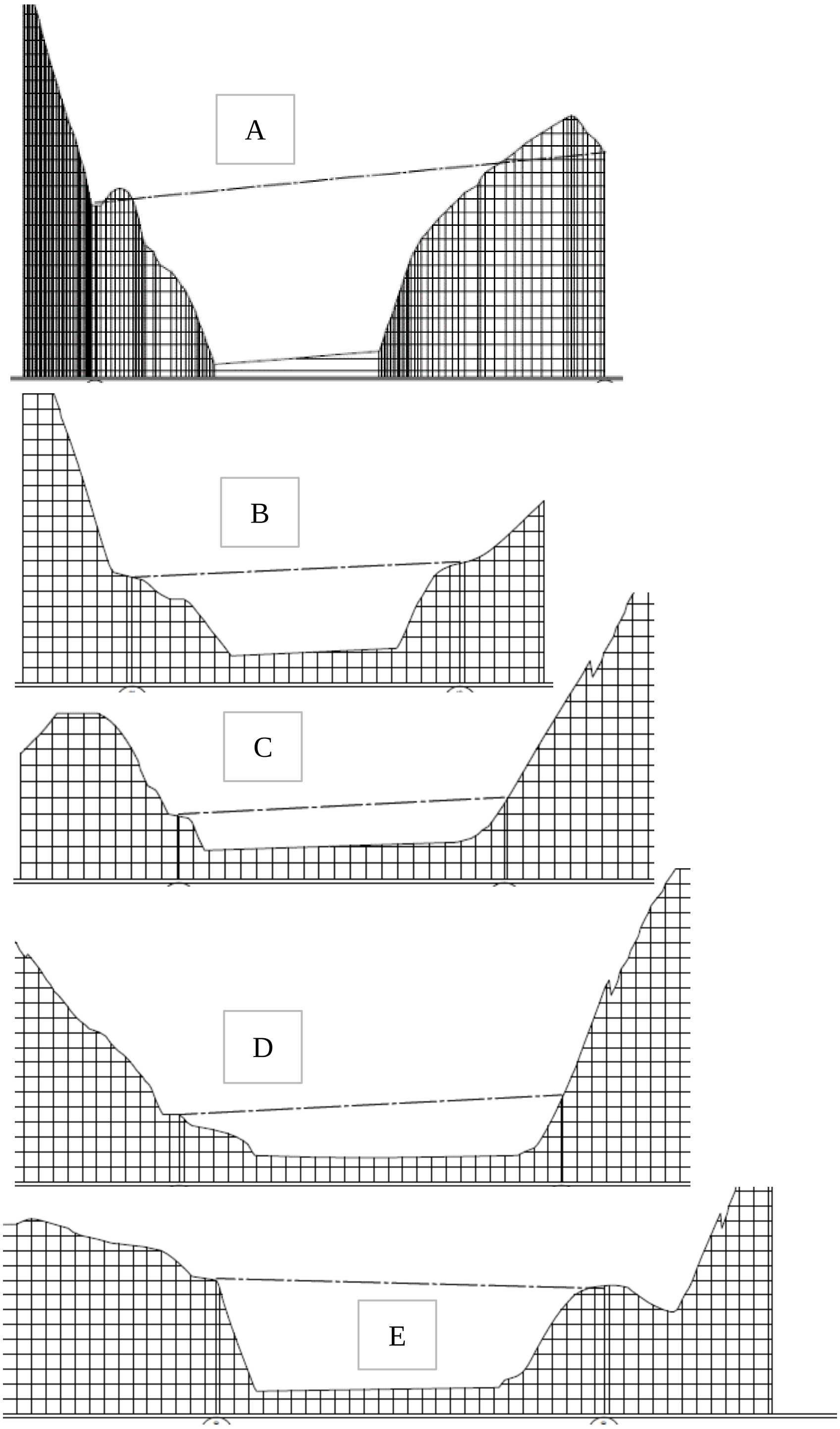


Figure 7.1-2 Cross Section of Bridge Location

7.2 Bridge type

Because the riverbed is transformed seasonally, a foundation should not be constructed in the area where a deep water channel is formed during the rainy season. As superstructure alternatives, the following are compared: (1) a four-span continuous prestressed concrete rigid-frame box girder bridge having a span length of 150 m, (2) the combination of a three-span continuous prestressed concrete box girder bridge having the same span length and prestressed concrete girder bridge having a span length of 30 m and (3) an extradosed bridge having a span length of 300 m. Steel bridge construction was not considered as an alternative in view of the considerable difficulty expected in transportation even from the nearest port, which is a considerable distance away from the bridge site, the increase in the unit cost of substructure construction work resulting from the decrease in the quantity of work, and problems associated with future maintenance.

Under ordinary circumstances, the method of using a combination of short-span prestressed concrete girders is the most economical solution. That approach, however, would not work in this project because at least one large bridge having a span length of 150 m is needed to avoid the riverbed transformation zone and the deep bearing layer in the river area increases the number of tall piers required to the extent of making the project uneconomical. For these reasons, four-span continuous prestressed concrete rigid-frame box girder bridge construction is the most suitable solution.

If the effects of the depth of the riverbed transformation zone and scouring are taken into consideration in the case where there is a thick layer of sand deposits having an SPT blow count (N-value) of 30 in the river channel, it is reasonable to conclude that a sand layer having a depth of 15 m or less from the riverbed surface should be used as a foundation bearing layer. A caisson foundation is an appropriate type of foundation in this case, and the method of sinking open caissons during the dry season is considered as a construction method. In this case, it is important to keep the water level in the open caissons relatively high so as to stabilize the sand layer at the excavation site.

Figure 7.1-2 shows the vertical bearing capacity and limitation bearing capacity estimated based on the Design Standard of the Japanese Road Bridge Design Standard, for the caisson foundation, supported on the sand layer of N=30, cohesion C=0, and internal friction angle of 30 degree. The vertical bearing capacity satisfies about 50% of that of weathered rock and the design of foundation is possible.

Table 7.2-1 Depth to Base of Footing and Vertical Bearing Capacity

Df (m)	β	γ1	B	Nγ	γ2	Nq	qd (kN/m2)	qyd (kN/m2)	Limitation of Bearing Capacity for 50m^2 Footing (kN)
5	0.8	10.0	5.0	15.0	10.0	18.0	1,200.0	631.8	31,590.0
10	0.8	10.0	5.0	15.0	10.0	18.0	2,100.0	1,105.6	55,280.0
15	0.8	10.0	5.0	15.0	10.0	18.0	3,000.0	1,579.5	78,975.0
20	0.8	10.0	5.0	15.0	10.0	18.0	3,900.0	2,053.3	102,665.0

Table 7.2-2 Comparison of bridge types

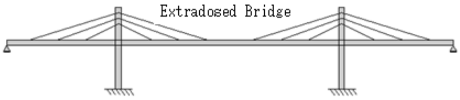
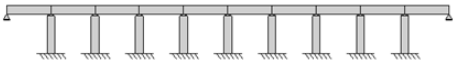
PC Box Girder Bridge 	Structure	Continuous PC girder bridge with box section
	Maintenance	Rigid frame makes maintenance easy
	Cost	Economical than extradosed bridge
	Structure	PC box girder with short tower and PC cables deviating upward from the deck
	Maintenance	Maintenance of cables and their anchorages is necessary
	Cost	Costly than PC box girder bridge
Connected Continuous PC Girder Bridge 	Structure	Continuous girder bridge with precast PC girders connected on piers
	Maintenance	Easy maintenance with fewer expansion joints
	Cost	Most economical for superstructure

Table 7.2-3 Comparison of foundation the substructure in river channel

Foundation type	Spread foundation	(Open) caisson foundation	Pile foundation
Bearing layer location	Applicable to a shallow bearing layer	Applicable to a somewhat deep bearing layer	Applicable to a deep bearing layer (a deep bearing layer to which neither a spread foundation nor a caisson foundation can be applied)
Main bearing mechanism	Vertical bearing capacity of bottom face	Vertical bearing capacity of bottom face and horizontal bearing capacity of side face	Vertical end-bearing capacity and side friction capacity of pile
Effect of riverbed transformation	Scouring	Scouring	Scouring, popping up of piles
Availability of construction equipment	Common type of construction equipment that is readily available	Common type of construction equipment that is readily available	Pile driving equipment needs to be made available.
Ease of construction	Excavation of a deep sand layer is difficult.	Open caisson work during the dry season is easy to carry out.	Relatively easy
Applicability to Luangwa River	Not applicable	Applicable	Mostly applicable
Overall evaluation	Not appropriate	Appropriate	Applicable only when more economical than caisson

7.3 Project section

The existing road is the only arterial road linking Lusaka and Eastern Province. It is therefore important to keep the road open to traffic even during bridge reconstruction. The planned road, which is about 1,600 m long, should branch from the existing road at the northern end of the village on the right bank on the Lusaka side, enter the earthwork section at the north slope of a small hill (elevation: 430 m) on the opposite bank on the Malawi side and join the existing road at an average slope of about 4%. The bridge section is a 480-m-long section of the 1,600-m-long road, and the remainder (1,120 m long) is an access road on the Malawi side.

The access road on the Malawi side will be used as a temporary transportation road during the construction of the bridge. After completion of the bridge, the access road will be used as a permanent road. The road currently used by local residents is narrow and crosses the central part of the village. That road, therefore, should not be used as a construction road.

Table 7.3-1 Project section

Bridge length	500m
Road length	1,100m
Lusaka side	50m
Malawi side	1,050m
Total	1,600m

7.4 Design Standard

It is appropriate to use the design standards which were applied to the Nacala Corridor in Zambia. This study considers the design conditions shown in **Table 7.4-1.**

Table 7.4-1 Major design condition

Design speed		60 km/h
Number of lane		2
Lane width		3.5 m×2
Shoulder width	Bridge	0.5 m×2
Sidewalk width	Bridge	0.75 m×2
Thickness of asphalt pavement	Bridge	80 mm
	Road	100 mm
Design standard	Bridge	SATCC Code of Practice for Design of Bridges
	Road	SATCC Code of Practice for Geometric Design

7.5 Construction schedule

In view of the track record data on the construction of a bridge of similar size in the area, the proposed construction period is 36 months after ground breaking.

Table 7.5-1 Proposed construction schedule

	First year	Second year	Third year
Preparation work			
Foundation work			
Substructure work			
Superstructure work			
Pavement etc.			

7.6 Summary of bridge plan

From the above companies and evaluations, the replacement plan of the Luangwa Bridge is summarized as follow:

- Considering of importance of the Nacala Corridor and Luangwa Bridge, the bridge should be often to free traffic
- Bypass route should be constructed
- Bridge length should be about 500m
- In order to materialize of economic construction of the new Luangwa Bridge foundation and substructure should be constructed during dry season
- The new road should be 2-Lane carriageway in line with the Nacala Corridor in Zambia
- Sidewalk should be provided on the bridge for the usage by local residents

8. Considerations in Subsequent Studies

Matters that should be taken into consideration in subsequent studies to be conducted on the basis of this study are listed below.

- This study was conducted during the rainy season that imposes a number of restrictions on activities. Subsequent studies should be conducted during the dry season when the situation of the project site may be significantly different.
- In order to collect information on the ground conditions of the Luangwa River area, which is part of the fundamental information necessary for bridge planning and design, boring surveys need to be conducted at least at or around the planned bridge pier locations.
- Site reconnaissance needs to be conducted in order to enhance the accuracy of access road planning.
- It is said that traffic volume on the Luangwa Bridge increases during agricultural harvesting periods. Twenty-four-hour surveys should be conducted, therefore, during such periods.
- Because Zambia is an inland country, it is necessary to collect information on suppliers of materials and equipment, along with their prices, necessary for bridge reconstruction in Zambia.
- It is necessary to study the concrete mixing method and facilities commonly used in Zambia.
- It is necessary to find places where facilities such as an office, lodging and plants can be located for use during the construction period and draw up a yard plan because there is no lodging in the vicinity of the Luangwa Bridge. It is also necessary to determine reconstruction procedures and draw up a temporary facility plan.
- It has been reported that there is a plan for the construction of a dam for power generation on the upstream side of the Luangwa Bridge. It is therefore important to check on the progress of that plan.

Appendix A　Collected materials and reports

	Title	Date
1	The Project for Nacala Corridor economic development strategies in Republic of Mozambique	2015.4
2	The project for Nacala corridor economic development strategies in the Republic of Mozambique	2015.4
3	(JP)Master plan for corridor development strategies in Africa (JICA Presentation)	2017.1
4	(JP)The project for supporting the promotion of Nacala corridor development	2018.3
5	(JP)Preparatory surve for Nacala corridor road network upgrading project	2018.5
6	(JP)Corridor development・strategic master plan (Presentation by JICA)	2017.1
7	(JP)Data collection and preparatory study for Nacala corridor development (Mozambique, Malawi)	2018.3
8	Multinational Malawi-Zambia Nacala Road Corridor Development Project Phase IV	2013.11
9	(JP)Project for master plan on logistics in northern economic corridor final report	2017.3
10	Infra-sector Profile 2013	2013
11	RDA Annual Report 2016	2016
12	Revised Regional Indicative Strategic Development Plan	2015
13	Zambia in Figure 2018	2018
14	ZDA 2014 ANNUAL REPORT	2014
15	(JP)Economy of Zambia 2018	2018
16	7 th National Development Plan	2017
17	(JP)Study on 5 th National Development Plan	2007.3
18	Link Zambia 8000 Project	2012
19	RDA road maintenance strategy 2015-2024	2015
20	Revised National Transport Policy	2016.11
21	(JP)Road Development in Africa by ODA Financial Assistance (Ethiopia, Ghana, Tanzania) (Basic Study Report)	2013.3
22	(JP)Supporting Project on Master plan for Delivery Network Development of Northern Corridor in Africa	2017.3
23	Luangwa Bridge Environmental Project Brief	2015/8
24	ROADS (Road Development Agency)	2016.1
25	(JP)Preliminary Study Report of Chirundu Bridge over Zambezi River	1998.10
26	Luangwa Final Feasibility Report	2016.2
27	Revised National Transport Policy (NTP) 2017	2017
28	SATC Draft Geometric Design Standard	1998.9
29	SATC Draft Bridge Design Standard	1998.9
30	African economic outlook (OECD)	2017
31	(JP)Economic Outlook of Zambia	2018.3
32	Database for Hydrological Time Series of Inland Waters, Technical University of Munchen	2018.11
33	ANALYSIS OF AVAILABLE AXLE LOADING DATA	2011.5

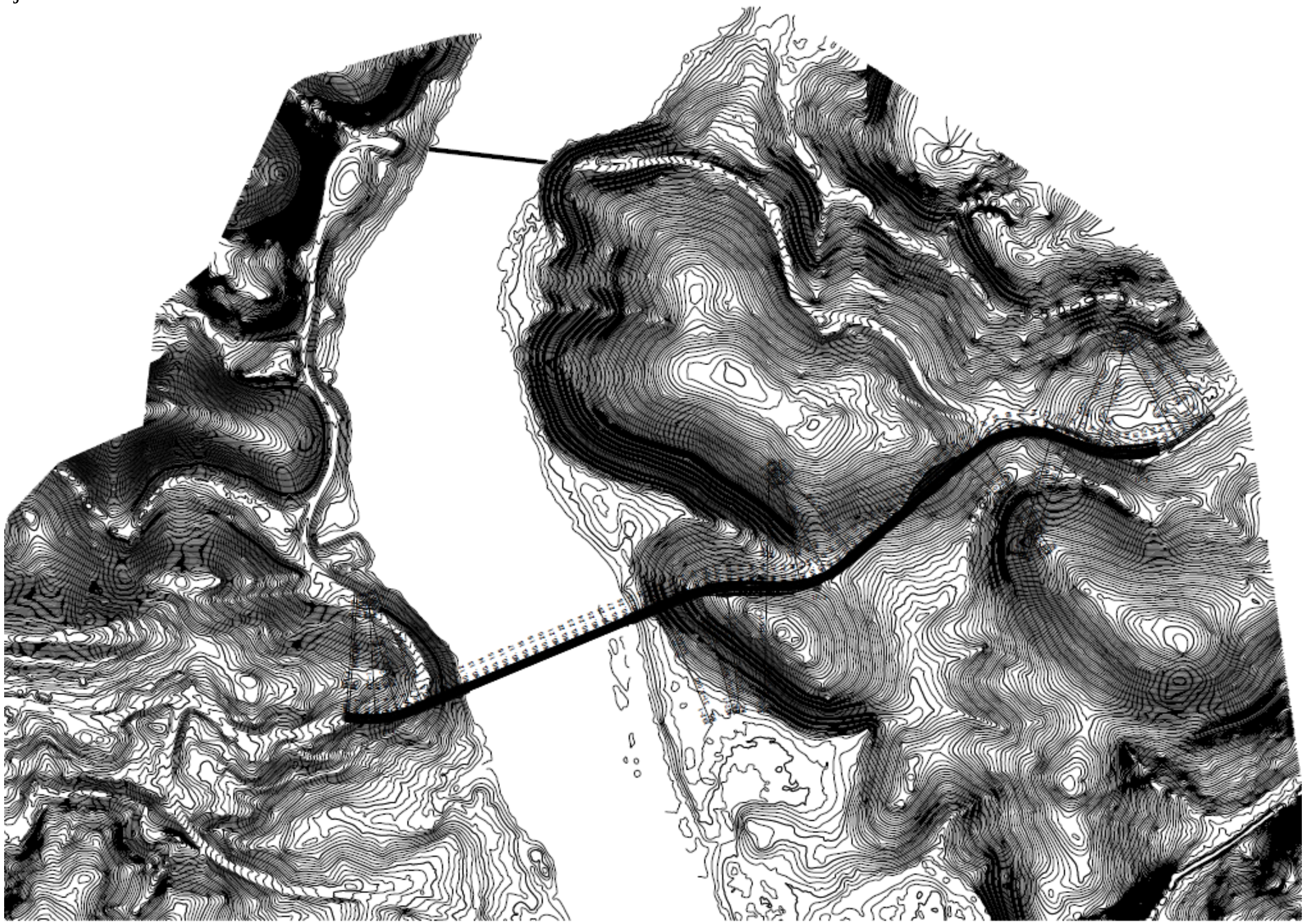


Figure BP.1-1   Plan View

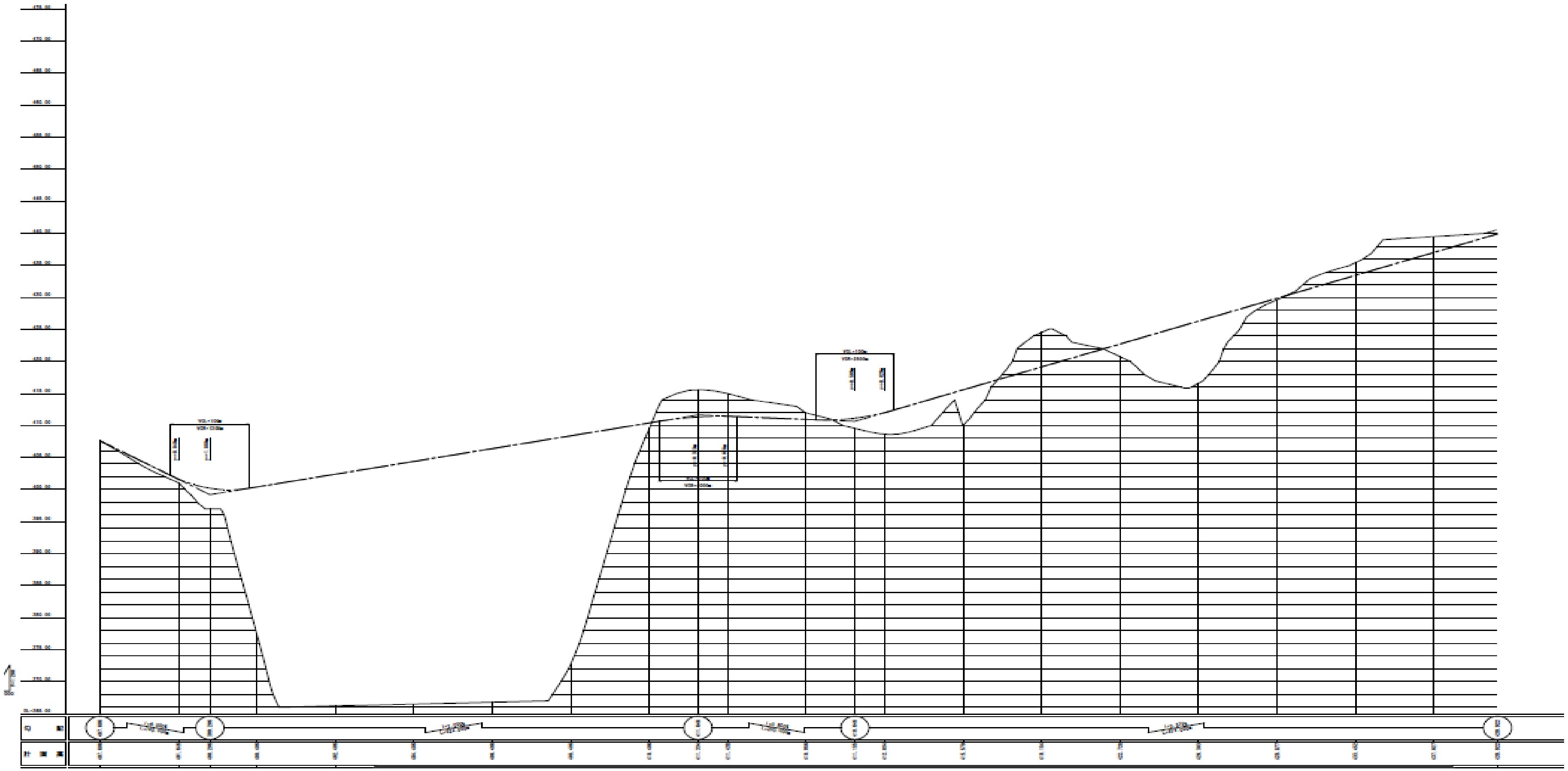


Figure BP.1-2 Vertical Alignment

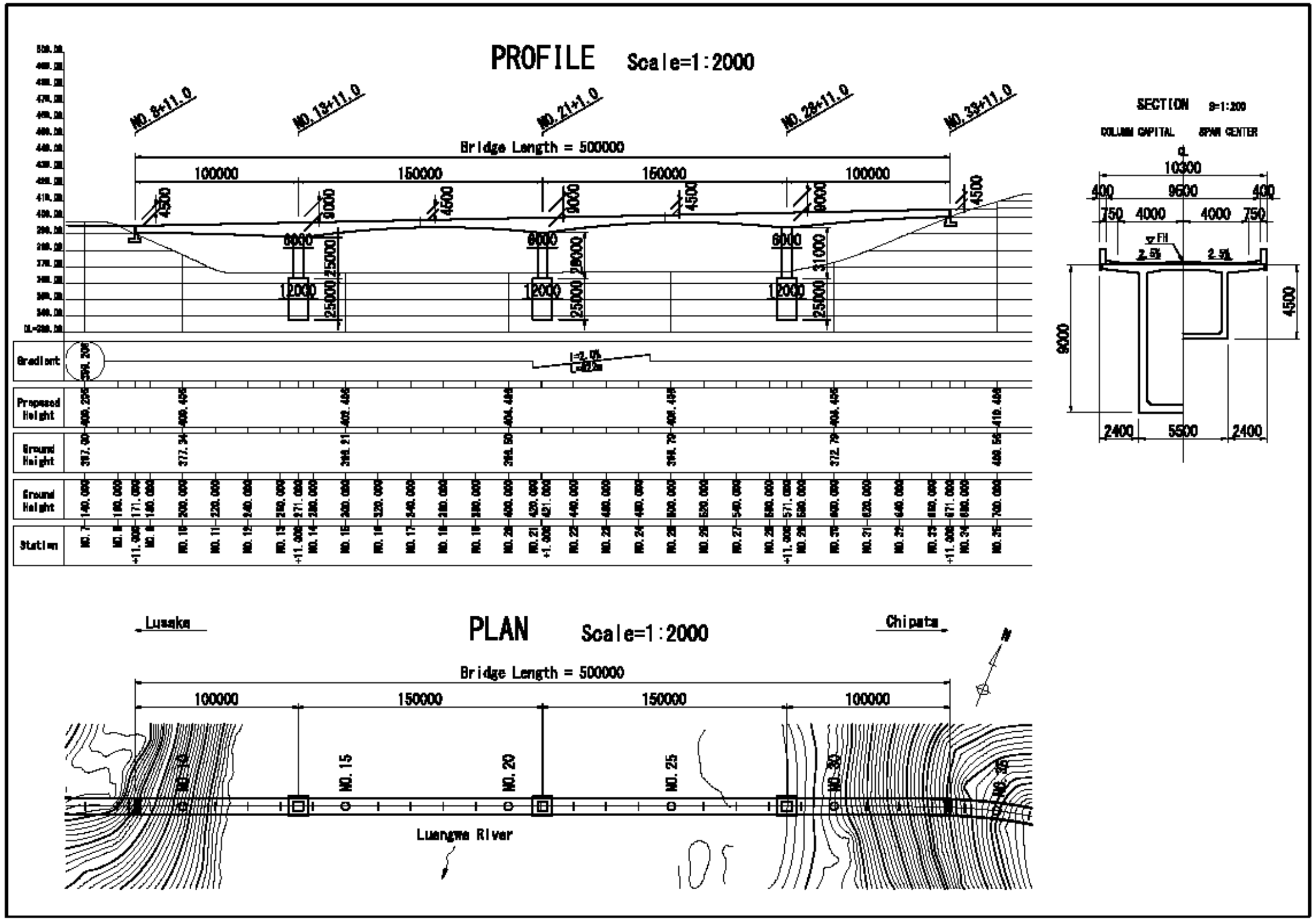


Figure CP. 1-1 General View

Appendix D　Geological Survey Result

The Boring survey position is shown below. Drilling of BH2 in the river was interrupted by rising water level.

Figure DP.1-1 Boring site

GEOTECHNICAL INVESTIGATIONS REPORT – NEW LUANGWA BRIDGE SITE

Client: **Nippon Engineering Consultants Co., Ltd.**

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Document No: 19/02/13 Revision: 03

Table of Contents

1. Introduction

This report represents the Geotechnical investigations performed at the Proposed New Luangwa Bridge site starting on 28th January 2019. The purpose of this investigation was to identify geotechnical condition at the site, to observe and sample the prevailing soil and rock conditions.

2. General Description of Project Area

The site is located between the Luangwa Bridge Market and the Existing Luangwa Bridge. The testing locations are all located on the Eastern Province side. From the western side the terrain drops steeply into the project site and the eastern side can be accessed by crossing the Luangwa River by way of the Luangwa Bridge and passing under the bridge. The middle point BH-2 is accessible from BH-3; it is located on drifting sand and is occasionally reclaimed by the river in the rain season. The river's level covered up BH-1 and BH-2 whilst we were on site. Fig. 1

Figure 3: Four Bore Hole Point

3. Regional Geologic Setting

The investigation site is located on a comparatively flat area where the crustal movement (orogenic movement, fault movement, etc.) is very small and the basement rocks of the Precambrian era (over 570 million years ago) is covered with weathered surface soil, and this area is called "African Shield".

The "Shield" is the stable land mass in the continental crust stabilized after the crustal movement in the Precambrian period, called "Craton". It forms very gentle convex topography due to erosive actions of long time.

Generally, the basement rocks of the "Shield" are composed of crystalline igneous rocks (granite, granodiorite, etc.) and high-grade metamorphic rocks (gneiss, crystalline schist, etc.) classified as hard rocks.

The original sedimentary strata covering the whole area is part of the Karoo system sedimentary rocks laid down from 175 to 300 million years ago. During this time, faulting occurred and volcanic materials was injected into the rifts' existing sediments.

The geology of the Luangwa Bridge area is mainly of kyanite-cordierite-anthophyl-lite rock, crystallised during the Irumide metamorphism (these rocks are divided into Gneiss in the broad sense).

4. Local Subsurface Conditions.

4.2 Subgrade Soil

On point BH-1', BH-1 and BH-3 this unit was encountered from surface of the top soil to a maximum depth of 0.5m; the borings encountered layers of residual silty sands and completely weathered rock thereafter a Very dense weathered rock was observed at 9 meters in BH-3.

4.3 Bedrock.

A highly fractured metamorphic bed rock at BH1 was observed at a depth of 6.6 meters and the coring went up to 9m before the water level raised to the borehole point. BH-1' had a hard dark greyish gneiss boulder at 4.5 meters and a weathered gneiss continues after that, it is considered the gneiss is a boulder in the talus deposit; bedrock with a very low RQD was encountered at 7.5 meters. A less fissured rock was encountered at 11 meters. At BH-3 consistence in rock formation appeared at a depth of 20 meters. The rocks in all the boreholes are of a metamorphic nature.

5. Groundwater Conditions

A moving ground water was observed in boring BH-1 at 4.0 meters below ground level, shifting sand was visible down the hole. BH-2 was reclaimed by the water level on the third day and BH-1 followed later. Been the rain season it is obvious the water level won't be coming down any time soon. The rising water is due to rain activity upstream.

Water at LG3 (BH-3) was observed at 9 meters.

6. Methodology

The disturbed samples were recovered by means of an SPT rig using plastic lined windowless samplers going up to the refusal level, thereafter a coring rig with a tungsten bit was used to core into dense weathered rock followed by rock coring to a depth of 3 meters. The laboratory works involved physical tests; these are Bulk density (Unit weight), Sieve analysis and Atterberg limit test from which soil classification is determined. The rock tests were carried out bulk and saturated density, specific gravity and compression test on the cores.

7. Standard Penetration Test.

The test was done in accordance with **BS 1377: 1990 Part 9** and covers the determination of the resistance of a split spoon sampler and obtaining disturbed samples of the soil for classification purposes. SPT tests were carried out on all the points. This test is used to directly determine the allowable bearing capacity under in-situ conditions. The number of blows required to advance the split spoon cone through the final 300mm of a 450mm test range is reported as the 'N' value. The allowable bearing capacity is a function of the foundation size and depth.

It should be borne in mind that conditions at the time of testing may not be the worst condition that can be experienced over the life of the foundation, particularly with respect to saturated conditions in soils which are highly susceptible to softening under moisture. Reference should therefore also be made to soil classification.

7.2.1 SPT N-Value Correction

The adoption of the 60% standard energy requires the SPT N-value obtained using the Hammer to be corrected. The correction is done in accordance with the following equation:

$$N_{60} = N_f * (ER_f/60)$$

Where;

N_{60} = SPT N- value corrected to 60% of the theoretical free fall hammer energy

N_f = SPT N- value obtained in the field

ER_f = Energy ratio for the hammer used in the investigation (estimated 50)

8. Profiling

Core logs are attached as Appendix A. The following sections describe the results at each location tested, as they relate to possible foundation.

BH1’

Point ID	GPS coordinates		Photo	
	E	N		Bulk
BH1'	36L200080	8341475		
	pH			
	Sulphate			
	Chloride			

This is the point slightly higher than BH1 and was a picked when the river reclaimed the lower point. No SPT was carried out on this point. The coring encountered very dense and hard rock at 4.5 meters and weathered gneiss continues after that; it is considered this gneiss is boulder stone in the talus deposit. Bedrock with a low RQD was encountered at 7.5 meters, after that this weathered rock ensued until the depth of 11 meters.

BH1

Point ID	GPS coordinates		Photo	
	E	N		Bulk
BH1	36L200092	8341476		 
	pH			
	Sulphate			
	Chloride			

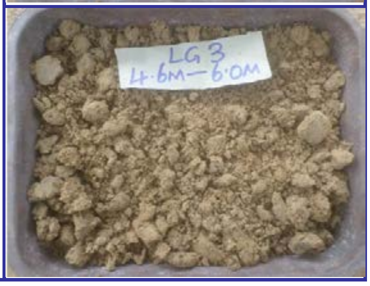
There were two layers of sandy soil above the bedrock. Bedrock was observed at 6.6 meters and the coring went up to 9 meters; work here had to stop because the water level had reached the Borehole point.

BH2

Point ID	GPS coordinates		Photo
	E	N	Bulk
BH2	36L200256	8341566	
	pH		
	Sulphate		
	Chloride		

A trial pit was dug to get material at 1 meter because the sand could not be retrieved in the sample liners. The soil sample from the trial pit is made up of the mixture of poorly graded sand with well-rounded pebbles coming from upstream during floods. The Probing went up to 15 meters, from the N values of the SPT it is considered mainly washed sand containing well rounded pebbles of diameter 5-10 cm in some places. It is clear that bedrock is deeper than 15 meters.

BH3

Point ID	GPS coordinates		Photo	
	E	N		Bulk
BH3	36L200397	8341642		    
	pH			
	Sulphate			
	Chloride			

This point reached the highly weathered gneiss rock at 9 meters; the soil stratum is comprised of four layers silty sands and two of clayey sands. The weathered gneiss bedrock was observed at 11 meters. No reasonable QRD could be recorded because the rock was high fractured and the mechanical action of the drill reduced some piece to smaller pieces which could not be captured. More reasoned QRD was recorded at a between 20 meters and 23 meters.

9. Results of the Laboratory Testing

Laboratory testing was performed on the obtained materials from the borings; the tests related to physical and mechanical properties were performed in the Noside Laboratory. See summarised results in Table 2.

9.1. Code of Practice

The laboratory tests were performed in accordance with the standards indicated in Table-1. The following laboratory test were carried out on the disturbed samples obtained from the boreholes

Table 1: Applied Standard for Laboratory Test

No.	Test Items	Ref. standard No.
1	Specific Gravity of Soil	ASTM D- 854
2	Natural Moisture Content of Soil	ASTM D-2216
3	Grain Size Analysis of Soil	ASTM D- 422
4	Atterberg Limits of Soil	ASTM D-4318
5	Soil Description and Classification	ASTM D-2487
6	Unit Weight (Wet Density) of Soil	BS 1377-part 2-7
7	Unconfined Compressive Strength of Rock	ASTM D-2938

9.2. Moisture Content

To determine the moisture content of soils, soil is dried at a temperature of 105 degrees Celsius to 115 degrees Celsius for about 24hours the loss of weight of the soil sample represents the weight of Moisture in the soil. The moisture content of the soil to the dry weight of the soil in Percentage is the moisture content of the testing soil.

9.3. Unit Weight

The Unit Weight of a soil is the mass per unit volume of the soil deposits including any water it contains. The dry density is the mass of dry soil contained in a unit volume. Both are expressed in KN/m^3.

9.4. Classification Tests

The Sieve analysis and Atterberg Limits tests were performed for general classifications purposes and to corroborate the site situation.

Atterberg Limits can be indicative of the soils expansivity; expansive soils consist of plastic clays and clay shales that often contain colloidal clay minerals. Silts with Liquid Limit (LL) <35 and Plasticity Index (PI) <12 have no potential for swell.

Table 2: Atterberg Limits

Degree of Expansive	Liquid Limit (%)	Plasticity index (%)
High	>60	>35
Marginal	50 – 60	25 – 35
Low	<50	<25

Identification; Degree of expansive Potential (Snethe, Johnson and Patrick 1977)

Most of the materials encountered were classified as silty sands.

9.5. Rock tests (UCS)

ASTM D2938-95(2002), Standard Test Method for Unconfined Compressive Strength of Intact Rock Core. This is measure of a Rock's strength. The unconfined compressive strength (UCS) is the maximum axial compressive stress that a right-cylindrical sample of rock can withstand under unconfined conditions—the confining stress is zero. Results are expressed in kN.

9.6. Rock Quality Designation (RQD).

RQD is defined as the length of intact core pieces longer than 10 cm relative to the total length of each drilled interval, expressed as a percentage. The relationship between rock mass quality and RQD was developed by Deere and Deer (1988) in table 3

Table 3: rock mass classed based on RQD (after Deere & Deere, 1988)

Rock mass classes based on RQD (after Deere & Deere, 1988)

RQD%	Description of Rock Quality
0 - 25	Very Poor
25 - 50	Poor
50 - 75	Fair
75 - 90	Good
90 - 100	Exellent

9.7. Laboratory Test Results

1. The soil samples from the four bore holes were mostly sandy soils; apart from BH2 the soils on river banks were mostly made up of hill wash followed by layers of residual soils and completely weathered Gneiss of plasticity index ranging from non-plastic to 15.6.

2. From the compression test (UCS) carried out on the rock sample, Rock found at 11 meter can be classified as R4 which is assigned intact rock strength of 75 MPa. The intact Rock on BH3 can be associated with a depth of 17 meters going up to the testing depth of 23 meters. The UCS test for this rock put it in class R3 with an intact strength of 38 MPa.

Table 4: Summary of Field and Lab Tests

Client: Kiran & Musonda Associates

PROJECT: Proposed Lunagwa Bridge Geotechinical Investigations

	Point 2	Sample No.	USCS Classification	Sieve Analysis							Grading Coefficient	Shrinkage Product	Linear Shrinkage	PI	Bulk Density	Dry Density	Specific Gravity	Bulk unit weight	Moisture Content %
	depth (m)			0.075	0.425	2	4.75	19	26.5	37.5					Kg/m³	Kg/m³	g/cm³	KN/m³	
BH1'	0.0m -1.0m		SM	22.7	57.1	63.7	66.0	71.7	74.4	84.2	11.5	163.1	2.9	N/P					
BH1	0.5m-4.0m	3280	SM	31	96	100	100	100	100	100	4.3	136.7	1.4	N/P	NP	NP	2.62	NP	20.9
	4.0m-6.0m	3281	SC	13	61	86	88	89	94	100	28.5	131.6	2.1	10.1	NP	NP	2.62	NP	22.1
BH2	0-1m TP	3282	SP	3	8	49	57	69	71	84	35.7	0.0	0.0	N/P					
BH3	0.5m-1.9m	3283	SM	31	89	100	100	100	100	100	10.9	318.3	3.6	7.3	NP	NP	2.61	NP	4.8
	1.9m-3.0m	3284	SP	0	96	99	100	100	100	100	4.3	0.0	0.0	N/P	1830	1646	2.62	17.95	11.2
	3.0m-4.6m	3285	SC	27	99	100	100	100	100	100	1.2	352.7	3.6	14.3	1905	1684	2.61	18.7	13.1
	4.6m-6.0m	3286	SM	15	98	100	100	100	100	100	1.8	561.3	5.7	N/P	2082	1813	2.63	20.4	14.8
	6.0m-7.0m	3287	SC	22	91	97	99	100	100	100	9.2	388.6	4.3	15.6	2218	1909	2.62	21.8	16.1
	7.0m-9.0m	3288	SM	12	57	82	89	99	100	100	38.1	204.8	3.6	N/P	2375	2086	2.62	23.3	13.8

BH1 5 x 8 pad foundation

Field test results					aboratory test result	
Point ID	**Depth**	**SPT 'N' value**	**N60**	**Allowable bearing capacity (kPa)**	**Layers**	**USCS classification**
SPTS split spoon	1	2	2	189		
	2	6	4	201	0.4 - 4	SM
	3	9	7	243		
	4	48	38	293		
	5	6	5	355	4.0-6.0	SC
	6	7	6	412		
Solid cone	6.6	>50	>50	>750		

SM Silty sands, poorly graded silty mixture
SC Clayey sands, poorly graded sand-clay mixtures
SP Organic silts and organic silt-clays of low plasticity

BH2 5 x 8 pad foundation

Field test results				
Point ID	**Depth**	**SPT 'N' value**	**N60**	**Allowable bearing capacity (kPa)**
SPT - solid Cone	1	9	7	273
	2	10	8	300
	3	21	16	349
	4	38	30	393
	5	34	29	433
	6	34	31	445
	7	27	34	447
	8	29	27	451
	9	42	40	454
	10	29	28	454
	11	40	39	462
	12	40	39	454
	13	35	34	465
	14	35	35	456
	15	28	28	440

BH3 5 x 8 Pad foundation

Field test results					aboratory test result	
Point ID	**Depth**	**SPT 'N' value**	**N60**	**Allowable bearing capacity (kPa)**	**Layers**	**USCS classification**
SPT	1	28	21	245		
	2	10	8	260	0.5 - 1.8	SM
	3	9	7	306	1.8 - 3.0	SP
	4	15	12	317	3.0 - 4.6	SC
	5	14	12	360	4.6 - 6	SM
	6	19	17	398		
	7	24	22	434	6.0 - 7.0	SC
	8	34	32	485	7.0 - 9.0	SM
	9	54	52	543		

Rock test results

Bore Hole	Sample Depth	Sample elevation	Rock Type	Unixial Compression Strength (Mpa)	Field strength Index
BH1'	4.5	366.5	Metamorphic	124	R5
BH1'	11.1	359.9	Metamorphic	46.2	R3
BH1'	11.3	359.7	Metamorphic	74.3	R4
BH3	10	362	Metamorphic	70.4	R4
BH3	17	355	Metamorphic	33.1	R3
BH3	23	349	Metamorphic	32.6	R3

Bore Hole	Sample Depth	RQD	Rock quality	q_a. On jointed rock (mPa)
BH1'	11 - 12m	71%	Fair	12
BH3	17 - 18	26%	Poor	3
BH3	21 - 22	58%	FAir	6.25
BH3	22 - 23m	26%	Metamorphi	3

10. GEOTECHNICAL CONSIDERATION

Based on the test carried out on the samples from the proposed new bridge site and findings from our site investigation, the primary geotechnical concerns for the project are:

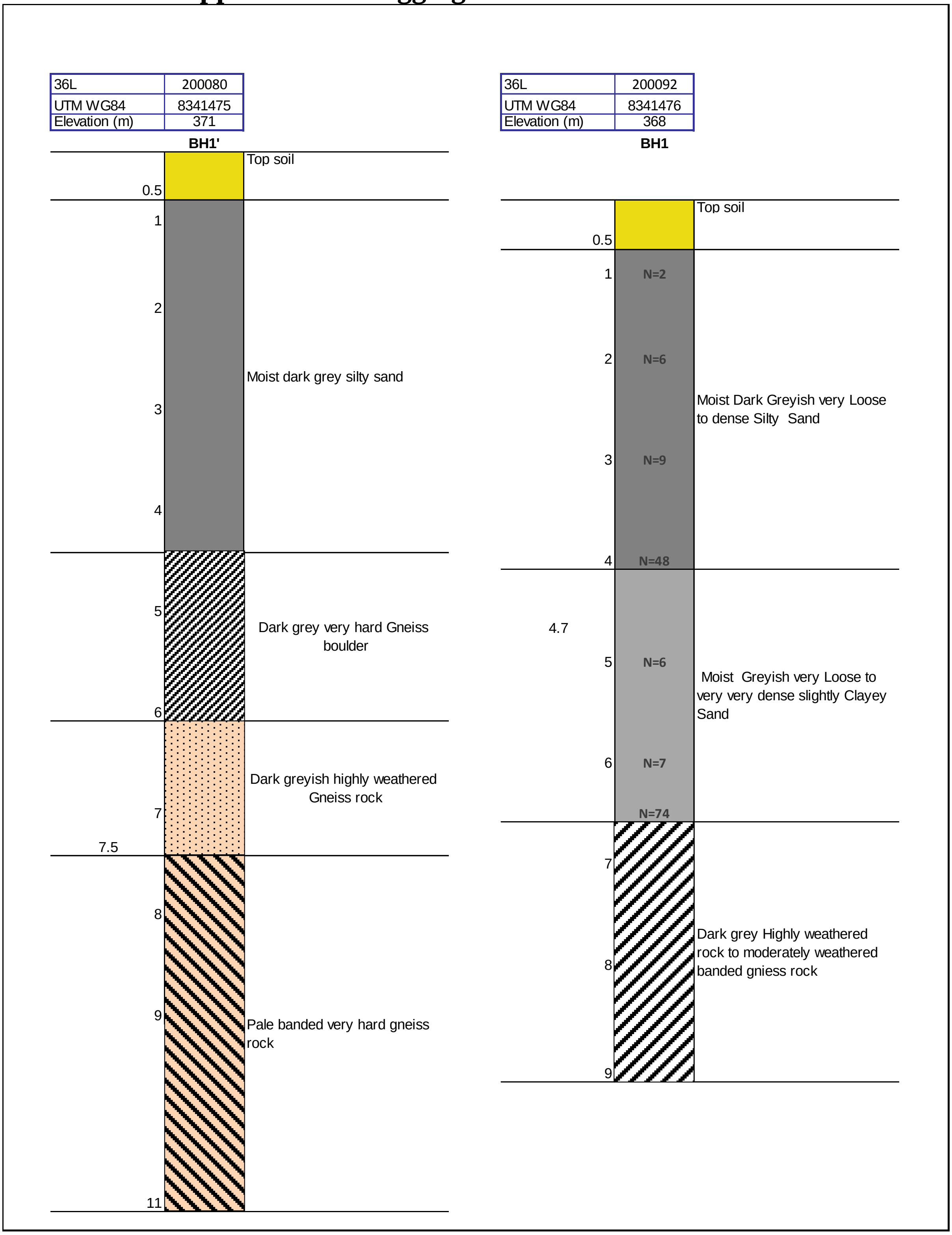
- Limited depth of overburden for the Western Bank.
- Boulders with the silty sands; encountered on both side of the river.
- Heavy ground water seepage and sloughing conditions with the silty sand stratum
- Poor quality of rock near the bedrock surface
- Rising water level during the rainy season.

11. Conclusions

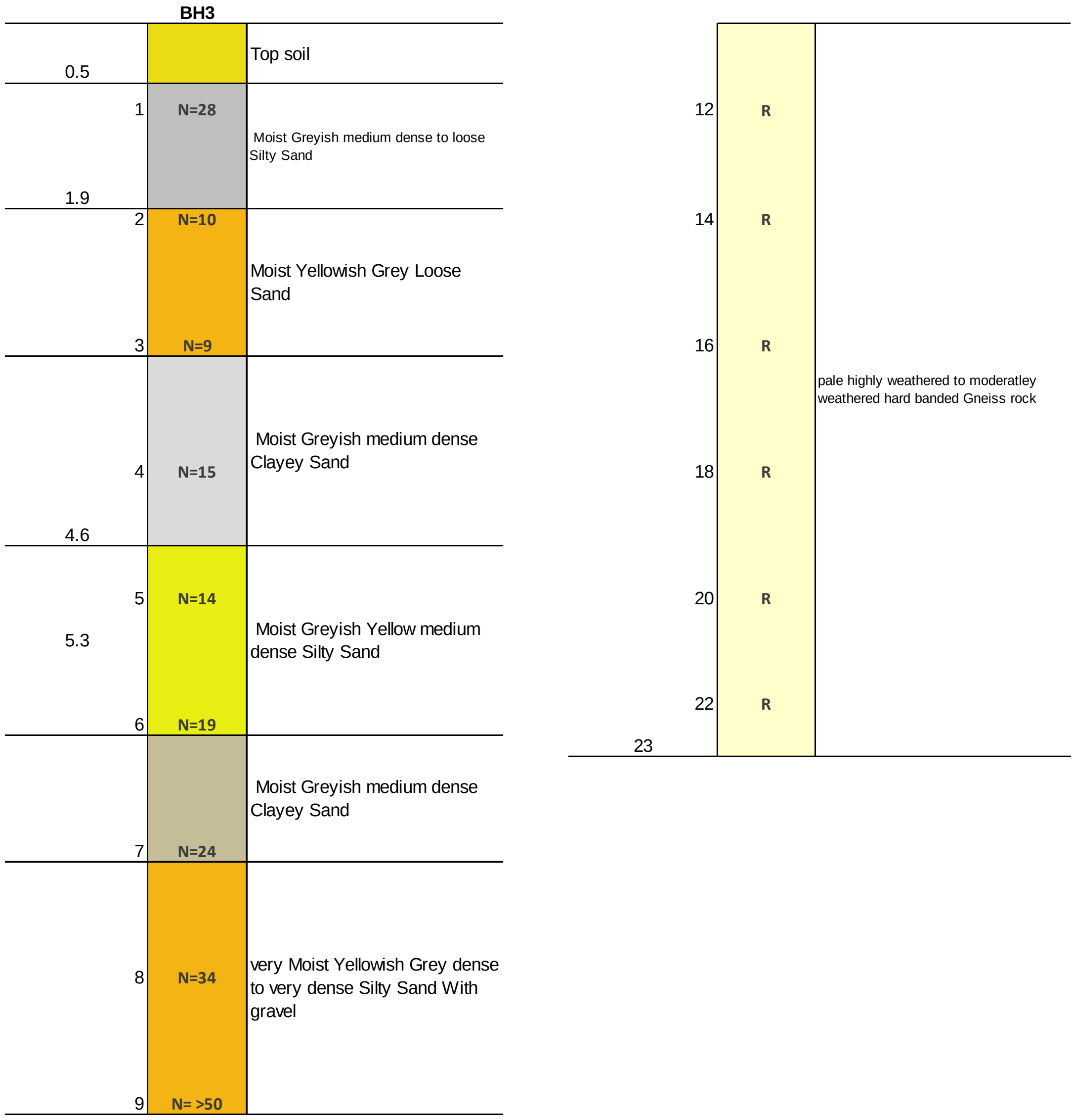
From the investigations carried out, the following conclusions have been drawn:

1. Boring will need to be carried out on BH2 to ascertain to depth of the bedrock.
2. Open caissons socketed into the underlying weathered metamorphic bedrock may be used to support the proposed bridge structure.
3. It should be noted that only a very limited part of the site has been covered by this investigation.

Appendix A: - Logging & SPT field Results



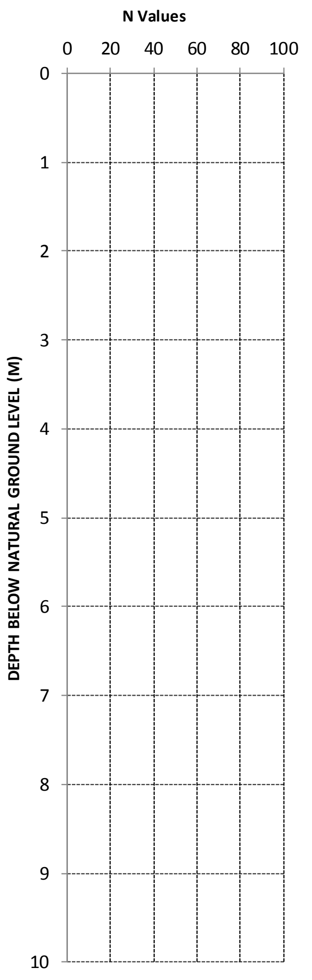
36L	200397
UTM WG84	8341642
Elevation	372



BOREHOLE LOG

Location	*Luangwa River*			**Drilling Date**	*12/02/2019*
Borehole No.	*BH1'*	**Page No.**	*1*	**Weather**	*Sunny*
Ground Elevation 371	**Coords**	36 L 200080	8341475	**SPT CONE TYPE**	*N/A*
Drill Rig	ARC	**Operator**	*SC*	**Checked by**	*AN*

Depth (m)	DESCRIPTION	Legend	USCS	SPT Counts 15cm	SPT Counts 15cm	SPT Counts 15cm	N	SPT Graph	W %	LL %	PI %
0–0.4	Top soil										
0.4–4.5	Moist Dark Greyish Silty Sand with gravel									28.7	NP
4.5–6.0	Dark greyish hard gneiss boulder										
6.0–7.5	Dark greyish highly weathered Gneiss rock										
7.5–10	Fracture bandaed pale highly weathered Gneiss rock										



Water Record

Levela at which water was encountered		Color of water
Water level 24hrs after completion		

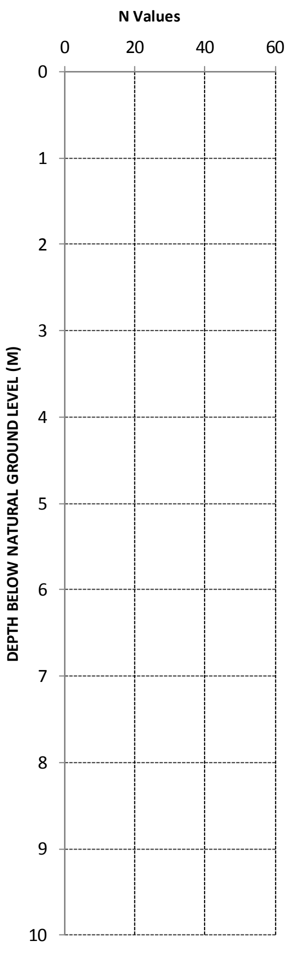
Remarks : **No SPT field test was carried out on this Bore hole point**
USCS - Unified Soil Classification System
R - Refusal (more than 50 blows)
Approved : *EG*

NSL - SPT-4-12-18

BOREHOLE LOG

Location	*Luangwa River*			**Drilling Date**	*12/02/2019*
Borehole No.	*BH1'*	**Page No.**	*2*	**Weather**	*Sunny*
Ground Elevation 371	**Coords**	36 L 200080	8341475	**SPT CONE TYPE**	*N/A*
Drill Rig	ARC	**Operator**	*SC*	**Checked by**	*AN*

Depth	DESCRIPTION	Legend	USCS	SPT Counts 15cm	SPT Counts 15cm	SPT Counts 15cm	N	SPT Graph	W %	LL %	PL %
11	Hard Pale banded weathered Gneiss rock										
2											
3											
4											
5											
6											
7											
8											
9											
10											



Water Record

Levela at which water was encountered			Color of water
Water level 24hrs after completion			

Remarks :
USCS - Unified Soil Classification System
R - Refusal (more than 50 blows)
Approved : *EG*

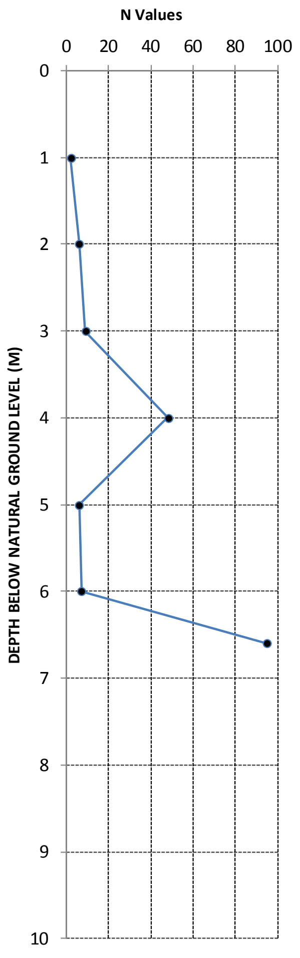
NSL - SPT-4-12-18

BOREHOLE LOG

Location	*Luangwa River*			**Drilling Date**	*29/01/2019*
Borehole No.	*BH1*	**Page No.**	*1*	**Weather**	*Sunny*
Ground Elevation 368	**Coords**	36 L 200092	8341476	**SPT CONE TYPE**	*Split spoon*
Drill Rig	ARC	**Operator**	*SC*	**Checked by**	*AN*

Depth	DESCRIPTION	Legend	USCS	SPT Counts 15cm	15cm	15cm	N	W %	LL %	PI %
	Top soil									
1	Moist Dark Grey very Loose to dense Silty Sand		SM	1	1	1	2		28.7	NP
2				2	3	3	6			
3				3	4	5	9			
4				30	25	23	48			
5	Moist Greyish very Loose slightly Clayey Sand		SC	3	3	3	6			
6				3	3	4	7			
6.6	Greyish highly weathered gneiss rock			21	24	50	95			
7										
8	greyish fractured weathered Gneiss rock									
9										
10							>50			

SPT Graph



Water Record

Levela at which water was encountered		Color of water	
Water level 24hrs after completion			

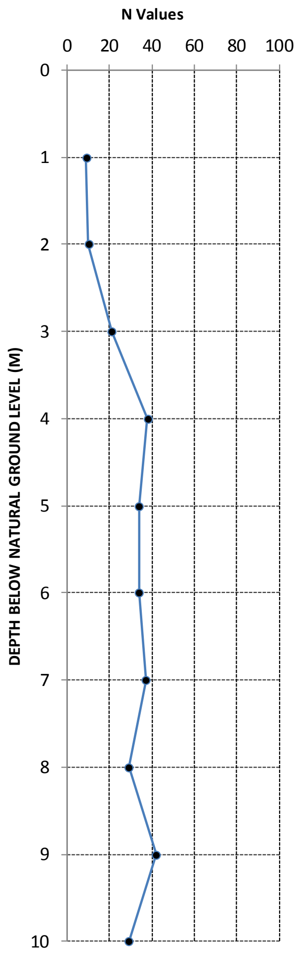
Remarks :
USCS - Unified Soil Classification System
R - Refusal (more than 50 blows)

Water level

Approved : *EG*

BOREHOLE LOG

Location	*Luangwa River*	**Drilling Date**	*28/01/2019*
Borehole No.	*BH2* — **Page No.** *1*	**Weather**	*Sunny*
Ground Elevation 367	**Coords** 36 L 200256 8341566	**SPT CONE TYPE**	*Solid cone*
Drill Rig ARCH SPT	**Operator** *SC*	**Checked by**	*AN*

Depth	DESCRIPTION	Legend	USCS	SPT Counts 10cm	SPT Counts 10cm	SPT Counts 10cm	N	SPT Graph	W %	LL %	PI %
1	Mainly, fine sand containing well rounded pebbles of diameter 5-10 cm in some places	TP	SP	3	4	5	9			25	NP
2				12	6	4	10				
3				10	9	12	21				
4				17	17	21	38				
5				19	18	16	34				
6				18	18	16	34				
7				15	17	20	37				
8				17	16	13	29				
9				20	21	21	42				
10				17	15	14	29				

Water Record

Levela at which water was encountered	**1m**	Color of water - light brownish
Water level 24hrs after completion		

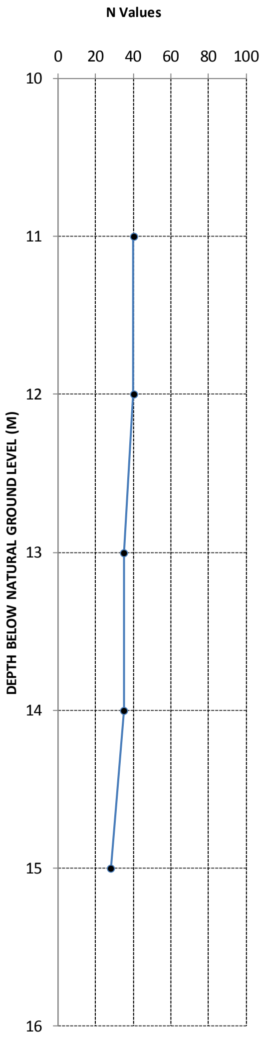
Remarks :
USCS - Unified Soil Classification System
R - Refusal (more than 50 blows)
Water level
Approved : *EG*

NSL - SPT-4-12-18

BOREHOLE LOG

Location	*Luangwa River*			**Drilling Date**	*28/01/2019*
Borehole No.	*BH2*	**Page No.**	*2*	**Weather**	*Sunny*
Ground Elevation 367	**Coords**	*36 L 200256*	*8341566*	**SPT CONE TYPE**	*Solid cone*
Drill Rig	ARCH SPT	**Operator**	*SC*	**Checked by**	*AN*

Depth	DESCRIPTION	Legend	USCS	SPT Counts 10cm	10cm	10cm	N	SPT Graph	W %	LL %	PI %
11				19	19	21	40				
12				23	21	19	40				
13				15	16	19	35				
14				17	14	21	35				
15	Mainly, fine sand containing well rounded pebbles of diameter 5-10 cm in some places			16	14	14	28				



Water Record

Levela at which water was encountered		Color of water
Water level 24hrs after completion		

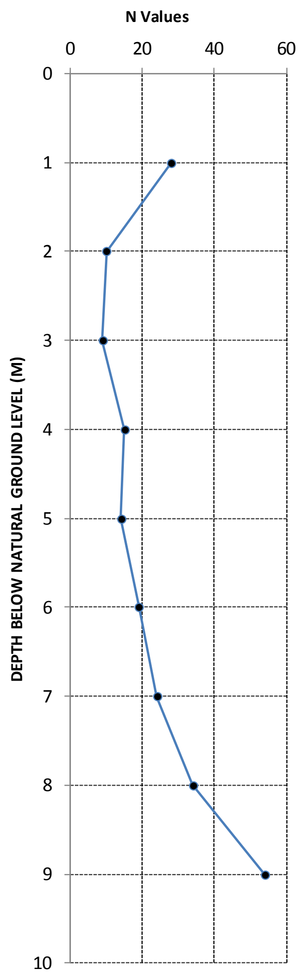
Remarks :
USCS - Unified Soil Classification System
R - Refusal (more than 50 blows)
Water level
Approved : *EG*

BOREHOLE LOG

Location	*Luangwa River*			**Drilling Date**	*28/01/2019*
Borehole No.	*BH3*	**Page No.**	*1*	**Weather**	*Sunny*
Ground Elevation 372	**Coords**	36 L 200397	8341642	**SPT CONE TYPE**	*Split spoon*
Drill Rig	ARC	**Operator**	*SC*	**Checked by**	*AN*

Depth	DESCRIPTION	Legend	USCS	SPT Counts 15cm	15cm	15cm	N	W %	LL %	PI %
1	Moist Greyish medium dense to loose Silty Sand		SM	12	14	14	28		25	7.3
2				6	5	5	10			
3	Moist Yellowish Grey Loose Sand		SP	5	4	5	9		29	NP
4	Moist Greyish medium dense Clayey Sand		SC	4	7	8	15		35	14
5	Moist Greyish Yellow medium dense Silty Sand			8	6	8	14		31	NP
6				6	7	12	19			
7	Moist Greyishmedium dense Clayey Sand			5	9	15	24		33	16
8	Very Moist Yellowish Grey dense to very dense Silty Sand With gravel			15	16	18	34		28	NP
9				12	24	30	54			
10	pale banded fissured highly weathered gneiss rock						>50			

SPT Graph



Water Record

Levela at which water was encountered	**9m**	Color of water	
Water level 24hrs after completion			

Remarks :
USCS - Unified Soil Classification System
R - Refusal (more than 50 blows)

Approved : *EG*

NSL - SPT-4-12-18

BOREHOLE LOG

Location	*Luangwa River*			**Drilling Date**	*28/01/2019*
Borehole No.	*BH3*	**Page No.**	*1*	**Weather**	*Sunny*
Ground Elevation 372	**Coords**	36 L 200397	8341642	**SPT CONE TYPE**	*Split spoon*
Drill Rig	ARC	**Operator**	*SC*	**Checked by**	*AN*

Depth	DESCRIPTION	Legend	USCS	SPT Counts 15cm	15cm	15cm	N	SPT Graph	W %	LL %	PL %
12											
14											
16	pale banded highly weathered to moderatley weathered hard Gneiss rock										
18											
20											
22											
24											
28											
9											
10											

Water Record

Levela at which water was encountered		Color of water	
Water level 24hrs after completion			

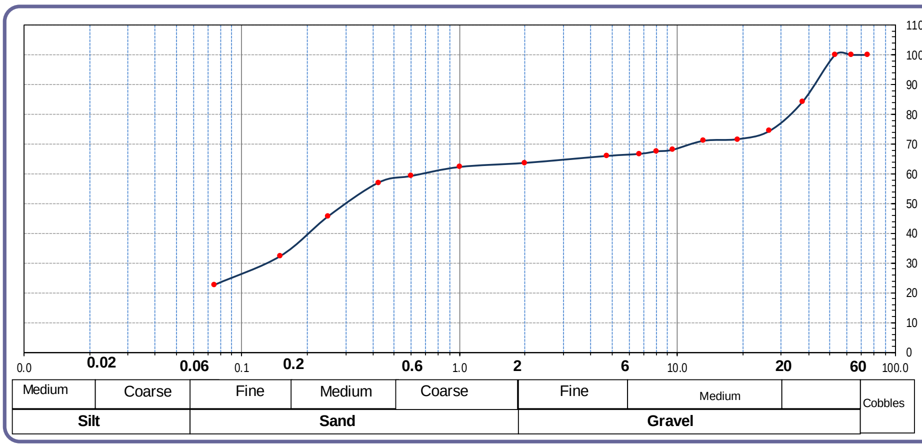
Remarks :
USCS - Unified Soil Classification System
R - Refusal (more than 50 blows)
Approved : *EG*

NSL - SPT-4-12-18

Appendix B - Sieve Analysis Results

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D-1586	Location	BH1' TP 1	Depth	0.0m -1.0m	Sample No.:	0

Clay/Silt:	22.7	Sand:	43.3	Gravel:	34
Material Description	Moist Dark Greyish Silty Sand with gravel				

Grd Modulus (GM):	1.6	$D_{(10)}$=	0.033	mm	Fineness Modulus:	2.566
Grading Coefficient (GC):	11.5	$D_{(30)}$=	0.13	mm	Liquid Limit	28.5%
USCS classification:	SM	$D_{(60)}$=	0.69	mm	Plastic Limit	N/P
		Coeff. of Curvature, C_C =	0.76		Plasticity Index	N/P
		Coeff. of Uniformity, C_U =	20.99			

Sieve Analysis Data

These results are for the exclusive use of the Client for whom they were obtained. They only apply to the samples tested and are not indicative of apparently identical samples. The use of our name must receive our approval. Reports must be reproduced in thier entirety

Initial Dry Mass (m_1)	**3541** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	561	561	15.8	84.2	84
26.5	344	344	9.7	74.4	74
19.0	98	98	2.8	71.7	72
Passing 19 mm (m_2)	2538				
total (checked with m_1	**3541**				

Riffled (m_3)	521
Riffled and washed (m_4)	361
Correction factor $\frac{m_2}{m_3}$	4.87

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing (p)	Cumulative % passing
13.2	4	19	0.6	71.1	71
9.5	22	107	3.0	68.1	68
8.0	4	19	0.6	67.5	68
6.7	6	29	0.8	66.7	67
4.75	5	24	0.7	66.0	66
2.0	17	83	2.3	63.7	64
1.0	10	49	1.4	62.3	62
0.6	22	107	3.0	59.3	59
0.425	16	78	2.2	57.1	57
0.250	82	399	11.3	45.8	46
0.150	98	477	13.5	32.3	32
0.075	70	341	9.6	22.7	23
<0.075 + 160.0	165.0	804	22.7		
TOTAL		**3541**			

Date: 31/01/2019

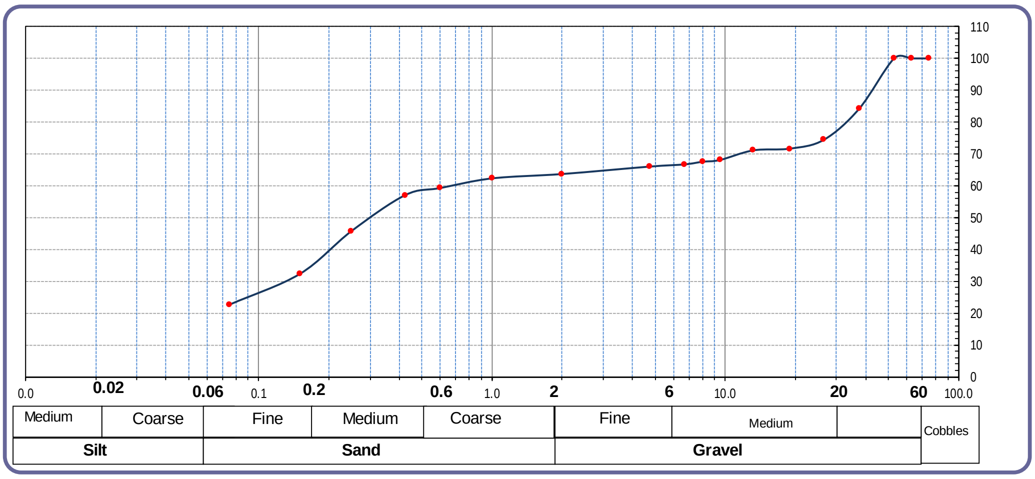
Tested By: MN

Checked by: AN

Approved by: EG

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D-1586	**Location**	**BH1' TP 1**	**Depth**	**0.0m -1.0m**	**Sample No.:**	0

Clay/Silt:	**22.7**	Sand:	**43.3**	Gravel:	**34**
Material Description	Moist Dark Greyish Silty Sand with gravel				

Grd Modulus (GM):	1.6	$D_{(10)}$=	0.033	mm	Fineness Modulus:	2.566
Grading Coefficient (GC):	11.5	$D_{(30)}$=	0.13	mm	Liquid Limit	28.5%
USCS classification:	SM	$D_{(60)}$=	0.69	mm	Plastic Limit	N/P
		Coeff. of Curvature, C_C =	0.76		Plasticity Index	N/P
		Coeff. of Uniformity, C_U =	20.99			

Sieve Analysis Data

These results are for the exclusive use of the Client for whom they were obtained. They only apply to the samples tested and are not indicative of apparently identical samples. The use of our name must receive our approval. Reports must be reproduced in thier entirety

Initial Dry Mass (m_1) 3541 g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	561	561	15.8	84.2	84
26.5	344	344	9.7	74.4	74
19.0	98	98	2.8	71.7	72
Passing 19 mm (m_2)	2538				
total (checked with m_1	**3541**				

Riffled (m_3)	521
Riffled and washed (m_4)	361
Correction factor $\frac{m_2}{m_3}$	4.87

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing	Cumulative % passing
13.2	4	19	0.6	71.1	71
9.5	22	107	3.0	68.1	68
8.0	4	19	0.6	67.5	68
6.7	6	29	0.8	66.7	67
4.75	5	24	0.7	66.0	66
2.0	17	83	2.3	63.7	64
1.0	10	49	1.4	62.3	62
0.6	22	107	3.0	59.3	59
0.425	16	78	2.2	57.1	57
0.250	82	399	11.3	45.8	46
0.150	98	477	13.5	32.3	32
0.075	70	341	9.6	22.7	23
<0.075 + 160.0	165.0	804	22.7		
TOTAL		**3541**			

Date: 31/01/2019

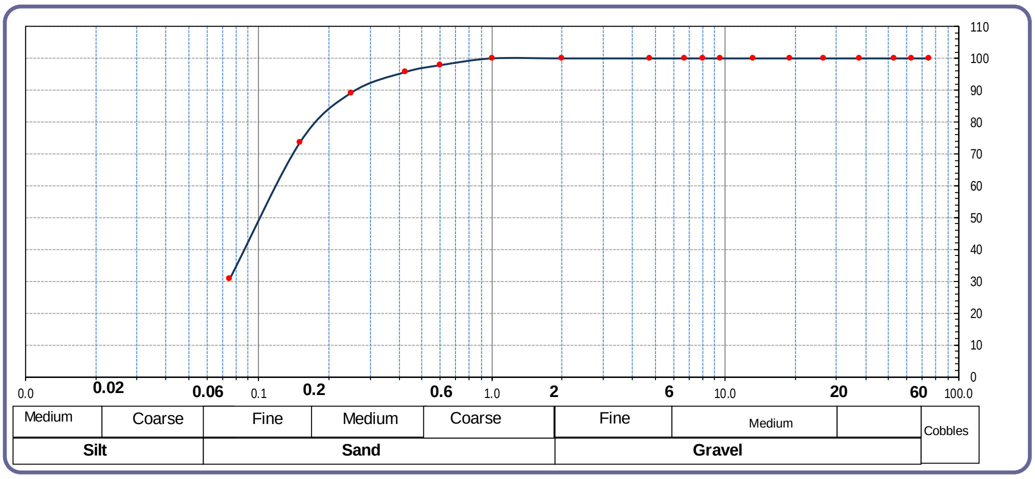
Tested By: MN

Checked by: AN

Approved by: EG

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D- 422	Location	BH1	Depth	0.5 - 4.0m	Sample No.:	3280

Clay/Silt:	30.7	Sand:	69.3	Gravel:	0
Material Description	Moist Dark Grey Loose Silty Sand				

Grd Modulus (GM):	0.7	$D_{(10)}$=	0.636	mm	Fineness Modulus:	13.201
Grading Coefficient (GC):	4.3	$D_{(30)}$=	0.72	mm	Liquid Limit	27.7%
USCS classification:	SM	$D_{(60)}$=	0.84	mm	Plastic Limit	N/P
		Coeff. of Curvature, C_C =	0.96		Plasticity Index	N/P
		Coeff. of Uniformity, C_U =	1.32			

Sieve Analysis Data

These results are for the exclusive use of the Client for whom they were obtained. They only apply to the samples tested and are not indicative of apparently identical samples. The use of our name must receive our approval. Reports must be reproduced in thier entirety

Initial Dry Mass (m_1)	**1800** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	0	0	0.0	100.0	100
26.5	0	0	0.0	100.0	100
19.0	0	0	0.0	100.0	100
Passing 19 mm (m_2)	1800				
total (checked with m_1	**1800**				

Riffled (m_3)	3.03
Riffled and washed (m_4)	105
Correction factor $\frac{m_2}{m_3}$	594.06

Date:
31/01/2019

Tested By:
MN

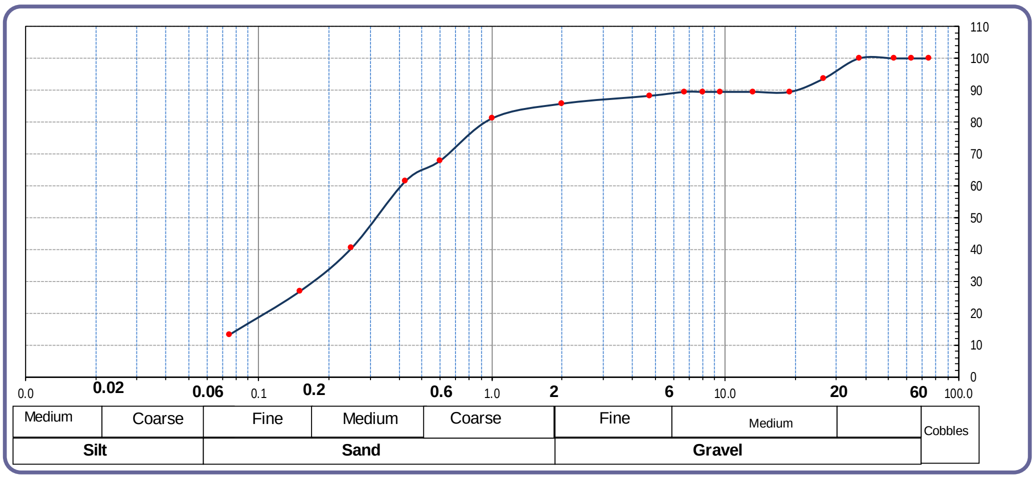
Checked by:
AN

Approved by:
EG

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing	Cumulative % passing
13.2	0	0	0.0	100.0	100
9.5	0	0	0.0	100.0	100
8.0	0	0	0.0	100.0	100
6.7	0	0	0.0	100.0	100
4.75	0	0	0.0	100.0	100
2.0	0	0	0.0	100.0	100
1.0	0	0	0.0	100.0	100
0.6	3	1782	2.1	97.9	98
0.425	3	1782	2.1	95.7	96
0.250	9	5347	6.4	89.3	89
0.150	22	13069	15.7	73.6	74
0.075	60	35644	42.9	30.7	31
<0.075 + -102.0	43	25545	30.7		
TOTAL		**83168**			

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D- 422	Location	BH1	Depth	4.0m-6.0m	Sample No.:	3281

Clay/Silt:	13.3	Sand:	75.0	Gravel:	12
Material Description	Moist Grey Loose slightly Clayey Sand				

Grd Modulus (GM):	1.4	$D_{(10)}$=	0.027	mm	Fineness Modulus:	1.307
Grading Coefficient (GC):	28.5	$D_{(30)}$=	0.09	mm	Liquid Limit	32.2%
USCS classification:	SC	$D_{(60)}$=	0.35	mm	Plastic Limit	22.1
		Coeff. of Curvature, C_C =	0.86		Plasticity Index	10.1
		Coeff. of Uniformity, C_U =	12.82			

Sieve Analysis Data

Initial Dry Mass (m_1)	1610 g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	0	0	0.0	100.0	100
26.5	85	85	6.3	93.7	94
19.0	56	56	4.2	89.5	89
Passing 19 mm (m_2)	1469				
total (checked with m_1	**1610**				

Riffled (m_3)	355
Riffled and washed (m_4)	252
Correction factor $\frac{m_2}{m_3}$	4.14

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing (p)	Cumulative % passing
13.2	0	0	0.0	89.5	89
9.5	0	0	0.0	89.5	89
8.0	0	0	0.0	89.5	89
6.7	0	0	0.0	89.5	89
4.75	4	17	1.2	88.3	88
2.0	8	33	2.5	85.8	86
1.0	15	62	4.6	81.2	81
0.6	43	178	13.3	67.9	68
0.425	21	87	6.5	61.4	61
0.250	68	281	21.0	40.4	40
0.150	44	182	13.6	26.8	27
0.075	44	182	13.6	13.3	13
<0.075 + 103.0	43	178	13.3		
TOTAL		**1341**			

Date: 31/01/2019

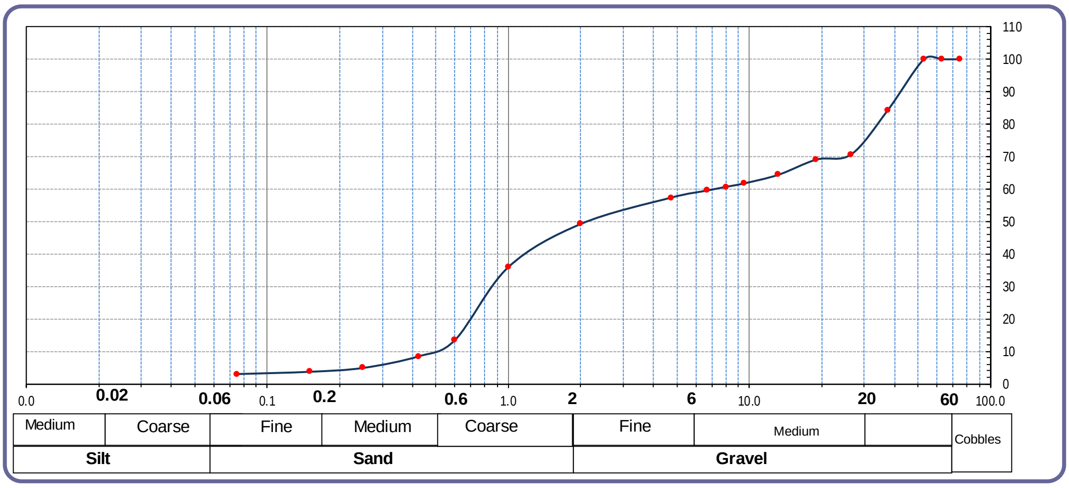
Tested By: MN

Checked by: AN

Approved by: EG

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D-422	Location	BH2	Depth	0-1m TP	Sample No.:	3282

Clay/Silt:	3.0	Sand:	54.4	Gravel:	43
Material Description	Very Moist Greyish poorly graded sand With well rounded pebble stones				

Grd Modulus (GM):	2.4	$D_{(10)}$=	0.569	mm	Fineness Modulus:	3.865
Grading Coefficient (GC):	35.7	$D_{(30)}$=	0.93	mm	Liquid Limit	24.8%
USCS classification:	SP	$D_{(60)}$=	8.65	mm	Plastic Limit	N/P
		Coeff. of Curvature, C_C =	0.18		Plasticity Index	N/P
		Coeff. of Uniformity, C_U =	15.19			

Sieve Analysis Data

Initial Dry Mass (m_1)	1924 g

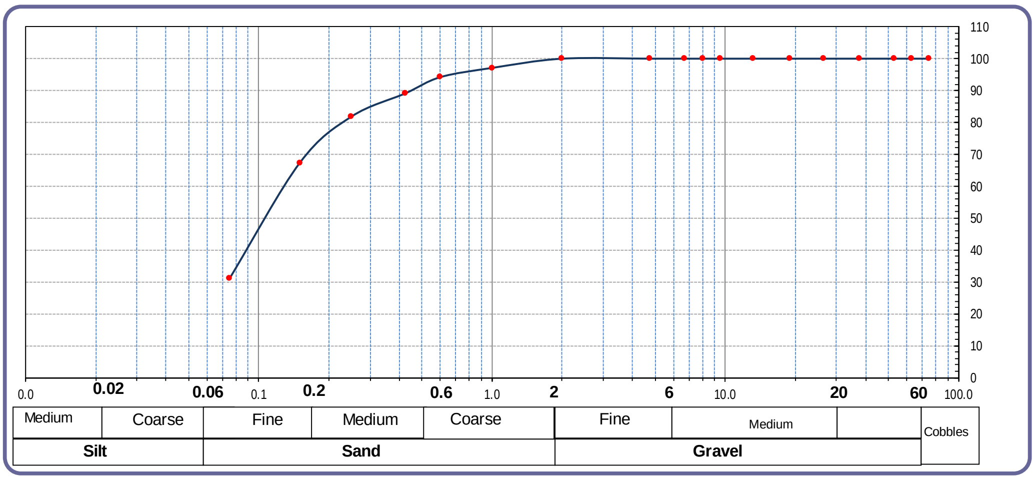
Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	312	312	15.8	84.2	84
26.5	268	268	13.5	70.7	71
19.0	32	32	1.6	69.1	69
Passing 19 mm (m_2)	1312				
total (checked with m_1	**1924**				

Riffled (m_3)	945
Riffled and washed (m_4)	945

Correction factor m_2 / m_3	1.39

13.2	67	93	4.7	64.4	64
9.5	38	53	2.7	61.7	62
8.0	15	21	1.1	60.7	61
6.7	16	22	1.1	59.6	60
4.75	31	43	2.2	57.4	57
2.0	116	161	8.1	49.3	49
1.0	190	264	13.3	36.0	36
0.6	321	446	22.5	13.5	13
0.425	71	99	5.0	8.5	8
0.250	51	71	3.6	4.9	5
0.150	17	24	1.2	3.7	4
0.075	10	14	0.7	3.0	3
<0.075 + 0.0	43	60	3.0		
TOTAL		**1981**			

SIEVE SIZE BY LOG SCALE



Ref: ASTM D- 422	**Location**	BH3	**Depth**	**0.5m-1.9m**	**Sample No.:**	3283

Clay/Silt:	**31.2**	Sand:	**68.8**	Gravel:	**0**
Material Description	Moist Greyish Medium Dense Silty Sand				

Grd Modulus (GM):	0.8	$D_{(10)}$=	0.011	mm	Fineness Modulus:	0.208
Grading Coefficient (GC):	10.9	$D_{(30)}$=	0.03	mm	Liquid Limit	24.6%
USCS classification:	SM	$D_{(60)}$=	0.07	mm	Plastic Limit	17.2
		Coeff. of Curvature, C_C =	1.50		Plasticity Index	7.3
		Coeff. of Uniformity, C_U =	6.00			

Sieve Analysis Data

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Initial Dry Mass (m_1) **2024** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	0	0	0.0	100.0	100
26.5	0	0	0.0	100.0	100
19.0	0	0	0.0	100.0	100
Passing 19 mm (m_2)	2024				
total (checked with m_1	**2024**				

Riffled (m_3)	274
Riffled and washed (m_4)	102
Correction factor m_2 / m_3	7.39

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing (p)	Cumulative % passing
13.2	0	0	0.0	100.0	100
9.5	0	0	0.0	100.0	100
8.0	0	0	0.0	100.0	100
6.7	0	0	0.0	100.0	100
4.75	0	0	0.0	100.0	100
2.0	0	0	0.0	100.0	100
1.0	4	30	2.9	97.1	97
0.6	4	30	2.9	94.2	94
0.425	7	52	5.1	89.1	89
0.250	10	74	7.2	81.9	82
0.150	20	148	14.5	67.4	67
0.075	50	369	36.2	31.2	31
<0.075 + 172.0	43	318	31.2		
TOTAL		**1019**			

Date: 31/01/2019

Tested By: MN

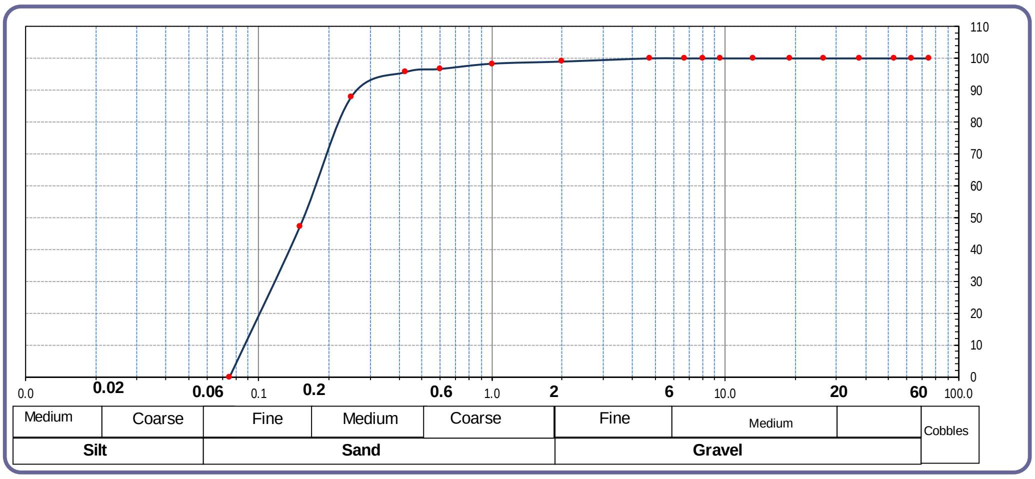
Checked by: AN

Approved by: EG

NS 1\1\04-2011

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D- 422	Location	BH3	Depth	1.9m-3.0m	Sample No.:	3284

Clay/Silt:	0.0	Sand:	100.0	Gravel:	0
Material Description	Moist Yellowish Grey Loose Sand				

Grd Modulus (GM):	1.1	$D_{(10)}$=	0.081	mm	Fineness Modulus:	0.542
Grading Coefficient (GC):	4.3	$D_{(30)}$=	0.12	mm	Liquid Limit	29.3%
USCS classification:	SP	$D_{(60)}$=	0.17	mm	Plastic Limit	N/P
		Coeff. of Curvature, C_C =	0.93		Plasticity Index	N/P
		Coeff. of Uniformity, C_U =	2.15			

Sieve Analysis Data

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Initial Dry Mass (m_1)	**1591** g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	0	0	0.0	100.0	100
26.5	0	0	0.0	100.0	100
19.0	0	0	0.0	100.0	100
Passing 19 mm (m_2)	1591				
total (checked with m_1	**1591**				

Riffled (m_3)	321
Riffled and washed (m_4)	309
Correction factor $\frac{m_2}{m_3}$	4.96

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing (p)	Cumulative % passing
13.2	0	0	0.0	100.0	100
9.5	0	0	0.0	100.0	100
8.0	0	0	0.0	100.0	100
6.7	0	0	0.0	100.0	100
4.75	0	0	0.0	100.0	100
2.0	3	15	1.0	99.0	99
1.0	2	10	0.7	98.3	98
0.6	5	25	1.7	96.7	97
0.425	3	15	1.0	95.7	96
0.250	23	114	7.6	88.0	88
0.150	123	610	40.9	47.2	47
0.075	142	704	47.2	0.0	0
<0.075 + 12.0					
TOTAL		**1492**			

Date:
31/01/2019

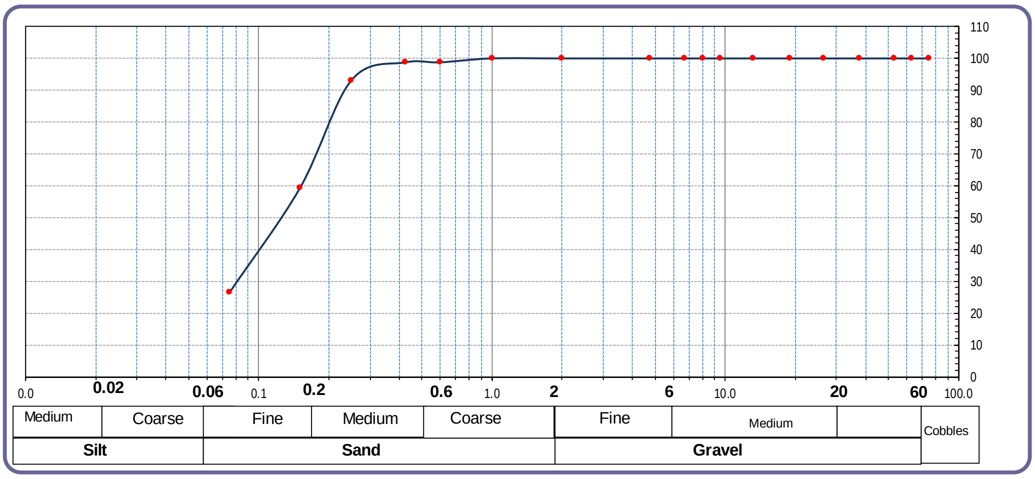
Tested By:
MN

Checked by:
AN

Approved by:
EG

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D- 422	Location	BH3	Depth	3.0m-4.6m	Sample No.:	3285

Clay/Silt:	26.5	Sand:	73.5	Gravel:	0
Material Description	Moist Greyish medium dense Clayey Sand				

Grd Modulus (GM):	0.7	$D_{(10)}$=	0.011	mm	Fineness Modulus:	0.195
Grading Coefficient (GC):	1.2	$D_{(30)}$=	0.03	mm	Liquid Limit	34.5%
USCS classification:	SC	$D_{(60)}$=	0.07	mm	Plastic Limit	20.2
		Coeff. of Curvature, C_C =	1.50		Plasticity Index	14.3
		Coeff. of Uniformity, C_U =	6.00			

Sieve Analysis Data

Initial Dry Mass (m_1)	1741 g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	0	0	0.0	100.0	100
26.5	0	0	0.0	100.0	100
19.0	0	0	0.0	100.0	100
Passing 19 mm (m_2)	1741				
total (checked with m_1	**1741**				

Riffled (m_3)	348
Riffled and washed (m_4)	125
Correction factor m_2 / m_3	5.00

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing	Cumulative % passing
13.2	0	0	0.0	100.0	100
9.5	0	0	0.0	100.0	100
8.0	0	0	0.0	100.0	100
6.7	0	0	0.0	100.0	100
4.75	0	0	0.0	100.0	100
2.0	0	0	0.0	100.0	100
1.0	0	0	0.0	100.0	100
0.6	2	10	1.2	98.8	99
0.425	0	0	0.0	98.8	99
0.250	9	45	5.6	93.2	93
0.150	55	275	34.0	59.3	59
0.075	53	265	32.7	26.5	27
<0.075 + 223.0	43	215	26.5		
TOTAL		**810**			

Date:
31/01/2019

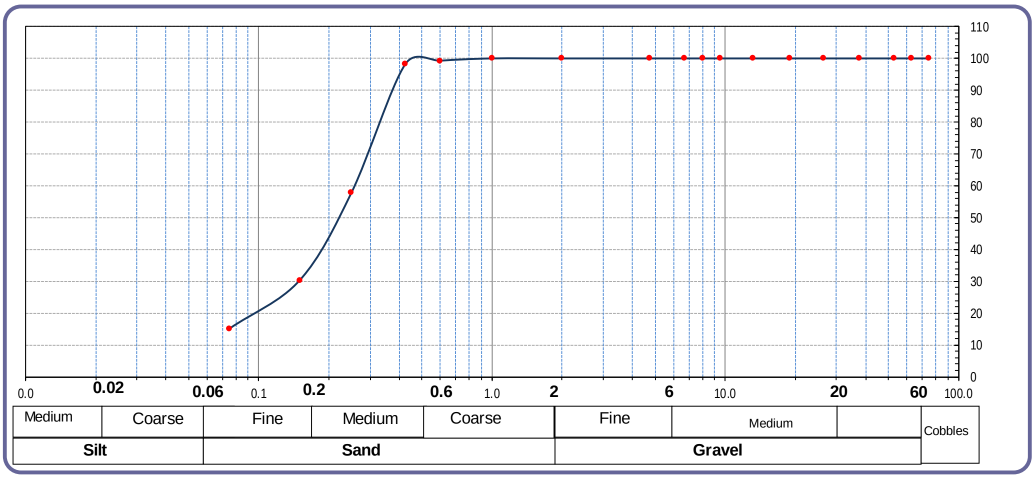
Tested By:
MN

Checked by:
AN

Approved by:
EG

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D- 422	Location	BH3	Depth	4.6m-6.0m	Sample No.:	3286

Clay/Silt:	15.2	Sand:	84.8	Gravel:	0
Material Description	Moist Greyish Yellow medium dense Silty Sand				

Grd Modulus (GM):	0.9	$D_{(10)}$=	0.024	mm	Fineness Modulus:	0.573
Grading Coefficient (GC):	1.8	$D_{(30)}$=	0.07	mm	Liquid Limit	30.6%
USCS classification:	SM	$D_{(60)}$=	0.22	mm	Plastic Limit	N/P
		Coeff. of Curvature, C_C =	0.97		Plasticity Index	N/P
		Coeff. of Uniformity, C_U =	9.23			

Sieve Analysis Data

Initial Dry Mass (m_1) 1585 g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	0	0	0.0	100.0	100
26.5	0	0	0.0	100.0	100
19.0	0	0	0.0	100.0	100
Passing 19 mm (m_2)	1585				
total (checked with m_1	**1585**				

Riffled (m_3)	347
Riffled and washed (m_4)	243
Correction factor m_2 / m_3	4.57

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing (p)	Cumulative % passing
13.2	0	0	0.0	100.0	100
9.5	0	0	0.0	100.0	100
8.0	0	0	0.0	100.0	100
6.7	0	0	0.0	100.0	100
4.75	0	0	0.0	100.0	100
2.0	0	0	0.0	100.0	100
1.0	0	0	0.0	100.0	100
0.6	2	9	0.7	99.3	99
0.425	3	14	1.1	98.2	98
0.250	114	521	40.3	58.0	58
0.150	78	356	27.6	30.4	30
0.075	43	196	15.2	15.2	15
<0.075 + 104.0	43	196	15.2		
TOTAL		**1293**			

Date: 31/01/2019

Tested By: MN

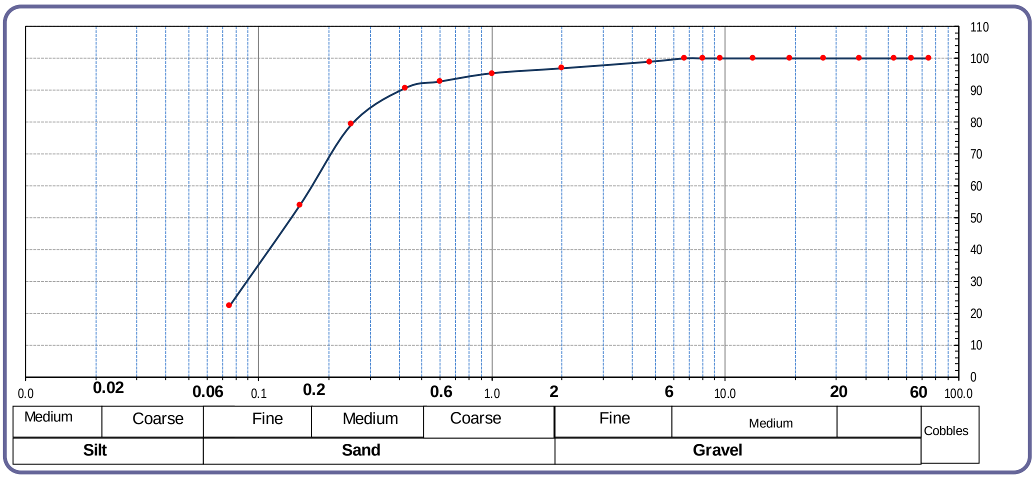
Checked by: AN

Approved by: EG

NS 1\1\04-2011

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D- 422	Location	BH3	Depth	6.0m-7.0m	Sample No.:	3287

Clay/Silt:	22.3	Sand:	76.7	Gravel:	1
Material Description	Moist Greyish Medium Dense Clayey Sand				

Grd Modulus (GM):	0.9	$D_{(10)}$=	3.898	mm	Fineness Modulus:	31.667
Grading Coefficient (GC):	9.2	$D_{(30)}$=	4.39	mm	Liquid Limit	32.6%
USCS classification:	SC	$D_{(60)}$=	5.30	mm	Plastic Limit	17.0
		Coeff. of Curvature, C_C =	0.93		Plasticity Index	15.6
		Coeff. of Uniformity, C_U =	1.36			

Sieve Analysis Data

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Initial Dry Mass (m_1)	1815 g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	0	0	0.0	100.0	100
26.5	0	0	0.0	100.0	100
19.0	0	0	0.0	100.0	100
Passing 19 mm (m_2)	1815				
total (checked with m_1	**1815**				

Riffled (m_3)	3.6
Riffled and washed (m_4)	154
Correction factor $\frac{m_2}{m_3}$	504.17

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing	Cumulative % passing
13.2	0	0	0.0	100.0	100
9.5	0	0	0.0	100.0	100
8.0	0	0	0.0	100.0	100
6.7	0	0	0.0	100.0	100
4.75	2	1008	1.0	99.0	99
2.0	4	2017	2.1	96.9	97
1.0	3	1513	1.6	95.3	95
0.6	5	2521	2.6	92.7	93
0.425	4	2017	2.1	90.7	91
0.250	22	11092	11.4	79.3	79
0.150	49	24704	25.4	53.9	54
0.075	61	30754	31.6	22.3	22
<0.075 + -150.4	43	21679	22.3		
TOTAL		**97304**			

Date:
31/01/2019

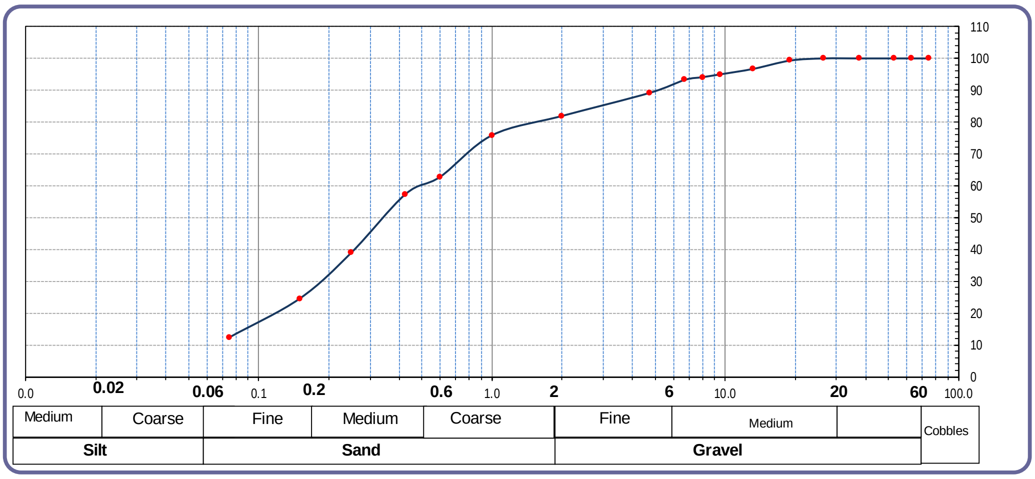
Tested By:
MN

Checked by:
AN

Approved by:
EG

Particle Size Distribution Report

SIEVE SIZE BY LOG SCALE



Ref: ASTM D- 422	Location	BH3	Depth	7.0m-9.0m	Sample No.:	3288

Clay/Silt:	12.5	Sand:	76.7	Gravel:	11
Material Description	Moist Yellowish Grey Dense to very dense Silty Sand				

Grd Modulus (GM):	1.5	$D_{(10)}$=	0.025	mm	Fineness Modulus:	1.233
Grading Coefficient (GC):	38.1	$D_{(30)}$=	0.08	mm	Liquid Limit	27.8%
USCS classification:	SM	$D_{(60)}$=	0.36	mm	Plastic Limit	N/P
		Coeff. of Curvature, C_C =	0.64		Plasticity Index	N/P
		Coeff. of Uniformity, C_U =	14.16			

Sieve Analysis Data

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Initial Dry Mass (m_1) 2582 g

Sieve Opening (mm)	Mass Retained (g) Actual	Mass Retained (g) Corrected	% Retained (m)*100 / (m_1)	% Passing (p)	Cumulative % passing
75.0	0		0	100.0	100
63.0	0	0	0.0	100.0	100
53.0	0	0	0.0	100.0	100
37.5	0	0	0.0	100.0	100
26.5	0	0	0.0	100.0	100
19.0	14	14	0.7	99.3	99
Passing 19 mm (m_2)	2568				
total (checked with m_1	**2582**				

Riffled (m_3)	429
Riffled and washed (m_4)	304
Correction factor m_2 / m_3	5.99

Sieve Opening (mm)	Actual	Corrected	% Retained	% Passing	Cumulative % passing
13.2	9	54	2.6	96.7	97
9.5	6	36	1.7	95.0	95
8.0	3	18	0.9	94.1	94
6.7	3	18	0.9	93.2	93
4.75	14	84	4.1	89.2	89
2.0	25	150	7.2	81.9	82
1.0	21	126	6.1	75.9	76
0.6	45	269	13.0	62.8	63
0.425	19	114	5.5	57.3	57
0.250	63	377	18.2	39.1	39
0.150	50	299	14.5	24.6	25
0.075	42	251	12.2	12.5	12
<0.075 + 125.0	43	257	12.5		
TOTAL		**2067**			

Date: 31/01/2019

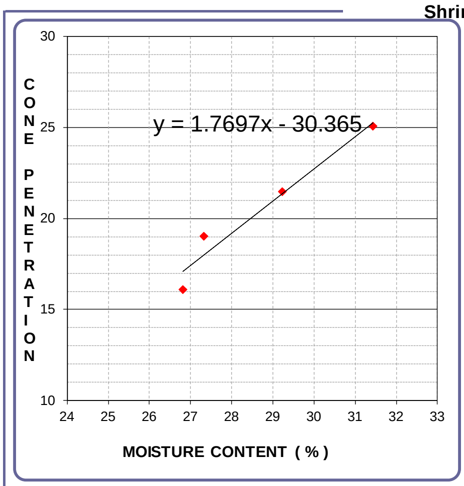
Tested By: MN

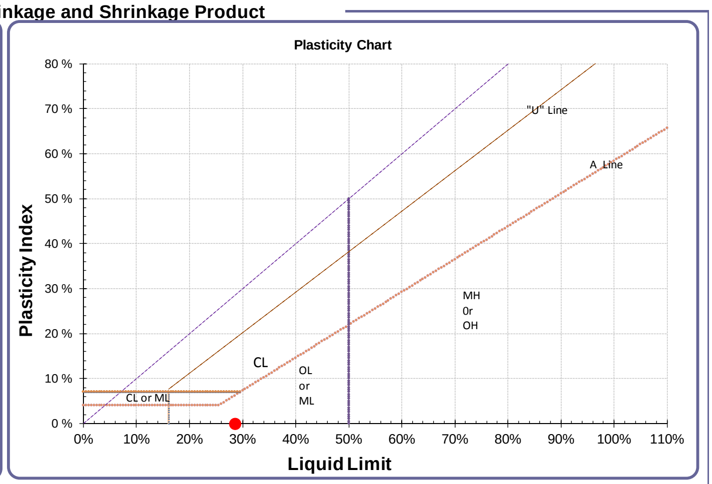
Checked by: AN

Approved by: EG

Appendix C - Atterberg Limits Test Results

Liquid and Plastic Limits. Linear Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. BS 1377 : Part 2 :1990	Location	BH1' TP 1	Depth	0.0m -1.0m	Sample No. **0**

correlation coefficient = 0.9755

LIQUID LIMIT (%)	**28.5**
PLASTIC LIMIT (%)	**N/P**
Plasticity Index (%)	**N/P**

Moist Dark Greyish Silty Sand with gravel

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		NL8
Initial Length L_0	mm	140
Oven dried length L_D	mm	136
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	2.86
Shrinkage Product, SP = LS* % <425um		163

Sample preparation :

a) As received	c) Washed on 425 µm		e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve :	57	f) Not known

Test Data

TEST NO.		LIQUID LIMIT 1			2			3			4			PLASTIC LIMIT 1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	16.0	16.2	16.1	19.0	19.1	19.0	21.6	21.4	21.4	25.1	25.0	25.1		
Average penetration	mm	**16.1**			**19.0**			**21.5**			**25.1**				

Container Number		M9	M	M5	N28		
Mass of wet soil & container	g	17.17	19.97	18.78	24.27		
Mass of dry soil & container	g	15.06	17.62	16.15	20.65		
Mass of container	g	7.19	9.02	7.15	9.13		
Mass of dry soil	g	7.87	8.6	9	11.52		
Mass of moisture	g	2.11	2.35	2.63	3.62		
Moisture content	%	**26.8**	**27.3**	**29.2**	**31.4**		

Approved By: EG

Checked AN

Tested By: JS

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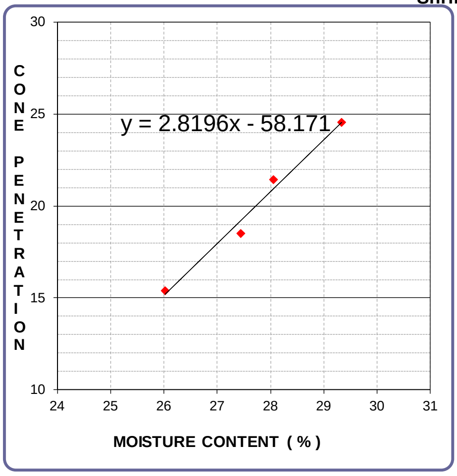
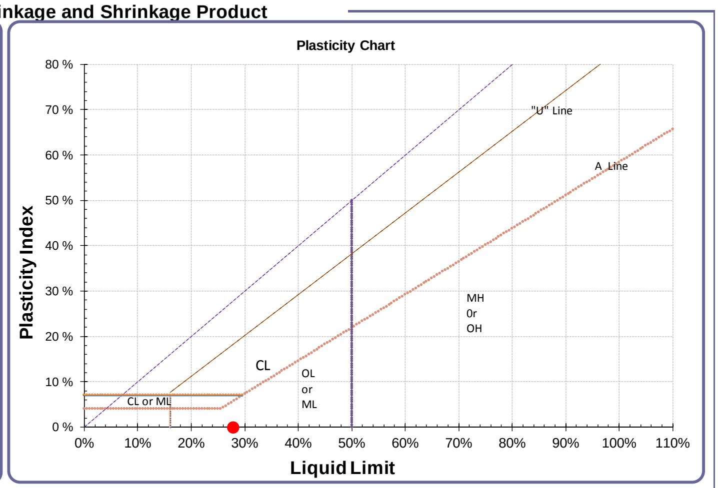
Liquid and Plastic Limits. Linear

Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. ASTM D - 4318	Location	BH1	Depth	0.5 - 4.0m	Sample No.	3280

correlation coefficient = 0.9911

LIQUID LIMIT (%)	27.7
PLASTIC LIMIT (%)	N/P
Plasticity Index (%)	N/P

Moist Dark Grey Loose Silty Sand

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		L57
Initial Length L_0	mm	140
Oven dried length L_D	mm	138
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	1.43
Shrinkage Product, SP = LS* % <425um		137

Sample preparation :

a) As received	c) Washed on 425 µm	e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve : 96	f) Not known

Test Data

		LIQUID LIMIT												PLASTIC LIMIT	
TEST NO.		1			2			3			4			1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	15.4	15.5	15.3	18.7	18.5	18.3	21.4	21.3	21.6	24.7	24.5	24.4		
Average penetration	mm	15.4			18.5			21.4			24.5				

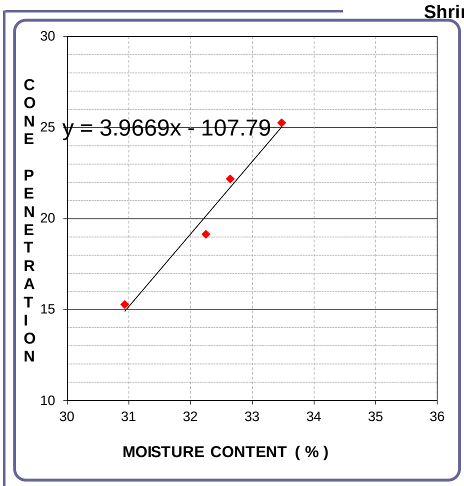
Container Number		M9	N45	M2	N18		
Mass of wet soil & container	g	23.24	24.40	25.45	26.02		
Mass of dry soil & container	g	19.92	21.20	21.45	22.23		
Mass of container	g	7.16	9.54	7.19	9.31		
Mass of dry soil	g	12.76	11.66	14.26	12.92		
Mass of moisture	g	3.32	3.2	4	3.79		
Moisture content	%	26.0	27.4	28.1	29.3		

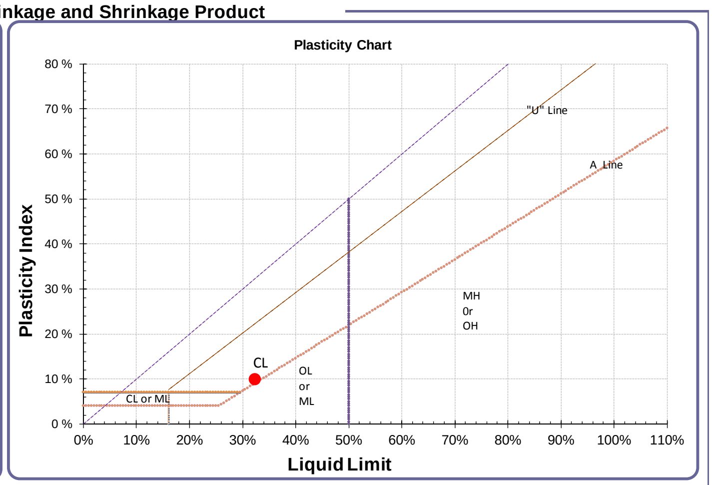
Approved By: EG

Checked AN

Tested By: JS

Liquid and Plastic Limits. Linear Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. ASTM D - 4318	Location	BH1	Depth	4.0m-6.0m	Sample No.	3281

correlation coefficient = 0.9869

LIQUID LIMIT (%)	32.2
PLASTIC LIMIT (%)	22.1
Plasticity Index (%)	10.1

Moist Grey Loose slightly Clayey Sand

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		L54
Initial Length L_0	mm	140
Oven dried length L_D	mm	137
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	2.14
Shrinkage Product, SP = LS* % <425um		132

Sample preparation :

a) As received	c) Washed on 425 µm		e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve :	61	f) Not known

Test Data

TEST NO.		LIQUID LIMIT 1			2			3			4			PLASTIC LIMIT 1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	15.4	15.1	15.3	19.0	19.3	19.1	22.0	22.4	22.1	25.1	25.2	25.4		
Average penetration	mm	15.3			19.1			22.2			25.2				

Container Number		N37	N17	0	X	C20	F	
Mass of wet soil & container	g	24.64	24.52	24.66	24.65	18.77	18.07	
Mass of dry soil & container	g	21.03	20.64	20.86	20.75	17.09	16.43	
Mass of container	g	9.36	8.61	9.22	9.10	9.39	9.09	
Mass of dry soil	g	11.67	12.03	11.64	11.65	7.7	7.34	
Mass of moisture	g	3.61	3.88	3.8	3.9	1.68	1.64	
Moisture content	%	30.9	32.3	32.6	33.5	21.8	22.3	22.08

Approved By: EG

Checked AN

Tested By: JS

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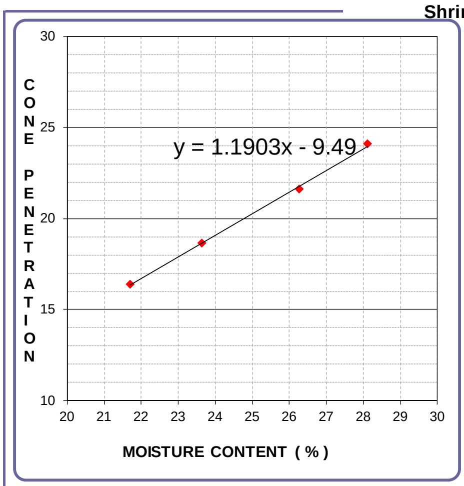
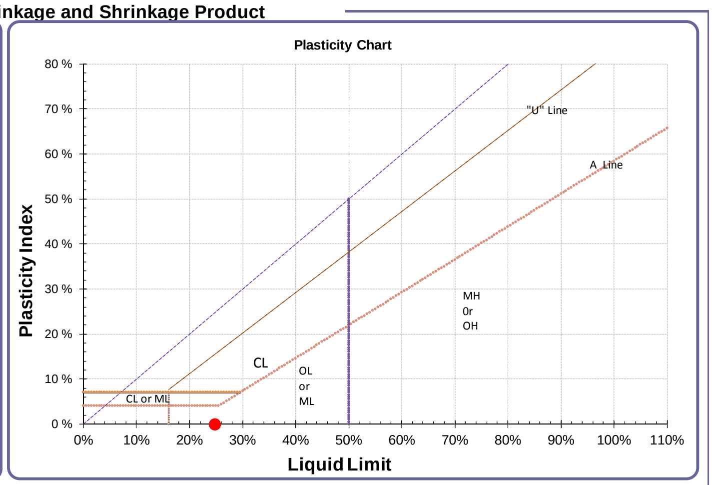
Liquid and Plastic Limits. Linear Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. ASTM D - 4318	Location	BH2	Depth	0-1m TP	Sample No. 3282

correlation coefficient = 0.9992

LIQUID LIMIT (%)	24.8
PLASTIC LIMIT (%)	N/P
Plasticity Index (%)	N/P

Very Moist Greyish Silty Gravel With Sand And well rounded pebble stones

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		L54
Initial Length L_0	mm	140
Oven dried length L_D	mm	140
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	0.00
Shrinkage Product, SP = LS* % <425um		0

Sample preparation :

a) As received	c) Washed on 425 µm		e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve :	8	f) Not known

Test Data

		LIQUID LIMIT												PLASTIC LIMIT	
TEST NO.		1			2			3			4			1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	16.2	16.4	16.6	18.9	18.6	18.4	21.5	21.6	21.7	24.1	24.2	24.0		
Average penetration	mm	16.4			18.6			21.6			24.1				

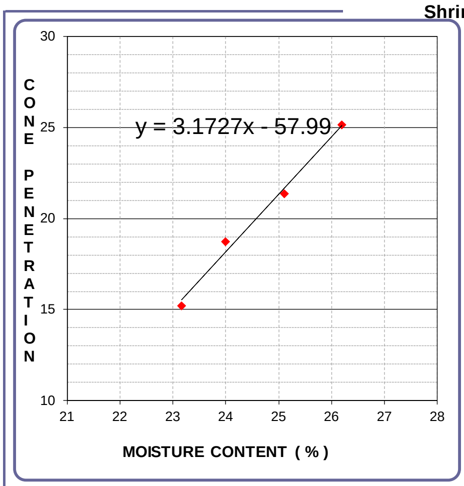
Container Number		N15	NC	18	Z		
Mass of wet soil & container	g	28.43	29.09	30.77	31.72		
Mass of dry soil & container	g	25.03	25.26	26.33	26.79		
Mass of container	g	9.36	9.06	9.43	9.25		
Mass of dry soil	g	15.67	16.2	16.9	17.54		
Mass of moisture	g	3.4	3.83	4.44	4.93		
Moisture content	%	21.7	23.6	26.3	28.1		

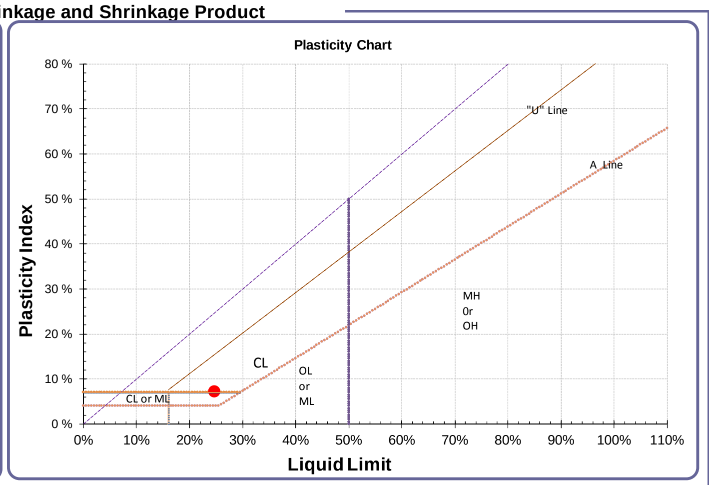
Approved By: EG

Checked AN

Tested By: JS

Liquid and Plastic Limits. Linear Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. ASTM D - 4318	Location	BH3	Depth	0.5m-1.9m	Sample No. **3283**

correlation coefficient = 0.9948

LIQUID LIMIT (%)	**24.6**
PLASTIC LIMIT (%)	**17.2**
Plasticity Index (%)	**7.3**

Moist Greyish Medium Dense Silty Sand

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		3
Initial Length L_0	mm	140
Oven dried length L_D	mm	135
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	3.57
Shrinkage Product, SP = LS* % <425um		318

Sample preparation :

a) As received	c) Washed on 425 µm		e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve :	89	f) Not known

Test Data

TEST NO.		LIQUID LIMIT 1			2			3			4			PLASTIC LIMIT 1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	15.2	15.0	15.4	18.8	18.6	18.8	21.5	21.4	21.2	25.2	25.1	25.1		
Average penetration	mm	**15.2**			**18.7**			**21.4**			**25.1**				

Container Number		Z	W18	N15	A	M4	N13	
Mass of wet soil & container	g	21.36	24.00	26.43	26.51	17.29	18.51	
Mass of dry soil & container	g	19.05	21.13	22.99	22.93	15.82	17.15	
Mass of container	g	9.08	9.17	9.29	9.26	7.25	9.31	
Mass of dry soil	g	9.97	11.96	13.7	13.67	8.57	7.84	
Mass of moisture	g	2.31	2.87	3.44	3.58	1.47	1.36	
Moisture content	%	**23.2**	**24.0**	**25.1**	**26.2**	**17.2**	**17.3**	**17.25**

Approved By: EG

Checked AN

Tested By: SJ

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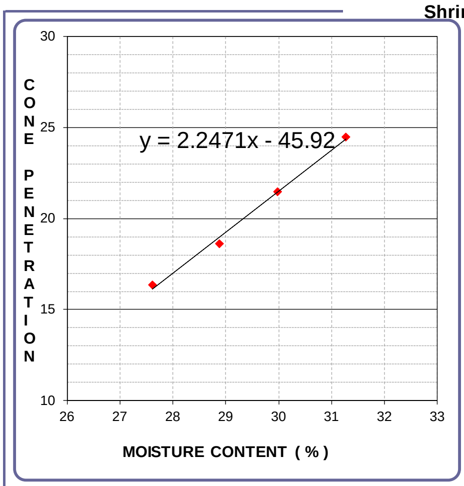
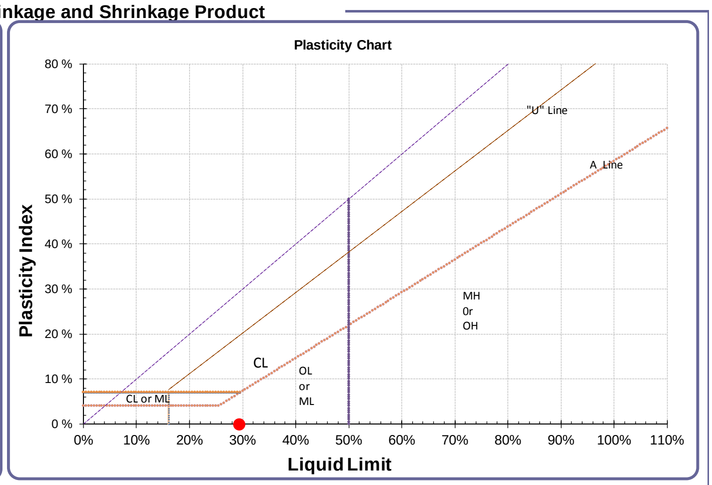
Liquid and Plastic Limits. Linear Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. ASTM D - 4318	Location	BH3	Depth	1.9m-3.0m	Sample No.	3284

correlation coefficient = 0.9969

LIQUID LIMIT (%)	29.3
PLASTIC LIMIT (%)	N/P
Plasticity Index (%)	N/P

Moist Yellowish Grey Loose Sand

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		L56
Initial Length L_0	mm	140
Oven dried length L_D	mm	140
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	0.00
Shrinkage Product, SP = LS* % <425um		0

Sample preparation :

a) As received	c) Washed on 425 µm		e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve :	96	f) Not known

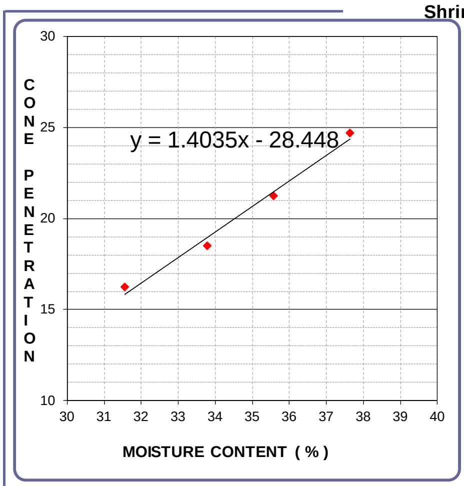
Test Data

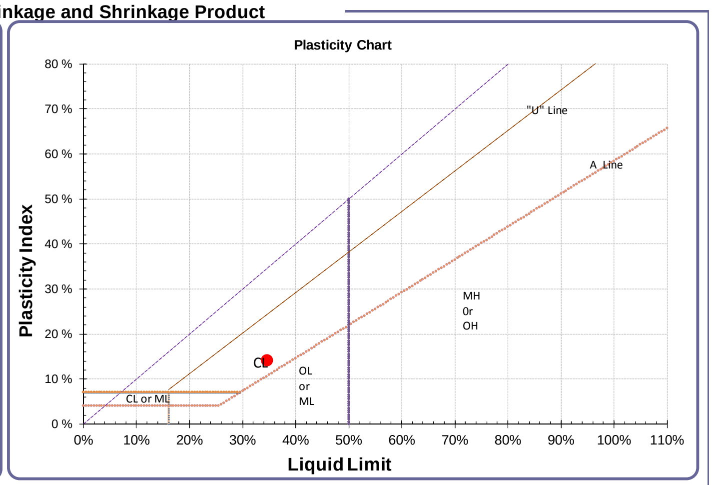
TEST NO.		LIQUID LIMIT 1			2			3			4			PLASTIC LIMIT 1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	16.4	16.5	16.2	18.4	18.6	18.8	21.4	21.6	21.4	24.5	24.4	24.5		
Average penetration	mm	16.4			18.6			21.5			24.5				

Container Number		12	N11	NC	19		
Mass of wet soil & container	g	19.89	20.81	22.99	24.50		
Mass of dry soil & container	g	16.82	18.17	19.77	20.92		
Mass of container	g	5.70	9.03	9.03	9.47		
Mass of dry soil	g	11.12	9.14	10.74	11.45		
Mass of moisture	g	3.07	2.64	3.22	3.58		
Moisture content	%	27.6	28.9	30.0	31.3		

Approved By: EG
Checked AN
Tested By: JS

Liquid and Plastic Limits. Linear Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. ASTM D - 4318	Location	BH3	Depth	3.0m-4.6m	Sample No. **3285**

correlation coefficient = 0.9930

LIQUID LIMIT (%)	**34.5**
PLASTIC LIMIT (%)	**20.2**
Plasticity Index (%)	**14.3**

Moist Greyish medium dense Clayey Sand

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		L83
Initial Length L_0	mm	140
Oven dried length L_D	mm	135
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	3.57
Shrinkage Product, SP = LS* % <425um		353

Sample preparation :

a) As received	c) Washed on 425 µm		e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve :	99	f) Not known

Test Data

TEST NO.		LIQUID LIMIT 1			2			3			4			PLASTIC LIMIT 1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	16.4	16.0	16.3	18.5	18.4	18.6	21.3	21.0	21.4	24.5	25.0	24.6		
Average penetration	mm	**16.2**			**18.5**			**21.2**			**24.7**				

Container Number		M5	M1	M9	M16	N45	N12	
Mass of wet soil & container	g	20.78	22.78	21.70	23.43	18.53	17.77	
Mass of dry soil & container	g	17.99	18.85	17.89	18.99	17.03	16.29	
Mass of container	g	9.15	7.22	7.18	7.19	9.52	9.03	
Mass of dry soil	g	8.84	11.63	10.71	11.8	7.51	7.26	
Mass of moisture	g	2.79	3.93	3.81	4.44	1.5	1.48	
Moisture content	%	**31.6**	**33.8**	**35.6**	**37.6**	**20.0**	**20.4**	**20.18**

Approved By: EG

Checked AN

Tested By: SJ

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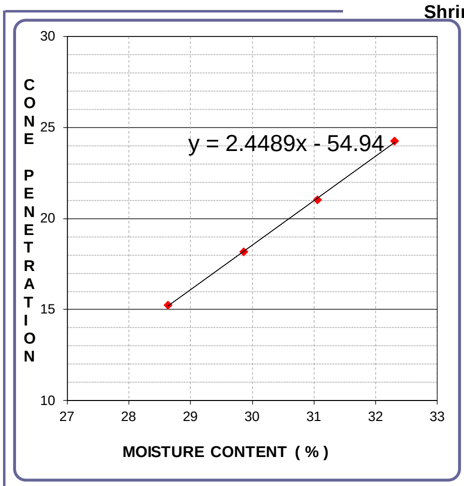
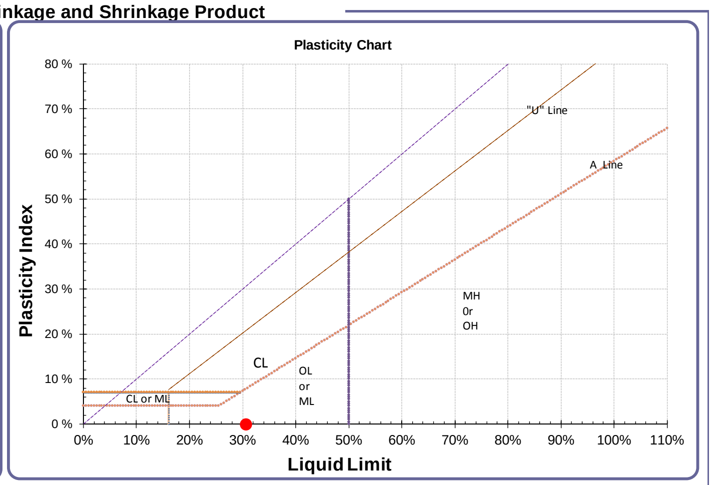
Liquid and Plastic Limits. Linear Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. ASTM D - 4318	Location	BH3	Depth	4.6m-6.0m	Sample No. **3286**

correlation coefficient = 0.9998

LIQUID LIMIT (%)	**30.6**
PLASTIC LIMIT (%)	**N/P**
Plasticity Index (%)	**N/P**

Moist Greyish Yellow medium dense Silty Sand

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		L57
Initial Length L_0	mm	140
Oven dried length L_D	mm	132
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	5.71
Shrinkage Product, SP = LS* % <425um		561

Sample preparation :

a) As received	c) Washed on 425 µm		e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve :	98	f) Not known

Test Data

TEST NO.		LIQUID LIMIT 1			2			3			4			PLASTIC LIMIT 1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	15.1	15.4	15.2	18.1	18.2	18.2	21.0	21.1	21.0	24.1	24.4	24.2		
Average penetration	mm	**15.2**			**18.2**			**21.0**			**24.2**				

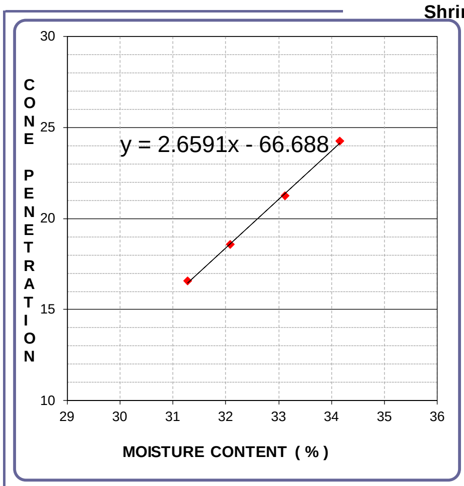
Container Number		14	N28	M	N6		
Mass of wet soil & container	g	25.62	23.02	22.58	20.30		
Mass of dry soil & container	g	21.98	19.04	19.53	17.58		
Mass of container	g	9.27	5.71	9.71	9.16		
Mass of dry soil	g	12.71	13.33	9.82	8.42		
Mass of moisture	g	3.64	3.98	3.05	2.72		
Moisture content	%	**28.6**	**29.9**	**31.1**	**32.3**		

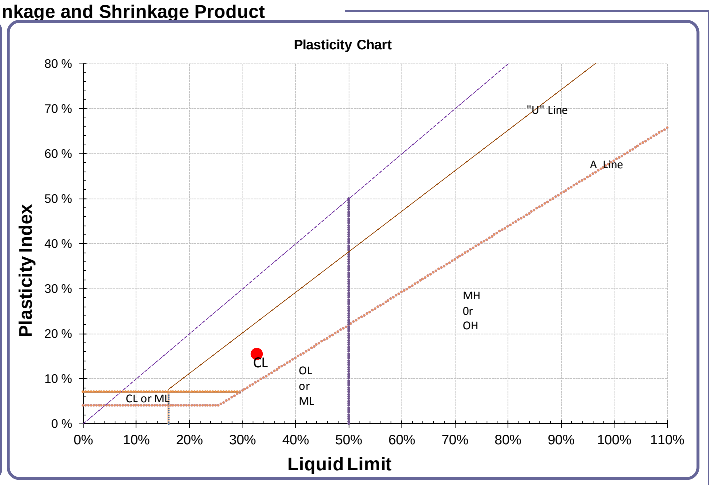
Approved By: EG

Checked AN

Tested By: JS

Liquid and Plastic Limits. Linear Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. ASTM D - 4318	Location	BH3	Depth	6.0m-7.0m	**Sample No. 3287**

correlation coefficient = 0.9993

LIQUID LIMIT (%)	**32.6**
PLASTIC LIMIT (%)	**17.0**
Plasticity Index (%)	**15.6**

Moist Greyish Medium Dense Clayey Sand

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		L58
Initial Length L_0	mm	140
Oven dried length L_D	mm	134
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	4.29
Shrinkage Product, SP = LS* % <425um		389

Sample preparation :

a) As received	c) Washed on 425 µm		e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve :	91	f) Not known

Test Data

		LIQUID LIMIT												PLASTIC LIMIT	
TEST NO.		1			2			3			4			1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	16.4	16.6	16.7	18.6	18.4	18.7	21.1	21.4	21.2	24.1	24.4	24.2		
Average penetration	mm	**16.6**			**18.6**			**21.2**			**24.2**				

Container Number		4	N12	M5	18	M1	M6	
Mass of wet soil & container	g	24.51	22.68	21.75	23.16	14.72	16.32	
Mass of dry soil & container	g	20.86	19.36	18.12	19.68	13.64	14.98	
Mass of container	g	9.19	9.01	7.16	9.49	7.22	7.20	
Mass of dry soil	g	11.67	10.35	10.96	10.19	6.42	7.78	
Mass of moisture	g	3.65	3.32	3.63	3.48	1.08	1.34	
Moisture content	%	**31.3**	**32.1**	**33.1**	**34.2**	**16.8**	**17.2**	**17.02**

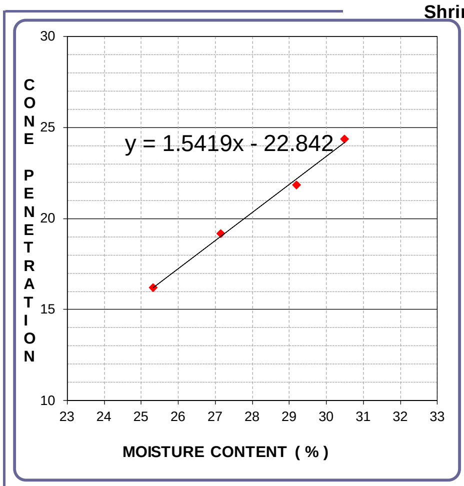
Approved By: EG

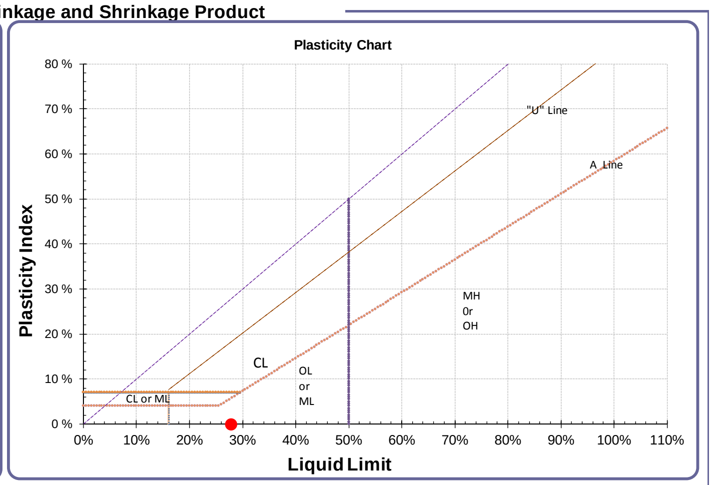
Checked AN

Tested By: JS

These results are for the exclusive use of the Client for whom they were obtained. They only apply to the samples tested and are not indicative of apparently identical samples.

Liquid and Plastic Limits. Linear Shrinkage and Shrinkage Product





TEST METHOD 1.2, 1.3, and 1.4. ref. ASTM D - 4318	Location	BH3	Depth	7.0m-9.0m	Sample No.	3288

correlation coefficient = 0.9975

LIQUID LIMIT (%)	27.8
PLASTIC LIMIT (%)	N/P
Plasticity Index (%)	N/P

Moist Yellowish Grey Dense to very dense Silty Sand

LINEAR SHRINKAGE and SHRINKAGE PRODUCT		
Specimen reference		L56
Initial Length L_0	mm	140
Oven dried length L_D	mm	135
Linear Shrinkage, LS = 100* (1-(L_D/L_O))	%	3.57
Shrinkage Product, SP = LS* % <425um		205

Sample preparation :

a) As received	c) Washed on 425 µm		e) Oven dried : ° C
b) Airdried : ° C	d) Proportion retained on 425 µm sieve :	57	f) Not known

Test Data

		LIQUID LIMIT												PLASTIC LIMIT	
TEST NO.		1			2			3			4			1	2
Initial gauge reading	mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Final gauge reading	mm	16.1	16.2	16.3	19.1	19.0	19.4	22.2	22.0	21.3	24.5	24.5	24.1		
Average penetration	mm	16.2			19.2			21.8			24.4				

Container Number		A	N18	4	N37		
Mass of wet soil & container	g	25.41	26.66	28.34	30.99		
Mass of dry soil & container	g	22.14	22.96	24.01	25.96		
Mass of container	g	9.23	9.33	9.18	9.46		
Mass of dry soil	g	12.91	13.63	14.83	16.5		
Mass of moisture	g	3.27	3.7	4.33	5.03		
Moisture content	%	25.3	27.1	29.2	30.5		

Approved By: EG

Checked AN

Tested By: JS

Appendix D – Bulk Density and Insitu Moistures

BULK DENSITY AND UNIT WEIGHT

Project	NEW LUANGWA BRIDGE SITE	**Location**	BH3	**Depth**	6.0m-7.0m
Client	KIRAN & MUSONDA ASSOCIATES LTD	**Lab No.**	3287	**Date**	12/02/2019
Responsible Technician	MN	**Checked**	AN	**Approved**	EG

Test Method	ref. BS 1377: Part 2 - 7

Specimen reference			1	2	3
Container No.			Z7	Z4	Z2
Mass of Wet Soil + Container		g	20.2	23.5	30.3
Mass of Dry Soil + Container		g	18.3	21	26.9
Mass of Container		g	6.3	5.8	5.8
Mass of Moisture		g	1.9	2.5	3.4
Mass of Dry Soil		g	12	15.2	21.1
Moisture Content	w	%	15.8	16.4	16.1
Average Moisture Content	w	%	**16.1**		
Particle Density (**assumed** or calculated)	ρ_s	Kg/m^3	2650		
Length of sample (1)	l_1	cm	13.1		
Length of sample (2)	l_2	cm	13		
Length of sample (3)	l_3	cm	13		
Length of Sample	L = Average($l_1 + l_2 + l_3$)	cm	13.0		
Internal Diameter	D	cm	7.5		
Area of Sample	$A = \frac{\pi}{4} \times D^2$	cm^2	44.2		
Volume of Sample	V = L x A	cm^3	575.9		
Mass of Sample	M	g	1277.0		
BULK DENSITY	$\rho = \frac{M}{V} \times 1000$	Kg/m^3	**2217.52**		
DRY DENSITY	$\rho_d = \frac{100\rho}{100 + w}$	Kg/m^3	**1909.49**		
VOID RATIO	$e = \frac{\rho_s}{\rho_d} - 1$		**0.39**		
DEGREE OF SATURATION	$S = \frac{w\rho_s}{e} \times 10^{-3}$	%	**110.23**		
BULK UNIT WEIGHT	$\gamma = \rho \times 9.81 \times 10^{-3}$	KN/m^3	**21.75**		

BULK DENSITY AND UNIT WEIGHT

Project	NEW LUANGWA BRIDGE SITE	**Location**	BH3	**Depth**	1.9m-3.0m
Client	KIRAN & MUSONDA ASSOCIATES LTI	**Lab No.**	3284	**Date**	12/02/2019
Responsible Technician	MN	**Checked**	AN	**Approved**	EG

Test Method	ref. BS 1377: Part 2 - 7

Specimen reference			1	2	3
Container No.			Z25	7	M6
Mass of Wet Soil + Container		g	20.8	23.62	30.8
Mass of Dry Soil + Container		g	19.3	21.9	28.3
Mass of Container		g	5.8	6.5	6.2
Mass of Moisture		g	1.5	1.72	2.5
Mass of Dry Soil		g	13.5	15.4	22.1
Moisture Content	w	%	11.1	11.2	11.3
Average Moisture Content	w	%	**11.2**		
Particle Density (**assumed** or calculated)	ρ_s	Kg/m^3	2650		
Length of sample (1)	l_1	cm	10.5		
Length of sample (2)	l_2	cm	10.6		
Length of sample (3)	l_3	cm	10.7		
Length of Sample	L = Average($l_1 + l_2 + l_3$)	cm	10.6		
Internal Diameter	D	cm	7.2		
Area of Sample	$A = \frac{\pi}{4} X D^2$	cm^2	40.7		
Volume of Sample	V = L x A	cm^3	431.6		
Mass of Sample	M	g	790.0		
BULK DENSITY	$\rho = \frac{M}{V} x1000$	Kg/m^3	**1830.25**		
DRY DENSITY	$\rho_d = \frac{100\rho}{100 + w}$	Kg/m^3	**1645.95**		
VOID RATIO	$e = \frac{\rho_s}{\rho_d} -1$		**0.61**		
DEGREE OF SATURATION	$S = \frac{w\rho_s}{e} x 10^{-3}$	%	**48.64**		
BULK UNIT WEIGHT	$\gamma = \rho x 9.81 x 10^{-3}$	KN/m^3	**17.95**		

BULK DENSITY AND UNIT WEIGHT

Project	NEW LUANGWA BRIDGE SITE	**Location**	BH3	**Depth**	3.0m-4.6m
Client	KIRAN & MUSONDA ASSOCIATES LTD	**Lab No.**	3285	**Date**	12/02/2019
Responsible Technician	MN	**Checked**	AN	**Approved**	EG

Test Method **ref. BS 1377: Part 2 - 7**

Specimen reference			1	2	3
Container No.			2	M	F1
Mass of Wet Soil + Container		g	29.5	26.6	26.3
Mass of Dry Soil + Container		g	26.8	24.2	24
Mass of Container		g	6.4	5.8	6.4
Mass of Moisture		g	2.7	2.4	2.3
Mass of Dry Soil		g	20.4	18.4	17.6
Moisture Content	w	%	13.2	13.0	13.1
Average Moisture Content	w	%	**13.1**		
Particle Density (**assumed** or calculated)	ρ_s	Kg/m^3	2650		
Length of sample (1)	l_1	cm	13		
Length of sample (2)	l_2	cm	13.1		
Length of sample (3)	l_3	cm	13.3		
Length of Sample	$L = Average(l_1 + l_2 + l_3)$	cm	13.1		
Internal Diameter	D	cm	7.4		
Area of Sample	$A = \frac{\pi}{4} \times D^2$	cm^2	43.0		
Volume of Sample	$V = L \times A$	cm^3	564.9		
Mass of Sample	M	g	1076.0		
BULK DENSITY	$\rho = \frac{M}{V} \times 1000$	Kg/m^3	**1904.70**		
DRY DENSITY	$\rho_d = \frac{100\rho}{100 + w}$	Kg/m^3	**1683.86**		
VOID RATIO	$e = \frac{\rho_s}{\rho_d} - 1$		**0.57**		
DEGREE OF SATURATION	$S = \frac{w\rho_s}{e} \times 10^{-3}$	%	**60.58**		
BULK UNIT WEIGHT	$\gamma = \rho \times 9.81 \times 10^{-3}$	KN/m^3	**18.69**		

BULK DENSITY AND UNIT WEIGHT

Project	NEW OF LUANGWA BRIDGE SITE	**Location**	BH3	**Depth**	4.6m-6.0m
Client	KIRAN & MUSONDA ASSOCIATES LTD	**Lab No.**	3286	**Date**	12/02/2019
Responsible Technician	MN	**Checked**	AN	**Approved**	EG

Test Method	ref. BS 1377: Part 2 - 7

Specimen reference			1	2	3
Container No.			M9	M2	M6
Mass of Wet Soil + Container		g	29.8	25.8	30.2
Mass of Dry Soil + Container		g	26.7	23.3	27.1
Mass of Container		g	6.4	6	6
Mass of Moisture		g	3.1	2.5	3.1
Mass of Dry Soil		g	20.3	17.3	21.1
Moisture Content	w	%	15.3	14.5	14.7
Average Moisture Content	w	%	**14.8**		
Particle Density (**assumed** or calculated)	ρ_s	Kg/m^3	2650		
Length of sample (1)	l_1	cm	16.6		
Length of sample (2)	l_2	cm	15.6		
Length of sample (3)	l_3	cm	15.6		
Length of Sample	$L = Average(l_1 + l_2 + l_3)$	cm	15.9		
Internal Diameter	D	cm	7.6		
Area of Sample	$A = \frac{\pi}{4} X D^2$	cm^2	45.4		
Volume of Sample	$V = L x A$	cm^3	722.9		
Mass of Sample	M	g	1505.0		
BULK DENSITY	$\rho = \frac{M}{V} x1000$	Kg/m^3	**2081.88**		
DRY DENSITY	$\rho_d = \frac{100\rho}{100 + w}$	Kg/m^3	**1813.42**		
VOID RATIO	$e = \frac{\rho_s}{\rho_d} -1$		**0.46**		
DEGREE OF SATURATION	$S = \frac{w\rho_s}{e} x 10^{-3}$	%	**85.04**		
BULK UNIT WEIGHT	$\gamma = \rho x 9.81 x 10^{-3}$	KN/m^3	**20.42**		

BULK DENSITY AND UNIT WEIGHT

Project	NEW LUANGWA BRIDGE SITE	**Location**	BH3	**Depth**	7.0m-9.6m
Client	KIRAN & MUSONDA ASSOCIATES LTD	**Lab No.**	3288	**Date**	12/02/2019
Responsible Technician	MN	**Checked**	AN	**Approved**	EG

Test Method	ref. BS 1377: Part 2 - 7

Specimen reference			1	2	3
Container No.			Z47	P	F7
Mass of Wet Soil + Container		g	295	305	263
Mass of Dry Soil + Container		g	266	276	238
Mass of Container		g	58	63	58
Mass of Moisture		g	29	29	25
Mass of Dry Soil		g	208	213	180
Moisture Content	w	%	13.9	13.6	13.9
Average Moisture Content	w	%	**13.8**		
Particle Density (**assumed** or calculated)	ρ_s	Kg/m^3	2650		
Length of sample (1)	l_1	cm	15.1		
Length of sample (2)	l_2	cm	15.3		
Length of sample (3)	l_3	cm	15.5		
Length of Sample	$L = Average(l_1 + l_2 + l_3)$	cm	15.3		
Internal Diameter	D	cm	6.2		
Area of Sample	$A = \frac{\pi}{4} \times D^2$	cm^2	30.2		
Volume of Sample	$V = L \times A$	cm^3	462.0		
Mass of Sample	M	g	1097.0		
BULK DENSITY	$\rho = \frac{M}{V} x1000$	Kg/m^3	**2374.57**		
DRY DENSITY	$\rho_d = \frac{100\rho}{100 + w}$	Kg/m^3	**2086.34**		
VOID RATIO	$e = \frac{\rho_s}{\rho_d} -1$		**0.27**		
DEGREE OF SATURATION	$S = \frac{w\rho_s}{e} \times 10^{-3}$	%	**135.51**		
BULK UNIT WEIGHT	$\gamma = \rho \times 9.81 \times 10^{-3}$	KN/m^3	**23.29**		

MOISTURE CONTENT (MC)

Project	NEW LUANGWA BRIDGE SITE	**Location**	BH1	**Depth**	0.5m-4.0m
Client	KIRAN & MUSONDA ASSOCIATES	**Lab No.**	3280	**Date**	12/02/2019
Responsible Technician	AN	**Checked**	AN	**Approved**	EG

Test Method	ref. ASTM D - 2216

Specimen reference					
Container No.			Z32	M8	C3
Mass of Wet Soil + Container		g	281.2	235.1	258.1
Mass of Dry Soil + Container		g	243	204	224
Mass of Container		g	62	55	60
Mass of Moisture		g	38.2	31.1	34.1
Mass of Dry Soil		g	181	149	164
Moisture Content	w	%	21.1	20.9	20.8
Average Moisture Content	w	%	**20.9**		

MOISTURE CONTENT (MC)

Project	NEW LUANGWA BRIDGE SITE	**Location**	BH1	**Depth**	0.5m-4.0m
Client	KIRAN & MUSONDA ASSOCIATES	**Lab No.**	3281	**Date**	12/02/2019
Responsible Technician	AN	**Checked**	AN	**Approved**	EG

Test Method	ref. ASTM D - 2216

Specimen reference					
Container No.			Z40	M8	C3
Mass of Wet Soil + Container		g	272	235.1	258.1
Mass of Dry Soil + Container		g	233	203	222
Mass of Container		g	59	55	60
Mass of Moisture		g	39	32.1	36.1
Mass of Dry Soil		g	174	148	162
Moisture Content	W	%	22.4	21.7	22.3
Average Moisture Content	W	%		**22.1**	

MOISTURE CONTENT (MC)

Project	NEW LUANGWA BRIDGE SITE	**Location**	BH3	**Depth**	0.5m-1.9m
Client	KIRAN & MUSONDA ASSOCIATES	**Lab No.**	3283	**Date**	12/02/2019
Responsible Technician	AN	**Checked**	AN	**Approved**	EG

Test Method	ref. ASTM D - 2216

Specimen reference					
Container No.			M3	M8	K12
Mass of Wet Soil + Container		g	237.2	235.1	308.21
Mass of Dry Soil + Container		g	229	227	297
Mass of Container		g	62	58	60
Mass of Moisture		g	8.2	8.1	11.21
Mass of Dry Soil		g	167	169	237
Moisture Content	W	%	4.9	4.8	4.7
Average Moisture Content	W	%		**4.8**	

Appendix E – UCS soil sample

Noside Soil Lab Ltd

Unconfined Compression Test Report (ASTM D2166)

Date

Checked By

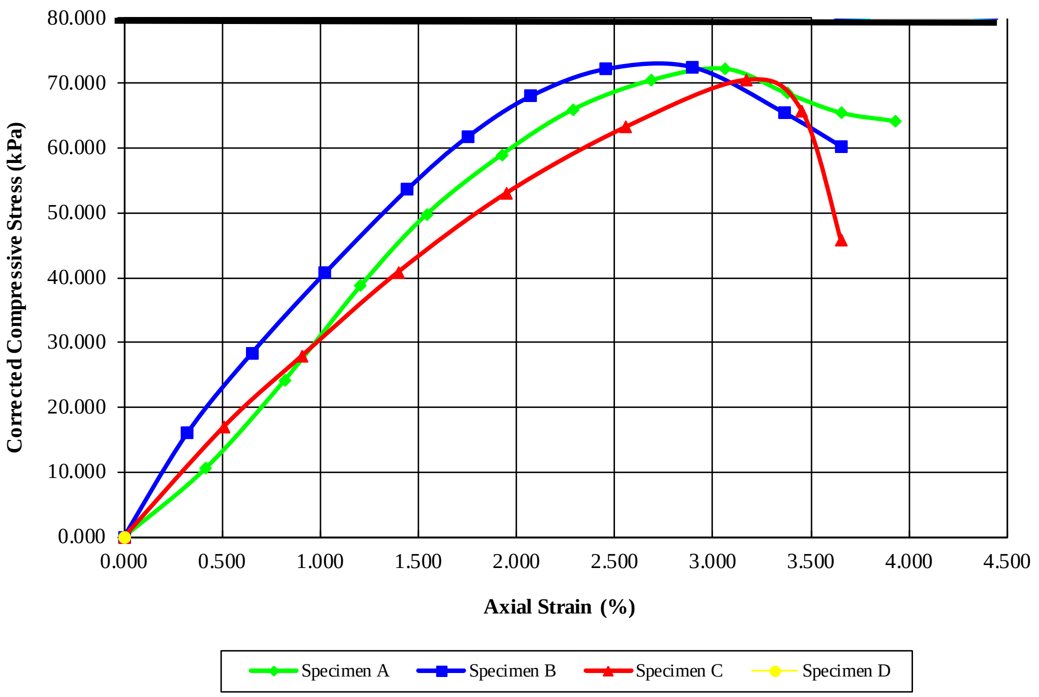
Date

Computed By

Date

Tested By

Compressive Stress Axial Strain Curve



	Specimen			
Before Test	**A**	**B**	**C**	**AVERAGES**
Water Content (%)	9.26	9.30	9.25	9.27
Dry Density (g/cm3)	1.983	1.980	1.984	1.98
Saturation (%)	72.95	72.83	73.02	72.94
Void Ratio	0.34	0.34	0.34	0.34
Diameter (mm)	151.333	151.333	151.333	151.33
Height (mm)	127.333	127.333	127.333	127.33
Test Data	**A**	**B**	**C**	**AVERAGES**
Unconfined Strength (kPa)	72.246	72.456	70.529	71.74
Undrained Shear Strength	0.737	0.739	0.719	0.73
Undrained Shear Strength	36.123	36.228	35.264	35.87
Rate of Strain (mm/min)	1.000000	1.000000	1.000000	1.00
Strain at Failure (%)	3.93	3.66	3.65	3.75
Description				

Project Information		**Specimen Description**	
Project	PROPOSED LUANGWA BRIDGE	Specimen A	
		Specimen B	
Location	BH -1 (4m - 6m)	Specimen C	
Sample #	3281		
Client	KIRAN & MUSONDA ASSOCIATES LTD	**Test Variables**	
		Liquid Limit:	32.2
		Plastic Limit:	22.1

Remarks

NOSIDE SOIL LABORATORY LIMITED

Unconfined Compression Test Report (ASTM D2166)

Date

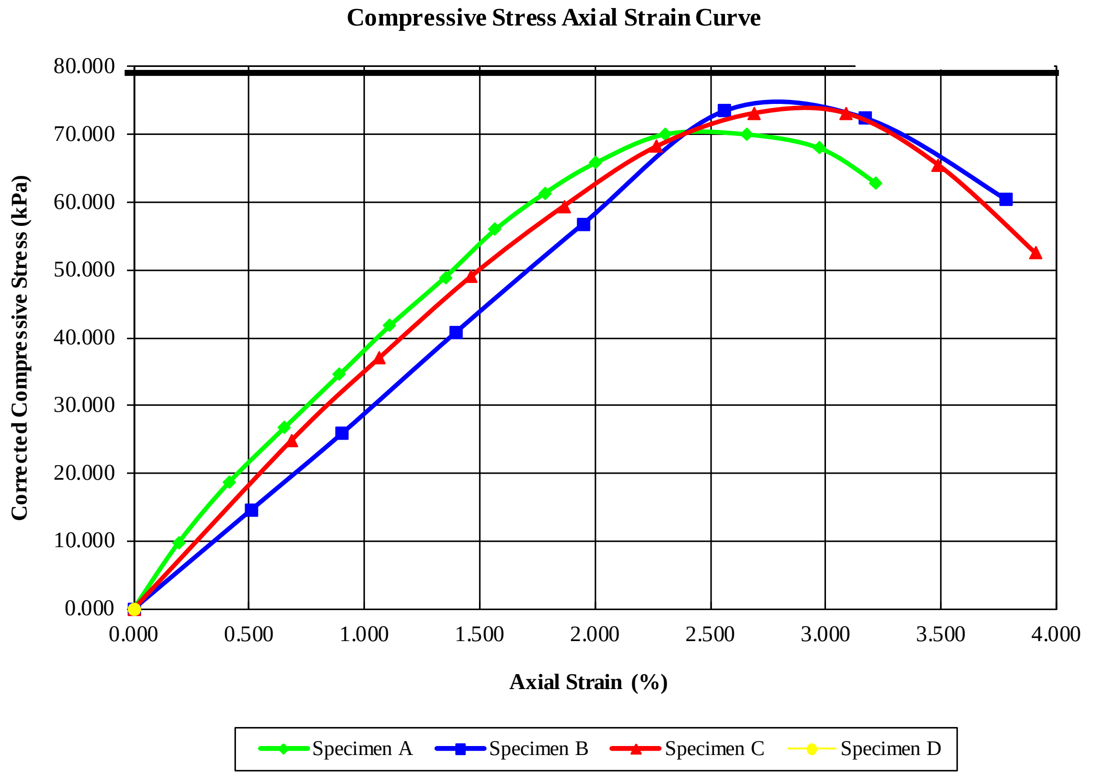
Checked By

Date

Computed By

Date

Tested By



Before Test	Specimen A	B	C	D
Water Content (%)	9.20	9.25	9.24	9.228
Dry Density (g/cm3)	1.987	1.983	1.984	1.985
Saturation (%)	73.07	72.84	72.94	72.949
Void Ratio	0.33	0.34	0.34	0.335
Diameter (mm)	152.000	152.000	152.000	152.000
Height (mm)	127.333	127.333	127.000	127.222
Test Data	**A**	**B**	**C**	**Average**
Unconfined Strength (kPa)	70.050	73.451	73.152	72.218
Undrained Shear Strength (kgf/cm^2)	0.714	0.749	0.715	0.726
Undrained Shear Strength	35.025	36.725	36.576	36.109
Rate of Strain (mm/min)	1.000000	1.000000	1.000000	1.000
Description				

Project Information		**Specimen Description**	
Project	PROPOSED LUANGWA BRIDGE		
Location	BH -3 (3m - 4.6m)		
Sample #	3285		
Client	KIRAN & MUSONDA ASSOCIATES	**Test Variables**	
		Liquid Limit:	34.5
		Plastic Limit:	20.2

Remarks

Appendix F – Rock Core tests

UNCONFINED COMPRESSIVE STRENGTH

Test Method: ref ASTM D-1586

Loacation: NEW LUANGWA BRIDGE SITE **Depth:** **4.5m-6.0m - 11m** **Lab Reference No.** 3289

Condition of Testing: **Saturated(Dry)**

Tested By: MN **Checked:** AN **Approved** EG

CYLINDRICAL STONE (CORING)

Specimen Reference No.	Specimen Dimensions		Mass (g)	Density	Coring Date	Tested Date	Compressive Strength		
							Individual		Average (Mpa)
	Diameter (m)	Height (m)		(Mg/m^3)			kN	Mpa	
BH1' 4.5 - 6	0.056	0.111	919	3.36	05/02/2019	12/02/2019	305.8	124.2	81.55
BH1' 11.1	0.069	0.100	1016	2.72			172.6	46.2	
BH1' 11.5	0.069	0.102	998	2.62			277.9	74.3	


BH1' 4.6- 6M


BH1' 11m


BH1' 11m

UNCONFINED COMPRESSIVE STRENGTH

Test Method: ref ASTM D-2938

Loacation: NEW LUANGWA BRIDGE SITE

Depth: **10m - 23m**

Lab Reference No. 3290

Condition of Testing: **Saturated (WET)**

Tested By: MN **Checked:** AN **Approved:** EG

CYLINDRICAL STONE (CORING)

Specimen Reference No.	Specimen Dimensions		Mass (g)	Density	Coring Date	Tested Date	Age of Specimen	Compressive Strength		
								Individual		Average (Mpa)
	Diameter (m)	Height (m)		(Mg/m^3)			(days)	kN	Mpa	
BH3 10m	0.057	0.111	713	2.52	**05/02/2019**	12/02/2019	7	179.6	70.4	45.38
BH3 17m	0.057	0.121	805	2.61				84.5	33.1	
BH3 23m	0.057	0.111	818	2.89				83.3	32.6	

BH3 10m

BH3 10m

BH3 17m

BH3 17m

BH3 23m

BH3 23m

Appendix G – Specific Gravity

Max. Specific Gravity of Mix

Sampling Location:	BH1' 0-1.0m TP			**Lab.no**	**3282**
Sampling Date:	29/01/2019	**Material Type**		**Date**	12/02/2019
Responsible Technician	MN	**Checked**	AN	**Approved**	EG

TEST METHOD ref.ASTM D-854

Volumetric Flask / Pyknometer Used 50 or **500** cm^3 Pyknometer No. 1

Specimen reference			E	H	D
Pyknometer + Water at 25°C (D),	**A**	g	140.88	142.58	140.70
Pyknometer + Material	**B**	g	76.88	62.01	62.38
Empty Pyknometer	**C**	g	35.77	19.88	41.49
Material at 25°C	**D**	g	41.11	42.13	20.89
Pyk + Mat + Water at 25°C	**E**	g	166.29	168.59	153.65
Max. Specific Gravity	S.G = D/(D+A-E)	g/cm³	2.62	2.61	2.63
Mean Value		g/cm³	2.62		

NS22\1\2013

Max. Specific Gravity of Mix

Sampling Location:	**LG1 0.5m-4.0m (LUANGWA BRIDGE)**			**Lab.no**	**3280**
Sampling Date:	**29/01/2019**	**Material Type**		**Date**	12/02/2019
Responsible Technician	**MN**	**Checked**	**AN**	**Approved**	EG

TEST METHOD ref.ASTM D-854

Volumetric Flask / Pyknometer Used 50 or **500** cm^3 Pyknometer No. 1

Specimen reference			E	H	D
Pyknometer + Water at 25°C (D),	**A**	g	140.62	141.58	144.61
Pyknometer + Material	**B**	g	61.51	62.01	63.69
Empty Pyknometer	**C**	g	46.73	19.88	45.58
Material at 25°C	**D**	g	14.78	42.13	18.11
Pyk + Mat + Water at 25°C	**E**	g	149.77	167.59	155.79
Max. Specific Gravity	S.G = D/(D+A-E)	g/cm³	2.63	2.61	2.61
Mean Value		g/cm³	2.62		

NS22\1\2013

Max. Specific Gravity of Mix

Sampling Location:	**BH1 4.0m-6.0m (LUANGWA BRIDGE)**			**Lab.no**	**3281**
Sampling Date:	**29/01/2019**	**Material Type**		**Date**	12/02/2019
Responsible Technician	**MN**	**Checked**	**AN**	**Approved**	EG

TEST METHOD ref.ASTM D-854

Volumetric Flask / Pyknometer Used 50 or **500** cm^3 Pyknometer No. 1

Specimen reference			D	F	C
Pyknometer + Water at 25°C (D),	**A**	g	144.74	145.89	145.61
Pyknometer + Material	**B**	g	58.07	56.59	63.69
Empty Pyknometer	**C**	g	45.64	46.68	45.58
Material at 25°C	**D**	g	12.43	9.91	18.11
Pyk + Mat + Water at 25°C	**E**	g	152.41	152.05	156.79
Max. Specific Gravity	S.G = D/(D+A-E)	g/cm^3	2.61	2.64	2.61
Mean Value		g/cm^3	2.62		

NS22\1\2013

Max. Specific Gravity of Mix

Sampling Location:	**BH3 0.5m-1.9m**			**Lab.no**	**3283**
Sampling Date:	**29/01/2019**	**Material Type**		**Date**	12/02/2019
Responsible Technician	**MN**	**Checked**	**AN**	**Approved**	EG

TEST METHOD ref.ASTM D-854

Volumetric Flask / Pyknometer Used 50 or **500** cm^3 Pyknometer No. 1

Specimen reference			A	B	C
Pyknometer + Water at 25°C (D),	**A**	g	140.69	140.82	81.81
Pyknometer + Material	**B**	g	55.01	50.67	39.51
Empty Pyknometer	**C**	g	41.45	35.71	27.51
Material at 25°C	**D**	g	13.56	14.96	12.00
Pyk + Mat + Water at 25°C	**E**	g	148.98	150.12	89.23
Max. Specific Gravity	S.G = D/(D+A-E)	g/cm^3	2.57	2.64	2.62
Mean Value		g/cm^3	2.61		

NS22\1\2013

Max. Specific Gravity of Mix

Sampling Location:	**BH3 1.9m-3.0m**	**Lab.no**	**3284**
Sampling Date:	**29/01/2019**	**Material Type**	
		Date	12/02/2019
Responsible Technician	**MN**	**Checked**	**AN**
Approved	EG		

TEST METHOD ref.ASTM D-854

Volumetric Flask / Pyknometer Used 50 or **500** cm^3 Pyknometer No. 1

Specimen reference			H	C	O
Pyknometer + Water at 25°C (D),	**A**	g	83.3	80.52	80.81
Pyknometer + Material	**B**	g	41.9	37.66	39.51
Empty Pyknometer	**C**	g	27.38	27.49	27.51
Material at 25°C	**D**	g	14.52	10.17	12.00
Pyk + Mat + Water at 25°C	**E**	g	92.27	86.82	88.23
Max. Specific Gravity	S.G = D/(D+A-E)	g/cm³	2.62	2.63	2.62
Mean Value		g/cm³	2.62		

NS22\1\2013

Max. Specific Gravity of Mix

Sampling Location:	**BH3 3.0m-4.6m**			**Lab.no**	**3285**
Sampling Date:	**29/01/2019**	**Material Type**		**Date**	12/02/2019
Responsible Technician	**MN**	**Checked**	**AN**	**Approved**	EG

TEST METHOD ref.ASTM D-854

Volumetric Flask / Pyknometer Used 50 or **500** cm^3 Pyknometer No. 1

Specimen reference			H	D	C
Pyknometer + Water at 25°C (D),	**A**	g	83.38	142.58	80.81
Pyknometer + Material	**B**	g	43.53	62.01	39.51
Empty Pyknometer	**C**	g	27.51	19.88	27.51
Material at 25°C	**D**	g	16.02	42.13	12.00
Pyk + Mat + Water at 25°C	**E**	g	93.25	168.60	88.23
Max. Specific Gravity	S.G = D/(D+A-E)	g/cm³	2.60	2.62	2.62
Mean Value		g/cm³	2.61		

Max. Specific Gravity of Mix

Sampling Location:	**BH3 4.6m-6.0m**			**Lab.no**	**3286**
Sampling Date:	**29/01/2019**	**Material Type**		**Date**	12/02/2019
Responsible Technician	**MN**	**Checked**	**AN**	**Approved**	EG

TEST METHOD ref.ASTM D-854

Volumetric Flask / Pyknometer Used 50 or **500** cm^3 Pyknometer No. 1

Specimen reference			H	C	Q
Pyknometer + Water at 25°C (D),	**A**	g	83.3	80.53	81.81
Pyknometer + Material	**B**	g	39.8	38.28	38.51
Empty Pyknometer	**C**	g	27.43	27.53	27.51
Material at 25°C	**D**	g	12.37	10.75	11.00
Pyk + Mat + Water at 25°C	**E**	g	90.93	87.22	88.63
Max. Specific Gravity	S.G = D/(D+A-E)	g/cm³	2.61	2.65	2.63
Mean Value		g/cm³	2.63		

NS22\1\2013

Max. Specific Gravity of Mix

Sampling Location:	**BH3 6.0m-7.0m**			**Lab.no**	**3287**
Sampling Date:	**29/01/2019**	**Material Type**		**Date**	12/02/2019
Responsible Technician	**MN**	**Checked**	**AN**	**Approved**	EG

TEST METHOD ref.ASTM D-854

Volumetric Flask / Pyknometer Used 50 or **500** cm^3 Pyknometer No. 1

Specimen reference			B	D	K
Pyknometer + Water at 25°C (D),	**A**	g	140.82	144.73	143.61
Pyknometer + Material	**B**	g	48.02	55.98	63.69
Empty Pyknometer	**C**	g	35.71	45.64	45.58
Material at 25°C	**D**	g	12.31	10.34	18.11
Pyk + Mat + Water at 25°C	**E**	g	148.44	151.12	154.79
Max. Specific Gravity	S.G = D/(D+A-E)	g/cm³	2.62	2.62	2.61
Mean Value		g/cm³	2.62		

Max. Specific Gravity of Mix

Sampling Location:	**BH3 7.0m-9.0m**			**Lab.no**	**3288**
Sampling Date:	**29/01/2019**	**Material Type**		**Date**	12/02/2019
Responsible Technician	**MN**	**Checked**	**AN**	**Approved**	EG

TEST METHOD ref.ASTM D-854

Volumetric Flask / Pyknometer Used 50 or **500** cm^3 Pyknometer No. 1

Specimen reference			J	F	A
Pyknometer + Water at 25°C (D),	**A**	g	83.4	145.88	140.69
Pyknometer + Material	**B**	g	39.8	62.48	52.58
Empty Pyknometer	**C**	g	27.43	46.64	41.45
Material at 25°C	**D**	g	12.37	15.84	11.13
Pyk + Mat + Water at 25°C	**E**	g	91.07	155.66	147.57
Max. Specific Gravity	S.G = D/(D+A-E)	g/cm³	2.63	2.61	2.62
Mean Value		g/cm³	2.62		

Appendix H – UU Triaxial Test

BILVIN ENGINEERING (Z) LIMITED

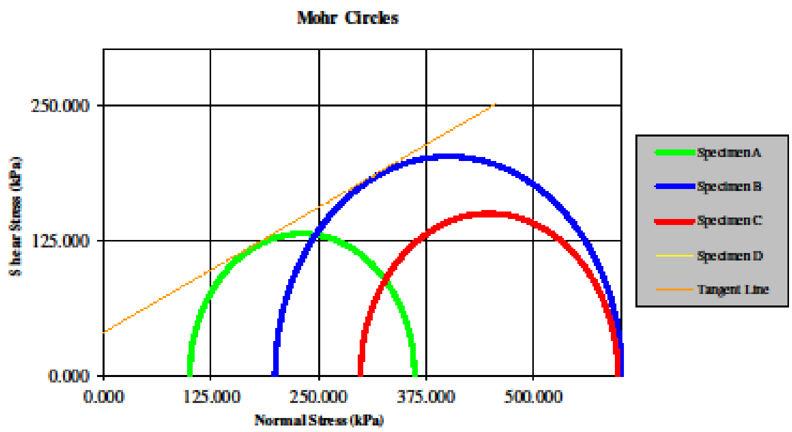
Unconsolidated Undrained Triaxial Test (ASTM D2850)

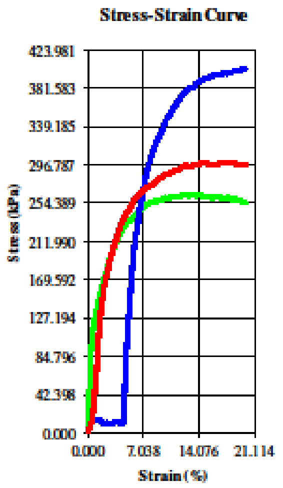
Date: 02/15/19

Checked By: Kelvin L. Amukusana

Date: 15/02/2019

Tested By: Kelvin L. Amukusana





	Specimen			
Before Test	**A**	**B**	**C**	**D**
Water Content (%)	22.65	22.65	22.65	0.00
Dry Density (g/cm3)	1.64	1.63	1.65	0.00
Saturation (%)	97.95	96.19	98.54	0.00
Void Ratio	0.61	0.62	0.61	0.00
Diameter (mm)	38.000	38.000	38.000	0.000
Height (mm)	76.000	76.000	76.000	0.000
Liquid Limit	0.0	0.0	0.0	0.000
Plastic Limit	0.0	0.0	0.0	0.000
Specific Gravity	0.000	0.000	0.000	0.000
After Test	**A**	**B**	**C**	**D**
Water Content (%)	22.65	22.65	22.65	0.00
Test Data	**A**	**B**	**C**	**D**
Strain Rate (mm/min)	38.10	38.10	38.10	0.00
Peak Deviator Stress (kPa)	263.382	403.791	300.303	0.000
Axial Strain @ Failure (%)	14.417	19.884	17.450	0.000
	Cell Pressure			
Cell (kPa)	100.0	200.0	300.0	0.0
Back (kPa)	n/a	n/a	n/a	n/a
	Principle Stresses at Failure			
σ1 (kPa)	363.4	603.8	600.3	0.0
σ3 (kPa)	100.0	200.0	300.0	0.0

Mohr-Coulomb Strength Parameters		**Sample Description**
C (kPa)	39.0	Green/Greyish Moist Silty Sand with Shiny Specs
Friction Angle Ø	24.78	

Project Information			
Project Name:	PROPOSED NEW LUANGWA BRIDGE		
Project Number:		Job Number:	BEL/NSL0219
Location:	LUANGWA EASTERN, ZAMBIA	Boring Number:	
Client:	NOSIDE SOILS LABORATORY	Sample Number:	BH 1 (4.0 - 6.0)m
Remarks:			

2

BILVIN ENGINEERING (Z) LIMITED

Unconsolidated Undrained Triaxial Test (ASTM D2850)

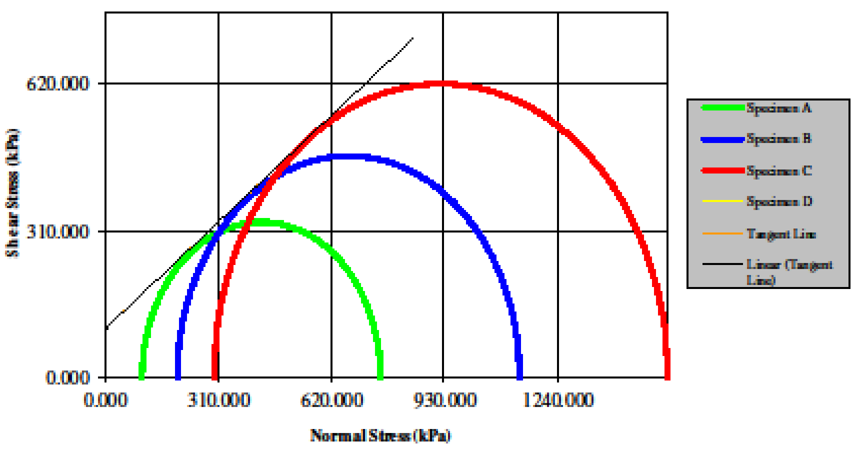
Date: 02/15/19

Checked By: KLA

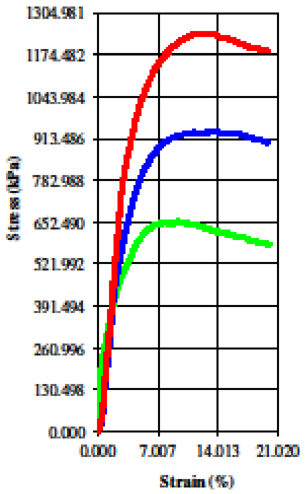
Date: 15/02/2019

Tested By: KLA

Mohr Circles



Stress-Strain Curve



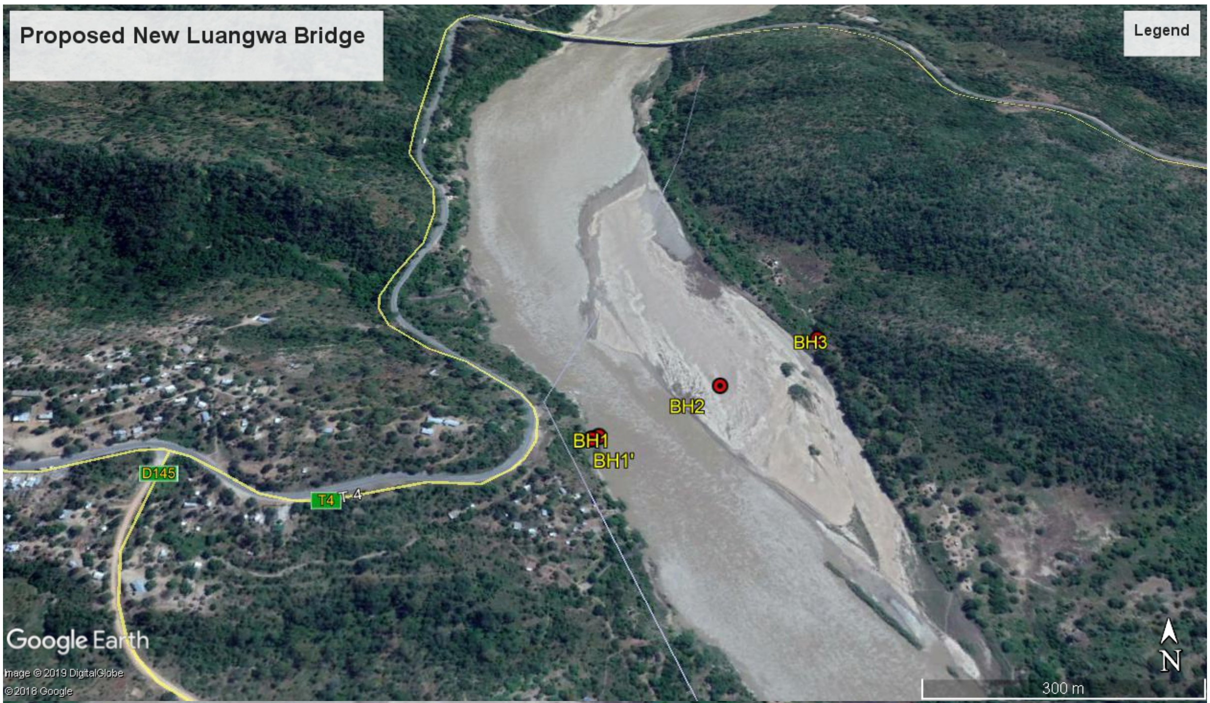
	Specimen			
Before Test	**A**	**B**	**C**	**D**
Water Content (%)	14.20	14.20	14.20	0.00
Dry Density (g/cm3)	1.74	1.74	1.74	0.00
Saturation (%)	72.63	72.63	72.63	0.00
Void Ratio	0.52	0.52	0.52	0.00
Diameter (mm)	38.000	38.000	38.000	0.000
Height (mm)	76.000	76.000	76.000	0.000
Liquid Limit	0.0	0.0	0.0	0.000
Plastic Limit	0.0	0.0	0.0	0.000
Specific Gravity	0.000	0.000	0.000	0.000
After Test	**A**	**B**	**C**	**D**
Water Content (%)	14.20	14.20	14.20	0.00
Test Data	**A**	**B**	**C**	**D**
Strain Rate (mm/min)	38.10	38.10	38.10	0.00
Peak Deviator Stress (kPa)	656.392	937.375	1242.839	0.000
Axial Strain @ Failure (%)	9.425	13.836	12.834	0.000
	Cell Pressure			
Cell (kPa)	100.0	200.0	300.0	0.0
Back (kPa)	n/a	n/a	n/a	n/a
	Principle Stresses at Failure			
σ1 (kPa)	756.4	1137.4	1542.8	0.0
σ3 (kPa)	100.0	200.0	300.0	0.0

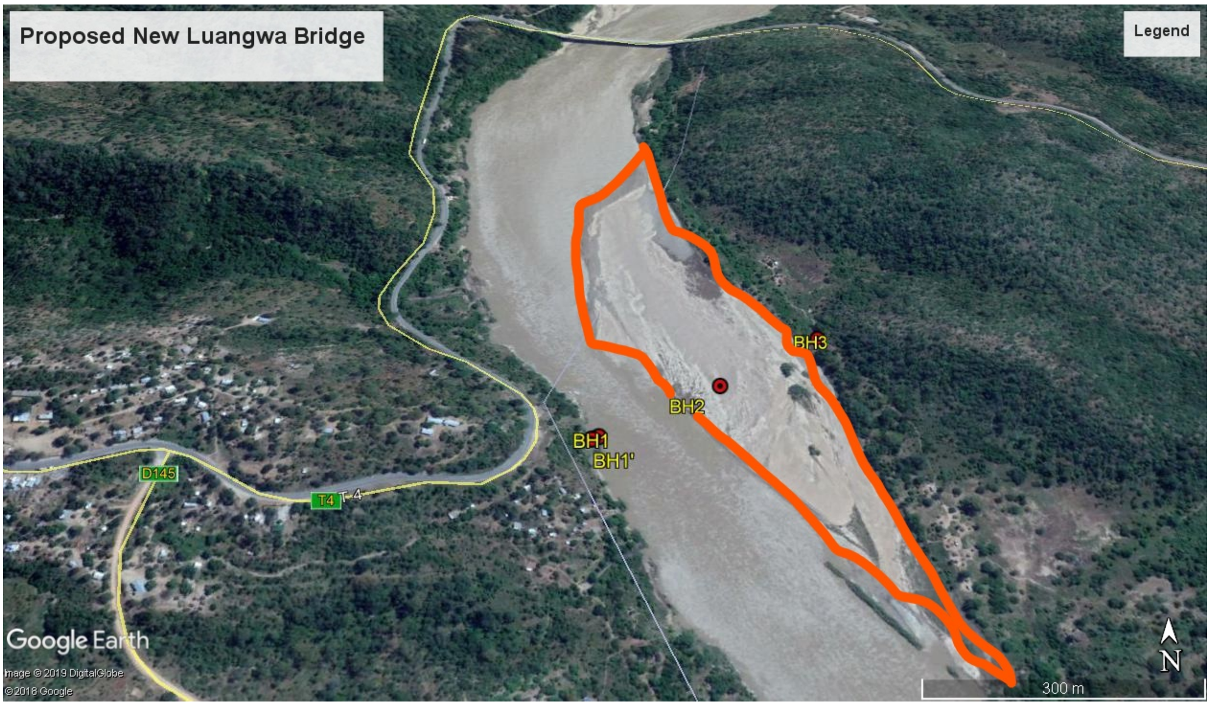
Mohr-Coulomb Strength Parameters		**Sample Description**
C (kPa)	99.5	Brown Moist Pinholed Fine Sand with Shiny Specs
Friction Angle Ø	36.09	

Project Information			
Project Name:	PROPOSED NEW LUANGWA BRIDGE		
Project Number:		Job Number:	BEL/NSL0219
Location:	LUANGWA, EASTERN ZAMBIA	Boring Number:	
Client:	NOSIDE SOILS LABORATORY	Sample Number:	BH 3 (3.0 - 4.6)m
Remarks:			

3

Appendix J – Site Map

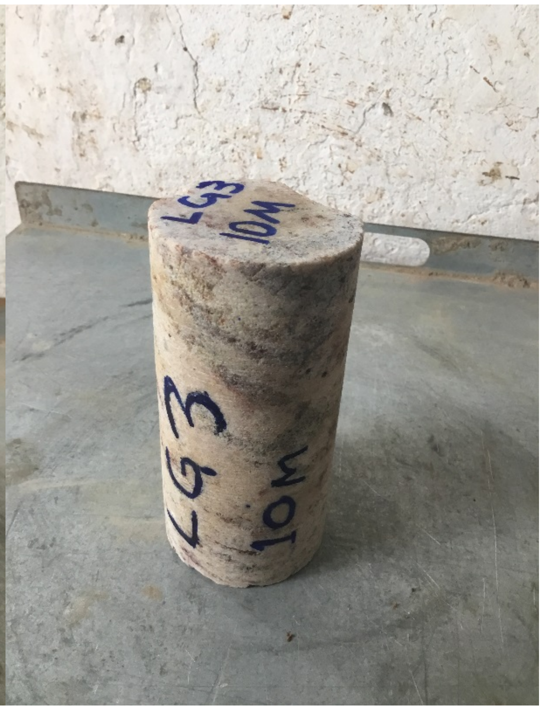




Sandbank area – this was reclaimed by the river during the site investigation works.

Appendix K – ROCK CORES

BH1' - 4.5m



BH3 - 10m

BH3 - 17m

BH3 - 23m


BH1' 11m

Appendix L – core Trays

BH1’ at 11m

BH1 at 23m

Appendix E　Topographic Survey Result

The major specification and accuracy of aerial photo survey is shown in Table EP 1-1. The total of more than 800 aerial photos were taken to cover the area of 4.65km2.

Table EP 1-1　Specification and accuracy

Item	Specifications, Accuracy
Coordinate system	UTM Zone 36 South
Datum	ARC 1950 Datum
Projection	Transverse Mercator
Camera model	SODA_10.6_5472X3648 (RGB)
Average ground sampling distance (GSD)	6.99cm
Covered area	4,653 km2
Approximate flying height	212.5 m
Number of ground control points	9
Accuracy of images	Media of 78119 key points per image
Dataset	786 out of 804 images calibrated (97%)
Camera optimization	0.72% relative difference between initial and optimal camera parameter
Matching	Media of 4263.5 matches per calibrated image

Photo EP.1-1 Fixed Wings UAV

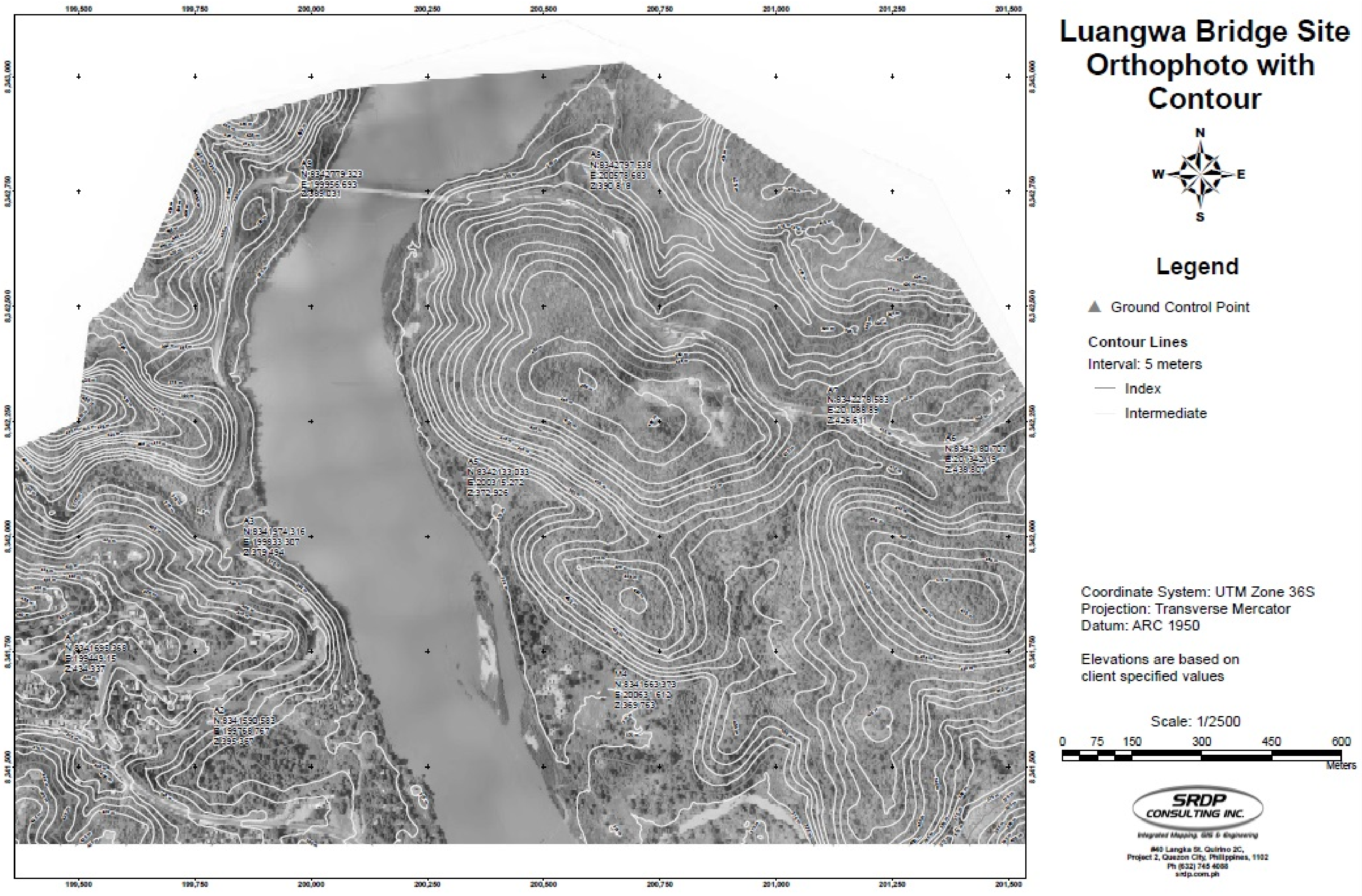


Figure EP .1-1 Orthomosaic with Contours

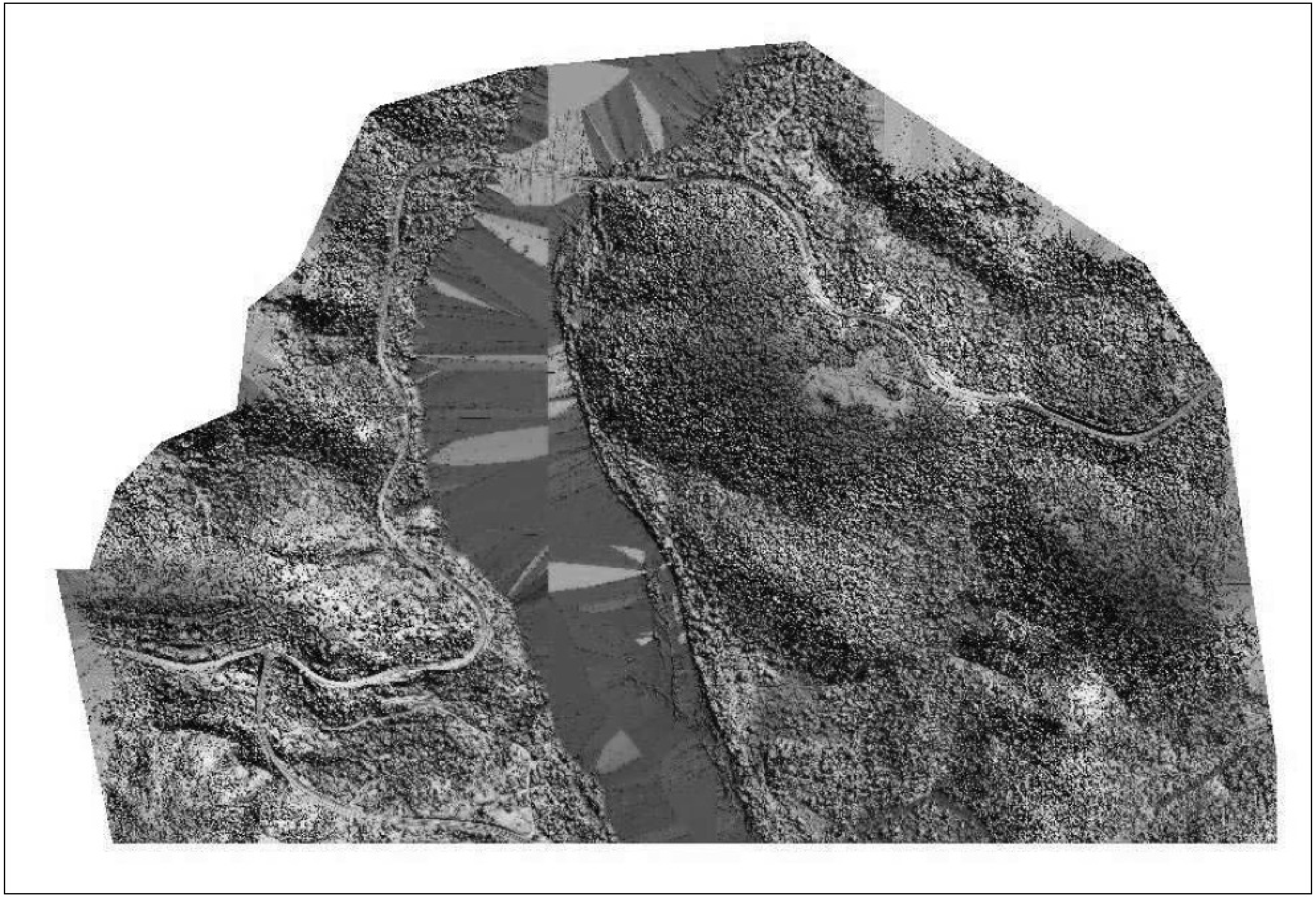


Figure EP. 1-2 Digital Surface Model (DSM)

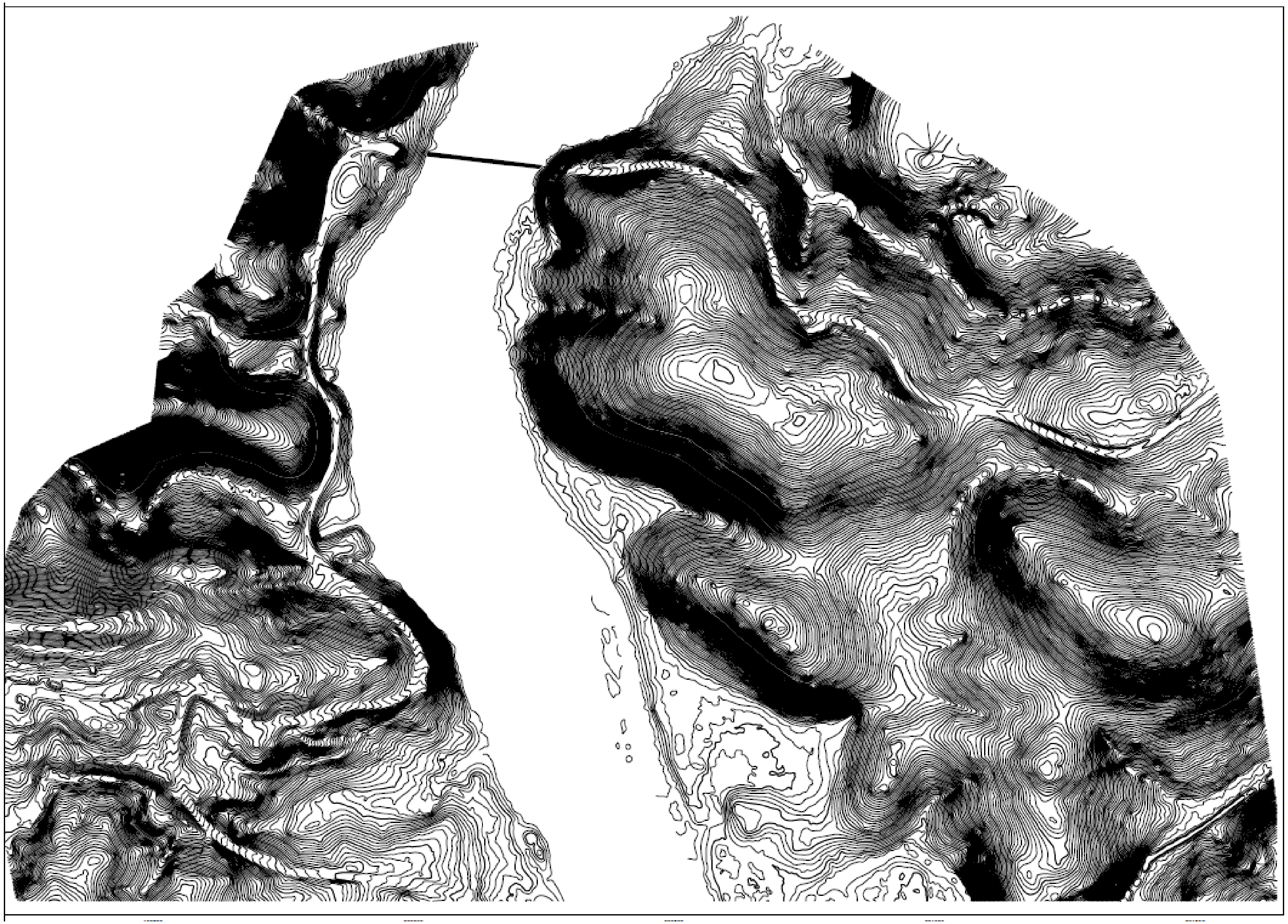


Figure EP.1-3 Topographic Map

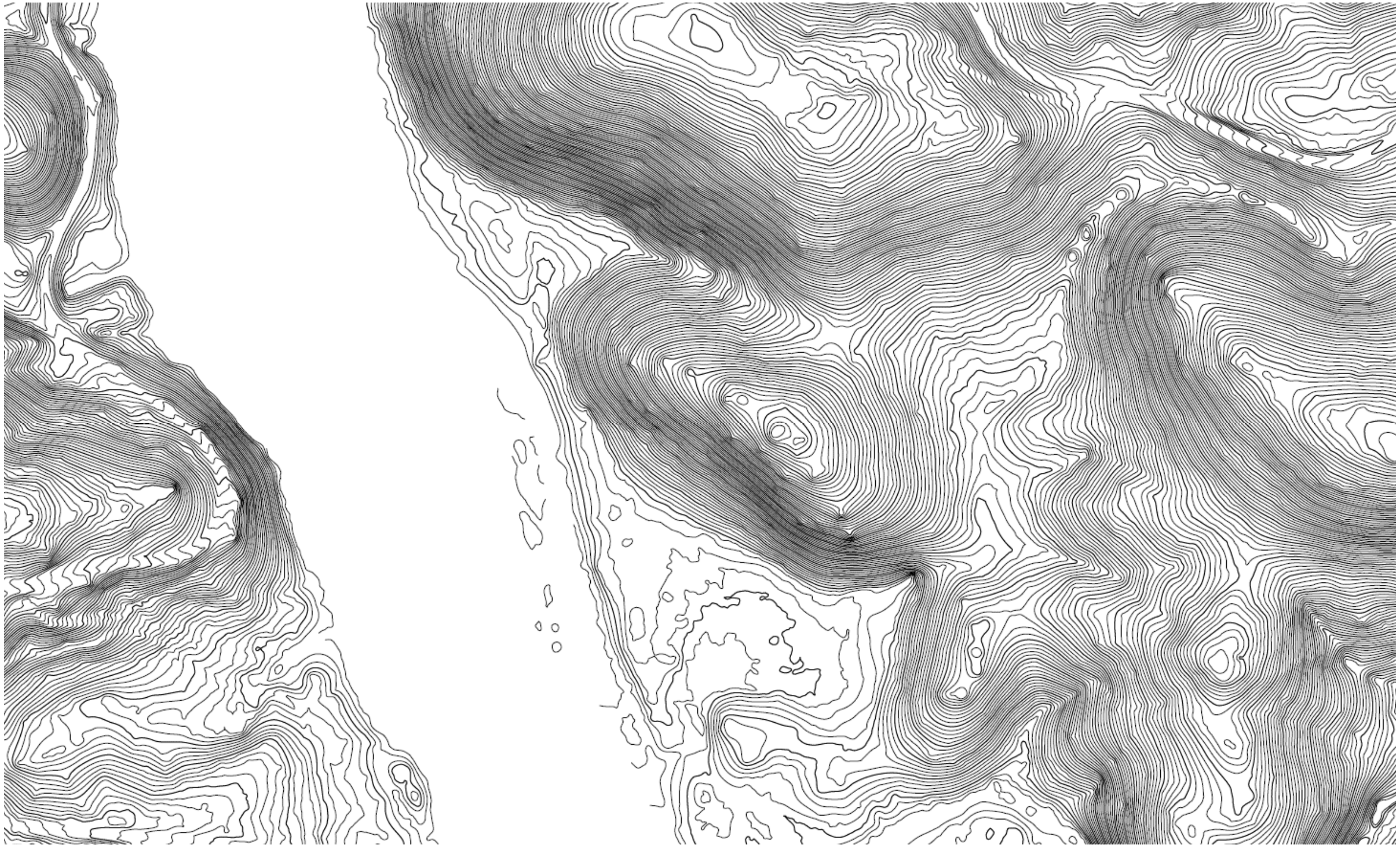


Figure EP.1-5 Planned Bridge Side Topographic Map

Appendix F Traffic Survey Result

Table FP. 1-1 Traffic Survey Result

Traffic Survey Result at Luangwa Bridge Site (Lusaka to Malawi: 36 hours)

Survey Period: 01 Feb. (Friday, 7:00) to 02 Feb. (Saturday, 19:00), 2019, Weather: Sunny

A Period of Time	Category						Total
	Passenger Car (1)	Small Truck (2)	Small Vehicles (1)+(2)	Bus (3)	Big Truck& Trailer (4)	Heavy Vehicles (3)+(4)	(1)+(2)+(3)+(4)
7:00 - 8:00	9	1	**10**	3	7	**10**	**20**
8:00 - 9:00	15	0	**15**	4	1	**5**	**20**
9:00 - 10:00	10	0	**10**	2	3	**5**	**15**
10:00 - 11:00	7	0	**7**	3	5	**8**	**15**
11:00 - 12:00	10	0	**10**	1	1	**2**	**12**
12:00 - 13:00	6	0	**6**	0	4	**4**	**10**
13:00 - 14:00	6	0	**6**	3	5	**8**	**14**
14:00 - 15:00	4	0	**4**	0	4	**4**	**8**
15:00 - 16:00	5	2	**7**	0	5	**5**	**12**
16:00 - 17:00	6	0	**6**	4	11	**15**	**21**
17:00 - 18:00	20	0	**20**	2	7	**9**	**29**
18:00 - 19:00	11	2	**13**	2	9	**11**	**24**
19:00 - 20:00	8	0	**8**	2	7	**9**	**17**
20:00 - 21:00	14	1	**15**	1	3	**4**	**19**
21:00 - 22:00	3	0	**3**	1	2	**3**	**6**
22:00 - 23:00	6	1	**7**	0	5	**5**	**12**
23:00 - 24:00	4	0	**4**	0	3	**3**	**7**
0:00 - 1:00	2	1	**3**	0	0	**0**	**3**
1:00 - 2:00	2	0	**2**	0	2	**2**	**4**
2:00 - 3:00	1	0	**1**	0	1	**1**	**2**
3:00 - 4:00	3	0	**3**	0	2	**2**	**5**
4:00 - 5:00	1	0	**1**	0	2	**2**	**3**
5:00 - 6:00	2	1	**3**	1	0	**1**	**4**
6:00 - 7:00	4	0	**4**	0	7	**7**	**11**
Total	159	9	**168**	29	96	**125**	**293**
7:00 - 8:00	5	1	**6**	2	10	**12**	**18**
8:00 - 9:00	9	1	**10**	3	4	**7**	**17**
9:00 - 10:00	7	0	**7**	2	10	**12**	**19**
10:00 - 11:00	8	1	**9**	1	11	**12**	**21**
11:00 - 12:00	10	1	**11**	1	3	**4**	**15**
12:00 - 13:00	11	0	**11**	2	4	**6**	**17**
13:00 - 14:00	10	1	**11**	1	0	**1**	**12**
14:00 - 15:00	8	2	**10**	0	3	**3**	**13**
15:00 - 16:00	9	0	**9**	3	9	**12**	**21**
16:00 - 17:00	11	3	**14**	1	6	**7**	**21**
17:00 - 18:00	10	1	**11**	0	7	**7**	**18**
18:00 - 19:00	14	0	**14**	1	6	**7**	**21**
Total	112	11	**123**	17	73	**90**	**213**

Table FP.1-2 Traffic Survey Result

Traffic Survey Result at Luangwa Bridge Site (Malawi to Lusaka: 36 hours)

Survey Period: 01 Feb. (Friday, 7:00) to 02 Feb. (Saturday, 19:00), 2019, Weather: Sunny

A Period of Time	Category						Total
	Passenger Car (1)	Small Truck (2)	Small Vehicles (1)+(2)	Bus (3)	Big Truck& Trailer (4)	Heavy Vehicles (3)+(4)	(1)+(2)+(3)+(4)
7:00 - 8:00	5	1	**6**	0	4	**4**	**10**
8:00 - 9:00	10	2	**12**	5	9	**14**	**26**
9:00 - 10:00	12	0	**12**	3	10	**13**	**25**
10:00 - 11:00	12	0	**12**	3	8	**11**	**23**
11:00 - 12:00	6	0	**6**	2	5	**7**	**13**
12:00 - 13:00	10	0	**10**	2	6	**8**	**18**
13:00 - 14:00	14	1	**15**	1	13	**14**	**29**
14:00 - 15:00	17	0	**17**	1	1	**2**	**19**
15:00 - 16:00	17	1	**18**	1	4	**5**	**23**
16:00 - 17:00	9	1	**10**	0	5	**5**	**15**
17:00 - 18:00	9	2	**11**	0	9	**9**	**20**
18:00 - 19:00	5	2	**7**	0	3	**3**	**10**
19:00 - 20:00	6	0	**6**	1	10	**11**	**17**
20:00 - 21:00	4	0	**4**	0	2	**2**	**6**
21:00 - 22:00	7	0	**7**	0	4	**4**	**11**
22:00 - 23:00	2	0	**2**	0	5	**5**	**7**
23:00 - 24:00	3	0	**3**	1	3	**4**	**7**
0:00 - 1:00	2	0	**2**	0	4	**4**	**6**
1:00 - 2:00	1	0	**1**	0	1	**1**	**2**
2:00 - 3:00	1	0	**1**	0	0	**0**	**1**
3:00 - 4:00	1	0	**1**	1	2	**3**	**4**
4:00 - 5:00	2	0	**2**	0	1	**1**	**3**
5:00 - 6:00	2	0	**2**	1	3	**4**	**6**
6:00 - 7:00	0	0	**0**	2	2	**4**	**4**
Total	157	10	**167**	24	114	**138**	**305**
7:00 - 8:00	3	0	**3**	0	6	**6**	**9**
8:00 - 9:00	8	0	**8**	2	5	**7**	**15**
9:00 - 10:00	6	1	**7**	2	9	**11**	**18**
10:00 - 11:00	15	1	**16**	5	1	**6**	**22**
11:00 - 12:00	10	0	**10**	2	11	**13**	**23**
12:00 - 13:00	4	0	**4**	0	4	**4**	**8**
13:00 - 14:00	10	1	**11**	4	1	**5**	**16**
14:00 - 15:00	5	0	**5**	0	2	**2**	**7**
15:00 - 16:00	5	0	**5**	4	7	**11**	**16**
16:00 - 17:00	11	3	**14**	0	4	**4**	**18**
17:00 - 18:00	16	1	**17**	0	0	**0**	**17**
18:00 - 19:00	7	1	**8**	0	6	**6**	**14**
Total	100	8	**108**	19	56	**75**	**183**

Table FP.1-3 Traffic Survey Result

Traffic Survey Result at Road to Chirundu Bridge Site (Chirundu to Lusaka: 12 hours)

Survey Period: 11 Feb. (Monday, 7:00) to 11 Feb. (Monday, 19:00), 2019, Weather: Sunny

A Period of Time	Category						Total
	Passenger Car (1)	Small Truck (2)	Small Vehicles (1)+(2)	Bus (3)	Big Truck& Trailer (4)	Heavy Vehicles (3)+(4)	(1)+(2)+(3)+(4)
7:00 - 8:00	19	0	**19**	1	2	**3**	**22**
8:00 - 9:00	23	1	**24**	2	6	**8**	**32**
9:00 - 10:00	33	2	**35**	3	7	**10**	**45**
10:00 - 11:00	40	0	**40**	1	13	**14**	**54**
11:00 - 12:00	25	1	**26**	1	16	**17**	**43**
12:00 - 13:00	28	0	**28**	0	17	**17**	**45**
13:00 - 14:00	19	3	**22**	2	18	**20**	**42**
14:00 - 15:00	18	0	**18**	1	20	**21**	**39**
15:00 - 16:00	18	1	**19**	1	18	**19**	**38**
16:00 - 17:00	20	0	**20**	0	19	**19**	**39**
17:00 - 18:00	24	2	**26**	2	17	**19**	**45**
18:00 - 19:00	27	1	**28**	1	13	**14**	**42**
Total	294	11	**305**	15	166	**181**	**486**

Traffic Survey Result at Road to Chirundu Bridge Site (Lusaka to Chirundu: 12 hours)

Survey Period: 11 Feb. (Monday, 7:00) to 11 Feb. (Monday, 19:00), 2019, Weather: Sunny

A Period of Time	Category						Total
	Passenger Car (1)	Small Truck (2)	Small Vehicles (1)+(2)	Bus (3)	Big Truck& Trailer (4)	Heavy Vehicles (3)+(4)	(1)+(2)+(3)+(4)
7:00 - 8:00	25	0	**25**	1	11	**12**	**37**
8:00 - 9:00	23	1	**24**	1	14	**15**	**39**
9:00 - 10:00	21	0	**21**	2	12	**14**	**35**
10:00 - 11:00	27	0	**27**	2	32	**34**	**61**
11:00 - 12:00	22	5	**27**	0	29	**29**	**56**
12:00 - 13:00	19	3	**22**	1	19	**20**	**42**
13:00 - 14:00	27	3	**30**	2	14	**16**	**46**
14:00 - 15:00	22	3	**25**	2	21	**23**	**48**
15:00 - 16:00	19	1	**20**	0	12	**12**	**32**
16:00 - 17:00	26	1	**27**	1	17	**18**	**45**
17:00 - 18:00	20	0	**20**	2	19	**21**	**41**
18:00 - 19:00	22	0	**22**	1	13	**14**	**36**
Total	273	17	**290**	15	213	**228**	**518**