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TUNNEL USE AND CONSTRUCTION FOR URBAN TRANSPORT: CASE STUDY OF OMDURMAN - TUTI-BAHRI TUNNEL

استخدام وتشييد الأنفاق للنقل الحضري
حالةدراسةنفق أمدرمان توتي بحري

A Thesis Submitted in PartialFulfillment forMScDegree in

CivilEngineering(ConstructionEngineering)

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DEDICATION

To my Parents, my sisters and brother

ACKNOWLEDGEMENTS

First and foremost, praises and thanks to the God, the Almighty, for His showers of blessings throughout my research work to complete the research successfully.

I would like to express my sincere gratitude to my supervisor Professor Galal Abdalla Ali for his guidance, supervision, and support throughout this study.

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ABSTRACT

Several cities worldwide have rapidly developed during the last few years with increase in population, vehicle fleet and business activities thereby creating severe traffic congestion. However, due to increasing complexity and constraints of constructing surface infrastructure, they have resorted to underground space for transportation systems via tunnels and underpasses. Khartoum State was not different and similar situations have prompted the State to consider the introduction and promotion of using flyovers and underground tunnels with the associated design, construction and development of specifications. This study aims at over viewing the state of usage, design and construction of transportation tunnels. One of the main objectives of this thesis is propose an efficient tunnel layout to facilitate traffic flow and relieve traffic congestion on the main roads and bridges of Khartoum State. Two tunnel layouts have been suggested: A direct route Khartoum – Bahri and the other one Omdurman – Tuti – Bahri (OTB) via Tuti Island. The latter one was considered optimal track based on traffic and soil conditions. Traffic flow details related to the selected site and soil profile data for 50-m depth were acquired. The study continues by comparing O.T.B tunnel cost to other Khartoum bridges cost.

تجريــد

العديد من المدن في مختلف أنحاء العالم شهدت تطورا سريعا خلال السنوات القليلة الماضية مع ازدياد عدد السكان، وأسطول المركبات والأنشطة التجارية وبالتالي خلق ازدحام مروري شديد. ويرجع ذلك إلى زيادة تعقيد مقومات بناء البنية التحتية، ولذلك لجأت هذه المدن إلى المساحات تحت الأرض لتشييد أنظمة النقل عبر الأنفاق والجسور.

لا تختلف ولاية الخرطوم عن تلك المدن كثيرا، فقد دفعت حالات مماثلة الدولة للنظر في وضع وتعزيز استخدام الجسور العلوية والأنفاق تحت الأرض مع تصميم وبناء وتطوير المواصفات.

وتهدف هذه الدراسة توضيح فكرة بناء وتصميم أنفاق النقل. واحدة من الأهداف الرئيسية لهذه الأطروحة هو اقتراح تشييد واستخدام الأنفاق لتسهيل تدفق حركة المرور وتخفيف الازدحام المروري على الطرق الرئيسية في ولاية الخرطوم. وقد تم اقتراح مسارين مختلفين لخدمة الحركة المرورية بشكل افضل: اولا المسار المباشر الخرطوم - بحري و ثانيا المسار من أم درمان الى بحري (امدرمان – توتي – بحري - OTB) عن طريق جزيرة توتي. واعتبر هذا الأخير المسار الأمثل بناءا على متطلبات الحركة المرورية وخواص التربة. تم الحصول على تفاصيل تدفق حركة المرور في شوارع الولاية وبيانات التربة لاعماق تصل الى 50 مترا، استمرت الدراسة بمقارنة تكلفة النفق المقترح OTB إلى تكلفة الجسور الاخرى في الولاية وذلك لمعرفة مدى امكانية انشاء مثل هذا المشروع في ولاية الخرطوم .

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

K.S	Khartum state
OTB	Omdurman Tuti Bahri tunnel
TBM	Tunnel Boarding Machine
SPB	Slurry Pressure Balance
EPB	Earth Pressure Balance
USCS	Unified System for Classifying Soil
KH	Khartum
BH	Bahri
WB	White Nile bridge
EB	Engaz Bridge
HB	Halfaya Bridge
SHB	Shambat Bridge
A	Algebraic difference in grade
V	vehicle design speed
L	Length of sag vertical curve
K	Expression of vertical curvature (constant for each design speed)

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The Republic of Sudan witnessed great development in recent years in terms of construction, particularly infrastructure, such as bridges and expansion in road.

The Republic of Sudan consists of 18 states; Khartoum State is the capital of Sudan.

Khartoum State experienced a remarkable development in recent years compared to activities in the other states. There is large number of bridges that connect the three cities (Khartoum, Khartoum Bahri, and Omdurman), these cities are connected to each other, and associated socially, culturally and historically.

Road networks concepts in modern urban designs have been extended; Wad al-Bashir tunnel in Omdurman was one of the latest projects that have been created.

Nowadays, bridges provide transport requirements between the three capital cities. It is articulated that Implementing tunnel such a project between the three main cities will result in a huge positive impact in the urban planning system.

Bridges usually require a larger footprint on each shore than tunnels. In farmland areas, industrial areas and areas with expensive real estate, such as Bahri and Omdurman, this is a strong factor in favor of a tunnel

Omdurman Tuti Bahri Tunnel (O.T.B) is proposed in order to improve access between the three cities, to make traffic flow simpler and to connect Tuti Island with Omdurman and Khartoum Bahri.

Government funds are often required for the creation of tunnels. When a tunnel is being planned or constructed, economics and politics play a large factor in the decision making process. Understanding the amount of time, the project requires, and the amount of labor and materials needed is a crucial part of project planning. The project duration must be identified. Also, the land needed for excavation and construction staging, and the proper machinery must be selected.

Tunnel projects are considered a long-term investment for sustainable growth and prosperity of country, as its role in reducing traffic congestion and easing the flow of traffic by utilization of underground space. Underground tunnel concept will be a new experience in Sudan.

1.2 Problem Statement

The purpose of this study was to make the preliminary proposal and analysis of tube tunnel to ease the Khartoum state area traffic congestion problem by providing a shortcut circulation of traffic.

The reason why we focused on this topic is that the population of the Khartoum city has been increase due to industry, university, and many big market presence, according to the State Institute of Statistics. Parallel to the population growth, the traffic congestion is also rising. Especially, people who live on the Omdurman or Bahri city are obliged to drive through the congested highway Bridges, although these highways Bridges do not meet the current traffic demand.

1.3 Objectives of the Project

- Study the possibility of creating tunnels in Khartoum state.

- Identify suitable methods for construction of tunnels in Khartoum.

- Use tunnels as alternative solution for the bridges.

- Increase the effectiveness of linking the three cities through the ring road.

- Shifting to the ECO-FRIENDLY highways and include this in the strategic urban planning of the city of Khartoum.

1.4 methodology

Infrastructure projects usually needs for extensive preparation, investigations, and data collection, tunnels are considered as most complex projects of infrastructure, large key data should be collected specially traffic and soil data.

Two tunnel tracks have been proposed for this thesis to connect Khartoum cities efficiently and to absorb traffic congestion so ease the movement under traffic loading. track length, construction method and the serviced area are considered.

The design requirements that have been covered in this thesis are:

-Traffic analysis.

-Soil investigation report.

traffic flow data have been collected for all main K.S bridges where the great congestion happen, then this data was analyzed on tables and diagram to find out the volume of traffic to be covered by the proposed track.

As well as soil investigation report for the study area was collected from Certified laboratory, soil investigation of a similar study Can not be done for the purpose of research only, where it is very costly.

Tunnel construction method was selected based on soil analysis data, where It was found that SPB TBM machine is the suitable method to build tunnel in such area. Soil analysis data helps to find appropriate shoring system for such clayey soil.

tunnel construction sequences were illustrated as per construction stages, showing entrance, tunnel body and exit.

1.5 hypothesis

The network of the overland roads is the major contributor in the transport of passengers and cargo in Sudan. Government has prepared a National Master Plan for Roads in K.S and planned to construct new roads for developing the rural areas, forming satellite cities and connect them to the busy city centers, commercial centers, universities and cooperatives.

Due to the increasing number of vehicles and the rapid development of the city, these connections are no more sufficient and there are serious traffic blockages and congestions in many intersections; those causing traffic accidents, increasing costs, time loss and also pollution. These traffic problems started to affect the daily business life considerably.

Previous planning studies of the government have recommended the development of new cities around Khartoum to absorb the increase in population and to preserve the agriculture land in State.

The enlargement of these towns and the industrial development experienced in the recent years have introduced the need for efficient connection of these towns.

Khartoum Intermediate Ring Road Project and the Bridges over Nile are part of National Master Plan for Roads.

Khartoum Intermediate Ring Road Project is a big transportation infrastructure project which aims to connect existing urban area and the new cities.

many bridges and fly-overs on either side of White Nile and Blue Nile are constructed as a part of this project, nevertheless it fails to cover the new traffic volume.

if we continue to believe that increasing bridges number will solve the traffic problem we'll never understand that we need to change our vision for better solution, creating a separate track and start using underground area might put us on the correct track , Tunnels in connection with the Ring Road Project will help to ease the traffic movement in the near future.

1.6 Project Outline

This research consists of six main chapters:

Chapter One: In the first chapter K.S current traffic system was discussed in the general introduction. project purpose and objectives are illustrated, beside the research methodology ,hypothesis and outline.

Chapter Two: Contains literature review, which provides general overview for the different types of tunnels, construction methods and tunneling machines.

Chapter Three: Reviews the flyovers and tunnels which existing in Khartum, and the previous study.

Chapter Four: This chapter discusses the tunnel proposal of Omdurman-Tuti-Bahri, it demonstrates the feasibility, layout and length, tunnel dimensions and cross section, traffic analysis, soil analysis, construction plan, tunnel safety and cost analysis.

Chapter Five

In the fifth chapter, obtained results of the study has been discussed and some suggestions were made about the selected track.

Chapter Six

Summary, conclusion and recommendation of research are illustrated in the last chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 General introduction

Tunnel is one of the solutions that resorted to facilitate traffic at intersections or when there are obstacles in the Mountain roads or bodies of water, and sometimes to the safety and pedestrian crossing away from the roadway as in highways within cities. The first tunneling was done by Prehistoric people seeking to enlarge their caves, all major ancient civilizations developed tunneling methods. In Babylonia, tunnels were used extensively for irrigation; and pedestrian passage under the Euphrates River.

Later on, manual excavation was improved by the application of the fire technique, which consisted in creating a fire close to the rock and extinguishing it quickly to make the rock mass crack due to the strong thermal gradient.

The Egyptians developed techniques for cutting soft rocks with copper saws and hollow reed drills, both surrounded by an abrasive.

The Greeks and Romans both made extensive use of tunnels they took all the knowledge of Babylon and Ancient Egypt, and improved it 10fold. With tunnels they were able to transforms marches, transport water through mountains, and create pedestrian tunnels trough very harsh terrains.

By 17^{th} century, tunnels were being used to support goods and materials over long distances from the country to the city and vice versa.

In the eighteenth century would witness a deep development in the construction of navigation channels across Europe.

The nineteenth century was a decisive time in the history of tunneling. An explosion in the construction of railway lines between the major urban centers all over Europe, leading need of excavating tunnels when topographic accidents were to be crossed.

In the United Kingdom, the railway connection between Liverpool to Manchester needed the construction of two tunnels, one of almost 5 km and the other of 1.6 km.

The first under river roadway tunnels was constructed beneath the Thames River in London to serve horse-drawn traffic. In its time, it was the longest underwater tunnel in existence.

The excavation of the tunnel was reliant on the first tunneling shield ever used in the construction of a tunnel through soft ground.
The most substantial advancement made in tunneling technology, in addition to the shield, was the invention of tunnel boring machines (TBMs).
Tunnel boring machines were first used in the latter part of the 19th century. The first tunneling machine to bore through rock was invented by an American engineer by the name of Charles Wilson in 1851.

After 1980, a new leap in tunnel engineering is made due to the quickly generalization of high speed railway lines, which need strictly low steepness values and very long radius for curves, leading to long and deep tunnels.

During the remaining part of The twentieth century and the first years of the twenty-century Tunnels has become one of the most important elements of the infrastructure of the cities of developed the current times has witnessed a revolution in the Construction industry of Tunnels.

2.1.1 Tunnel Definition

Tunnels were being divided into three main types by AASHTO:

1) AASHTO defines an underpass as a part of roadway extending through and under some natural or man-made structure; it is limited length-to-height ratio of approximately (10:1) or lower, thus requires no supplementary daytime lighting.

2) Short Tunnels – defined as those where, in the absence of traffic, the exit and the area behind the exit can be clearly visible from a point ahead of the entrance portal. For lighting purposes, the length of short tunnel is limited to 150 ft (46 m); tunnels up to 400 ft (122 m) long may be classified as short if they are straight, level, and have a high width/height to length ratio.

3) Long Tunnels - defined as those with an overall length greater than the safe stopping sight distance. (AASHTO LRFD SI 12, 2004).

2.1.2 Tunnels Advantages

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

When planning for infrastructure projects, should be taking into consideration the book Lands of the proposed project and put the cost of the compensation owed to landowners. Tunnels can reduce this part of the project costs, so it could be more efficiency.

2.2 Tunnel Types

Tunnel types are described by their shape, liner type, invert type, construction method, and tunnel finishes.

It should be noted that other types may exist currently or be constructed in the future as new technologies become available.

2.2.1 Shapes of Tunnel

The different shapes typically relate to the method of construction and the ground conditions in which they were constructed. Some tunnels may be constructed using combinations of these types due to different soil conditions along the length of the tunnel. Although many tunnels will appear rectangular from inside, due to horizontal roadways and ceiling slabs, the outside shape of the tunnel defines its type. (FHWA Highway and Rail Transit Tunnel Inspection Manual, 2003)

- **Highway Tunnels**

There are three main shapes of highway tunnels

1- Circular

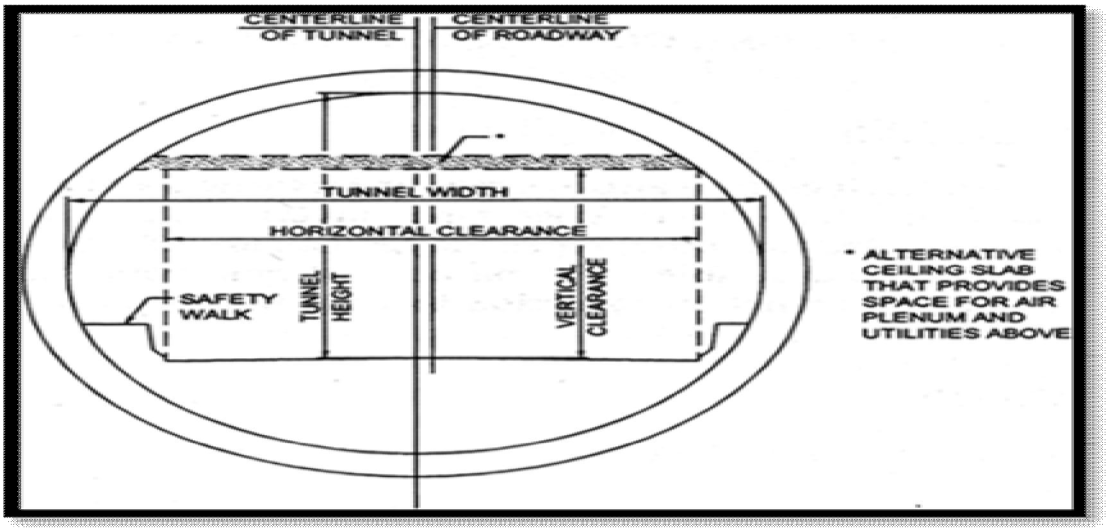

Figure 2-1 Section of Circular Tunnel

2- Rectangular

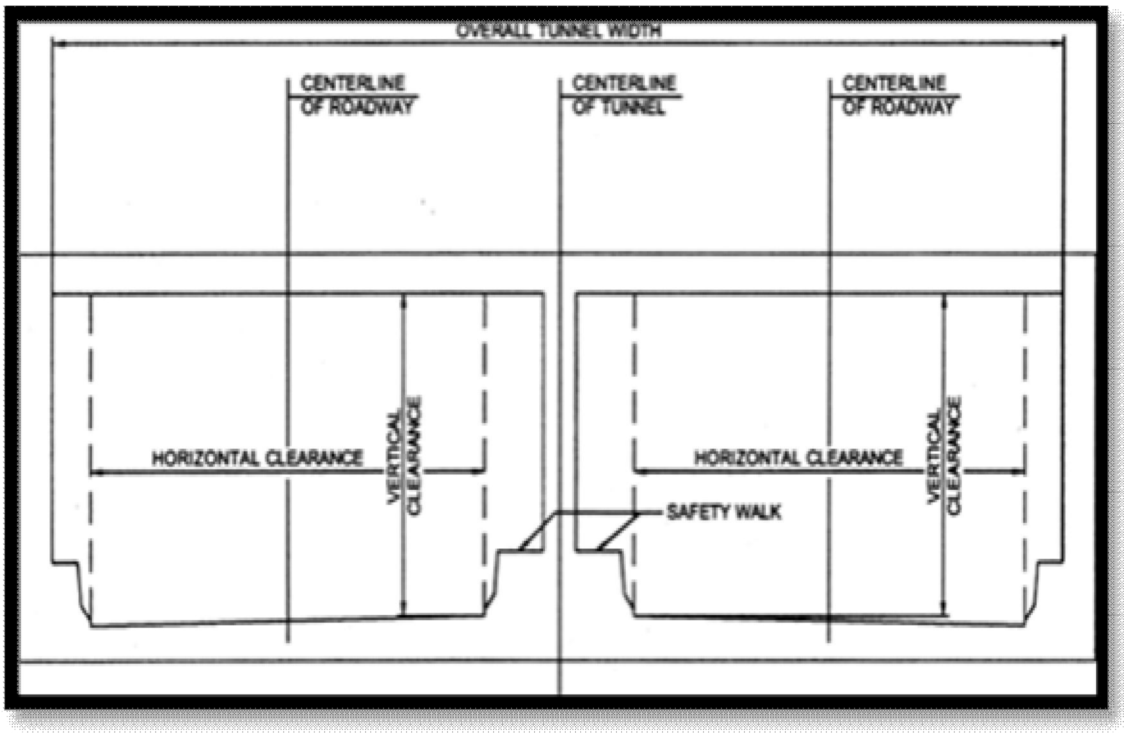

Figure 2-2 Section of Rectangular Tunnel

3- Horseshoe

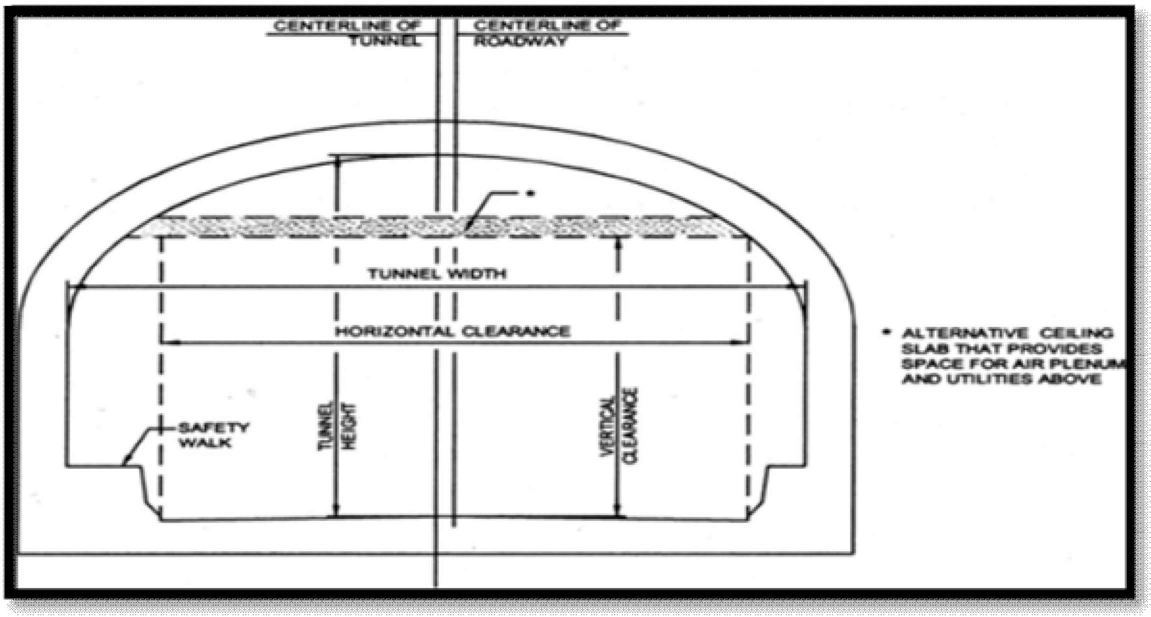

Figure 2-3 Section of Horseshoe Tunnel

2.2.2 Liner Types

- **Unlined Rock**
  An unlined rock tunnel is one in which no lining exists for the majority of the tunnel length. This type of liner was common in older railroad tunnels.

- **Rock Reinforcement Systems**
  Rock reinforcement systems are used to add additional stability to rock tunnels in which structural defects exist in the rock.
  Reinforcement systems include the use of metal straps and, un-tensioned steel dowels, or tensioned steel bolts.

- **Shotcrete**
  Shotcrete is primarily used as a temporary application prior to a final liner being installed however; shotcrete can be used as a final lining. It is typically placed in layers and can have metal or randomly oriented, synthetic fibers as reinforcement.

- **Ribbed Systems**
  Ribbed systems are typically a two-pass system for lining a drill-and-blast rock tunnel. The first pass consists of timber, steel, or precast concrete ribs. The second pass typically consists of poured concrete that is placed inside of the ribs.

- **Segmental Linings**
  Segmental linings are primarily used in conjunction with a tunnel boring machine (TBM) in soft ground conditions.

- **Slurry Walls**
  Slurry wall construction types vary, but typically, they consist of excavating a trench that matches the proposed wall profile. It is continually kept full with a drilling fluid, then a reinforcing cage is lowered into the slurry at a predetermined interval and finally concrete is placed into the excavation, which displaces the drilling fluid.

2.3 Construction Methods

As mentioned previously, the shape of the tunnel is largely dependent on the method used to construct the tunnel. Table 2-1 lists the six main methods used for tunnel construction with the shape that typically results. Brief descriptions of the construction methods follow**:**

Table 2-1: Shape to Construction Methods

	Circular	Horseshoe	Rectangular
Cut and Cover			X
Shield Driven	X		
Bored	X		
Drill and Blast	X	X	
Immersed Tube	X		X
Sequential Excavation		X	
Jacked Tunnels	X		X

Methods of construction also depend on soil types as shown in the following Figure.

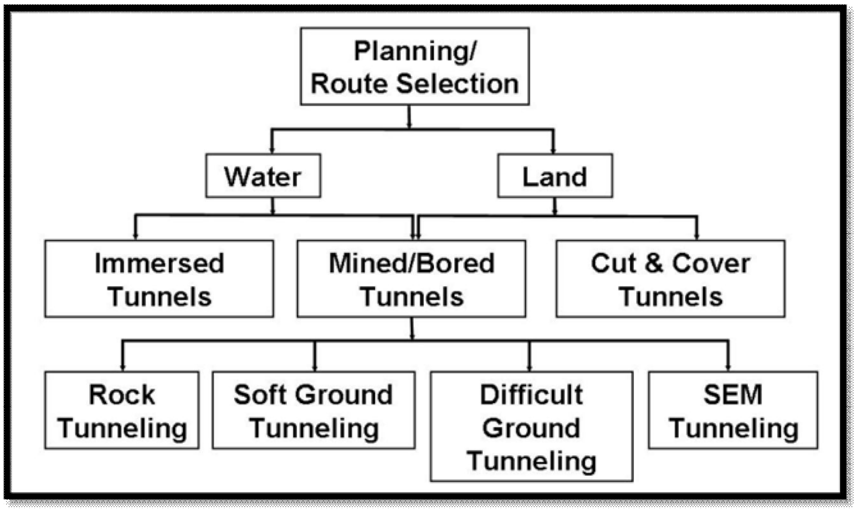

Figure 2-4 Method of Construction According to Soil Types

2.3.1 Cut and Cover

This method involves excavating an open trench in which the tunnel is constructed to the design finish elevation and subsequently covered with various compacted earthen materials and soils. Certain variations of this method include using piles and lagging, tie back anchors or slurry wall systems to construct the walls of a cut and cover tunnel. Structure is built inside an excavation and covered over with backfill material when construction of the structure is complete. Cut and cover method is used when tunnel profile is shallow For depths of 10 m to 12 m and the excavation from the surface is possible, in such case it is usually economical, and acceptable.

The cut-and-cover tunnel is usually designed as a rigid frame box structure.
In urban areas, due to the limited available space, the tunnel is usually constructed within excavation line using braced or tied back excavation supporting walls.
Where the tunnel alignment is beneath a city street. Two types of construction are employed to build cut and cover tunnels; bottom-up and top-down.

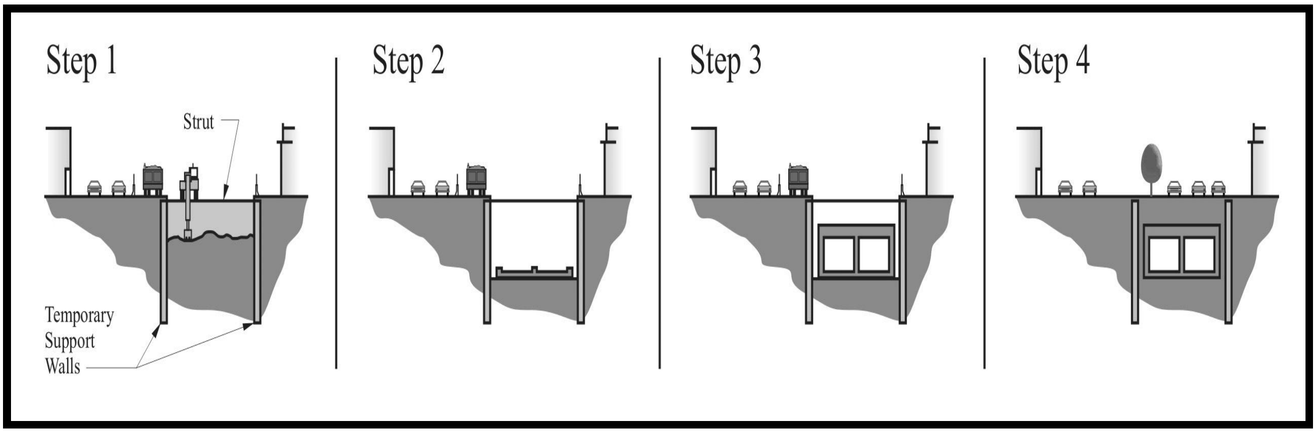

Figure 2-5(a): Cut-and-Cover Tunnel Construction Sequence Bottom-Up

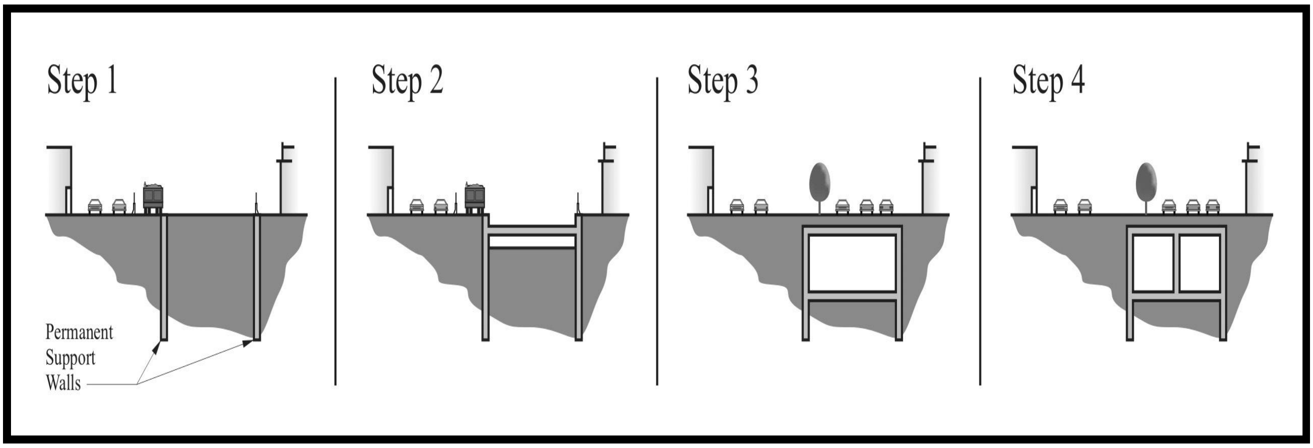

Figure 2-5(b): Cut-and-Cover Tunnel Construction Sequence Top-Down, (FHWA, March 2003)

a) **Bottom-Up Construction**

As shown in Figure 2-5, in the conventional "bottom-up" construction, a trench is excavated from the surface within which the tunnel is constructed and then the trench is backfilled and the surface restored afterward.

The trench can be formed using open cut, or with vertical faces using an excavation support system. In bottom-up construction, the tunnel is completed before it is covered up and the surface reinstated.

Conventional bottom-up sequence of construction in Figure 2-5(a) generally consists of the following steps:

Step 1a: Installation of temporary excavation support walls, such as soldier pile and lagging, sheet piling, slurry walls, tangent or secant pile walls
Step 1b: Dewatering within the trench if required
Step 1c: Excavation and installation of temporary wall support elements such as struts or tie backs
Step 2: Construction of the tunnel structure by constructing the floor;
Step 3: Complete construction of the walls then the roof and apply waterproofing as required;
Step 4: Backfilling to final grade and restoring the ground surface.

Bottom-up construction offers several advantages:
• It is a conventional construction method well understood by contractors.
• Waterproofing can be applied to the outside surface of the structure.
• The inside of the excavation is easily accessible for the construction equipment and the delivery, storage and placement of materials.
• Drainage systems can be installed outside the structure to channel water or divert it away from the structure.

b) **Top-Down Construction**
With top-down construction in Figure 2-5 (b), the tunnel walls are constructed first, usually using slurry walls, although secant pile walls are also used.
In this method the surface is reinstated before the completion of the construction. The remainder of the excavation is completed under the top slab. Upon the completion of the excavation,
In this method the support of excavation is often the final structural tunnel walls. Secondary finishing walls are provided upon completion of the construction. Next, the roof is constructed and tied into the support of excavation walls.

Disadvantages of top-down construction include:
• Disability to install external waterproofing -outside the tunnel walls-.
• More complicated connections for the roof, floor and base slabs.
• Potential water leakage at the joints between the slabs and the walls
• Risks that the exterior walls (or center columns) will exceed specified installation tolerances and extend within the neat line of the interior space.
• Access to the excavation is limited to the portals or through shafts through the roof.
• Limited spaces for excavation and construction of the bottom slab. (FHWA, March 2003)

2.3.2 Shield Driven

This method involves pushing a shield into the soft ground ahead. The material inside the shield is removed and a lining system is constructed before the shield is advanced further

2.3.3 Drill and Blast

An alternative to using a TBM in rock situations would be to manually drill and blast the rock and remove it using conventional conveyor techniques.

This method was commonly used for older tunnels and is still used when it is determined cost effective or in difficult ground conditions

2.3.4 Jacked Tunnels

The method of jacking a large tunnel underneath certain obstructions (Highways, Buildings, Rail lines, etc.) That prohibits the use of typical cut-and-cover techniques for shallow tunnels have been used successfully in recent years. This method is considered when the obstruction cannot be moved or temporarily disturbed. First jacking pits are constructed. Then tunnel sections are constructed in the jacking pit and forced by large hydraulic jacks into the soft ground, which is systematically removed in front of the encroaching tunnel section. Sometimes if the soil above the proposed tunnel is poor then it is stabilized through various means such as grouting or freezing.

2.3.5 Tunnel Boring Machine (TBM)

This method refers to using a mechanical Tunnel Boring Machine (TBM) in which the full face of the tunnel cross section is excavated at one time using a variety of cutting tools that depend on ground conditions soft ground or rock. The TBM designed to support the adjacent soil until temporary (and subsequently permanent) linings are installed. It is a modern way to build tunnels in urban areas; it could work successfully at challenged areas. There are many type of the TBM machine according to the used technique:

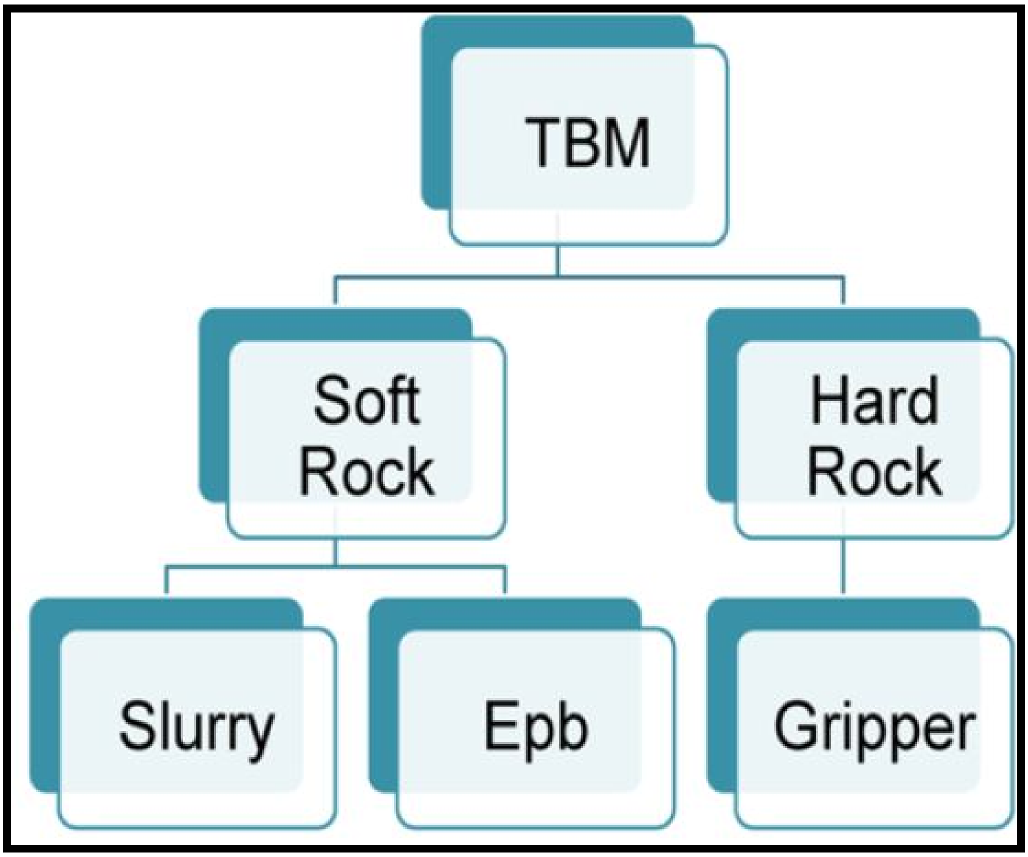

Figure 2-6 TBM Types

2.3.5.1 Soft Ground TBMs

a) Earth Pressure Balance Machines (EPB)

These machines operate like Single Shield TBMs, using thrust cylinders to advance forward by pushing off against concrete segments. Earth Pressure Balance Machines are used in soft ground with less than 7 bar of pressure. The cutter head does not use disc cutters only, but instead a combination of tungsten carbide cutting bits, carbide disc cutters, and/or hard rock disc cutters. The EPB gets its name because it is capable of holding up soft ground by maintaining a balance between earth and pressure. EPB operator and automated systems keep the rate of soil removal equal to the rate of machine advance. Thus, a stable environment is maintained. In addition, additives such as bentonite, polymers and foam are injected into the ground to further stabilize it.

While the use of TBMs relieves the need for large numbers of workers at high pressures, a caisson system is sometimes formed at the cutting head for slurry shield TBMs. Workers entering this space for inspection, maintenance and repair need to be medically cleared as "fit to dive" and trained in the operation of the locks. This is a mechanized tunneling method in which spoil is admitted into the tunnel Boring machine (TBM) via a screw conveyor arrangement which allows the pressure at the face of the TBM to remain balanced without the use of slurry.

- **Advantages of EPB**

- Limits ground settlement

-In case of face collapse amount of ground loss is limited

-Muck is immediately ready for disposal

- Able to take advantages of self-supporting grounds

- Smaller site and launch shaft

- Lower consumption of additives.

- **Disadvantages of EPB**

-The major disadvantage is the upfront capital cost.

-Requires higher torque

-Requires greater Cutting head power

-Required confinement pressure must be calculated

-Muck is exposed into tunnel

- **Main characteristics of EPB**

- Tunnel Lining – Precast Concrete Segments.

- Typical Performance - 9m to 35m per day. Actual performance and costs will depend on ground conditions and tunnel diameter.

- Typical Costs – USD 6,460 to USD 42,760 per meter. . (FHWA, 2005)

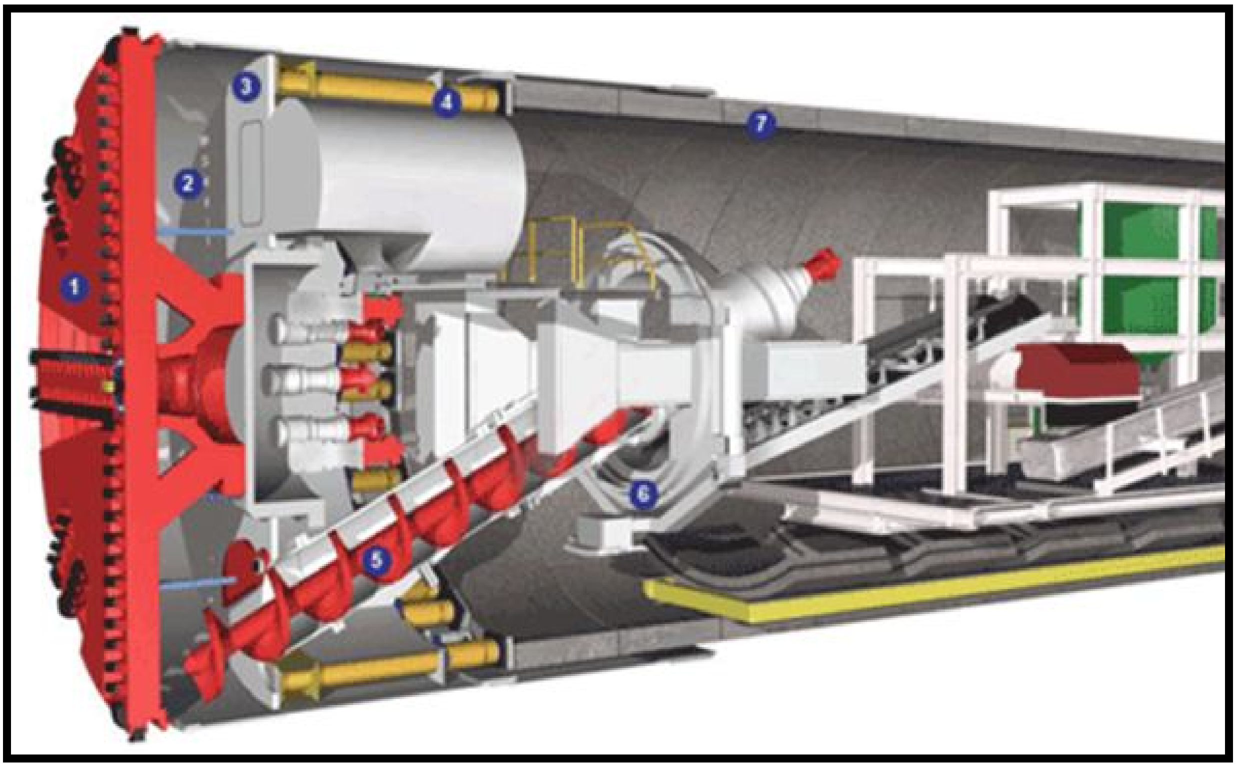

Figure 2-7 Overview of Earth Pressure Balance Machine (EPB)

b) Slurry Pressure Balance (SPB) TBM

The basic principle of this TBM is to maintain the face pressure during the excavation phase by filling the working chamber, located behind the cutter head, with slurry. (FHWA, 2005)

- **Advantages of SPB**

- Allows soft, wet, or unstable ground to be tunneled with a speed and safety not previously possible

- Suitable for ground with high water pressures (below water table)

- Limits ground settlement and makes it suitable to use in heavily urbanized areas.

- Required pressure is determined / controlled by system

- Lower torque

- Lower Cutting Head Power

- Contaminated muck is not exposed until it reaches the surface

- Able to integrate rock crusher

- Cleaner Tunnel Environment

- **Main characteristics of SPB**

  - Tunnel Lining – Precast Concrete Segments

  - Typical Performance - 5m to 30m per day. Actual performance and costs will depend on ground conditions and tunnel diameter.

  - Typical Costs – USD 7,106 to USD 47,036 per meter. (FHWA, 2005)

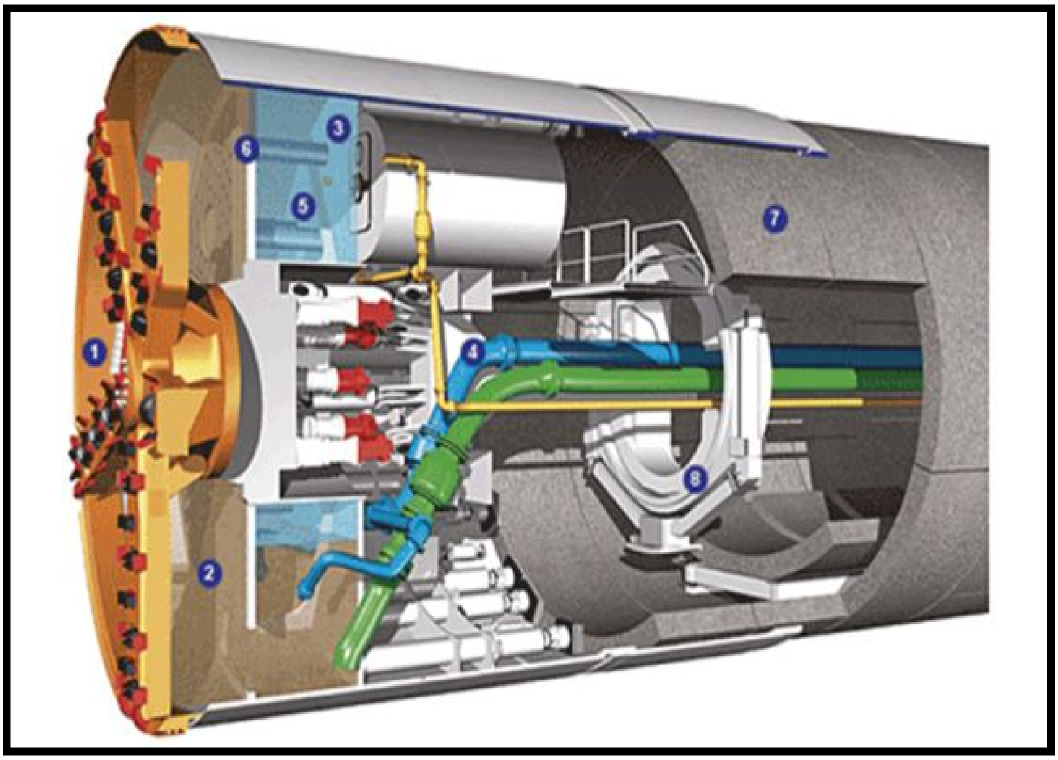

Figure 2-8 Overview of Slurry Pressure Balance (SPB)

2.3.5.2 Hard Rock TBM

This method involves the use of a Tunneling machine with a shield and cutter head suitable for hard rock. In hard rock, either shielded or open-type TBMs can be used. All types of hard rock TBMs excavate rock using disc cutters mounted in the cutter head. The disc cutters create compressive stress fractures in the rock, causing it to chip away from the rock in front of the machine, called the tunnel face. The excavated rock, known as muck, is transferred through openings in the cutter head to a belt conveyor, where it runs through the machine to a system of conveyors or muck cars for removal from the tunnel.

Open-type TBMs have no shield, leaving the area behind the cutter head open for rock support. To advance, the machine uses a gripper system that pushes against the sidewalls of the tunnel. The machine can be continuously steered while gripper shoes push on the sidewalls to react the machine's forward thrust. At the end of a stroke, the rear legs of the machine are lowered, the grippers and propel cylinders are retracted. The retraction of the propel cylinders repositions the gripper assembly for the next boring cycle. The grippers are extended, the rear legs lifted, and boring begins again. The open-type, or Main Beam, TBM does not install concrete segments behind it as other machines do. Instead, the rock is held up using ground support methods such as ring beams, rock bolts, shotcrete, steel straps, and wire mesh.

In fractured rock, shielded hard rock TBMs can be used, which erect concrete segments to support unstable tunnel walls behind the machine. Double Shield TBMs are so called because they have two modes; in stable ground they can grip against the tunnel walls to advance forward. In unstable, fractured ground, the thrust is shifted to thrust cylinders that push off against the tunnel segments behind the machine. This keeps the significant thrust forces from impacting fragile tunnel walls. Single Shield TBMs operate in the same way, but are used only in fractured ground, as they can only push off against the concrete segments.

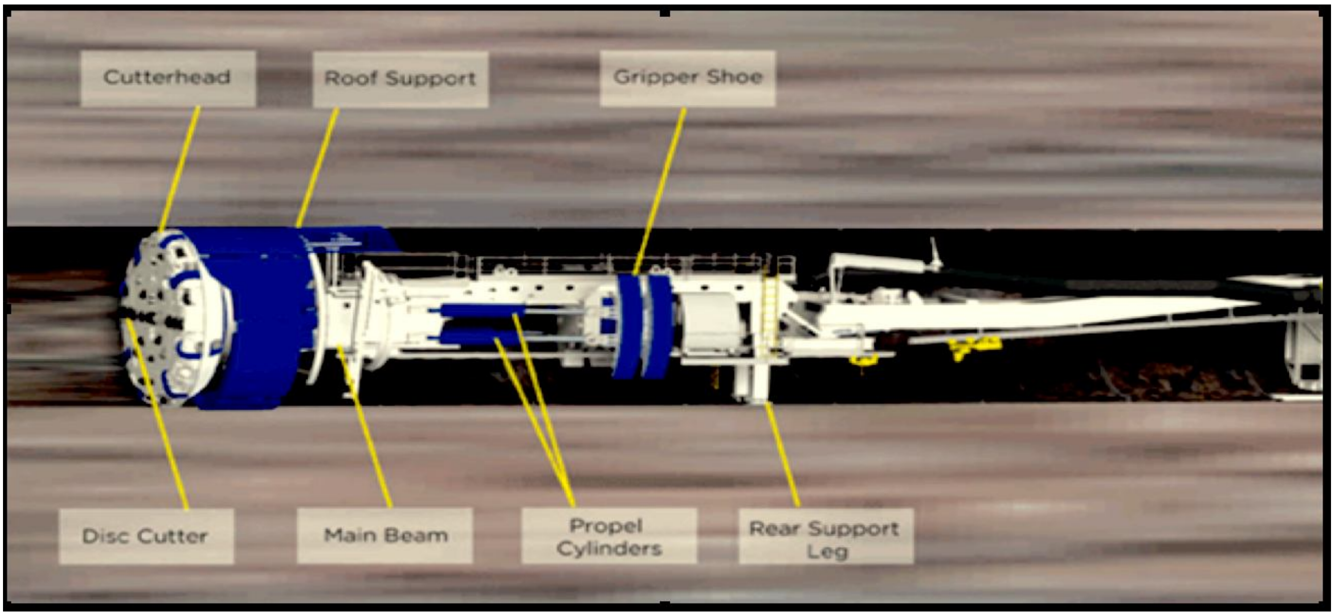

Figure 2-9 Hard Rock TBMs. (FHWA, 2005)

- **Advantages of hard rock TBMs**

  They offer a continuous and controlled means of tunneling capable of high rate of advance under favorable conditions.

- **Disadvantages of hard rock TBMs**

  - The major disadvantage is the upfront capital cost. TBMs are expensive to

  Construct, difficult to transport, require significant backup systems and power.

  - Their applicability is limited to long tunnels where the high rates of advance and tunnel quality can offset their high capital cost.

- **Main characteristics of hard rock TBMs**

  - Tunnel Lining – Precast Concrete Segments / Sprayed Concrete / No lining

  - Typical Performance - 12m to 67m per day. Actual performance and cost will depend on ground conditions and tunnel diameter

3- Typical Costs – USD 3,300 to USD 33,075 per meter. (FHWA, 2005)

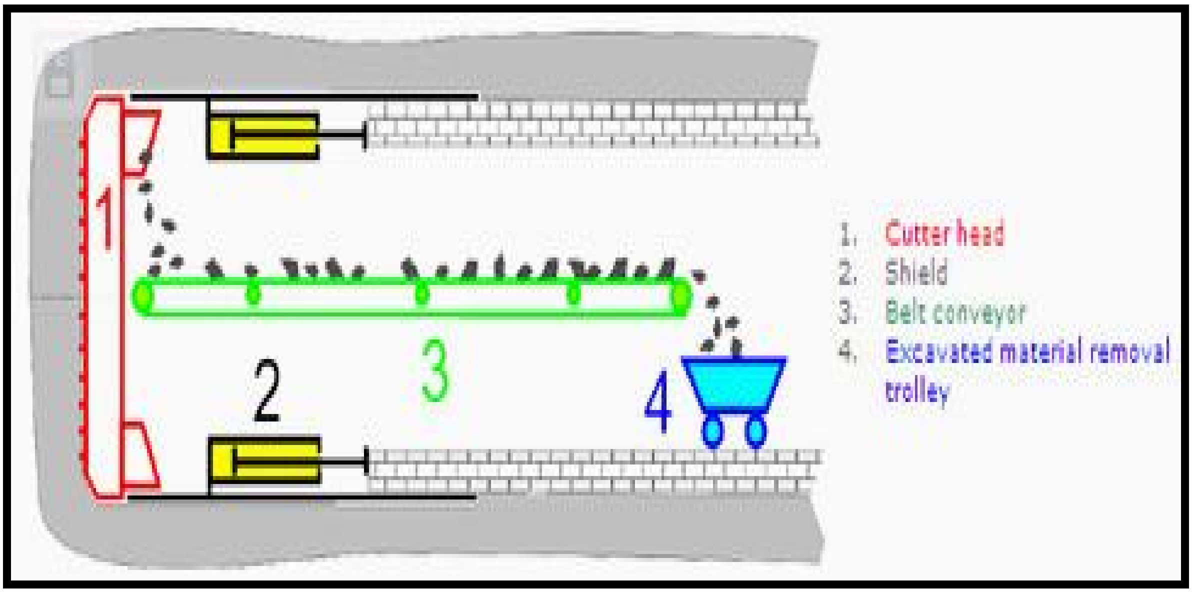

Figure 2-10 Belt Conveyor System (FHWA, 2005)

2.4 Tunneling Machines

Tunneling machine depends upon the complexity of geological conditions; hence, the justification for adopting tunneling machines should be judiciously, there is many type of tunneling machine we can mention the following :

2.4.1 Tunnel Jumbo Machine

The tunnel jumbo usually consists of light rock drill of high performance, which is mounted on mechanical arms. Hydraulic jacks move these arms.

The wheeled jumbo is mobile and fast. Initial cost is only a small portion of the overall cost of tunneling. All booms can be used to drill upwards, downwards, besides horizontally. The number of booms can go up to seven, The rate of tunneling goes up with more number of booms and the cost of jumbo also goes up.

The vertical drilling mechanism is used for drilling bolt holes and horizontal booms are used for drilling blast holes.

2.4.2 Muck Hauling Equipment

Efficient removal of excavated rock blocks (muck) is an important operation. Use of belt conveyers is very economical and efficient. Belt conveyers load into the muck cars hauled by diesel, electricity or battery. As the area available is limited in a tunnel driving the mucking equipment should occupy minimum working space.

Rail track should be well laid on rock mass and should be maintained well for efficient operation. The rail lines move upwards in squeezing rock conditions or swelling rocks. In former case, rock anchors should be installed in the floor and shotcreted. In the latter case, swelling of rocks should be prevented by spraying shotcrete immediately all round the tunnel including the floor to prevent ingress of moisture inside the rock mass. However, the inverts delay mucking. Figure 2-11 shows Hag loader, which is mounted on a rubber, tired chassis.

It uses digging and gathering arms in the front of the machine. The muck is brought into the transport equipment by a conveyer (shown by inclined line). This model is highly efficient and safe for the operator.

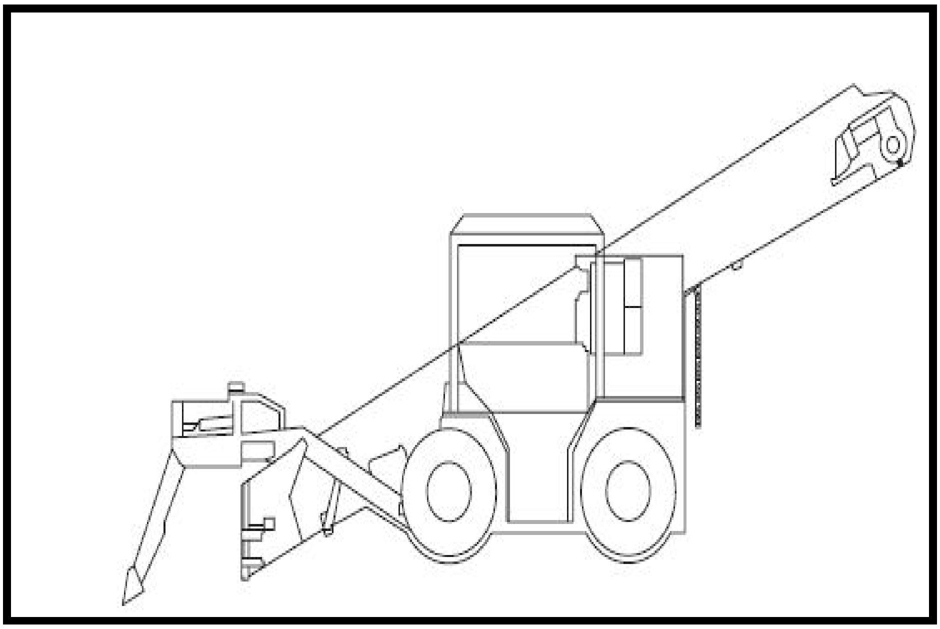

Figure 2-11 Hag Loader Machine

2.4.3 Tunnel Boring Machine (TBM)

A Tunnel Boring Machine (TBM) is a machine used to excavate tunnels with a circular cross section through a variety of soil and rock strata. They can bore through hard rock, sand, and almost anything in between. Tunnel diameters can range from a meter (done with micro-TBMs) to almost 20 meters to date.

After nearly 150 years of development, the TBM has been perfected to excavate in fair to hard rock masses. The TBM has the following technical advantages.

• Reduction in over breaks

• Minimum surface and ground disturbance

• Reduced ground vibrations cause no damage to nearby structures, an important consideration for construction of underground tunnel.

• The rate of tunneling is several times of that of other methods

• Better environmental conditions – low noise, low gas emissions

• Better safety of workers

• Producing a smooth tunnel wall

Usually when use the TBM machine engineering geological investigations has to be done in detail because of a very varied condition of soil. The TBM can be designed by contractors according to the given soil conditions

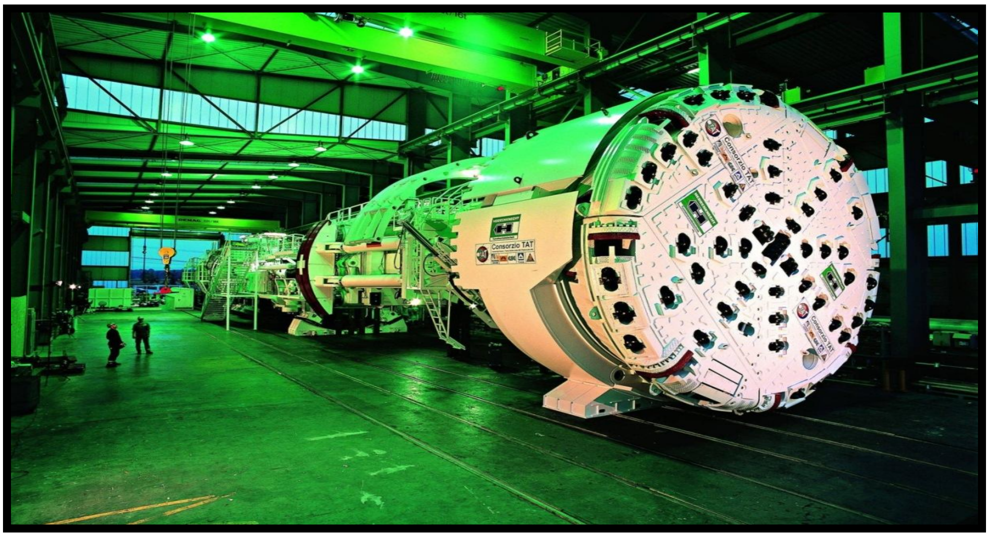

Figure 2-12 TBM Machine

2.5 Support of Excavation

Excavations for building cut and cover tunnels must be designed and constructed to provide a safe working space, provide access for construction activities and protect structures, utilities and other infrastructure adjacent to the excavation. The design of excavation support systems requires consideration of a variety of factors that affect the performance of the support system and that have impacts on the tunnel structure itself.

Excavation support systems fall into three general categories:

• Open cut slope

This is used in areas where sufficient room is available to open cut the area of the tunnel and slope the sides back to meet the adjacent existing ground line (Figure 2-13).

The slopes are designed similar to any other cut slope taking into account the natural repose angle of the in-situ material and the global stability.

Figure 2-13 Cut and Cover Construction using Side Slopes Excavation

• Permanent Support of Excavation

This structure designed to support vertical or near vertical faces of the excavation in areas where area to open cut does not exist. This structure forms part of the permanent final tunnel structure. It may consist of secant pile walls, or tangent pile walls.

Tangent pile walls consist of a series of drilled shafts located such that the adjacent shafts touch each other, hence the name tangent wall. The shafts are usually 60 to 120 cm in diameter and extend below the bottom of the tunnel structure for stability. The typical sequence of construction of tangent piles begins with the excavation of every third drilled shaft. The shafts are held open if required by temporary casing. A steel beam or reinforcing bar cage is placed inside the shaft and the shaft is then filled with concrete. If a casing is used, it is pulled as the tremie concrete placement progresses. Once the concrete backfill cures sufficiently, the next set of every third shaft is constructed in the same sequence as the first set. Finally, after curing of the concrete in the second set, the third and final set of shafts is constructed, completing the walls. Excavation within the walls then proceeds with bracing installed as required to the bottom of the excavation. Roof and floor slabs are constructed and tied into the tangent pile. The roof and floor slabs act as

Bracing levels. Figure 2-14 is a schematic showing the sequence of construction in plan view. (Technical Manual for Design and Construction for Road Tunnel, NHI, 2009)

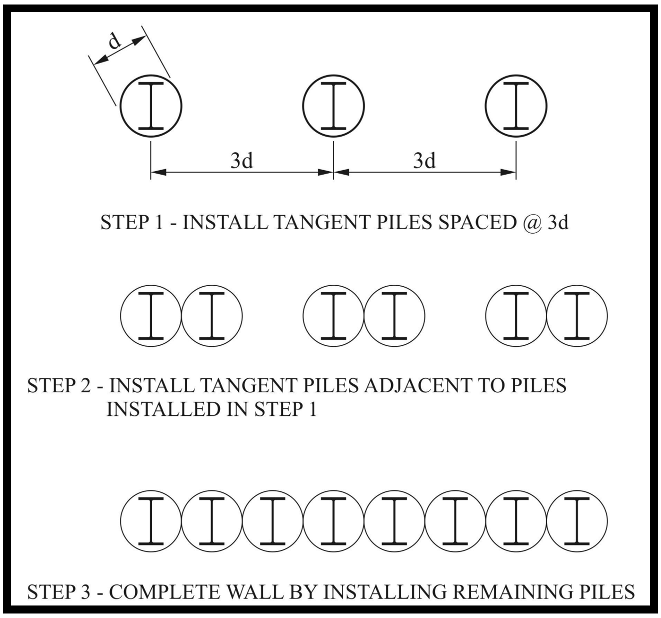

Figure 2-14 Tangent Pile Wall Construction Schematic

Secant pile walls (Figure 2-15 shows a completed secant pile wall) are similar to tangent pile walls except that the drilled shafts overlap each other rather than touch each other. This occurs because the center-to-center spacing of secant piles is less than the diameter of the piles.

Secant pile walls are stiffer than tangent piles wall and are more effective in keeping ground water out of the excavation. They are constructed in the same sequence as tangent pile walls. However, the installation of adjacent secant piles requires the removal of a portion of the previously constructed pile, specifically a portion of the concrete backfill.

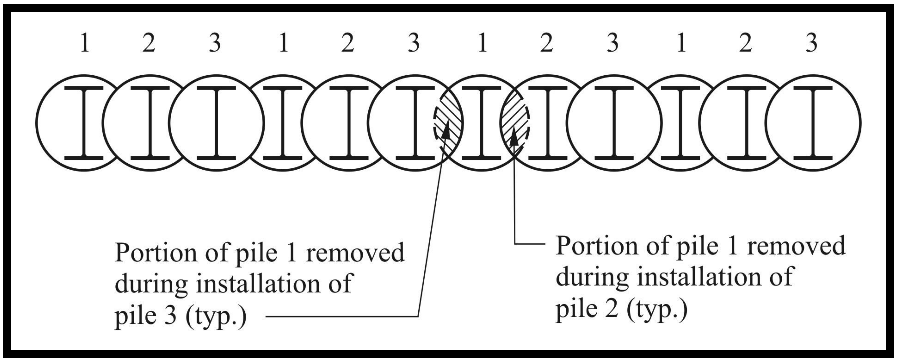

Figure 2-15 Completed Secant Pile Wall Plan View

In general, rigid support systems have more load carrying capacity than flexible systems. This additional load carrying capacity means that they require less bracing. Minimizing the amount of bracing results in less obstruction inside the excavation if struts or braces are used, making construction activities easier to execute. Rigid wall systems incorporated into the final structure can also reduce the overall cost of the structure because they combine the support of excavation with the final structure. Waterproofing permanent support walls and detailing the connections between the walls and other structure members are difficult. This difficulty can potentially lead to leakage of groundwater into the tunnel. The design and detailing of the support of excavation must consider the sequence of installation and account for the changing loading conditions that will occur as the excavation proceeds and the system is installed.

2.6 Back-up Systems

Behind all types of tunnel boring machines, inside the finished part of the tunnel, are trailing support decks known as the back-up system. Support mechanisms located on the back-up can include: conveyors or other systems for muck removal, slurry pipelines if applicable, control rooms, electrical systems, dust removal, ventilation and mechanisms for transport of pre-cast segments. (Technical Manual for Design and Construction for Road Tunnel, NHI, 2009)

2.7 Urban Tunneling and Near Surface Tunneling.

Urban tunneling has the special experiment of requiring that the ground surface be undisturbed. This means that ground subsidence must be avoided.

The normal method of doing this in soft ground is to maintain the soil pressures during and after the tunnel construction. There is some difficulty in doing this, particularly in varied strata.

TBMs with positive face control, such as EPB and SPB, are used in such situations. Both types (EPB and SPB) are capable of reducing the risk of surface subsidence and voids if operated properly.

When tunneling in urban environments, other existing utility lines and deep foundations need to be addressed in the early planning stages. The project must accommodate measures to mitigate any detrimental effects to other infrastructures.

CHAPTER 3

PREVIOUSSTUDYS

3.1 General Introduction

According to rapid development, population and traffic has been increased, so more number of vehicles has been added in the roads; thus problem of congestion, which occurs due to the increase in number of vehicles, bring out the needs for tunnel and under pass solutions.

3.2 Based Tunnels and Flyovers in Khartoum

a) El-Inqaz Bridge underpass (completed 1996) (Ministry of Physical Planning and Public Utilities (2014).)

In El-Inqaz Bridge there are two tunnels one in the access and the other in the exit of bridge as shown in Figure 3-1 and Figure 3-2.

Figure 3-1 General Layout of El-inqaz Tunnel Omdurman Side

Figure 3-2 General Layout of El-inqaz Tunnel Khartoum Side

b) Afraa Underpass (completed 2008):

Recently Africa Street tunnel (which known as Afraa Tunnel) was constructed, and is considered one of the more recent experiments as shown in Figure 3-3.

Figure 3-3 Afraa Underpass

Afraa Underpass Dimension properties:

- Orientation North/South
- 2 lanes for each direction
- Total width 21.6 m

- Cell width 10.1 m
- External walls thickness 50 cm
- Internal wall thickness 40 cm
- Deck and bed thickness 50 cm
- Clearance 5.60 m
- Longitudinal Slope 3%

c) MckNimir Bridge Approaches [Bahry Side (constructed 2006)]

Culver was constructed to ease and enable crossing under the bridge as short cut from both sides of the bridge.

Culver properties:

- The total length of the culver is 22 m
- The width is 10 m, Clearance 5.5 m
- Structural type (Rigid Single Box Culvert)

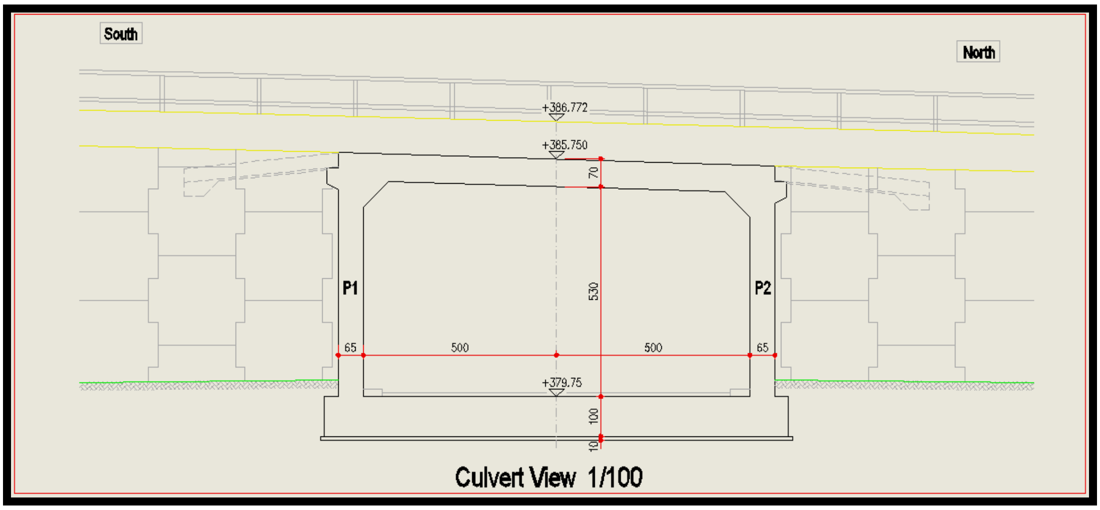

Figure 3-4 El-Mack Nimir Culvert Elevation

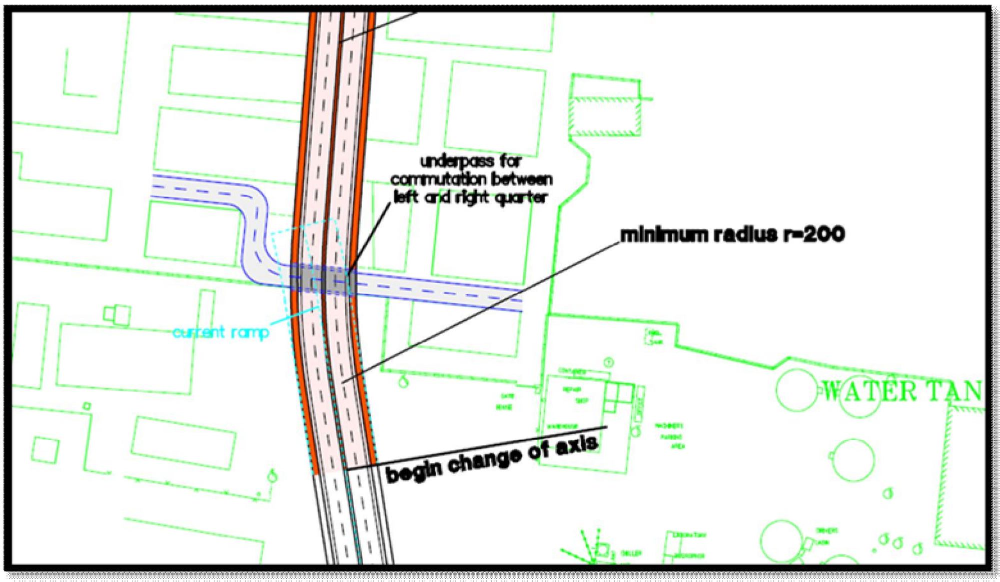

Figure 3-5 Mack Nimir Culvert Site Layouts

d) El-Markazi Flyover (Completed 2011)

- A four Span concrete bridge, length 60 m, north approach 236 m , south approach is 213 m (total length 509 m)
- Each span consists of 9 girders at 2m spacing
- A three column concrete piers with 1.5 m deep pier cap
- Three piles per Axle for piers (diameter 1 m, length 8.0 m)
- 14 piles per Axle for Abutment (diameter 1m, length 8.0 m)
- Clearance 5.50 m
- Total width 18.10 m
- Contract Value 16,500,000 (SDG)

Figure 3-6 El-Markazi Intersection Layouts

3.3 Previous Studies

3.3.1 Wad El-basher Intersection (Alternative Proposed)

Figure 3-7 shows the open section of Wad El-Basher intersection where

a) Tunnel Properties

- Longitudinal slope 4.9 %
- Transverse slopes 2 %
- Design Speed 75 km /Hr.
- Estimated cost 16,000,000 (SDG)
- Total Length 480 m
- Tunnel width 16.40 m

- 4 lanes (4 * 3.5) median 1m sidewalk (2*0.70m)
- Minimum clear height for closed part 5.50 m

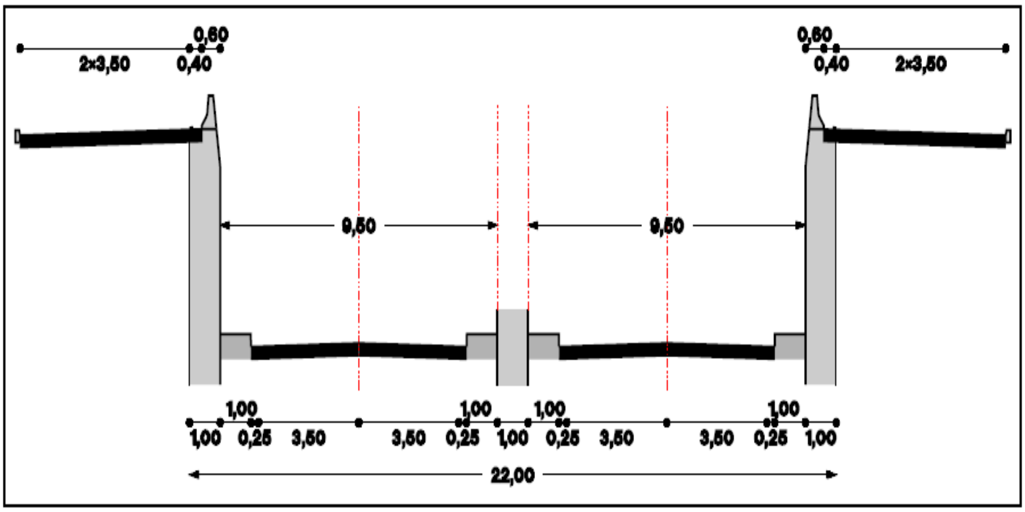

Figure 3-7 Wad EL-Basher Underpasses (Open Section)

b) Design Criteria

Geometrical data

- Tunnel class: main highway
- Total Length 480 m
- Tunnel width 16.40 m
- 4 lanes (4 * 3.5) median 1m sidewalk (2*0.70m)
- Minimum clear height for closed part 5.50 m

Tunnel structural system consists of:
Closed parts consist of reinforced concrete box section with 114.00 m length, open parts consist of reinforced concrete U-section with counterforts with 114.6 m + 113.80 m length, reinforced concrete retaining walls with 76.40 m+ 69.20m length (Ministry of Physical Planning and Public Utilities (2014).)

c) Methods of construction:

Two possible methods for construction for such tunnel

- Construction by deep Excavation System, which sequence as:
  Step 1: Install temporary excavation support walls and Dewatering if required
  Step 2: Excavation and install temporary wall support elements such as stud or

Backs
Step 3: Construction of the tunnel floor
Step 4: Complete construction of walls and then apply roof water proofing as required
Step 5: Backfilling to the final grade and restoring the ground surface.

- Construction by open cut, which sequence as:

Step 1: Excavation of soil with slopes 1:1
Step 2: Construction of retaining walls
Step 3: Backfilling behind the retaining wall to final grade

3.3.2 Al sayed Ali Street / Al-Azhari Street Underpass (Proposed)

Al-Azhari intersection will be an east-west underpass to Shambat Bridge with 2 lanes per direction, divided by a raised separator in the middle and standard clearance of 5.25m.

The longitudinal slope on the western ramp will be 4.0 % (ramp 236m) with comfortable crests and sags. The longitudinal slope on the eastern ramp has to be 5.0 % (ramp 210m) because of the adjacent intersection (Shabea/Al-Azhari intersection) to gain a longer length of intersection approach.

In the eastern intersection approach of Al-Azhari intersection (on the tunnel) is added a U-turn.

Fig 3-8 shows Al-Sayed Ali /Al-Azhari Street Underpass plan and Fig 3-9 show the tunnel cross-section.

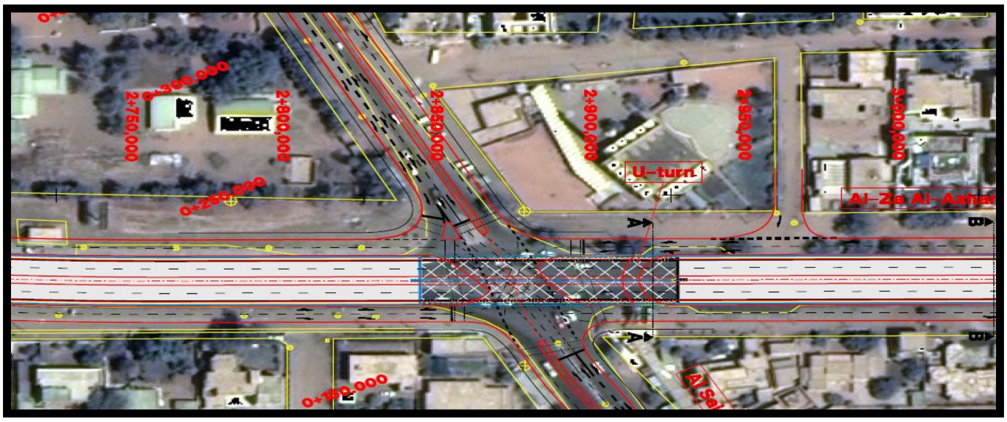

Fig 3-8 Al Sayed Ali / Al-Azhari Street Underpass (plan)

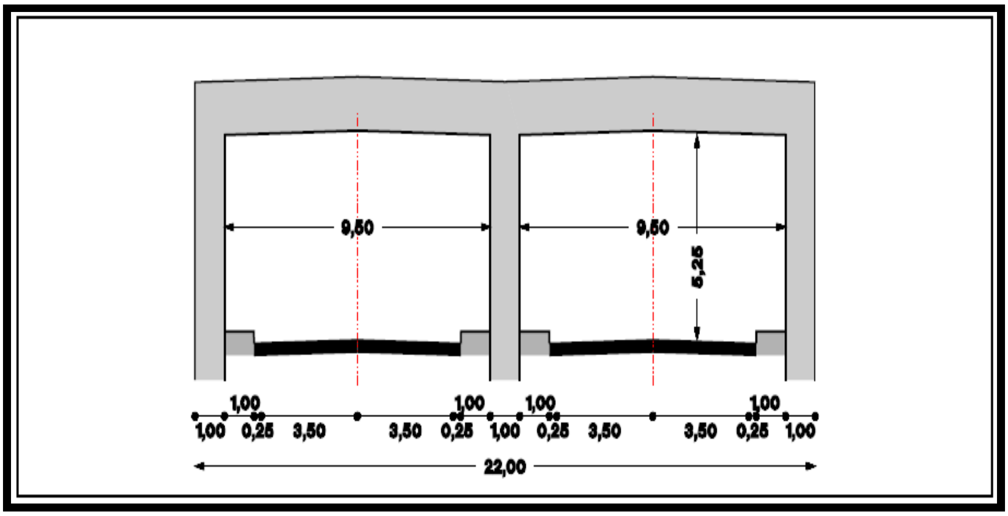

Fig 3-9 Al-Sayed Ali / Al-Azhari Street Underpass (Section)

3.3.3 Jamaa/MckNimir Street Underpass (Proposed)

Jamaa Street is a one-way road from east to west; Atbara Street is a one-way road from south-west to north-east.

In future it is planned by Khartoum State to integrate Tram from S-W Atbara Street to Mack Nimir Bridge.

There are two alternatives for this underpass: -

1) East-West underpass with 2 lanes in the course of the one-way tunnel and 1 remaining at-grade lane in Jamaa Street on the length of the tunnel ramps and a 1-lane tunnel link to Atbara Street, showing the needed space for Tram.
2) East-West underpass with 2 lanes in the course of the one-way tunnel and 1 remaining at-grade lane in Jamaa Street on the length of the tunnel ramps without a tunnel link to Atbara Street, showing the needed space for Tram. The clearance of the tunnel in the course of Jamaa Street will be 5.25m.

For this intersection the most two main traffic is a tunnel in the course of Jamaa Street and a separate left turning lane in the southern approach of Mack-Nimir Street. Mack-Nimir Street is an existing road with 2 lanes per direction divided by a raised separator, leading to the new Mack-Nimir Bridge over Blue Nile River. The northern leg has additional parallel ramps to Nile Street. In the approach to Nile Street, could be added a U-turn (under the bridge).

Start of the tunnel:

The intersection with Abdulla Al-Nor Street has to be free, so the tunnel ramp will begin certainly 10m west of Al-Nor Street. A short tunnel ramp (170m) is proposed, so there will remain enough space for additional lanes in the eastern approach of the remaining intersection and it will be possible to guarantee the access to the museum area. The main entrance to the Ministry of Labor will be organized from Perlman Street.

End of the tunnel:

The tunnel should end/the ramp should begin certainly100m west of Atbara Street, because of the merging traffic in Jamaa Street.

The tunnel ramp should end west of Abu Sinn Street to avoid accidents at this intersection; the proposed length is 170m Fig 3-10) shows the general Layout of the underpass.

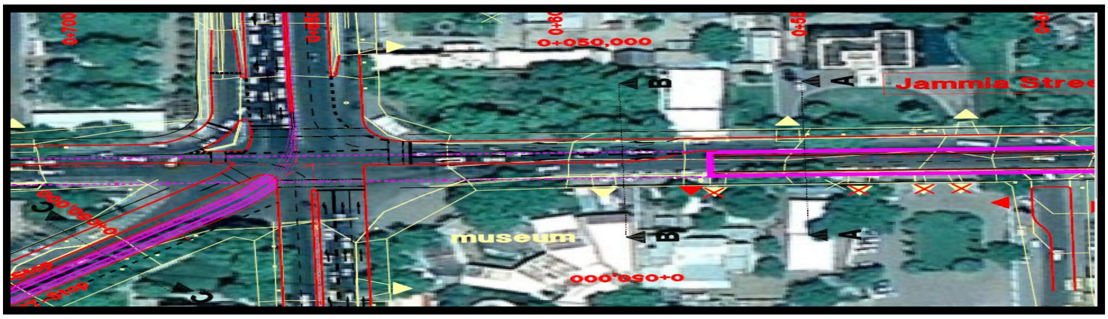

Fig 3-10 Jamaa / MckNimir Street Underpass Layout

Fig 3-11, Fig 3-12 and Fig 3-13 shows cross sections thought the open, covered parts of underpass and at grade respectively (Ministry of Physical Planning and Public Utilities (2014).)

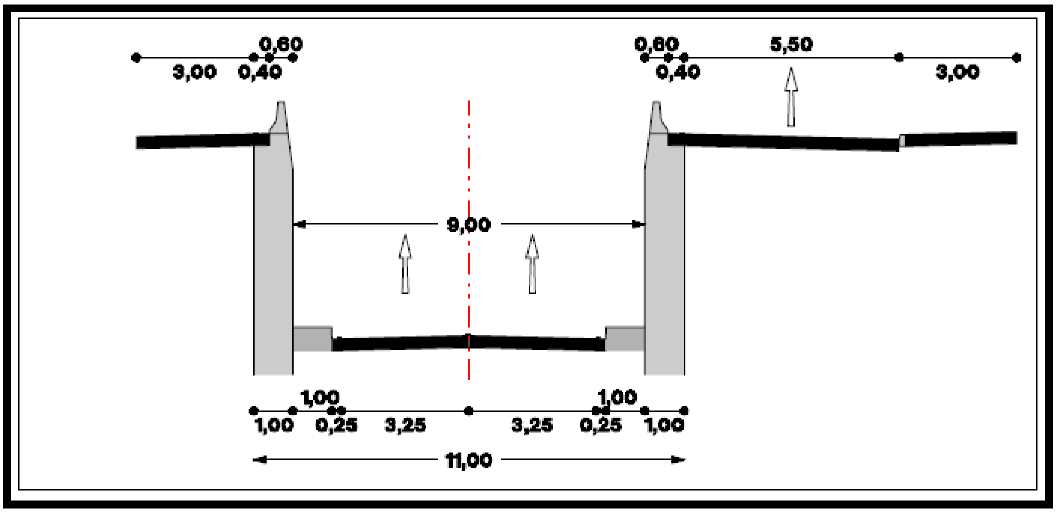

Fig 3-11 Mack Nimir Tunnel (Open cross section)

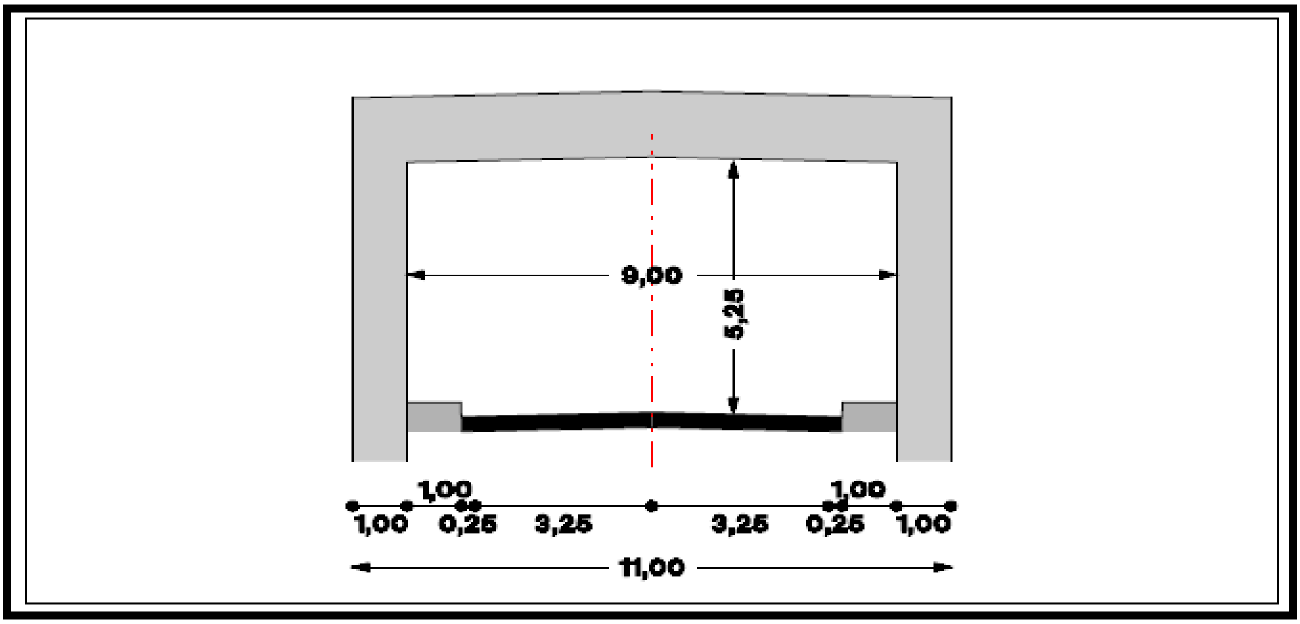

Fig 3-12 MckNimir Tunnel (Closed cross section)

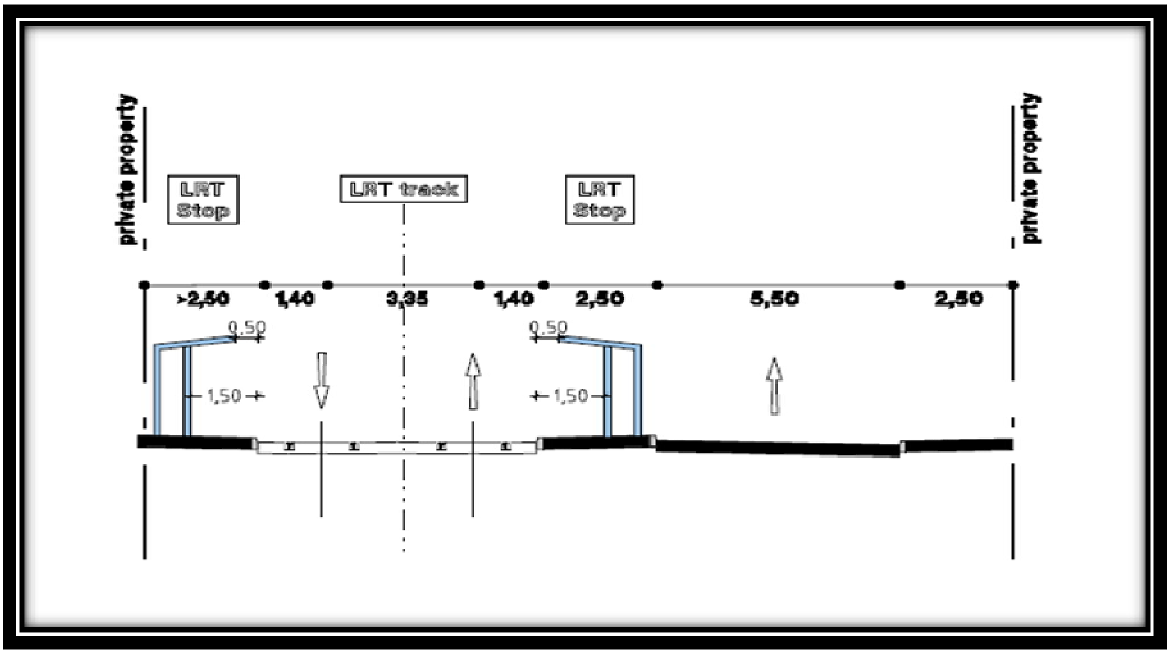

Fig 3-13 MckNimir Tunnel (Cross Section at road)

3.4 Proposed Tunnel Tracks.

Proposed tunnel tracks of this thesis are shown in Fig 3-14, they are two tunnels proposal, which will differentiate to select the most effective track under traffic loading and environmental conditions.

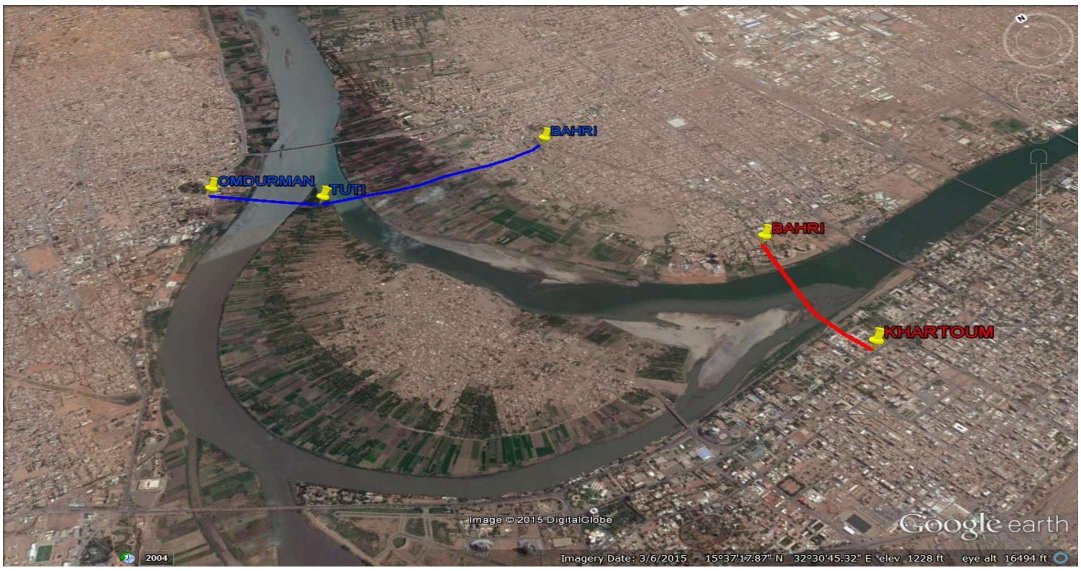

Fig 3-14 the Proposed Tunnel Tracks

3.4.1 Khartoum Bahri Proposal

The first proposal is connect Khartoum with Bahri through the Nile as shown in fig 3-15,in this case the tunnel will cross a body of water which the Blue Nile river.

- **Characteristics of Tunnel**:

Track length is 1.25 kilometer; it suggested being rectangular shape with 15 m wide and 8 m height. It will have 2 lanes both ways.

This tunnel reduces the traffic rush in the morning from Bahri to Khartoum and vice versa in afternoon, it will decrease the traffic density at Mack Nimir Bridge and the Blue Nile Bridge.

It helps indirectly to reduce the traffic from Khartoum to Omdurman through Bahri to Shambat or Alhalfaia Bridge. It could be also useful for those who move from Bahri to Tuti they can cross the tunnel then take the Nile Street and Tuti Bridge with a shorter distance, but the area at Khartoum side is very narrow to construct the right accesses to the tunnel so it need accurate design.

Fig.3-15 Khartoum-Bahri Tunnel Track

According to the Unified System for Classifying soils (USCS) using the results obtained from laboratory for previous project the soil type is clay soil , it grading between silty clay and clayey sand , so in this type of soil the suitable method of excavation could boring method or immersed tube tunnel. (See Figure A-1, appendix A)

3.4.2 Omdurman Tuti Bahri Tunnel

Fig 3-16 shows the second proposal, which connect Omdurman, Tuti and Bahri.

Fig 3-16 Omdurman Tuti Bahri tunnel

- **Characteristics of Tunnel**:

This track starts from Omdurman at Almulazmin area to Alsbabi at Bahri city crossing Tuti Island for 2.8 km length.

This track can connect three cities together (Omdurman, Tuti and Bahri), it could reflect a huge development in area, it will connect Tuti with Omdurman so it can reduce time and distance of vehicles movement which they have to pass by Khartoum Tuti Tunnel.

Cost could be reduced by link the tunnel in Tuti area by highway. This track is the most efficient one because it runs for long distance; uses of TBM machine are more proficient for tracks more than 2 km.

Table 3-1 Comparison of the Tunnel Proposed Tracks

	Khartoum Bahri Tunnel	**Omdurman Tuti Bahri Tunnel**
Tunnel Length	1.25 km	2.8 km
Number of Lain	2 lain both way	2 lain both way
Availability of Construction Area	Narrow construction area almost Residential area	Wide construction area almost
Served Area	Khartoum and Bahri	Omdurman, Tuti, Bahri, and Khartoum

Omdurman Tuti Bahri path has been chosen to study in this thesis because it connects a large area of the major cities making it the most economical, and acceptable track.

CHAPTER 4

CASE STYDY OF OMDURMAN – TUTI –BAHRI TUNNEL (OTB)

4.1 Introduction

Omdurman Tuti Bahri tunnel was proposed to solve traffic congestion problem at Khartoum state, it has been selected in the previous chapter after compare it with Khartoum Bahri track, because it will serve wide area of Khartoum cities.

To make a preliminary study for the design of tunnel, there are several factors that must be studied and analyzed, usually in such huge projects government set share from project cost as a value of these detailed studies, initial studies will illustrate at this chapter, such as soil testing and classification ,as well as traffic analysis to predict the volume of traffic in the proposed tunnel.

4.2 Importance of Proposed Tunnel (OTB).

OTB can connect Khartoum, Omdurman, Tuti and Khartoum North efficiently; the vehicles which move from Omdurman to Khartoum can go through the tunnel to Tuti ring road then cross Tuti Bridge to the Khartoum.

It found that traffic flow from Omdurman to Tuti has to pass through Khartoum because the only Access to Tuti is Mack Nimir Bridge. By using OTB tunnel vehicles direct reach Tuti without bass by Khartoum, which will reduce the traffic flow from White Nile Bridge.

Also the tunnel can reduce traffic on the Shambat Bridge. Vehicles can cross to Bahri through the tunnel which is short and easier.

Therefore, this tunnel will be more efficient at the peak hour when people go early morning from Omdurman to Khartoum to their work and when they come back to home.

4.3 Tunnel Design Sequence

The main process used in the tunnel design is:

- Outline the functional requirements
- Provide the necessary investigations and analyses data

- Conduct environmental, cultural, and institutional studies to evaluate the design and construction of the tunnel
- Perform tunnel type studies to determine the most appropriate method of tunneling.
- Establish design criteria and perform the design of the various tunnel elements. Appropriate initial and final ground support and lining systems are critical for the tunnel design, considering both ground conditions and the proposed method of construction. Perform the design in Preliminary and Final design phases. Interim reviews should be made if indicated by ongoing design issues.
- Establish tunnel alignment, profile and cross-section.
- Perform risk analysis and identify mitigation measures and implement those measures in the design.
- Prepare project documents including construction plans, specifications, schedules, estimates, and geotechnical baseline report (GBR).

4.4Tunnel Geometry

4.4.1 General Omdurman-Tuti-Bahri Tunnel Layout

OTB would run from Nile Street on Omdurman side at AL-Mulazmine to AL-Sababi on Bahri side, crossing Tuti Island passing under the Nile River. Total length of the track is 2.8 km. Figure (4-1 to 4-4) shows the track layout.

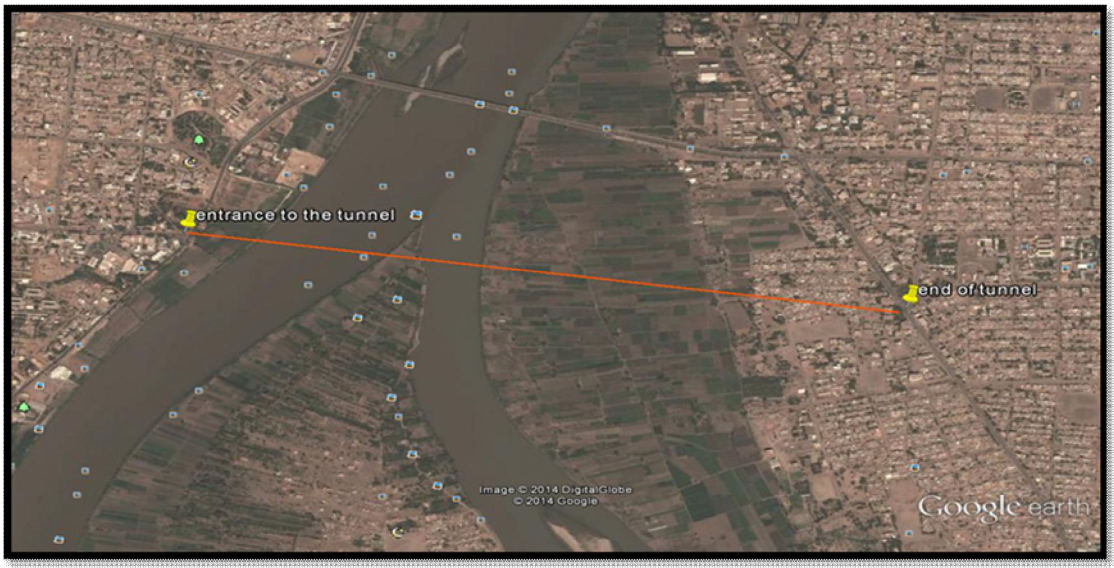

Figure 4-1 General Layout of Proposal Tunnel –OTB-

Figure 4-2 Entrance Area of OTB Tunnel

Figure 4-3 Exit Area of OTB Tunnel

Figure 4-4 OTB Tunnel Crossing Area on Tuti Island

4.4.2 Tuti Tunnel Approach

Track starts underground at Omdurman side, then goes under Nile River and reaches Tuti Island at the western north area crossing the ring road, which makes it more easer to build an exit road to Tuti connecting with ring road which make a good improvement to the island area. Track will cross the ring road in two points, Entrance and Exit as shown in figure 4-5, then goes under Blue Nile River to reach Bahri side. the total length of Tuti arms is around 320m.

figure 4-5 Entrance and Exit for Tuti Island

4.5Tunnel Dimension and Cross Section

4.5.1 Cross Section Design

Road tunnels should have at least the same traffic capacity as that of surface roads. Studies suggest that in tunnels where traffic is controlled, throughput is more than that in uncontrolled surface road suggesting that a reduction in the number of lanes inside the tunnel may be warranted. However, traffic will slow down if the lane width is less than standards (too narrow) and will shy away from tunnel walls if insufficient lateral clearance is provided inside the tunnel. Also, very low ceilings give an impression of speed and tend to slow traffic. Therefore, it is important to provide adequate lane width and height

Comparable to those of the approach road, it is recommended that traffic lanes for new tunnels should meet the required road geometrical requirements. It is also recommended to have a reasonable edge distance between the lane and the tunnel walls or barriers (NHI, 2009).

The tunnel is assumed to be circular 19.0m diameter depending to the TBM machine method.

Tunnel will consist of concrete roadway of 2 Lanes each direction. Each lane width is 3.5 m, which makes the tunnel capacity around 75,000 vehicles per day. Exhaust extraction fans for the traffic lanes will be on the top, utilities and drainage in the invert, ventilation and emergency exit from traffic level to the exit area on right side. Figure 4-6 shows the proposal shape and arrangement.

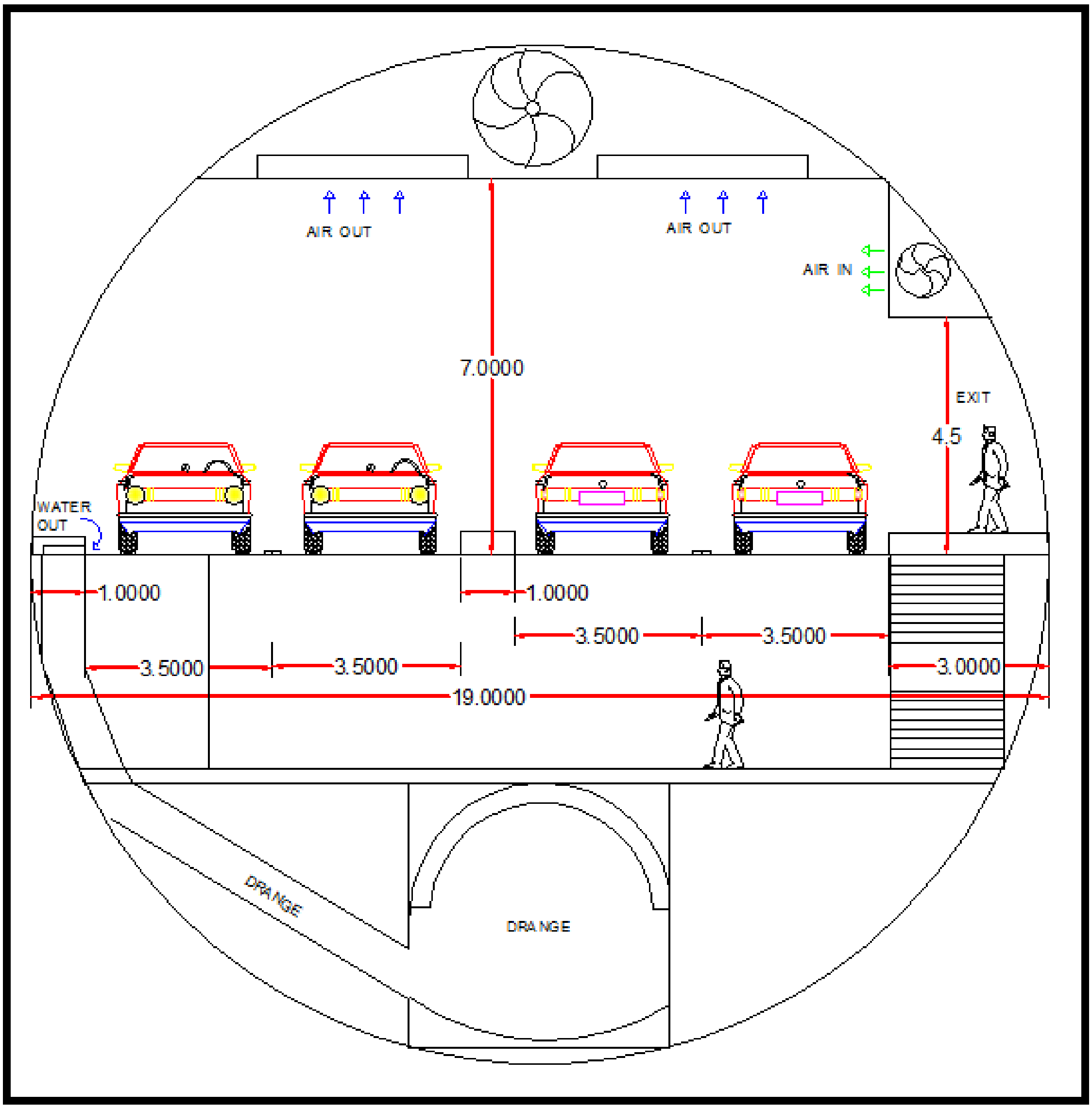

Figure 4-6 Proposal of OTB Tunnel Section Design by Researcher

4.5.2 Vertical Section Design

For tunnel Entrances and exits, appropriate sloped should be constructed for all paths of OTB tunnel. The main design criteria should consider are:

1- vehicle speed

2- stopping sight distances

3- Slop and length of sag vertical curve, m

Headlight sight distance has been used directly for determining the length of sag vertical curves. for drivers to see the roadway ahead, as per AASHTO a sag vertical curve should be long enough that the light beam distance, is approximately the same as the stopping sight distance. Accordingly, it is appropriate to use stopping sight distances for different design speeds as the value of S in the above equations. The resulting lengths of sag vertical curves for the recommended stopping sight distances for each design speed are shown in Figure 4-7 with solid lines using rounded values of K.

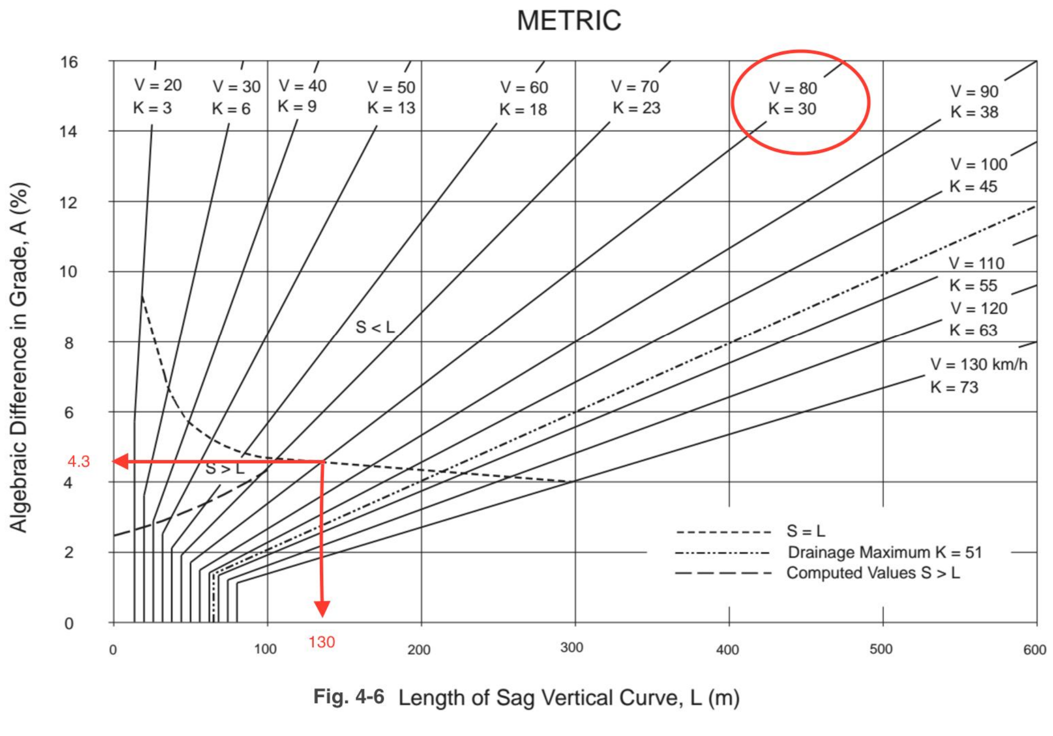

Figure 4-7 Length of Sloped Entrances

It's been assumed that the vehicle speed v is 80 km/h so we need for at least 130m for each entrance length to take vehicle out side or inside the tunnel safely, fig 4-8 shows the slope dimensions.

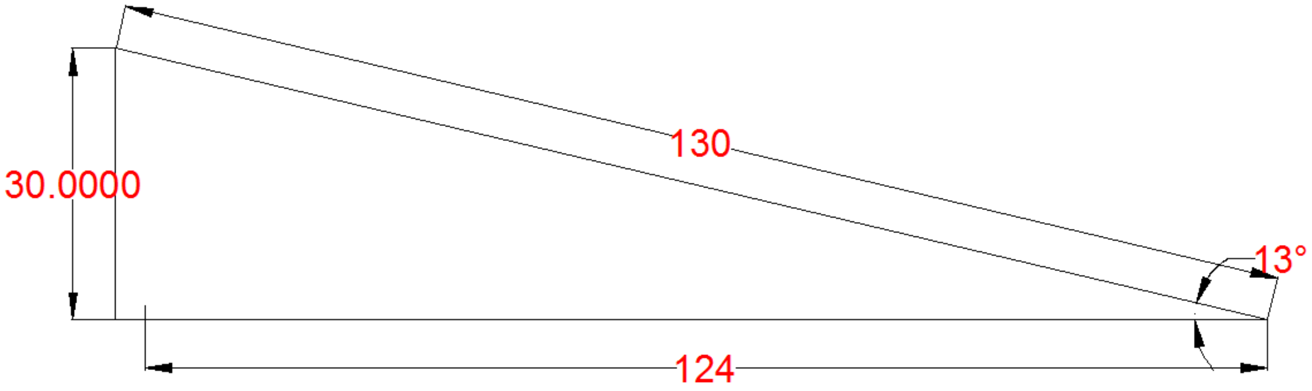

Figure 4-8 Sloped Entrance Dimensions

For 130m curve length and 30m depth the slope percentage (A) should be 4.3 and we need for 128m horizontal distance.

Figure 4-9 Maximum Depth of Water at Track Area

As shows in fig 4-9 the level of natural land is 1273 ft. (388m) from see level and the level of bottom of the Nile is 1225 ft. (373m), Thus the maximum depth of water within our track is assumed to be 15m.

4.6 Proposal Tunnel Analyses and Design

4.6.1 Traffic Analysis

Demand for transport is a reflection of the growth in the economy. Apart from the normal increase in travel due to natural growth in population, the need to transport passengers and cargo is related closely to the economic performance. It increases with the expansion in investments and the growth in trade volumes. Investments in different sectors of the economy will result in substantial increase in exports and imports.

There is a fast growing migration to Khartoum city and its surroundings from other parts of the country. Such constructions of roads and tunnel project at the Region will prevent the undesired acquisition of the land.

Little information is available about vehicles registered at traffic police department. Tables and Figures collected from the Ministry of Physical Planning and Public Utilities are as shown in Fig.4-10 to Fig 4-15 for the period of 2013 to 2014

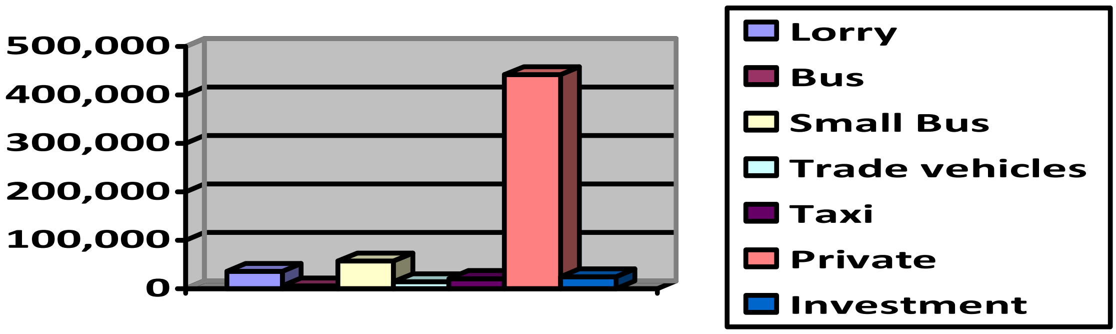

Figure 4-10 Number of Registered Vehicles in 2013-2014

Increase in the number of driving licenses issued during the period from 2013 to 2014 is another indication of fast motorization in Sudan. There is a massive increase in the numbers of licenses issued parallel to the growth in GDP during the last years. (Source: Ministry of Physical Planning and Public Utilities)

Table 4-1 Number of Driving Licenses That have been Issued in 2013-2014

Type of Licenses Issued	2013	2014
General	40110	46335
Private	107781	107954
Heavy	32	48
Government	1854	2689
Total	149802	157077

Environmental pollution will also be prevented by bringing municipal public utilities services and applying urban plans. New businesses will be developed in new developing cities.

The Ring Road route alignment surrounds urban land uses of different levels in the three towns forming Greater Khartoum. It covers Khartoum Area, Omdurman Area and Khartoum Bahri Area. Data such as traffic direction and capacity is one of the main required data needed for tunnel projects. Table 4-2 shows traffic capacity per day on the bridges in Khartoum capital according to Khartoum traffic authority (espm-eser, 2008).

Table 4-2 Number of Vehicles Crossing Khartoum Bridges in 2014

Number	**Bridge name**	**Vehicle /day**	
		Direction one	direction two
1	Alhalfaia bridge	8400	8523
2	Shambat bridge	33430	33431
3	White Nile bridge	37000	37200
4	Alingaz bridge	30000	31759
5	Kobar bridge	30000	36087
6	Blue Nile bridge	18000	21000
7	Mack Nimir bridge	26400	2730
8	Almanshia bridge	30000	30000

These statistics show that there is a high traffic demand on the bridges. Usually congestion concentrated at those which links the Khartoum Capital with the other cities, therefore we need to improve the traffic system and one of the ways of doing that is to follow the modern methods in infrastructure facilities. (Source: Ministry of Physical Planning and Public Utilities)

Knowing the movement of vehicles and trip directions enables us to sets both distance and trips time and thus enable us to put a correct track, which can relieve traffic congestion, and be more flexible in use and more economical.

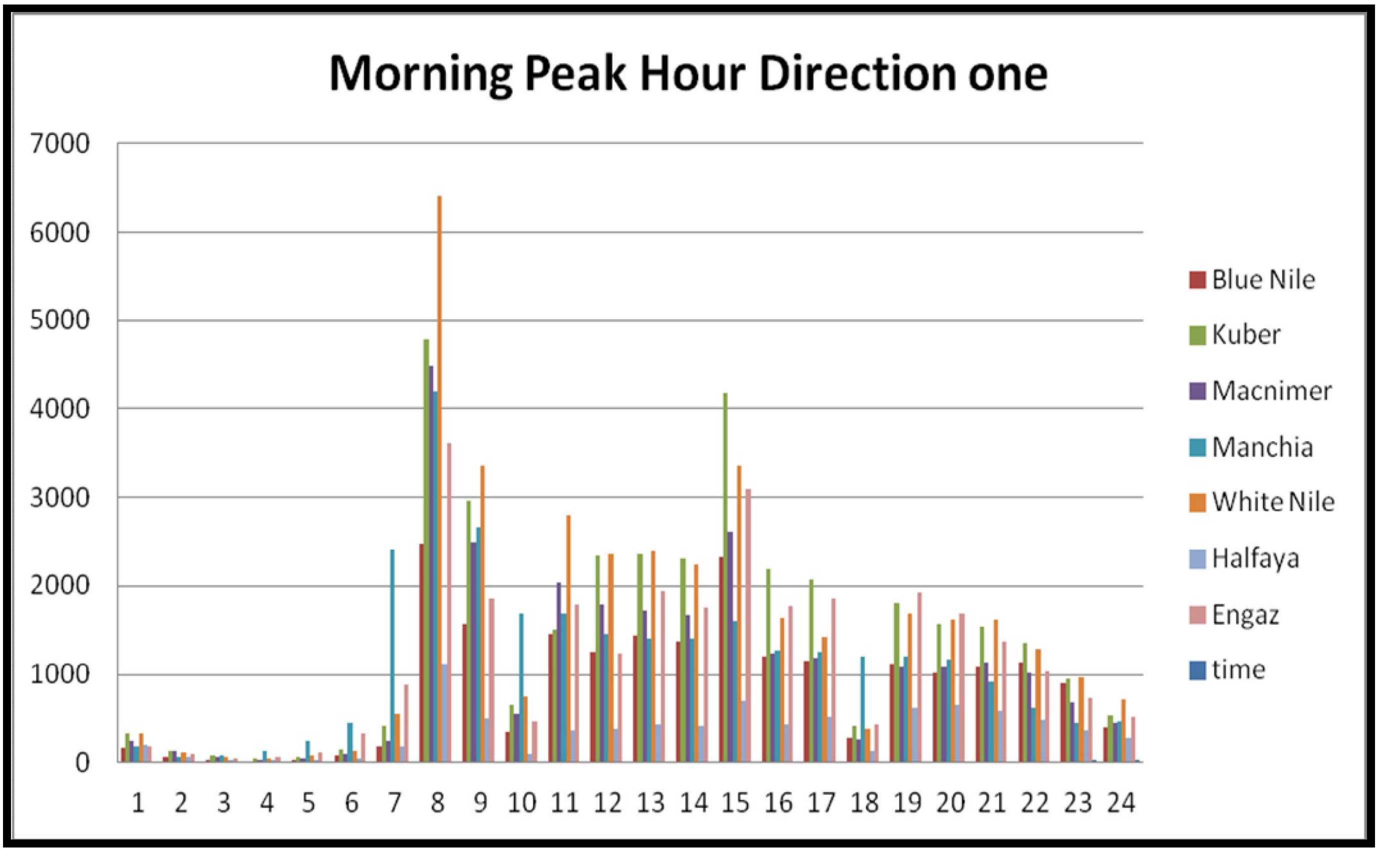

Figure 4-11 Traffic Flow During Morning Peak Hour (x - time, y- vehicle numbers)

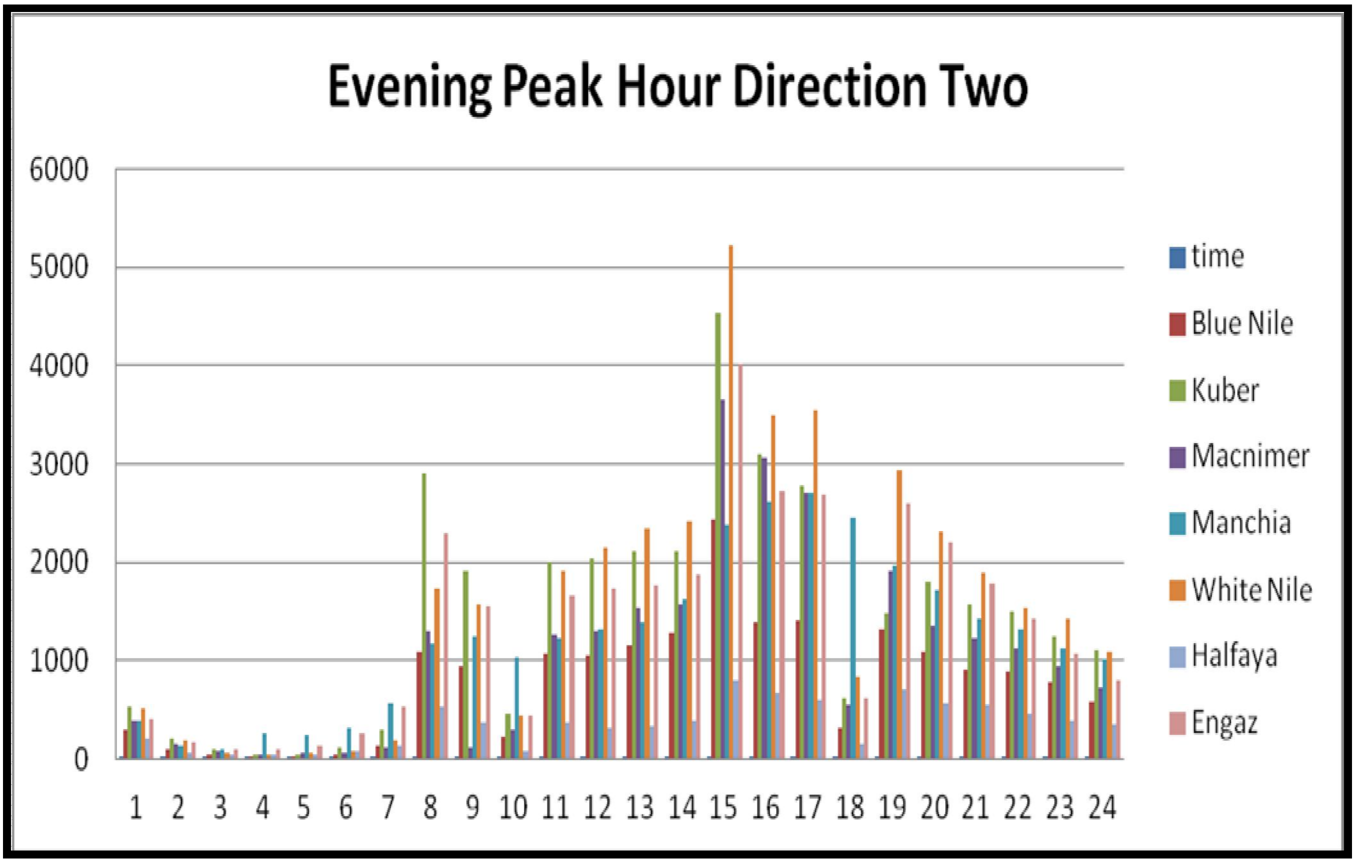

Figure 4-12 Traffic Flow During Evening Peak Hour(x- vehicle numbers, y- time)

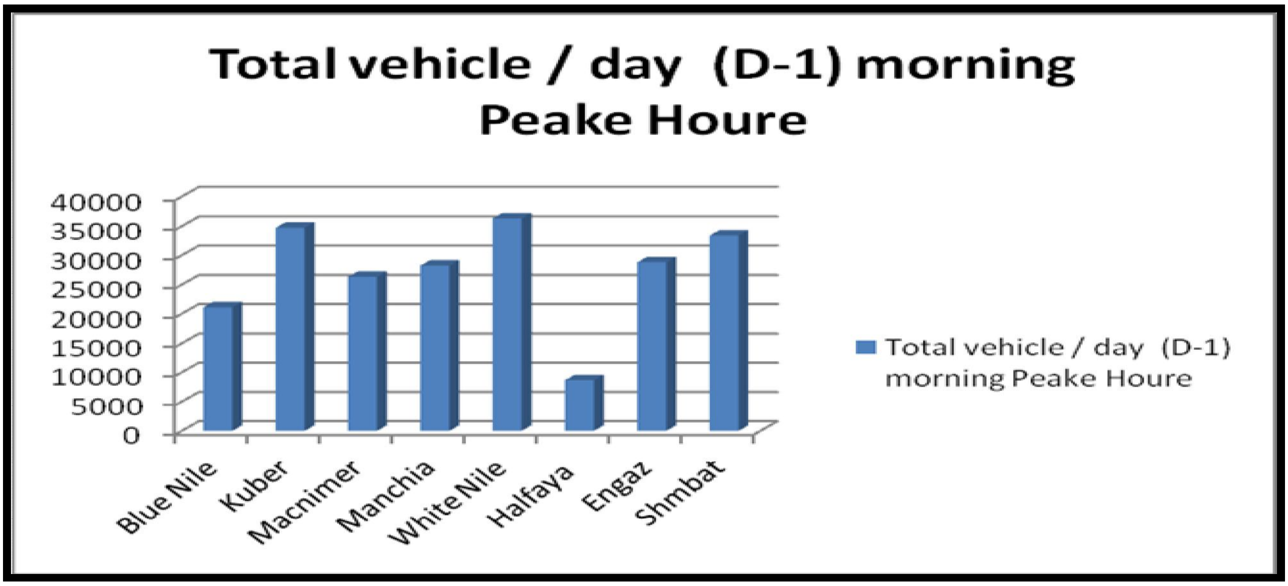

Figure 4-13 Total Traffic Flow / Day (D-1) During Morning Peak Hour

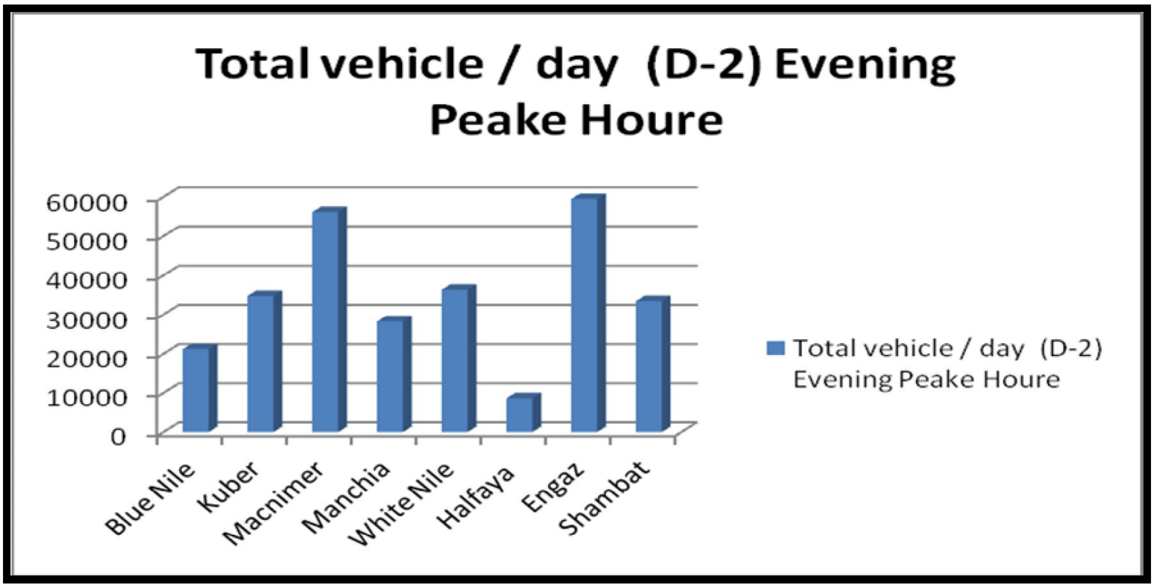

Figure 4-14 Total Traffic Flow / Day (D-2) During Evening Peak Hour

4.6.1.1 Traffic Estimates

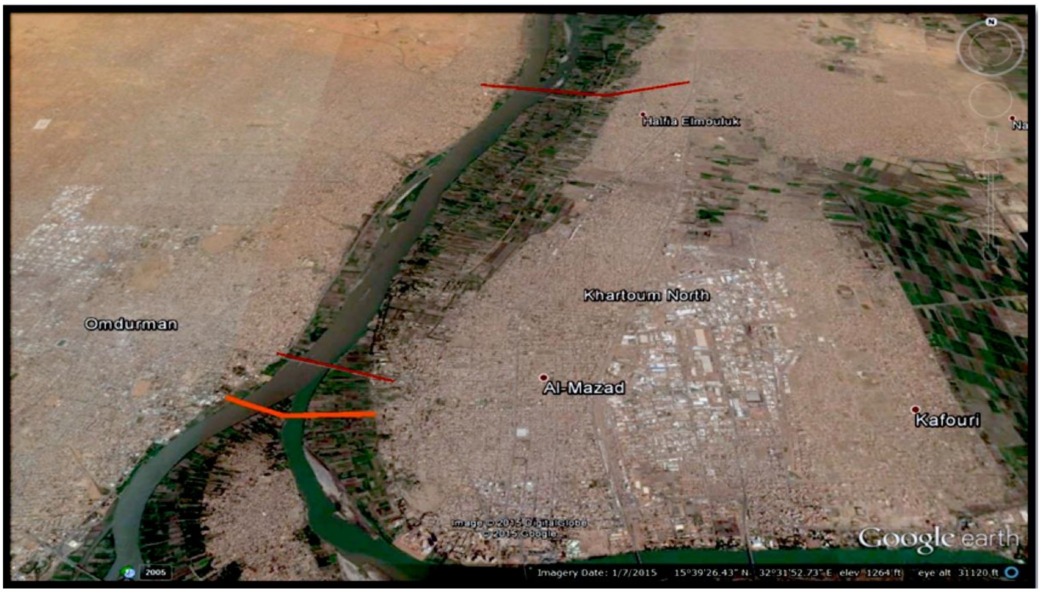

Figure 4-15 Traffic Flow Outline from Omdurman to Bahri

Usually when vehicles are traveling from Omdurman to Bahri there is two bridges, Shambat and Alhalfaia, which marked by red color in the Figure 4-15. The orange track is the proposed tunnel, which can reduce traffic from the other bridges.

If the total number of vehicles in both bridges is around 84185 vehicles per day, at least using OTB tunnel as predicted in table 4-3 will reduce 30% of this number.

Figure 4-16 Traffic Flow Outline from Omdurman to Khartoum

White Nile Bridge and Al Inqaz Bridge are two main bridges that connect Omdurman with Khartoum, which are marked by red color in Figure 4-16.

By providing the new proposal tunnel vehicles can take Tuti direction and then follow Tuti ring road to Khartoum Tuti Bridge. The track, which is colored by orange in the Figure 4-12, will reduce the congestion from the two other bridges. If the total number of vehicles in both bridges is around 160891vehicles/day, at least using OTB tunnel so as predicted in table 4-3 the total number of vehicle may cross tunnel per day is 73524 can reduce 30% of this number.

Table 4-3 OTB Traffic Estimate

	KH			BH			OTB
	W.B	E.B	Total	H.B	SH.B	Total	
OM (D-1)	36303	28809	65112	8662	33430	42092	32162
OM (D-2)	36303	59476	95779	8662	33431	42093	41362
Total			160891			84185	73524

4.6.2 Soil Investigation and Analysis

- Omdurman area:

According to the results obtained from laboratory(ESD -2011) as shown in table A-1 (refer to appendix A) using the Unified System for Classifying soils (USCS), Type of soil at Omdurman is grading between Silty-Clay and Clayey-sand. In this type of soil the excavation method for tunnel entrance could be cut and cover method and then continued by TBM. The best way to support the excavation at the tunnel entrance is to use pile wall system as permanent rigid system because required depth can reach up to 30m.

- Tuti area:

The results generally indicated that the site is dominated by top loose poorly graded silty sand to Very dense whitish yellowish silty sand with completely weathered sedimentary sandstone as shown in table A-2 and A-3 (refer to appendix A)

- Bahri area:

The results indicate that the site is dominated by alluvial soil formation towards the bottom of the boreholes. The Alluvial deposits are loose to very dense Silty sands (SP-SM, SP to SM) and stiff silt of high to low plasticity (MH to ML) as shown in table A-4 and A-5 (refer to appendix A) (ESD, 2011).

4.7 Construction plan

To construct a tunnel projects, we should put an accurate plan for the project, the work should be divided to stages, and each stage should have time and cost schedule and a clear method statement of work. Project will be divided to three main stages:

- Entrance
- The Tunnel
- Exit

4.7.1 Entrance

To start work at the site many processes should be taken to provide a safe working area, provide access for construction activities and protect structures, utilities and other infrastructure adjacent to the work.

Figure 4-17 Proposal of Converted Track and Organization of Entrance Working Area

Figure 4-17 Indicates converting the tracks, which marked, by orange color and the entrance work area in light blue color so as to create a new path for moving traffic and avoid accidents during the project period.

Speed will be determined in the alternative streets to avoid accidents, which could be dangerous especially at areas of deep excavations, warning signs will be fixed and safety tapes of reflective colors mode will be used.

Such projects must comply with all safety requirements of the internationally agreed protection rules for road users and workers.

Excavation is the first step on the project after the site preparation and mobilization. The design of excavation stages and support systems requires consideration of a variety of factors that affect the performance of the support system and that have impacts on the tunnel structure itself, type of soil and the available project area are the most important factors, careful site investigation is essential to provides a clear understanding of the subsurface conditions and to determining the correct support system.

The design and detailing of the support of excavation must consider the sequence of installation and account for the changing loading conditions that will occur as the system is installed.

For the initial Excavations support systems, the suitable type is the permanent rigid system because of the soil characteristics as mentioned in 4.5.2

Permanent rigid system is structure designed to support vertical faces of excavation and to be part of the permanent final tunnel structure. This system is suitable to be use in the project.
Permanent support of excavation typically employs rigid systems. According to the soil record and tunnel depth will use tangent pile walls.

Pile walls consist of a series of drilled holes located adjacent each other, the holes are usually 0.6 to 1.2 meter in diameter and extend below the bottom of the tunnel structure for stability. The typical sequence of construction of piles begins with the excavation of every third drilled shaft. The holes are held open by temporary casing. A reinforcing bar cage is placed inside the hole and then filled with concrete. The case is pulled as the concrete placement progresses. Once the concrete backfills cures sufficiently, the next set of holes is constructed in the same sequence as the first set.
Finally, after curing of the concrete and completing the walls, Excavation within the walls will take place as required.

Figure 4-18 Tangent Pile Walls

4.7.2 The Tunnel

To build the body of the tunnel will use TBM machine, which have been selected, based on type of soil (refer to 4.5.2).

After the initial stage of excavation large space for work will be opened, TBM machine could be lowered in the bottom of excavated area where the tube tunnel face has been marked.

Lower down TBM components to the working Area needs heavy lifting usually around 600 – 700-ton crawler crane is used.

Figure 4-19 Lower Down TBM Machine

Earlier in this thesis we explained types of TBM machines, hence, according to the type of the existing soil will use SPB TBM Machine, it fit with drilling under the river with a high water pressure, and with the Silty-Clay and Clayey-sand soil.

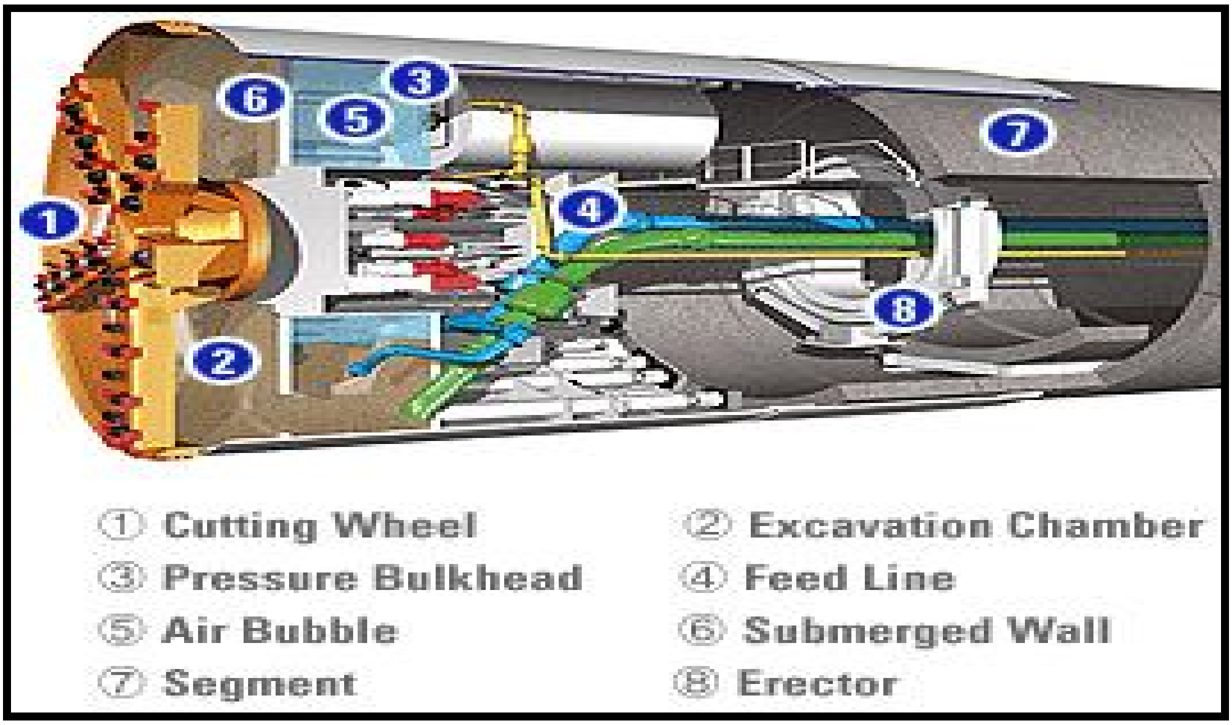

Figure 4-20 SPB TBM Machine

- **Main Machine Part:**

  (1) Cutter head

  There is many type of cutter head depending on soil type (Figure 4-21). This cutter heads pressed against tunnel face with a force of 26 tons .it is changeable so after it get week it could be changed with new one.

Figure 4-21 Cutter Head versus Soil Types

The cutter head does not use disc cutters only, but instead a combination of tungsten carbide cutting bits, carbide disc cutters.

(2) Excavation Chamber

Which located behind the cutter and filling with slurry during the work, the cutter head cheeps the soil away, the broken soil falls on the pocket wheel and then transfer to conveyor belt behind the cutter head .

(3) Pressure bulkhead, to introduce pressure against tunnel face.

(4) Slurry feed line

This feed the excavation chamber with slurry.

(5) Air bubble

It is to introduce air bubbles to create pressure to get the slurry out to the outside pipe.

(6) Submerged wall

(7) Segmental Lining

Segmental linings are primarily used in conjunction with a tunnel boring machine (TBM) in soft ground conditions. The prefabricated lining segments are founded within the cylindrical tail shield of the TBM. These prefabricated segments can be made of steel, concrete, or cast iron and are usually bolted together to compress gaskets for preventing water penetration.

(8) Segment erector

The segment erector built as mechanical arm with suction cup, so-called vacuum pick up system, positioned in the rear area of the head with the function of moving, rounding and put in place the segments of the tunnel.

The erector picks up the piece form the sled with a vacuum pick up system with three suction cups, and places it in its seat. The segments of a ring are bolted together in a radial direction and are connected to the previous ring by means of connectors.

The principle of TBM is to push cutters against the tunnel face and then rotate the cutters for breaking the rocks in chips.

The performance of a TBM depends upon its capacity to create largest size of chips of rocks with least thrust, and to the soil type. The rate of boring through hard weathered rock mass is found to be below expectation.

Disc cutters are used for tunneling through soft and medium hard rocks. Roller cutters are used in hard rocks, although their cost is high.

A typical TBM is shown in Figure 4-22 together with the ancillary equipment.

The machine is gripped in place by legs with pads on rocks. A cutting head of welded steel and convex shape performs the excavation, with cutters arranged on it optimally.

The long body of TBM contains the four hydraulic jacks to push forward the cutting head and also drive motors, which rotate the cutting head for chipping rocks. Figure 4-23 shows schematically a method of advance of the cutter head.

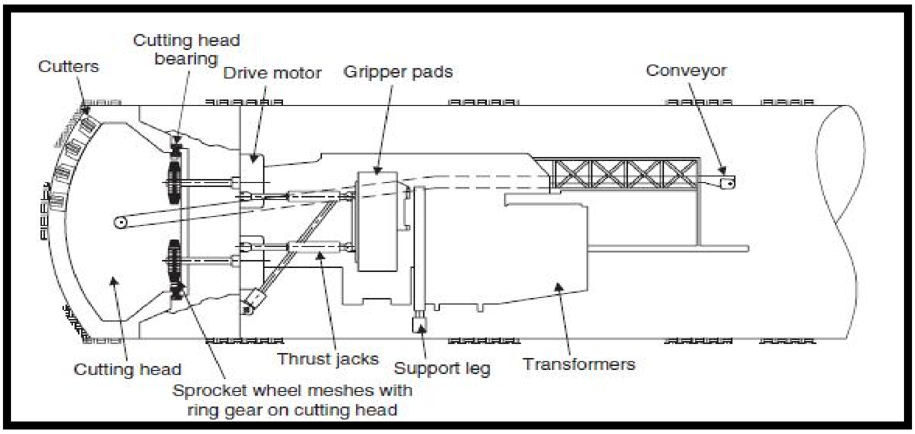

Figure 4-22 Typical TBM

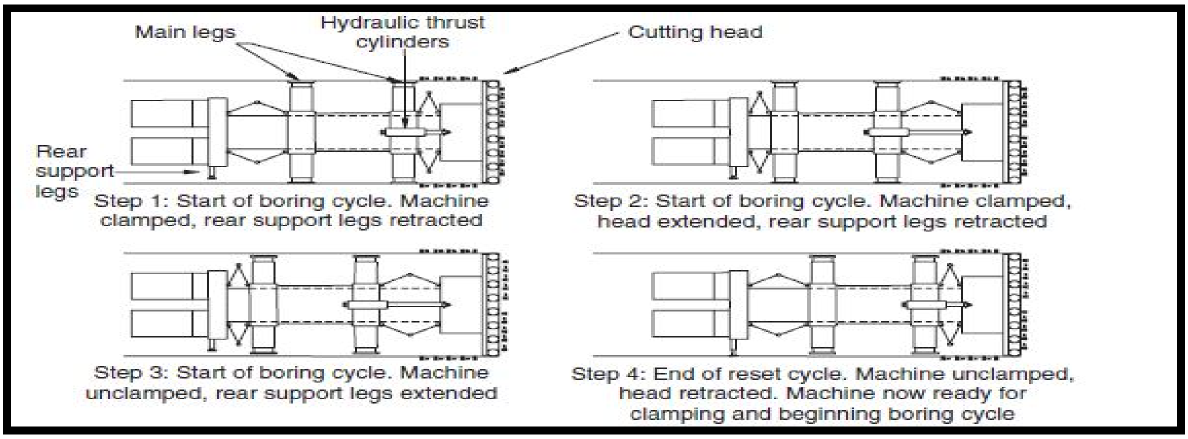

Figure 4-23 Method of Advance of the TBM in four steps.

Typically, even when a TBM operates well, only 30 to 50 percent of the operating time is spent on boring.

fig 4-23 also shows the removal system for muck (rock chips). The excavated material is collected and scooped upwards by buckets around the cutter head. These buckets then drop the rock pieces on a conveyer belt and transported it to the back end of the TBM. There, it is loaded into a train of mucking cars. (HRT, 2005)

- The following precautions should be taken:

1- There should be adequate store-keeping of spare parts for all the tunneling machines at the project site. Arrangement should be made to procure machine parts on a quick emergency basis by air cargo to reduce break down periods, Funds should be available for the same.

2- Maximum efforts for maintenance are needed at the project site.

3- Extra machines and Spare parts should be purchased as standby tunneling machines.

Thus standby machines can be used when there is a major breakdown of machines; as the completion of a tunnel before target date is important to start earning profit from the completed project. The completion of a project is normally delayed due to the difficulties in long tunneling.

4-There is high cost over-run and time over-run in long deep tunnels (>500 m). Best management conditions help.

5- There should be good workshop of adequate capacity for repairs of machines.

6- There should be a preventive maintenance program, as it is of vital importance to the successful and continuous operations of all machines.

7- Modern fleet of tunneling machines are more sophisticated, more versatile, more powerful and very fast, and therefore safety of workers in limited space of unsafe tunnels should be the top priority.

4.7.3 Tunnel – The Exit

Excavation will continue till marked end point at Bahri land, the same initial excavation should be done at Bahri side; tunnel track will be defined accurately so the TBM machine could get out correctly and safely as shown in Figure 4-24 and 4-25.

Figure 4-24 TBM Exit Process

Figure 4-25 Exit Way of TBM Body

The TBM machine will be removed and transported from the site; other excavation process will be completed to merge both body and the exit together.

Tuti exit could be constructed by rigid Pile system to reach deep depth and connect tunnel with Tuti Ring Road.

4.8 Tunnel Lining

Precast segmental linings will be used in tunnel. It fit with the soft ground and the soil type, which we have.

Several curved precast elements or segments are assembled inside the tail of the tunnel boring machine. The number of segments used to form the ring is a function of the ring diameter and to a certain respect, contractor's preferences. The segments are relatively thin, 20 to 30 cm and typically 1 to 1.5 m wide measured along the length of the tunnel.

Precast segmental linings will be used as final lining (the "one-pass" system) straight out of the tail of the TBM.

The segments are erected inside the tail of the TBM. The TBM pushes against the segments to advance the tunnel excavation.

Once the shield of the TBM is passed the completed ring, the ring is jacked apart (expanded) at the crown or near the spring lines. Jacking the segments helps fill the annular space that was occupied by the shield of the TBM. After jacking, contact grouting may be used to finish filling the annular space and to ensure complete contact between the segments and the surrounding ground.

A waterproofing membrane is installed over the final concrete lining. Using tapered rings creates horizontal and vertical curvature in the tunnel alignment.

- Advantages of a precast segmental lining are as follows:

- Provides complete stable ground support that is ready for follow-on work.
- Materials are easily transported and handled inside the tunnel.
- No additional work such as forming and curing is required prior to use.
- Provides a regular sound foundation for tunnel finishes.
- Provides a durable low maintenance structure. (FHWA, 2003)

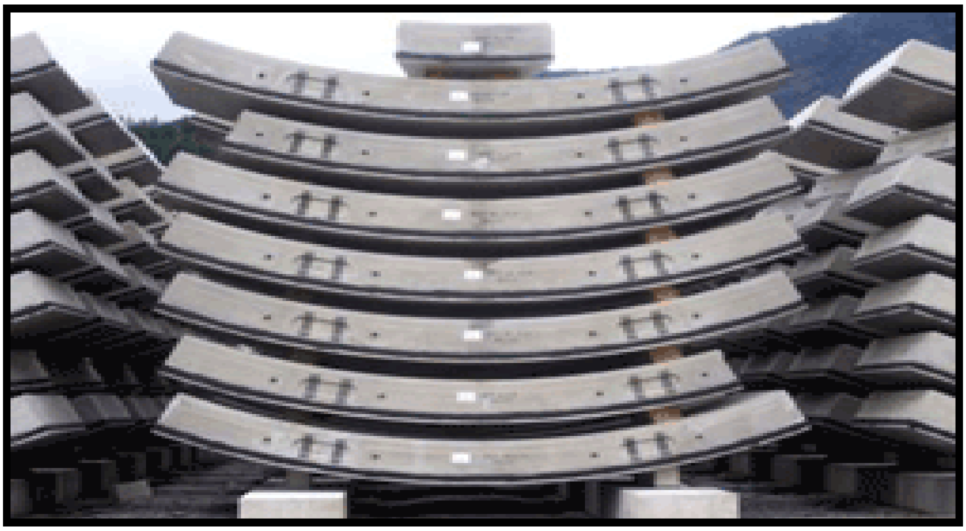

Figure 4-26 Precast Segments

4.9 Invert Types

The invert of a tunnel is the slab on which the roadway or track bed is supported. There are two main methods for supporting the roadway or track bed

1- By placing the roadway or track bed directly on grade at the bottom of the tunnel structure. It is used in most rail transit tunnels because their ventilation systems rarely use supply ductwork under the slab. This method is also employed in many highway tunnels over land where ventilation is supplied from above the roadway level.

2- By spanning the roadway between sidewalls to provide space under the roadway for ventilation and utilities. It is commonly found in circular highway tunnels that must provide a horizontal roadway surface that is wide enough for at least two lanes of traffic and therefore the roadway slab is suspended off the tunnel bottom a particular distance. The void is then used for a ventilation plenum and other utilities.

The roadway slab in many of the older highway tunnels is supported by placing structural steel beams, encased in concrete, the span transversely to the tunnel length, and are spaced between 750mm and 1,500 mm on centers. Newer tunnels provide structural reinforced concrete slabs that span the required distance between supports.

It is necessary to determine the type of roadway slab used in a given tunnel because a more extensive inspection is required for a structural slab than for a slab-on-grade.

Our Tunnel will consist of one-deck road-way slabs as discussed in 4.4

With the progress of science and enormous revolution that occurred in the concrete world we could use a precast reinforced concrete system, which should be designed for a heavy movement load of vehicles, and long durability (FHWA, 2005)

4.10 Safety Plan

Accidents in tunnels and other underground structures often lead to serious consequences, for this reason careful consideration of safety during design, and execution is necessary. OSHA’s standard consists of many topics about project’s site and worker.

For the safety plan following point should be considering:

1- Ventilation

All underground work areas are usually gathering of dust, fumes, mists, vapors, or gases. In absent of fresh air, mechanical ventilation should be provide. OSHA standers recommended providing 5.7 m^3 of fresh air per minute for each employee.

Linear velocity of airflow should not be less than 9.15 m per minute, in the tunnel bore, shafts, and all other underground work areas.

2- Fire Prevention and Protection

Fire prevention for underground construction projects has specific conditions**,**

Open flames and fires are not allowed in underground construction.

Smoking inside working areas is forbidden unless an area is free of hazards.

All construction materials, which used on Underground structures (within 30.48 m) must lie within a fire resistance rating of at least one hour.

Gasoline, Oil, grease, and diesel fuel must be kept in tightly sealed containers and there is a specific requirement to the use of diesel fuel in underground construction see appendix

3- Personal Protective

A full responsibility will be taken by a ‘ competent person’ OSHA define him as “One who is capable of identifying existing and predictable hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them.”

Check–in/ check-out report should be maintained daily to make sure that an accurate accounting of the number of underground worker is correct; Worker’s number monitoring is one of successful safety application.

Warning signs that read, “Keep out” should be applied whenever found excavation and hazardous; to avoid accidents.

All access and opening should be safe to use, and must be well supported to prevent from land sliding. (OSHA, 2003)

4.11 Cost Estimate

In general; main components of the costs in transportation project are:

- Construction cost
- Land acquisition cost
- Construction management and supervision
- Planning permits and Government dues

Benefits obtained from the transportation projects can be classified as follows:

- Less fuel used by vehicles due to the shortened distance and reduced congestion on the route: Saving on consumption of fuel is a social benefit because fuel is an asset to the community.
- Less traveling time taken due to shortened distance and less congestion. Saving on travelling time of passenger means that people will not spend their time without doing anything but they will be reaching the place earlier for being utilized to do other activities, some of them generating output to the society.
- Fewer accidents and hazard to the properties and vehicles: Hazards' keeping the vehicles from operating is a social cost and loss from the national assets.
- Land near the project location will be gaining extra value which is the benefit of the owners of these lands. Government will be receiving revenues from the sale of these lands.
- Profits from Sales of Surrounding Land

It is assumed that the Government will be able to sell part of the land surrounding; to persons and companies wishing to construct houses, villas, business and shopping centers, etc. Mogran Re-development Project is a sample of such settlement in Khartoum (espm-eser, 2008).

Table 4-4 Khartoum Bridges costs per Meter

Bridge	Total Cost USD	Length	Cost USD / m
Ingaz	35,000,000	757.2 m	46,222.9
AL Manshia	10,426,766	340 m	30,666.9
AL Mack Nimir	27,000,000	854 m	31,615.9
AL Halfaya	40,000,000	910 m	43,956.1
AL Dabaseen	37,000,000	1670 m	22,155.7

As shown in table 4-4 the average of Bridge costs / meter is around 35,000 $, This amount depends on the project specification such as length, width, and facilities. Ingaz Bridge is consisting of two way, 8.75m each, with 2m pedestrian walk of each side and 80 cm service both sides and 1.25m for middle island, total width is 23.55m.

AL Manshia Bridge consists of two way, 8.25m each side, with 1.35m pedestrian walk distance for each side, 80 cm service both side, and 0.5m for middle island, the total width is 20.5m

MckNimir Bridge is consist of two way, 8.3m each, with 1.8m pedestrian walk distance for each side, 80 cm service both side, and 1m for middle island, the total width is 22.0m

OTB Tunnel cost is estimated by rate per meter, the SBP machine cost 42,636 SDG to 60,000 SDG per meter (converting from USD to SDG @ 6.00 rate as per Sudan central bank)

For overall path of 2.8 km for the main tunnel and 0.32 km for Tuti arms:

3.12 x 42,636 = 133,024,320 as minimum cost and

3.12 x 60,000 = 192,600,00 as maximum cost

Average cost = 133,024,320 + 192,600,00 / 2 = 162,812,16 SDG .

This cost includes all expenses of project considering the entrance and exit of the tunnel.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Results and Discussion

Constructing a tunnel is one of the most complex challenges in the field of civil engineering. Many tunnels are considered technological masterpieces, although some other tunnel projects have encountered major setbacks. but these challenges didn't disturb engineers from going even for advance.

Tunnels are considered one of the most important integrated solutions to control traffic jams and reduce the rush hours on streets and main roads, Moreover, the fluidity of movement and free of constraints lead to reduce significantly the rate of accidents and assists in the provision of a safe and comfortable environment.

The number of vehicles which used Khartoum bridges in 2014 amounted as detailed in Table 4-2. The huge volume indicates the importance and significances' of shifting to more contemporary ways in finding appropriate and efficient solution for congestion. Tunneled is recommend here as acceptable alternative.

O.T.B tunnel was selected from two proposals as the most suitable one. First, it serves a large area for three cites (Omdurman, Bahri and Khartoum via Tuti). Second, it makes Khartoum ring road more efficient through linking Tuti Island, Bahri and Omdurman and creating new routs for traffic.

About 161,000 cars bridges between Omdurman and Khartoum per day. In addition, 84185 cars use between Omdurman and Bahri. Moreover, severe vehicles choose to cross indirect route to their destination to avoid traffic congestion.

OTB tunnel was proposed to alleviate overcrowding in the main bridges, 75000 car per day are estimated with two lanes each direction.

Although many road tunnels appear rectangular from inside bordered by walls, ceiling and pavement, the actual tunnel section is mainly decided by the ground condition and construction methods as discussed in Chapter 2 above.

As pre dominant soil in the area is silty sand and silty clay, the most suitable method for construction is to use TBM machine. The method allows excavate in this type of soil safely and fast producing nearly 30 cubic meters per day. T.B.M machine is suitable for tracks longer than one km. It has been chosen because of its suitability to excavation under

River Nile for 2.8 km. The S.P.B type has been chosen for the silty clay soil with high Nile water pressure.

To support vertical faces of excavation at the earliest stage and before lowering down the TBM machine. Permanent rigid system is suitable method for use in the same soil with greater depth.

The tunnel section is influenced by the method of construction (T.B.M) machine that has a circular shape with the size of diameter as in Chapter 4. A cross section of 19 m diameter was proposed, On the other hand, all bridges in Khartoum have widths virtually around 20 meters as in Chapter 4. For example, Ingaz Bridge has width of 23.55 m. Almanshia Bridge 20.5 m. Al Mack Nimer Bridge 22 m. Therefore, it is efficient to make a tunnel section for 19 meters to cover all of the miscellaneous tunnel appurtenances such as:

• Travel lanes, (two lanes with 3.5m width for each lane).

• Shoulders (1 m is suggested for, and 3m width for right shoulder.)

• Sidewalks/Curbs

• Tunnel drainage

• Tunnel ventilation

• Tunnel lighting

• Tunnel utilities and power

• Cabinets for hose reels and fire extinguishers

• Signals and signs above roadway lanes

• CCTV surveillance cameras

The Tunnel section consists of all services for operation of the tunnel in a correct and safe way. The section contains separate area for each service such as electric components, air exhaust, pumping and drainage system, as well as emergency exits beside traffic runway.

Although pedestrians are typically not permitted in road tunnels, sidewalks are required in road tunnels to provide emergency egress and access by maintenance personnel. It is recommended that raised sidewalks or curbs with a width of 0.7 to l.0 m or wider beyond the shoulder area are desirable to be used for emergency egress, in addition requires an emergency egress walkway within the cross-passageways be of a minimum clear width of 1.12 m, and that a raised barrier to prevent the overhang of vehicles from damaging the wall finish or the tunnel lighting fixtures be provided.

Drainage must be provided in tunnels to deal with surface water as well as water leakage. However, drainage lines and sump-pumps should be sized to accommodate water intrusion and/or firefighting requirements. PVC, fiberglass pipe, or other combustible materials should not be used for safety reasons.

Additional elements may be needed under certain design requirements and should be taken into consideration when developing tunnel geometry configuration.

The average cost of each existing bridge per meter is about 35,000 $. This amount is almost the average cost of tunnel construction by T.B.M machine. Furthermore, TBM is more economic for long track more than 1 km, by taking this account, reducing of the work force and less land repayment for owners beside the development of the surrounding area.

Precast segmental lining system is the type used to cover the internal face of the tunnel, TBM machine is loaded with concrete segments, where the machine will push them in the direction of the tunnel interior surfaces. Hereafter, installation process will take place mechanically.

Safety plans have been developed to facilitate the process of establishing tunnel safely in order to avoid dangerous incidents. The tunneling process is one of the most dangerous construction that lead to deadly accidents and disasters.

Ventilation, Fire prevention and personal protective are the most important practices that should be implemented in the tunneling process.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6. 1 Summary

It is proposed to establish a tunnel linking Omdurman and Bahri through Tuti island (OTB) so as to obtain the maximize benefits and reduce traffic congestion on main roads and bridges in Khartoum State this was selected after a comparison with another proposal linking Khartoum and Bahri directly, it was found that the path of OTB is more effective as it helps to use Khartoum and Tuti ring road more efficiently.

Traffic data analysis showed the high current and future traffic demand.

o construct a tunnel under water needs special excavation and construction techniques, TBM machine has been proposed to be used as safe and effective way as it proved in similar situation .

Soil analysis has been carried out to obtain soil type and choose proper construction method. Such soil analysis is costly and needs huge machine. Thus, previous soil data was collected from different large projects such as Tuti bridge and Tuti Bahri proposed bridge (ESD -2011).

The cross section design has been proposed which contains all the services that should be installed for use tunnel in an efficient way. Moreover, safety and financial feasibility are illustrated.

6. 2 Conclusions

It is considered appropriate time to shift into modern infrastructure solutions for solving traffic congestion in Khartoum, especially with rapidly growing population and traffic. It is justifiable to conclude that O.T.B tunnel could be used as an efficient traffic congestion relive alternative solution to bridge economically.

O.T.B tunnel will increase the effectiveness of the ring road by linking to Tuti Island with other Khartoum cites and by creating new paths connected to the ring road.

Khartoum is one of the major cities that can accommodate infrastructure projects. Simple study of tunnel elements and components shows that it possible to construct a similar tunnel spatially with the help of TBM machine with less cost and in a reasonable time.

6. 3 Recommendations

Within the scope of this study, the following recommendations are made: -

- To make complete study of the alternative tunnel track (Khartoum Bahri) in order to determine its effectiveness in more details.
- Such a project needs to be considered for a comprehensive study of all related components and element. There include structures details, soil data investigation, mechanical and electric aspects. It’s recommended to complete this research by designing of tunnel concrete elements as precast segments and roadway structure.
- It is also recommended to study an alternative method of construction for O.T.B tunnel such as tunnel-immersed tube.

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APPENDIX A

ESD SOIL REPORT TABLES

Table A-1 Soil Analysis Result for Omdurman Area

Depth (m)	Description	Group Symbol	Atterberg Limits			N.M.C %	%pass sieve #200	SPT-Results	
			L.L %	P.L %	P.I %			Blows for 6,3,3,3,3 inch	N Value
1.00	Dense yellowish whitish clayey sand with calcareous								
	materials	SC	32	24	8	4.64	40.21	6,8,9,9,10	36
2.00									
3.00	same but very dense		32	23	9	5.49	48.58	12,15,21,15	>50
4.00	Hard yellowish brownish silty clay of low plasticity	CL	26	20	6	14.35	50.32	7,7,9,15,15	46
5.00									
6.00			30	15	15	19.39	54.44	11,17,19,15	>50
7.00	same but with numerous of calcareous materials								
8.00	Medium dense yellowish brownish silty sand	SM		NP	NP	18.24	36.19	13,7,6,6,7	26
9.00	same but very dense			NP	NP		35.77	14,12,22,17	>50
10.00									
11.00	Very dense yellowish brownish silty sand	SM		NP	NP		39.36	15,10,13,15,13	>50
12.00				NP	NP		35.96	15,13,13,17,8	>50
13.00									
14.00				NP	NP		36.21	24,39,12	>50
15.00				NP	NP		38.85	21,51	>50
16.00									
17.00	Hard dark brown to yellowish brwonish silty clay of low	CL	22	16	6		58.27	29,51	>50
18.00	plasticity possible very weak mudstone		23	15	8		54.38	38,51	>50
19.00									
20.00	Very dense dark brown to yellowish brownish low plastic silt	ML	23	21	2		54.51	51	>50

Table A-2 Soil Analysis Result for Tuti Area

Depth (m)	Description	Group Symbol	Atterberg Limits			N.M.C %	%pass sieve #200	SPT-Results		Remarks
			L.L %	P.L %	P.I %			Blows for 6,3,3,3,3 inch	N Value	
1.00	Loose light brown poorly graded silty sand	SP-SM		NP	NP		5.49			
								1,1,1,1,1	4	
2.00										
3.00		SP		NP	NP		1.45	2,1,1,1,2	5	
4.00										
	same but dark brown						4.64	3,2,1,2,2	7	
5.00										
6.00								2,2,1,2,3	8	
7.00										
	same but medium dense light grey	SP-SM		NP	NP		7.02	3,3,4,3,3	13	
8.00										
9.00		SP		NP	NP		4.36	5,4,5,5,4	18	
10.00										

Table A-3 Cont. Soil Analysis Result for Tuti Area

Depth (m)	Description	Group Symbol	Atterberg Limits			N.M.C %	%pass sieve #200	SPT-Results		Remarks
			L.L %	P.L %	P.I %			Blows for 6,3,3,3,3 inch	N Value	
	Very dense whitish yellowish silty sand with	SP		NP	NP		3.86	10,39,13	>50	
11.00	completely weathered sedimentary sandstone									
12.00							2.62	51/4"	>50	Penetration = 4"
13.00										
	same but yellowish greyish							51/3"	>50	Penetration = 3"
14.00										
15.00		SP-SM		NP	NP		10.23	51/4"	>50	Penetration = 4"
16.00										
	same but whitish greyish							51/3"	>50	Penetration = 3"
17.00										
18.00							9.07	51/3"	>50	Penetration = 3"
19.00										
	same but yellowish whitish							51	>50	No penetration
20.00										

Table A-4 Soil Analysis Result for Bahri Area

Depth (m)	Description	Group Symbol	Atterberg Limits			N.M.C %	%pass sieve #200	SPT-Results		Remarks
			L.L %	P.L %	P.I %			Blows for 6,3,3,3,3 inch	N Value	
1.00	Loose light grey poorly graded silty sand with some mica									
		SP-SM					10.30	1,1,2,2,3	8	
2.00										
3.00							5.31	3,2,2,2,3	9	
4.00										
	same but medium dense	SP					2.71	5,4,3,4,4	15	
5.00										
6.00							4.62	2,4,3,4,5	16	
7.00										
		SP-SM					10.25	5,5,4,5,4	18	
8.00										
9.00	same but well graded	SM					14.60	6,5,6,4,4	19	
10.00										
	same but poorly graded	SP					2.04	5,7,4,5,5	21	

Table A-5 Cont. Soil Analysis Result for Bahri Area

Depth (m)	Description	Group Symbol	Atterberg Limits			N.M.C %	%pass sieve #200	SPT-Results		Remarks
			L.L %	P.L %	P.I %			Blows for 6,3,3,3,3 inch	N Value	
11.00										
	Medium dense light grey poorly graded silty sand									
12.00		SP					2.69	6,3,3,4,4	14	
13.00										
		SP-SM					5.08	3,4,3,4,4	15	
14.00										
15.00								2,4,3,2,3	12	
16.00										
		SP					3.46	4,3,3,4,4	14	
17.00										
18.00								3,3,3,4,5	15	
19.00										
							3.93	5,4,5,5,4	18	
20.00										
21.00	Very dense light yellow clayey sand	SC	35	22	13		38.26	15,17,34	>50	

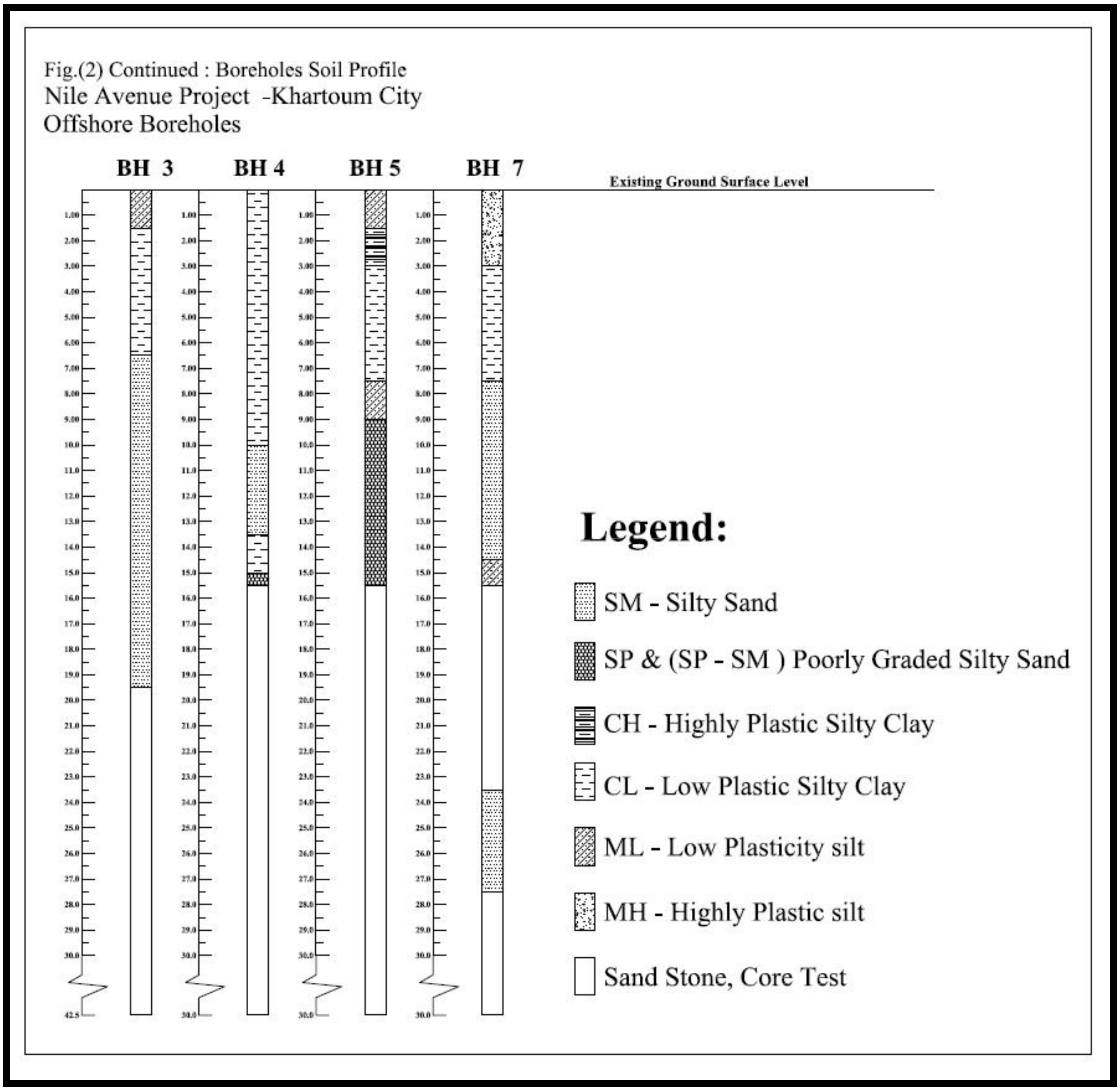
Fig.(2) Continued : Boreholes Soil Profile
Nile Avenue Project -Khartoum City
Offshore Boreholes
BH 3
BH 4
BH 5
BH 7
Existing Ground Surface Level
Legend:
SM - Silty Sand
SP & (SP - SM) Poorly Graded Silty Sand
CH - Highly Plastic Silty Clay
CL - Low Plastic Silty Clay
ML - Low Plasticity silt
MH - Highly Plastic silt
Sand Stone, Core Test

Figure A-1

APPENDIX B

Tunnel Ventilation

B-1 Ventilation:

Tunnel ventilation systems can be categorized into five main types or any Combination of them. The five types are as follows:

· Natural Ventilation

· Longitudinal Ventilation

· Semi-Transverse Ventilation

· Full-Transverse Ventilation

· Single-Point Extraction.

It should be noted that ventilation systems are more applicable to highway tunnels due to high concentration of contaminants. Rail transit tunnels often have ventilation systems in the stations or at intermediate fan shafts, but during normal operations rely mainly on the piston effect of the train pushing air through the tunnel to remove stagnant air. Many rail transit tunnels have emergency mechanical ventilation that only works in the event of a fire. For further information on tunnel ventilation systems refer to NFPA 502 (National Fire Protection Agency).

a) Natural Ventilation

A naturally ventilated tunnel is as simple as the name implies. The movement of air is controlled by meteorological conditions and the piston effect created by moving traffic pushing the stale air through the tunnel. This effect is minimized when bi-directional traffic is present. The meteorological conditions include elevation and temperature differences between the two portals, and wind blowing into the tunnel. Figure B-1 shows a typical profile of a naturally ventilated tunnel. Another configuration would be to add a center shaft that allows for one more portal by which air can enter or exit the tunnel. Many naturally ventilated tunnels over 180 m (600 ft.) in length have mechanical fans installed for use during a fire emergency.

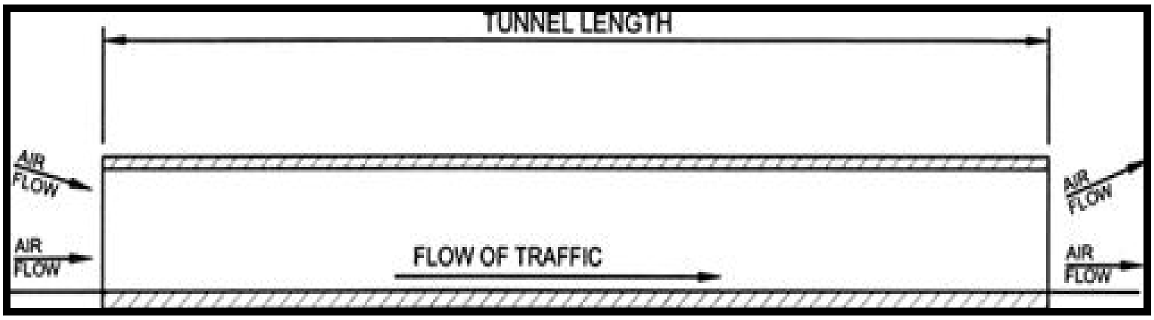

Figure B-1

b) Longitudinal Ventilation

Longitudinal ventilation is similar to natural ventilation with the addition of mechanical fans, either in the portal buildings, the center shaft, or mounted inside the tunnel. Longitudinal ventilation is often used inside rectangular-shaped tunnels that do not have the extra space above the ceiling or below the roadway for ductwork. Also, shorter circular tunnels may use the longitudinal system since there is less air to replace; therefore, the need for even distribution of air through ductwork is not necessary. The fans can be reversible and are used to move air into or out of the tunnel. Figure B-2 shows two different configurations of longitudinally ventilated tunnels.

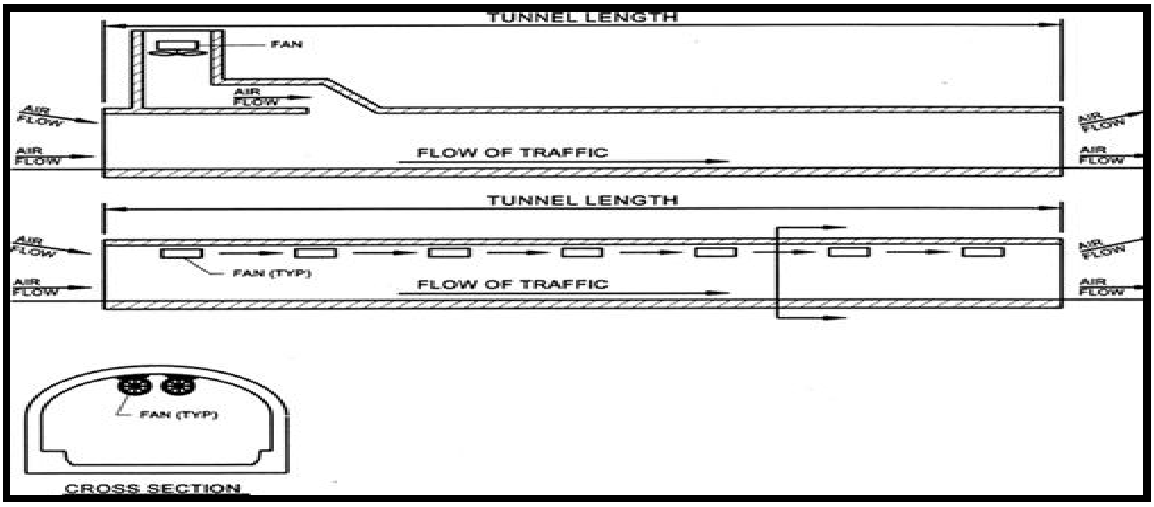

Figure B-2

c) Semi-Transverse Ventilation

Semi-transverse ventilation also makes use of mechanical fans for movement of air, but it does not use the roadway envelope itself as the ductwork.

A separate plenum or ductwork is added either above or below the tunnel with flues that allow for uniform distribution of air into or out of the tunnel. This plenum or ductwork is typically located above a suspended ceiling or below a structural slab within a tunnel with a circular cross-section. Figure B-3 shows one example of a supply-air semi-transverse system and one example of an exhaust-air semi-transverse system. It should be noted that there are many variations of a semi-transverse system. One such variation would be to have half the tunnel is a supply-air system and the other half an exhaust-air system.

Another variation is to have supply-air fans housed at both ends of the plenum that push air directly into the plenum, towards the center of the tunnel. One last variation is to have a system that can either be exhaust-air or supply-air by utilizing reversible fans or a louver system in the ductwork that can change the direction of the air. In all cases, air either enters or leaves at both ends of the tunnel (bi-directional traffic flow) or on one end only (unit-directional traffic flow.)

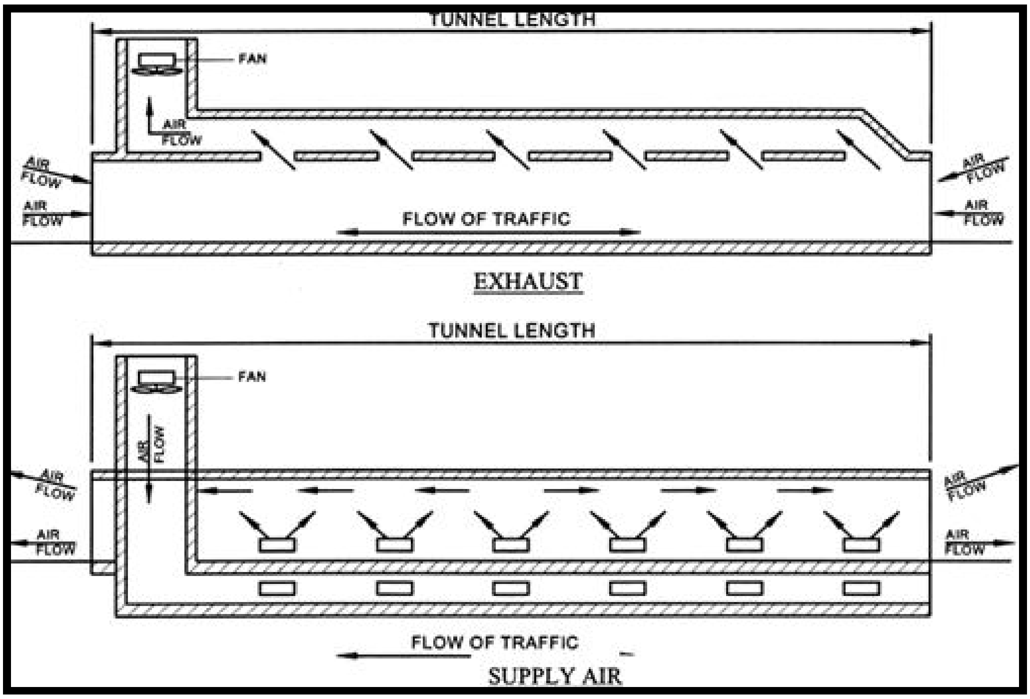

Figure B-3

d) Full-Transverse Ventilation

Full transverse ventilation uses the same components as semi-transverse ventilation, but it incorporates supply air and exhaust air together over the same length of tunnel. This method is used primarily for longer tunnels that have large amounts of air that need to be replaced or for heavily traveled tunnels that produce high levels of contaminants. The presence of supply and exhaust ducts allows for a pressure difference between the roadway and the ceiling; therefore, the air flows transverse to the tunnel length and is circulated more frequently.

This system may also incorporate supply or exhaust ductwork along both sides of the tunnel instead of at the top and bottom. Figure B-4 shows an example of a full-transverse ventilation system.

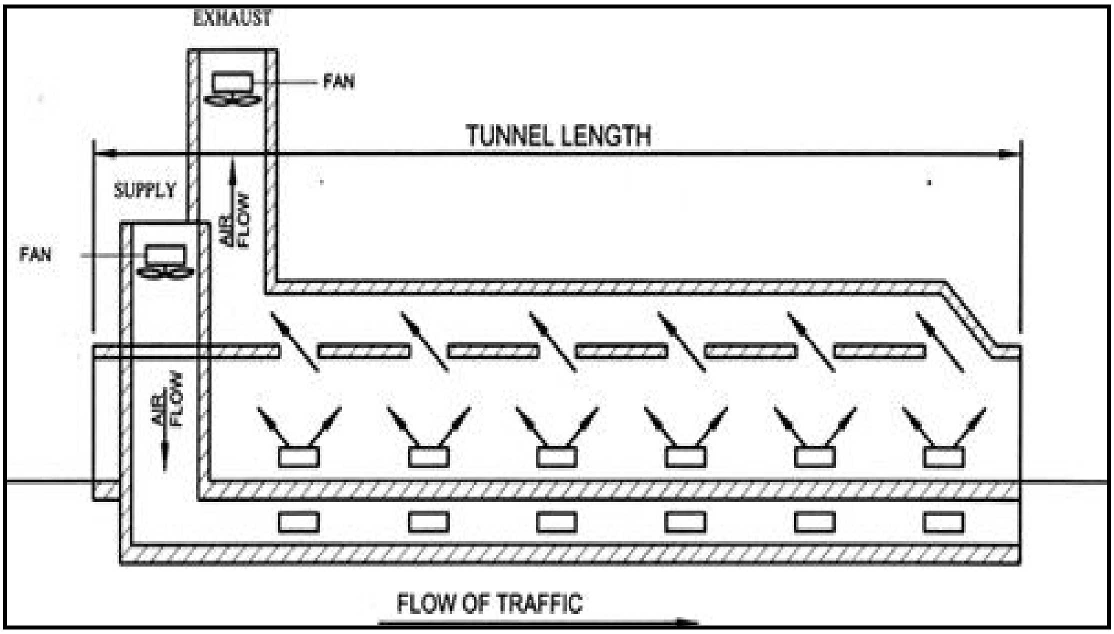

Figure B-4

e) Single-Point Extraction

In conjunction with semi- and full-transverse ventilation systems, single point extraction can be used to increase the airflow potential in the event of a fire in the tunnel. The system works by allowing the opening size of select exhaust flues to increase during an emergency. This can be done by mechanically opening louvers or by constructing portions of the ceiling out of material that would go from a solid to a gas during a fire, thus providing a larger opening. Both of these methods are rather costly and thus are seldom used. Newer tunnels achieve equal results simply by providing larger extraction ports at given intervals that are connected to the fans through the ductwork.

Equipment

a) Fans

There are two main types of axial fans—tube axial fans and vane axial fans as shows in fig B-5.

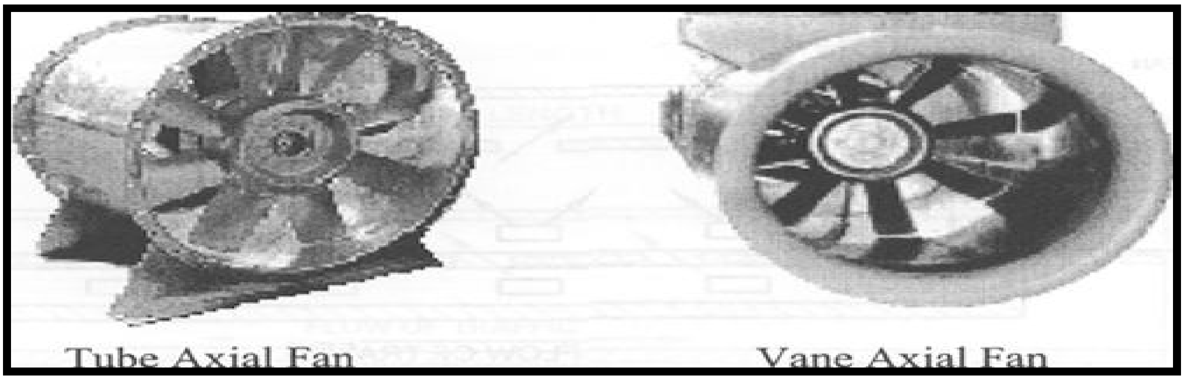

Fig. B-5 Axial Fans

Centrifugal type of fan outlets the air in a direction that is 90° to the direction at which air is obtained. Air enters parallel to the shaft of the blades and exits perpendicular to that. For tunnel applications, centrifugal fans can either be backward-curved or airfoil-bladed. Centrifugal fans are predominantly located within ventilation or portal buildings and are connected to supply or exhaust ductwork. They are commonly selected over axial fans due to their higher efficiency with less horsepower required and are therefore less expensive to operate.

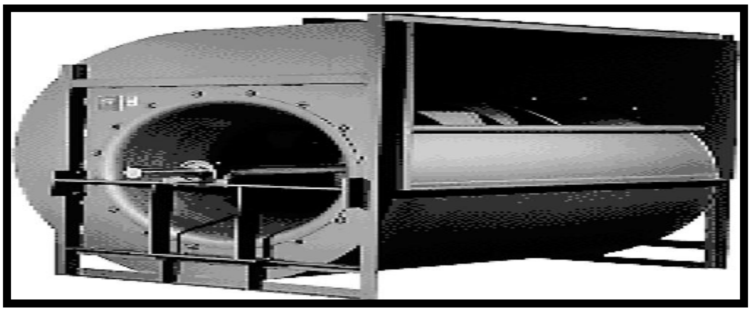

Figure B-6 Centrifugal Tunnel

APPENDIX C

TUNNEL LIGHTING

C- 1 Tunnel Lighting Systems

a) Highway Tunnels

There are various light sources that are used in tunnels to make up the tunnel lighting systems.

These include fluorescent, high-pressure sodium, low-pressure sodium, metal halide, and pipe lighting, which is a system that may use one of the preceding light source types. Systems are chosen based on their life- cycle costs and the amount of light that is required for nighttime and daytime illumination. Shorter tunnels will require less daytime lighting due to the effect of light entering the portals on both ends, whereas longer tunnels will require extensive lighting for both nighttime and daytime conditions. In conjunction with the lighting system, a highly reflective surface on the walls and ceiling, such as tile or metal panels, may be used.

Fluorescent lights typically line the entire roadway tunnel length to provide the appropriate amount of light. At the ends of the roadway tunnel, low-pressure sodium lamps or high-pressure sodium lamps are often combined with the fluorescent lights to provide higher visibility when drivers' eyes are adjusting to the decrease in natural light. The transition length of tunnel required for having a higher lighting capacity varies from tunnel to tunnel and depends on which code the designer uses.

Both high-pressure sodium lamps and metal halide lamps are also typically used to line the entire length of roadway tunnels. In addition, pipe lighting, usually consisting of high-pressure sodium or metal halide lamps and longitudinal acrylic tubes on each side of the lamps, are used to disperse light uniformly along the tunnel length.

b) Rail Transit Tunnels

Rail transit tunnels are similar to highway tunnels in that they should provide sufficient light for train operators to properly adjust from the bright portal or station conditions to the darker conditions of the tunnel. Therefore, a certain length of brighter lights is necessary at the entrances to the tunnels.

The individual tunnel owners usually stipulate the required level of lighting within the tunnel.

However, as a minimum, light levels should be of such a magnitude that inspectors or workers at track level could clearly see the track elements without using flashlights. (FHWA)