AKADEMIA GÓRNICZO-HUTNICZA
im. Stanisława Staszica w Krakowie

WYDZIAŁ WIERTNICTWA, NAFTY I GAZU

Studia stacjonarne drugiego stopnia

PRACA MAGISTERSKA

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Kierunek studiów: **Wiertnictwo Naftowe**

Moduł: **Wiertnictwo i Geoinżynieria**

Temat pracy dyplomowej:

Technika budowy tuneli

Technique of tunnels excavation

Promotor:

Prof. dr hab. inż. Andrzej Gonet

Ocena pracy: ....

Kraków 2018

Kraków, 09/06/2018

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Fernando Ecum[illegible]

(Podpis autora)

ABSTRACT

Technique of tunnels excavation

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This master thesis is dealing with tunneling, more precisely with tunneling construction techniques applies to excavate underground constructions, and more specifically the discussion of using the mechanized technology of excavation (TBM) tunnel.

Tunnel construction techniques employs the analyzes of parameters during excavation process of tunnel aims to optimize maximum excavate rate depend on throughout analyzes of the main factors such as the natural conditions of the grounds, the environments effects, the construction effects, the equipment available, labor force, and the nature and the cost of labor.

The construction techniques applies to tunnel differ depend of the parameters affecting the construction and as an oil and engineer always had a knowledge of drilling with small dimeter to explore the hydrocarbon in deep depth. Tunnel as well are differentiate on size of diameter of the construction and the purpose of the tunnel .The different tunnel are horizontal drilled tunnel for the sanitation purpose, drainage with small diameter and metro tunnel or the road employs bigger diameter.

Commonly knowing method used to excavate tunnel are the cut and cover, drill and blast and the mechanized method which excavation is done using tunnel boring machines (TBMs, Tunnel Boring Machines) has gained increasing importance in the last age of tunnel construction, particularly in urban environments because of their techniques of construction such as allows the possibility of crossing complex geological and hydrological conditions with safety to the environment and labor force, and relative economy when excavating longer tunnel. Tunneling boring machines are mainly manufactured to adapt in a certain ground mass, the charactering of this machines allows the efficiency performance of the machines, and technical ability of an engineer to analyze during the stages of the construction, the safety inside and outside the tunnel, driving force of the machines to efficiently excavate the specify ground mass, the time necessary to apply support into the excavation and the type of cutterhead to be used.

My interesse to the topic of tunnel construction is to find alternative way of reducing traffic jam in Luanda, Angola. Currently major projects base on a design and an engineering plans are being carried for the realization of a possibility tunnel construction in Angola by THE SENDESA group. The group consists of Angolan students from different faculties at the technical university AGH.

STRESZCZENIE

TECHNIKA BUDOWY TUNELI

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Praca magisterska dotyczy drążenia tuneli, a dokładniej technik budowy tuneli stosowanych do wykopów pod ziemią, w szczególności omówienia wykorzystania zmechanizowanej technologii wykopu (TBM).

Technika budowania tuneli wykorzystuje analizy własności skał podczas procesu drążenia tuneli w celu zoptymalizowania maksymalnego poziom wykopu. Zależy to głównie od takich czynników jak naturalne warunki gruntu, skutki środowiskowe, skutki budowy, dostępne wyposażenie, siła robocza oraz charakter i koszt pracy.

Techniki budowlane zależne są od parametrów wpływających na konstrukcję tuneli. W inżynierii ropy naftowej wiercimy otwory (tunele) o małej średnicy, aby wydobyć węglowodory, które znajdują się na dużej głębokości. Tunele zróżnicowane są również pod względem średnicy i przeznaczenia tunelu. Tunele o małych średnicach wykorzystywane są jako kanalizacja, a o dużych średnicach jako tunele kolejowe lub drogowe.

Powszechnie znaną metodą jest metoda odkrywkowa, metoda górnicza (strzałowa) oraz zmechanizowana metoda, w której wykopy są wykonywane za pomocą maszyny do drążenia tuneli (TBM, Tunnel Boring Machines). Metody te zyskały na znaczeniu w ostatnim wieku budowania tuneli, szczególnie w środowiskach miejskich ze względu na ich techniki budowy pozwalające na przekraczanie złożonych warunków geologicznych i hydrologicznych z bezpieczeństwem dla środowiska i siły roboczej oraz względną ekonomię podczas ich realizacji. Maszyny drążące są wytwarzane głównie w celu dostosowania do określonego rodzaju gruntu. Charakterystyka tych maszyn pozwala na sprawne działanie maszyn i zdolność techniczną inżyniera do analizy podczas etapów budowy, bezpieczeństwo wewnątrz i na zewnątrz tunelu, odpowiednią siłę napędowa maszyn do sprawnego wykopywania określonej masy ziemi, czasu potrzebnego do zastosowania podparcia w wykopie.

Moim celem w tym temacie było znalezienie alternatywnego sposobu ograniczenia korków drogowych w Luandzie w Angoli. Obecnie opracowywany jest projekt związany z realizacją budowy tunelu w Angoli przez grupę THE SENDESA. To grupa angolskich studentów na AGH, która obejmuje mnie i moich rodaków.

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NOMENCLATURE

Roman

Symbol		Unit [SI]
a	formation thickness for anticline	[m]
b	formation thickness for syncline	[m]
e	void ratio	[-]
Kt	total tension ratio	[-]
LI	liquilidy limit	[-]
M_w	skeleton mass of the rock	[Kg]
M_t	total mass of the rock	[kg]
M_w	mass of water in rock	[kg]
n	porosity	[-]
PI	plasticity limit	[-]
PL	atterberg limit	[-]

$\sigma 1$, $\sigma 2$, $\sigma 3$	principal tension	[Pa]
σv	vertical tension	[Pa]
s	degree of saturation	[-]
V_s	total volume	[m3]
V_v	void volume	[m3]
V_w	volume of the water	[m3]
w	moisture saturation	[-]
w_p	atterberg boundaries	[-]
γ	volumetric weight	[kg/m3]

Greek

Symbol		**Unit [SI]**
ρ	total density	[kg/m3]
ρ_d	rock density	[kg/m3]
ρ_{sat}	water density	[kg/m3]

1. Introduction

The construction of tunnels under urban areas and in difficult subsoil layers of faults or flexures, as well as the growing depend on rapid transport (People, goods, sewage, water, energy and etc.), have led to the need for designing equipment that performs the excavation in order to maintain the highest possible safety, as well as to make the cost-effective for an excavation of a tunnel [1].

To excavate the tunnel with tunnel boring machines requires a vast knowledge of Geotechnics and the mechanics of the soil and this allows selection of machine to be used with the right components. For instance the use of a TBM (Tunnel Boring Machine) compare to conventionally technique, it has brought an improve to the working conditions of workers, the possibility of crossing complex geological and hydrogeological conditions safely inside and outside the tunnel, and relative more economy in long tunnel .Furthermore, These machines perform the tunneling excavation much faster, works as temporary support and allows a possibility of placing an immediate prefabricated support and walls to the excavate ground, and the techniques causes less disturb to the surround business, limits traffic jam and less frighten to decompose the soil.

Types of tunneling

To understand the mechanism of the construction techniques of tunneling one needs to analyze the tunnels types to see the method and application techniques to be applied on the selected tunnel**.** To better understand refers to the (fig.1.1.).

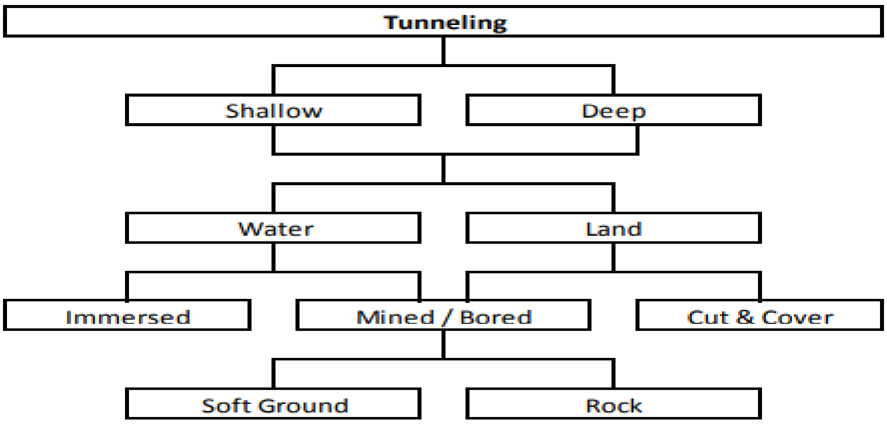


Fig.1.1. Types of Tunnels.[17]

The construction of tunnel various on techniques depend on the type of tunnel, tunnel profile which eventually define the tunnel technology. Since the earlier discover of tunneling to the present date these methods for construction have seen great improvements. The history outlines uses pickles, labor force to excavate and transport of mucking. The discovery of dynamite allowed the blasting method and the recent use of the TBM machines which does the assemble the excavating, support of the cavity and removal of mucking (excavated earth). The thesis will discuss some of most common methods used in nowadays, and highlights their applications and limitations. Apart of

tunnels types and tunnels profile knowledge which allows the selection of the method to be used, one needs to understand the behavior/characteristics of a soil particles, the impact of the construction on the surrounding environment, economic bearing, and health and safety issues.
Some of most common tunnel construction techniques which will be discussed in the thesis are the drilling and blasting (D&B) and mechanized continuous heading; tunnel-boring machine (TBM) and this method was used to constructed one of the longest tunnel in the world the famous Gotthard (Swiss tunnel). Drilling and blasting is preferably used when the tunnel is relatively short, thus the high investment cost needed for the TBM is not financially sustainable, or if the ground hardness is relatively high, causing greater wear on the cutting tools. In addition, the B&D allows alternative cross sectional profiles, other than just a circular profile. It is also easier to construct safe passages between twin tube tunnels. However, the drilling and blasting procedures are often conducted sequentially, due to safety hazards when handling explosives, thus the tunneling speed is generally lower compared with TBM tunneling

1.1. Main purpose

This dissertation intends to analyze and archive information on the tunnel excavation using tunnel boring machines, presenting the different techniques and types of TBM currently used around the world according to their suitability for excavation of a certain georgical layers. It is also intended to present the parameters of the masses ground to be taken into account for the proper selection and dimensioning of a TBM.
The tunneling bored machines have brought improvements to the tunneling process to an industrial scale with a consequent reduction in costs, time and a good quality of the final product, that is, less change of the surrounding mass, possibility of placing of immediate support, prefabricated coating and more regular excavation walls.
It is also intended to present a case study of relevant tunnels constructed with TBM technology around the World.

1.2. Thesis outline

In addition to the introductory chapter, this thesis present chapter, which explains some general considerations and motivations that led to the compilation of this dissertation, it is composed of seven more chapters, the most relevant aspects of which are presented below.

- The second chapter " history of tunnel" outlines the excavation period of tunnel. This chapter discuss the earlier ages, middle age and the improvement on the tunnel construction techniques .
- The third chapter "geotechnics considerations" understand the behavior of the ground to be excavated to apply the TBM technology
- The s chapter " tunneling technologies" outlines the excavation of tunnel. This chapter discuss the cut and cover, conventional method and the introduction to tunneling boring machines.

- The fourth third chapter ”TBM techniques on hard rocks” outlines in detail the TBM components to excavate the tunnel.
- The firth chapter ”TBM techniques on hard soft ground/rocks” outlines in detail the TBM components to excavate the tunnel.
- The sixth chapter ”TBM techniques on hard rocks” outlines in detail the TBM components to excavate the tunnel.
- Case study tunnel construction techniques.
- Finally considerations to sum up the dissertation.
- Reference biography

2. History of tunnel construction

The antiquity of the use of the subterranean space assumes almost as old as the humanity itself, being that it used caves and natural caves like shelters, which still today there are vestiges of this use, this tunnel were excavated in 500 BC in Malta to connect caves.

2.1. Ancient time

Traces of excavation of tunnels and wells for mineral extraction are also found, such as the case of the Grimes Grave mine, England, throughout the Mesolithic period, from the Neolithic period to the beginning of the Metal Age, more specifically the Bronze Age, that is, between about 10,000 and 1500 BC where red deer horns were used as digging tools.
The oldest tunnel was constructed between 2180 and 2160 A.C. in Babylon under the river Euphrates, divert the river from its original bed and used the technique now called "Cut and Cover". This tunnel had the objective of connecting the royal palace to the temple, being these distanced about 1 km. In ancient times, between 95 and 326 AD, the largest network of tunnels of this period was built. With about 940 m connecting 60 catacombs, it houses 6 million Christians underground in Rome from the time of persecution of Christians (Fig.2.1.).

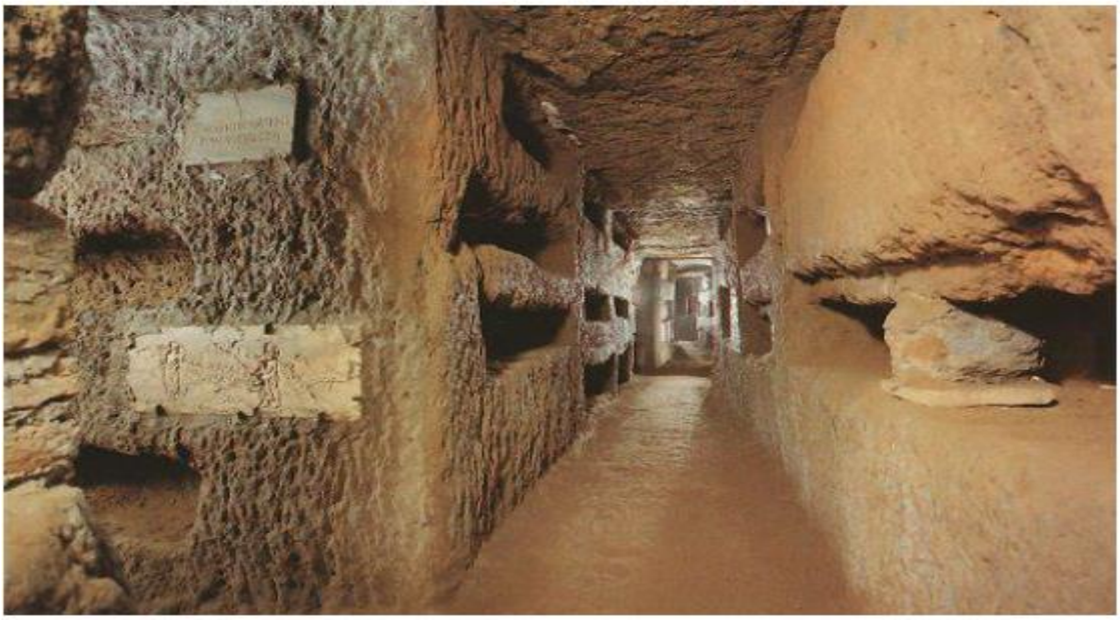


Fig.2.1. Catacombs of Domitila, Rome, Italy [7]

About 600 BC Nebuchadnezzar was building the first arched traffic tunnel. Its length was about 1 km (3280 ft) and the dimensions were about 3,6 to 4,7 m (11,8 to 15,4 ft). A historical innovation of this tunnel was the first proofed use of iron made tools.

The fire-quenching method was used to excavate the Lacus Fucinus tunnel built in 41 AD. The tunnel of 6km long and this time was consider as to be long tunnel in Roman, the excavation took about 10years to complete with a labor work of 30 000 men. The method was applied by heating up the rocks with fire and a suddenly cooling with water, and rocks could not withstand the pressure and eventually cursed in pieces . The history prove the use of slaves, prisoners of wars and other powerless men, worked as forced labor in the constructions of underground structure in Greece, Italia (Roman empire) and in the great Egypt. Contract were offered skilled labors in the middle European countries.

2.2. Middle ages

During the Middle Ages, tunnels were built only for military purposes and the use of the underground decreases significantly. With the Industrial Revolution and the steam engine machinery turn to the most productive times for tunnel engineering with the need to build railway lines.[3]

2.3. The coming back of tunnel

Today's tunnel borers originate in the tunneling shield developed by the French engineer Sir Marc Isambard Brunel for the excavation of the tunnel under the River Thames in London, United Kingdom in 1825, this being the first tunnel built under a navigable river. This was made only possible because the time France had political stability and offering no resistance to their engineers or scientist to perform their activities.[8]
During this time France constructed varies qualities structured and Austrian-Hungry empire definitely superior to France infrastructures.
Tunnels constructed during this period were:

1627 Schemnitz (Slovakia): In the Schemnitz or Selmecbanya mines gunpowder was introduced. Although it was already tested in some German mines, Selmecbanya was the first mine using it properly to exploit the minerals.

1666 Canal du Midi (France): The Canal du Midi had a length of about 157 m (515 ft) and is supposed to be the first tunnel with mayor use of blasting gunpowder. It was also one of the first tunnels after centuries of stagnation.

1678 Malpas Tunnel (F): The Malpas Tunnel is also one of the first tunnels after time of stagnation. It was about 157 m (515 ft) long and at first build without lining. The cross-section with more than 8 m (26 ft) was also very impressive.

1761 Bridgewater Canal Tunnel (Great Britain): The Bridgewater Canal Tunnel was part of a canal system built for boat traffic shipping coal from the Worsley Mine to Manchester. It was the first modern tunnel in Great Britain.

1770 Tunnel de Gier (F): After the Malpas Tunnel was build, it took 90 years till another big and challenging tunnel project was started. It was the 522 m (1.700 ft) long Tunnel de Gier, part of the railroad track between St. Etienne and Lyon.

2.5. Industry ages

1803 Canal of St. Quentin (F): The Tunnel of Tronquoy as part of the Canal of St. Quentin was a big step into modern tunneling. It was one of the first tunnels with a diameter of about eight meter (26 ft) in squeezing rock. The engineers decided to excavate the tunnel profile in multiple sections. So a separate lining in each of the sections was possible which reduced the stresses. Once all lining works were finished the core of the tunnel was removed safely. This tunnel was the beginning of a new age in tunneling, because it was the first tunnel using proper engineering principles.[7]

1824 Tunnel of Pouilly (F): The Tunnel of Pouilly is another important tunnel in France which was also built using the above mentioned Core-Method.

1825 Wapping-Rotherhithe Tunnel (GB): The Wapping-Rotherhithe Tunnel was the first tunnel using a tunnel shield, developed by Bruce, and his son Isambard, Brunel. The tunnel was built under the River Thames and became the first subaqueous tunnel. Because of several floodings the work stoped Historical Development and Innovations 17 for several years. In 1841, after a construction time of nine years, the 365 m (1.200 ft) long tunnel was finally finished.

1831 Staple Bend Tunnel (USA): The Staple Bend Tunnel was part of the Allegheny Portage Railroad System and the first railroad tunnel in the United States. Its length was about 275 m (901 ft) and the height was about 5,8 m (19 ft).

1836 / 1837 (Germany): The first and second Railroad tunnels in Germany were constructed.

1839 Gumpoldskirchen (Austria): Near Gumpoldskirchen the first railroad tunnel in Austria was built as a part of the railway line between Vienna and Trieste.

1840 Woodhead Tunnel (GB): The Woodhead Tunnel was part of the railroad line between Sheffield and Manchester. With its length of about 4.840 m (3 mi) it was one of the longest railroad tunnels at this time.

1849 Semmering Tunnel (A): It was about 1400 m (4600 ft) long. More than 1200 men were working at this tunnel, which was part of the first European mountain standard railway.

1855 Hoosac Tunnel (USA)43 : The Hoosac Tunnel was part of the canal system between Boston and Albany and about 7,3 km (4,5 mi) long. It took about 22 years to construct the 6,4 m (21 ft) high and 7,3 m (24 ft) wide bore. It was the first time dynamite and electric firing explosives were used in tunneling. Another big impact for the whole construction industry was the invention and use of power drills with air, which gave the impulse for the development of the whole compressed air technology.

1857 Mount Cenis (F): The Mount Cenis Tunnel near Frejus in the French Alps was the first tunnel forced by a mechanical tunneling machine. It took about 14 years to build this 13,7 km (8,5 mi) long tunnel and it is a milestone in tunneling. Innovations like rail mounted drills, hydraulic ram air compressors and more advanced boring technology were introduced, and led to much better forcing rates. Furthermore better methods of ventilation and surveying were used. Another novelty was the construction of houses and camps for the miners, including housing for their families, schools and hospitals.

1872 St. Gotthard (Swiss): The St. Gotthard is a 15 km (9 mi) long railway tunnel through the Swiss Alps. About 3.000 workers needed about seven and a half year to finish the tunnel. The tunnel was one of the most impressive constructions at his time but also turned the small villages at the portals into worker-towns with awful living conditions. The Gotthard is probably one of the most famous tunnels.

1880 Hudson Tunnel (USA): The Hudson Tunnel was the first attempt to force a tunnel with just compressed air. After mayor fatalities the project was stopped. Second half of 19th century: London Subway (GB): At this time the city of London started to build the first underground railway system in the world. The amount of underground tubes continued steadily during the second half of the 19th century.

1898 Simplon Tunnel (CH): With its length of 19,3 km (12 mi) the Simplon Tunnel was the longest mountain tunnel for over 70 years. Like at the Gotthard tunnel the working conditions were pretty bad and a lot of workers died under the harmful conditions.

1901 Tauern Tunnel (A): Construction of the Tauern Railroad Tunnel with a length of 8550 m (5,3 mi) 1906 Loetschberg Tunnel (CH): The Loetschberg Tunnel is also located in the Swiss Alps. It is 14,6 km (9,1 mi) long and is inglorious famous for the death of 26 workers because of an inflow of water and gravel on a length of 1.500 m (4.900 ft). The surface above this area settled about 3 m (10 ft). 1906 Detroit Tunnel: The central Michigan Railway Tunnel or Detroit Tunnel was the first modern immersed tunnel. It is about 2.560 m (1,6 mi) long and still connects the American city Detroit with the Canadian city Windsor under the Detroit River.

1927 Holland Tunnel (USA): The Holland Tunnel is connecting the cities New York and New Jersey below the Hudson River. It was named after the chief-engineer Clifford Holland and the first automotive tunnel ever built. For its purpose of automotive traffic it was in need of a proper ventilation system to blow the exhausts out of the tunnel and fresh air into it.

1954 Oahe Dam (USA): At the Oahe Dam in South Dakota the first use of a mechanical rotary excavator, named the Mittry Mole, was conducted.

2.5. Recent age

In recent years great progress of techniques to facility the tunnel construction is being developed in most advance way and a constant change of the process result into better tunneling. Nowadays regardless of the location of the intentioned tunnel to be constructed if either in the city center of Warsaw city in Poland or into the mountains of the Switzerland, the tunnel construction technology response to the demand and prevent failures or provide stability and safety not only to the surrounding environment but as well as to the labor force.[8]

List of some famous tunnels

- 1971 - 1988 Seikan Tunnel (Japan)
  The Seikan Tunnel (Fig.2.2) is a 53.85 km (33.46 mi) long construction located in Japan. 23.3 km (14.5 mi) of the tunnel are built up to 240 m (790 ft) beneath sea-level. Till 2010 it was the longest tunnel in the world. The cutterhead appearing at the through ground mass (fig.2.3).

Fig.2.2. Plan of the Seikan Tunnel [8]

Fig.2.3. Seikan tunnel, YBM excavation [6]

- 1980 – 1978 (second Tube 1998 – 2003) Plabutsch Tunnel (A)
  The Plabutsch Tunnel in the southern part of Austria is about 10 km (6,2 mi) long and the second longest twin-tube motorway tunnel in Europe.

- 1988 – 1998 Channel Tunnel (GB/F)
  The Channel Tunnel connects Great Britain and France under the Strait of Dover. It is 50.5 km (31.4 mi) long, which makes it the longest underwater tunnel in the world, and has a maximum depth of 75 m (250 ft) below sea-ground. About 15.000 workers were employed in peak times and 10 fatalities happened during construction (fig.2.4).

Fig.2.4. Channel tunnel (midpoint Fr/GB situated at 100m below sea level) [8]

- 1999 – 2016 Gotthard base Tunnel (CH)
  The Gotthard Base Tunnel is the longest tunnel in the world. With the cut-through in 2010 it reached a continuous length of 57 km (35,4 mi). The whole system is consisting of 151,84 km (94,3 mi) of underground constructions like tunnels, shafts and passages.

The support system applied on the tunnel(fig.2.6). the entrance of the longest in tridimensional shown the control room, safety gate to allow entrance control and system of communication(fig.2.5.).[7]

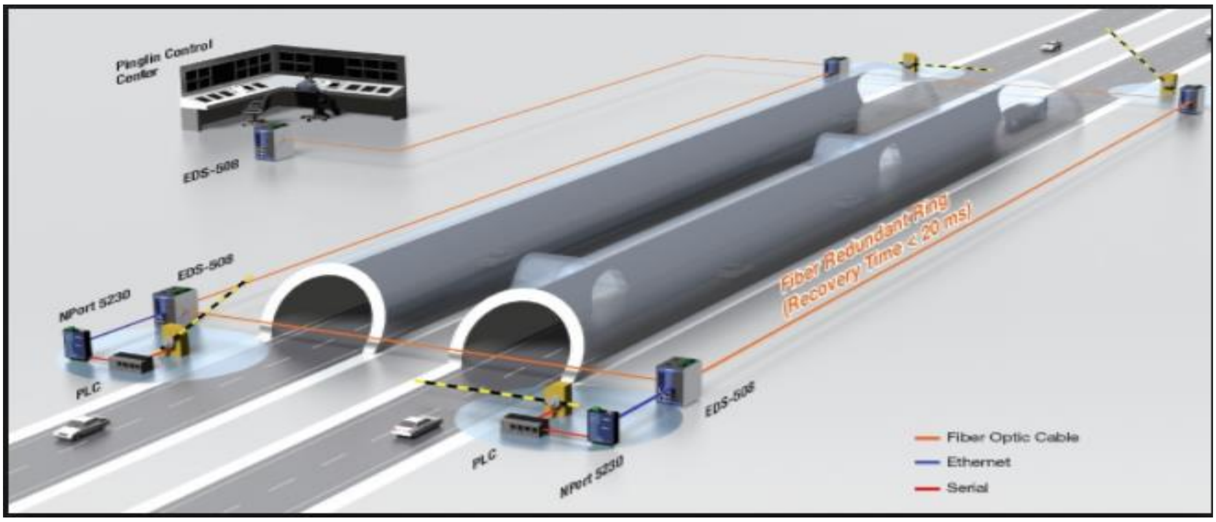


Fig.2.5. Tridimensional Gotthard base tunnel [7]

Fig.2.6. Cross section view of Gotthard base tunnel [7]

- 2000 – 2003 Metro do Porto
  The metro do Porto cover an area of 67km and just 7.7km is a tunnel, and about 6.5km were excavated by a mean of tunnel boring machine. The construction of the tunnel faced a tremendous difficulty due of Porto being an old city and took 3 years to complete the construction.

3. Geotechnical engineering considerations

In order to guarantee safety conditions and the economic viability of the project, it is necessary to carry out an adequate geotechnical engineering survey of the underground properties.

However, it is necessary to carry out a meticulous identification of the different geological formations and different mass rock layers stability depends on geological condition such as in-situ stresses, burial depth, residual strength, tunnel dimensions, excavation disturbance factor and material properties which influence stress magnitudes and deformation (the Poisson's ratio, Young's modulus, shear modulus and stiffness).[17]

Furthermore, a part geological parameters the geotechnical engineering considerations consists as well of parameters as geotechnical parameters, the construction process parameters and the material process parameters. This are catharized as main geotechnical engineering parameters which estimate the load a ground can withstand and allows to fabricate the right tunnels support to constructed in the tunnel. The hydrogeological condition of the ground should be analyzed for the presence of groundwater, being one of main parameters to determine the excavation method. In general, it is on highly importance, in relation to physical parameters, to identify the material to be excavated, its degree of change, expansibility and discontinuities, mechanical parameters, resistance and deformability of the ground, and hydrogeological, neutral pressure, permeability, and possible existence of aquifers. Addition parameters to be taken into account in the excavation of a tunnel, and which is essentially related to the chosen excavation technique, are the constructability parameters, such as the possibility of the soil to be glued the machine and the abrasiveness. The links channel factors affecting the stability of ground illustrated (fig.3.1).[2]

It should be noted that it is of utmost importance to carry out surveys and analyzes throughout the course of the work, since the construction of a tunnel is carried out underground, that is, the heterogeneity of the mass in depth may cause discomfort to the construction if the characterization of the same is not duly executed and updated preferably on each advance. Thus, it becomes possible to adjust the technique used in order to optimize its performance. Tunnel construction requires an illegal documentation of the land to be constructed through the various ministries, the ministry of land or environmental requires a proper documentation to carry the construction process.

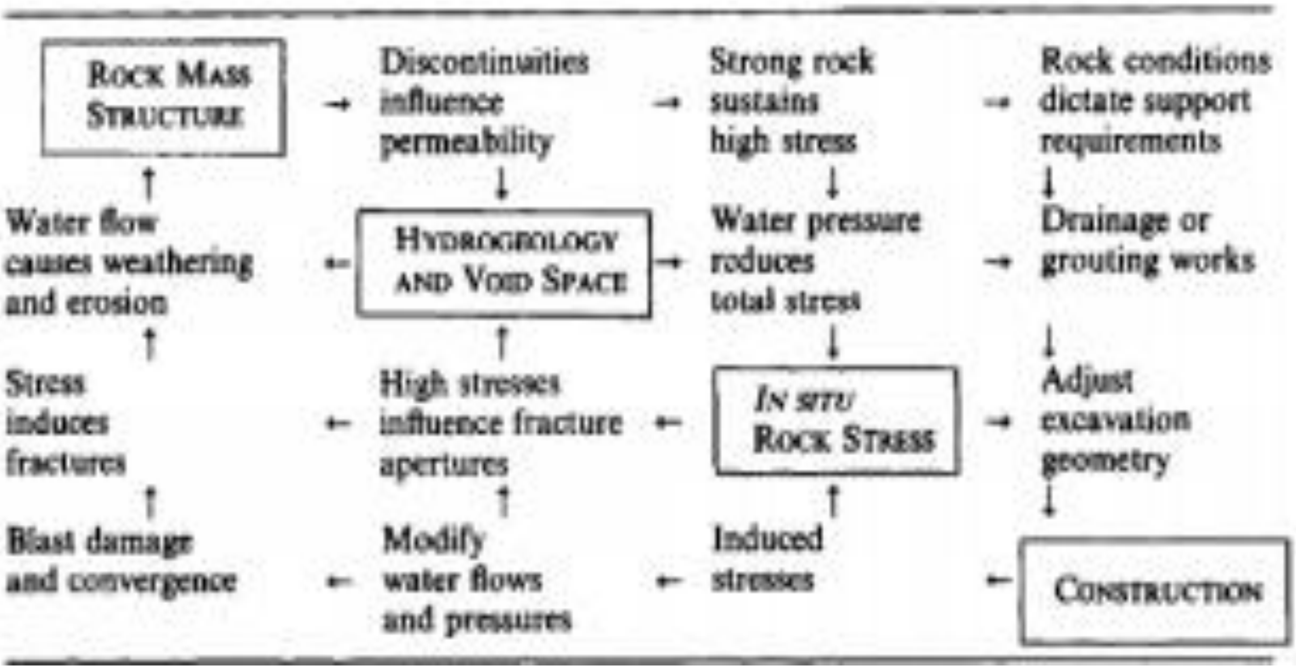


Fig.3.1. Web of ground factors influencing stability [2]

3.1. Geological parameters

As earlier mentioned, the correct characterization of the excavated ground mass is the only way to make tunneling a safe and economically viable procedure. Characterizing these relevant parameters allows to review the planning procedure to execute the excavation construction of the tunnel and the type of excavation method to be applied is affect the ground mass in-situ. The important features are discussed below.

Geological parameters key features:

- Compressive strength,
- Tensile strength,
- Shear strength,
- Bearing capacity,
- Rock mass structure (type of rocks formation),
- Condition of discontinuities (roughness, type, orientation and width of the, discontinuity).

- **Types rocks analyze**

Igneous rocks

Lavas are magma that reaches the earth's surface and flow out over it. This magma cools to form extrusive rocks, which are either of a fine crystalline Grain or of a glossy texture. Intrusive rocks have a coarse crystalline texture. The most common intrusive rock is granite. Large bodies of intrusive rock Deep in the earth's crust is known as "plutonic rocks." Hypabyssal rocks Are intrusive rocks that are fairly near the earth's surface and fill cracks or Fissures, forming sheets between existing layers.[6]

Sedimentary rocks

Sedimentary rocks are formed near the earth's surface by deposition and accumulation of clastic and biogenic sediments. classification table to escribe the sedimentary rocks.[6]

Table.3.1. Intrusive and Extrusive rocks [6]

Intrusive Rocks	**Extrusive Rocks**
Quartz	Andesite
Diorite	Basalt
Pyridotite	Diabase
Gabbo	Scoria
Pegmatite	Trachyte
Granite	Obsisian
Syenite	Rhyolite

Metamorphic rocks

Metamorphic rocks are rocks that have undergone a change in mineral content, texture, or both from their igneous or sedimentary predecessors. Metamorphic rocks are formed by the high pressure deep within the earth at temperatures ranging from 200 to 980 ◦ C (400 to 1800 ◦ F). classification table to escribe the common metamorphic rocks.[2]

Table.3.2. Metamorphic rocks [6]

Name	Rock Texture Unfoliated	Commonly Formed by Metamorphism
Quartzite	Granular (breaks through grains)	Sandstone
Marble	Granular	Limestone, dolomite
Hornfelds	Dense Foliated	Fine grained rocks
Slate	Fine grained	Shale, mudstone
Pyrite	Fine grained	Shale, mudstone
Schist	Fine grained	Shale, mudstone. Andesite, basalt
Gneiss	Coarse grained	Granite

➢ **Discontinuities and bedding planers shear**

Discontinuities

In the excavation of relatively superficial tunnels in rocky masses, the stability of these tunnels is directly linked to the discontinuities of the ground. As such, all information that can be determined on discontinuities becomes an asset to the entire project. The strike and dip on ground surface (fig.3.2) and the location to which a strike maybe formed (fig.3.3).

The possibility of rocks wedge falls or sliding into the tunnel cavity may be account by:

- Estimating the average dip and the its direction compare to tunnel alignment.
- Identify the bucking or the unstable area to withstand pressure.
- Provide the necessary support to weak point to avoid failure.

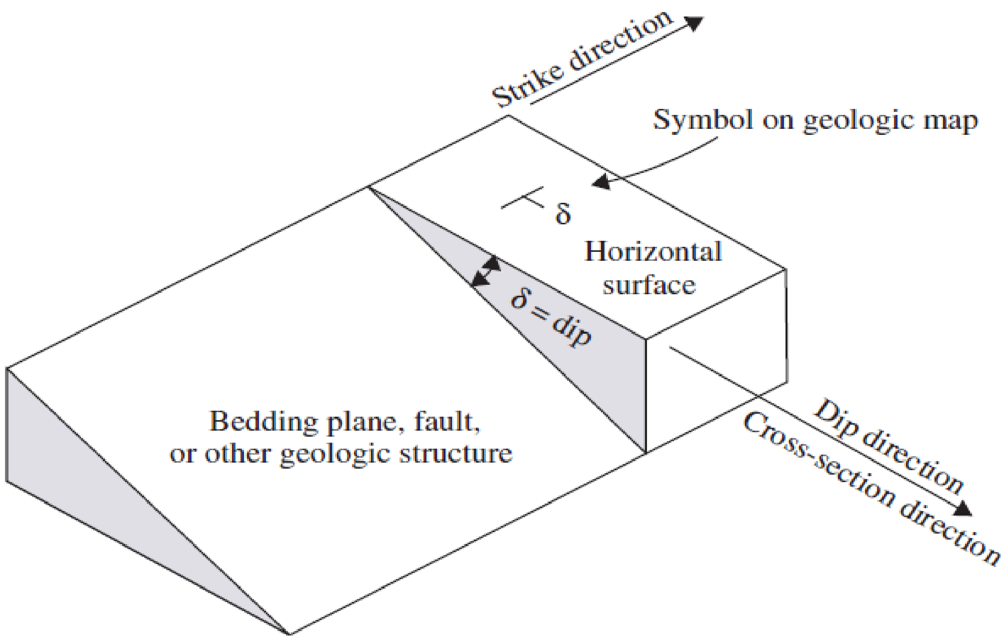


Fig.3.2. Strike and Dip [6]

Inclined bedding

- Bedding strike parallel to the tunnel
  The strike parallel to the construction direction of the tunnel may cause a possibility of rocks fall.

- Bedding strike perpendicular to the tunnel
  The perpendicular strike to the tunnel construction are relatively stable.

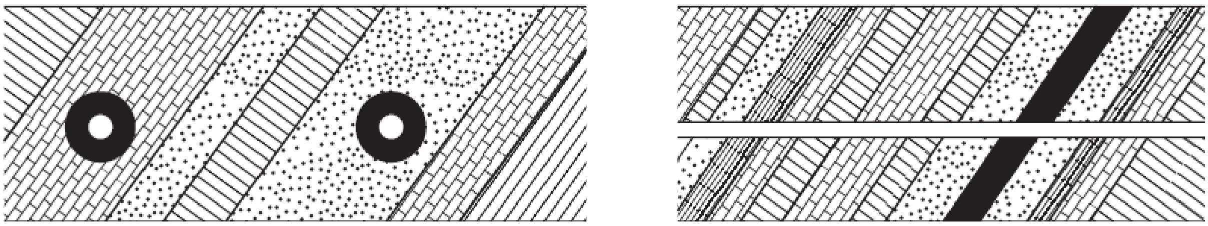


Fig.3.3. Locations of Tunnels Relative to Strike [6]

It is important to plan the construction of tunnel through the analyze ground structure. The rock mass in the ground structure may have concave or convex formation. Figure.3.4 illustrate the different ground formation(ground fold).

The earth structure is in a constant changes caused by the weathering factor. The weathering may cause a disintegrating of the rock mass or rock mass moving away from each due to high temperature and pressure. This types of discontinuities of the ground mass are described as faults, joints or flexures. Shown the different discontinuities (fig.3.4). The ground with weak discontinuous are very unstable and compulsory support should constructed immediately.

Tunneling through rock mass the degree of the bending or convex needs to be measured. Tunneling in high in-situ stress at the bottom of the syncline and at the top of anticline the construction may face a high possible of instability in this regions.

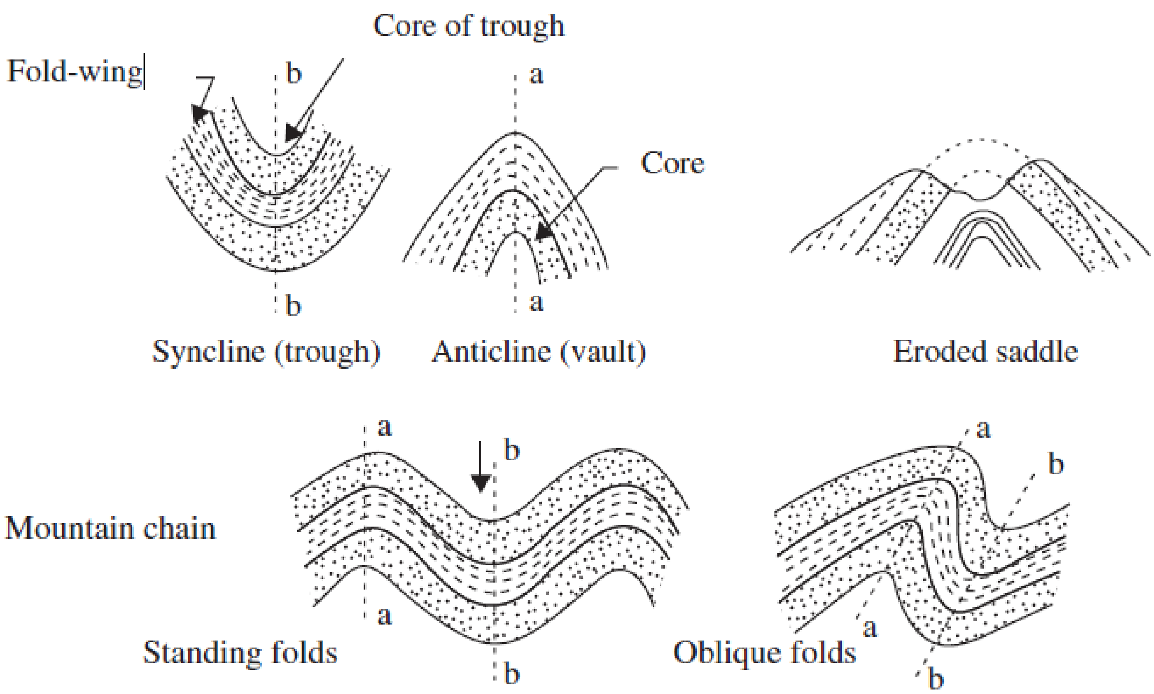


Fig.3.4. Main fold formations (Syncline and anticline).[6]

Tunneling through faults

- Faults activities
  - Avoid activities faults
  - Mobilize faults by readjustment stress
  - Possible of faults creep lead to serviceability ancillary facilities may be affected.

Tunneling through faults problems

The possible of faults movement should accounted in the design plan of the tunneling. Deep tunneling the mobilize of the stress affecting the opening of the tunnel construction is essential factor due earthquake which can be caused by the faults movements.

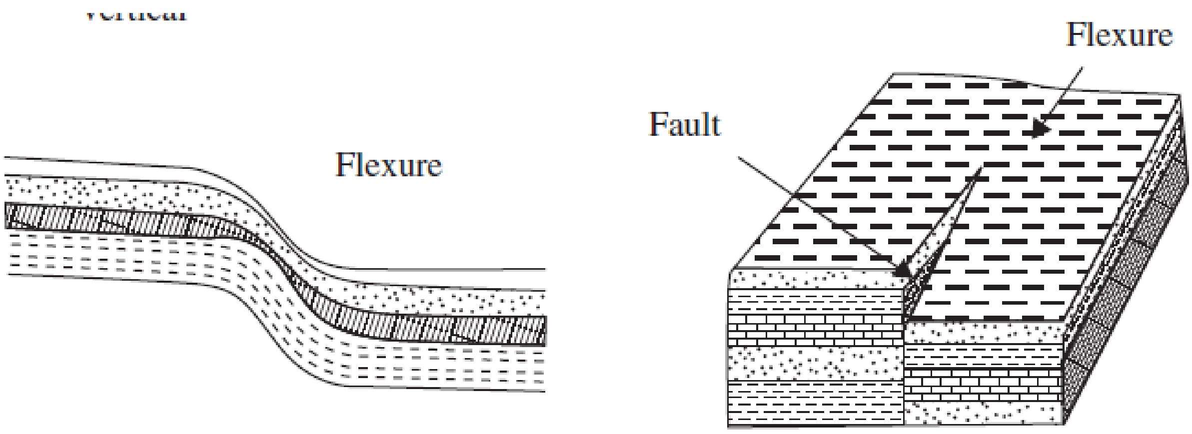


Fig. 3.5. Main Fold Formations (Flexure and fault) [6]

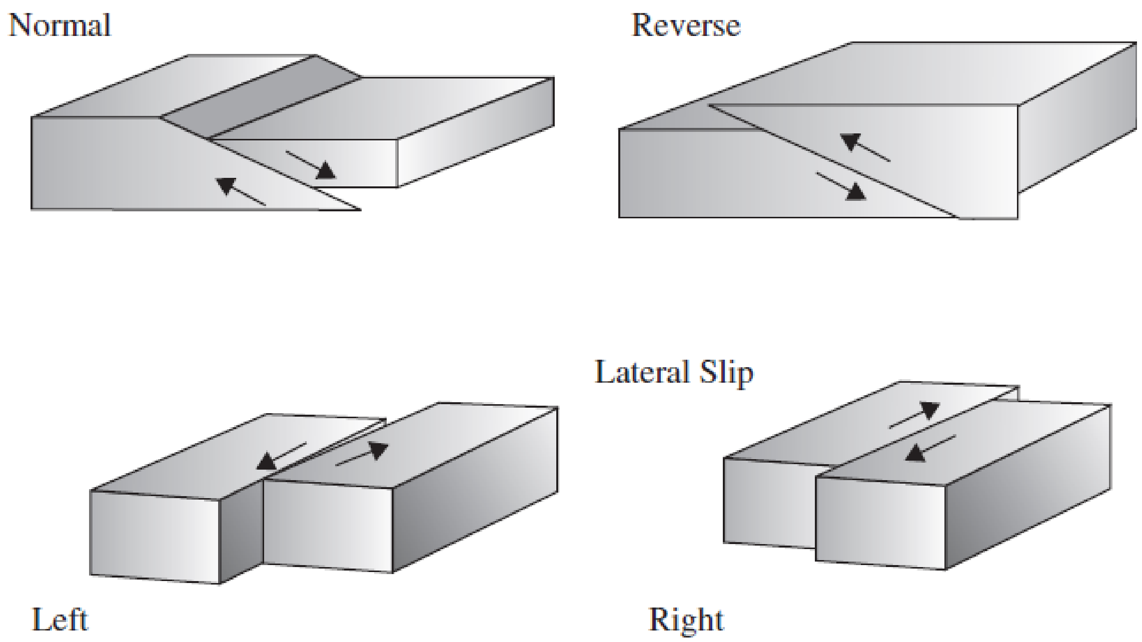


Fig.3.6. Faults [6]

- **Groundwater**

  - Alignment of the tunnel
    The alignment can be near or intercept the water bearing permeable to rock mass
      - Seepage interception and dewatering fault gouges or shear zone
      - Fractured rock potential determine a high permeability

  - Groundwater chemistry
      - Acid rocks drainage may speed up the weathering.

- Ventilation of the tunnel
    - Proper ventilation should be acquired during the construction process of the tunnel
    - The possible of the presence of gases into the cavity of the tunnel e.g. gases such as carbon dioxide, carbon monoxide, hydrogen sulfide, and etc.

- Geothermal gradient
    - Temperature in the soil depending from regions.
      The common account geothermal gradient is 30 degree Celsius should be taken of while designing the tunnel

3.2. Geotechnics parameters

These parameters are directly related to the analyzes of the ground. It is necessary to know in concrete the magnitude and the orientation of the initial tensions. For mechanized excavation with tunnel boring machines it is necessary to obtain information on the following parameters:

Principal tensions ($\sigma 1$, $\sigma 2$, $\sigma 3$); vertical tension (σv); Total tension Ratio ($Kt= \sigma h/ \sigma v$); ratio of effective tension or coefficient impulse ratio (Ko); degree of over consolidation (OCR). It should be noted that in deep tunnels, besides the action of gravity, a highly conditioning aspect of the initial stress state are the tectonic forces originating inside the Earth's crust. **Figure.3.6** illustrate the acting of different pressure on the rock mass.

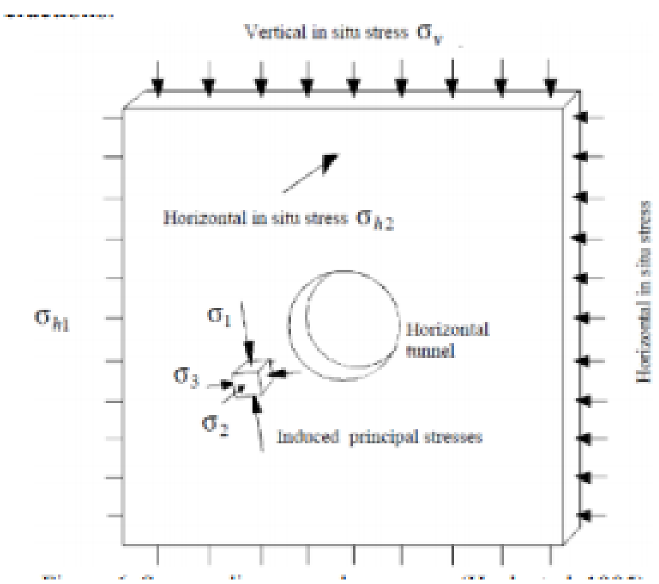


Fig.3.7. Pressure acting on the surface

Tunneling construction the pressure is constantly measure to avoid failure and keep the stability of the construction to the estimate project. Tunnel project is composite by the technical drawing describing excavation geometry, the geology, material properties and geotechnical influence on the choosing of the excavation method, safety equipment and the type of support to be installed into the tunnel.

3.3. Construction process parameters

- Failure
  Due to instability the cavity of the tunnel.
    - Rocks cannot support itself
    - Adequate design to withstand the tensile strength.

- Stability

- Support system
  - Frames
    - Steel sets
    - Timber sets

  - Rocks bolts
  - Liners
    - Concrete
    - Shotcrete
    - Steel

3.3. Material properties parameters

Material properties parameters describes as the internal stresses represent overburden weight, pore water pressure, tectonic stresses and mineralogy. Tunneling through the rock mass need to consider the factor influence the rocks.

Definition of parameters are extremely important, especially when using a pressurized front boring machine. It is necessary to have the most accurate knowledge possible of soil particle size, porosity and moisture content for the determination of the confinement mode of the front of the TBM as well as, if necessary, the type of additives to be used in this confinement. The factors to take in account are volumic weight (γ, γd, γs); water content, degree of saturation, index of voids (w, S, e); Atterberg boundaries (wL, wp); Porosity (n); Sieve characteristics; Activity of the clay fraction; density; Mineralogical and Petrographic Characteristics.

Table.3.3. Soil/rock characteristics [6]

Rock Characteristics	Soil Characteristics
Water content Soil density (wet and dry soil) Grain shape and hardness Atterberg limit Pure volume Poisson ratio and elastic modulus Mineralogical analysis Cohesion Permeability Undrained shear strength	Petrography Rock density Abrasiveness and content of quartz Mineralogical Elastic modulus and Poisson ratio Cohesion Permeability Angle of friction Tensile splitting strength Swelling capacity Stability Bedding

- **Porosity and void ratio**

Define the volume of total soil particles occupied by water contents. The porosity n is define as:

$$n = \frac{V_v}{V_t}$$

The void ratio e define as:

$$e = \frac{V_v}{V_s}$$

The porosity and void ratio related by:

$$n = \frac{1+\mathrm{e}}{\mathrm{e}} \text{ or } n = \frac{\mathrm{n}}{1-\mathrm{n}}$$

The degree of saturation present the void which are occupied by water.

$$s = \frac{V_w}{V_t}\,[\%]$$

- **Density**

  The density of soil ρ define as:

$$\rho_t = \frac{M_t}{V_t}$$

$$\rho_{sat} = \frac{M_{s+M_w}}{V_t}$$

$$\rho_d = \frac{M_s}{V_t}$$

$$\rho = \rho_{sat} + \rho_d$$

- **Moisture content**

  The moisture content W is define as:

$$w = \frac{M_w}{M_s} [\%]$$

- Atterberg limits

  Atterbeg limits PL define as:

PL =LL-Pl

The Atterberg test allows the measured limits of shrinkage , lower limit of volume change and liquid index define as (fig.3.8):

$$LI = \frac{w - PL}{PI} [\%]$$

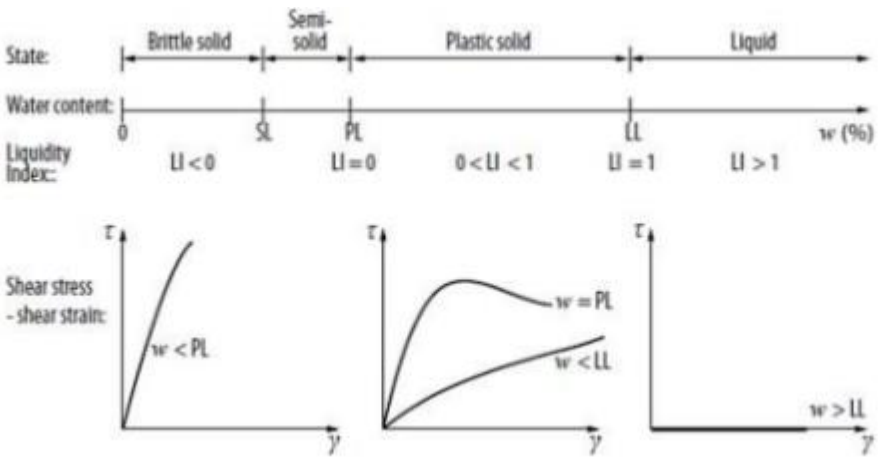


Fig.3.8. Atterberg limits in soil.[1]

Hydrogeological analyzes

The analyzes of the water presence in a ground is of highly importance for choosing both the method of excavation of a tunnel and its feasibility. The parameters to take into account are: Isotropic permeability (k); Anisotropic Permeability (kx, ky, kz,); Hydraulic load (h); Hydraulic Gradient (i); Location of the Groundwater.

Estimating rock load

The ground plane to be excavated are exposed by the surrounding weight imposing a different pressure onto the rocks from different angle, and direction. The pressure imposed onto the rock mass is mainly a function of the earth material's geomechanically characteristics and dimensions of the tunnel excavation. Estimating the support for the cavity of the tunnel is based on the discussed. This analysis provide the necessary aspect to select a support for peak load which acts at the centre of the tunnel roofs and invert, and sidewall. Supportive system tunnel which withstand the surrounding pressure applied into the cavity (fig.3.9).

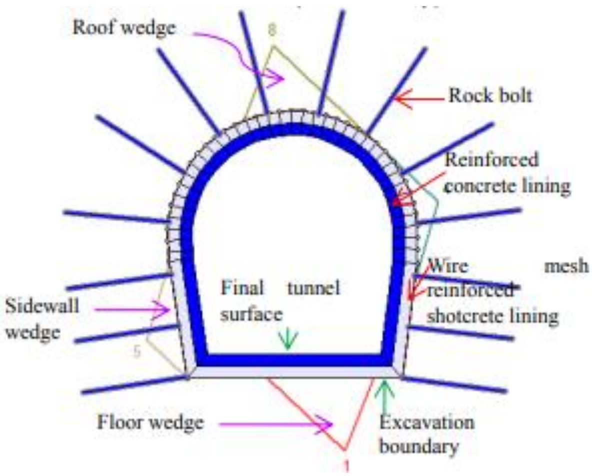


Figure.3.9. Typical tunnel support system

4.Tunnel construction techniques

There are several existing techniques for the excavation of tunnels and these techniques are accordingly adjusted to are suit particular ground excavation (4.1). The development of these techniques have been gained with years of practical experience and difficulties face to excavate tunnel with longer length in a more complex ground, offering more safety, environment and economically wise, these techniques have acquired the several ability necessary to dig the ground (fig.4.2) . [1]

The modern technologies give a more practical analyzes of the soil condition and this allowed the improvements of varying equipment excavate the different ground (fig.4.3). This chapter intend to discuss the different excavation methods and the equipment used to perform digging of the ground (4.4).[2]

Tunnel profile and tunneling notations

The tunnel shape changes according to the method used to construct the tunnel and the constructions purposes. Selecting a tunnel cross one has to bear in mind the accessibility to maintenance, ventilation and availability of space (4.5).

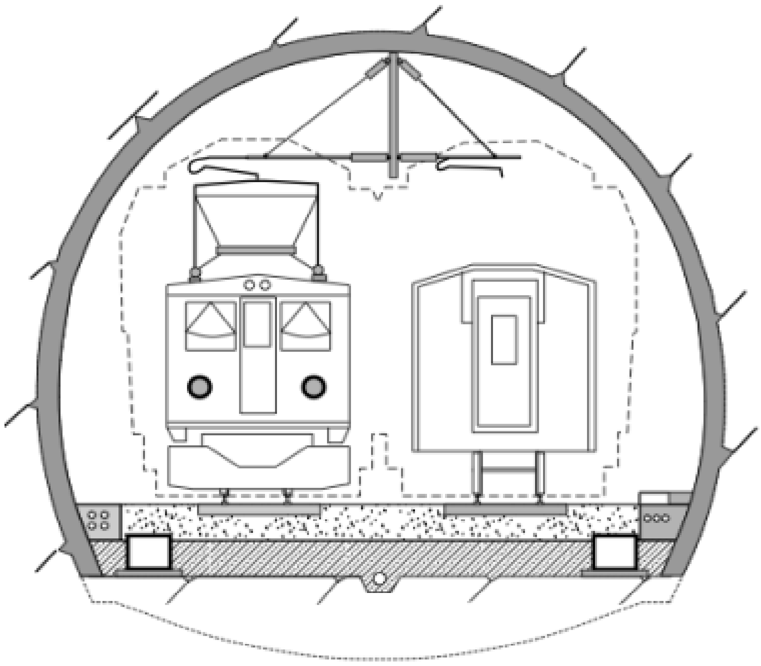


Fig.4.1 Mouth profile [1]

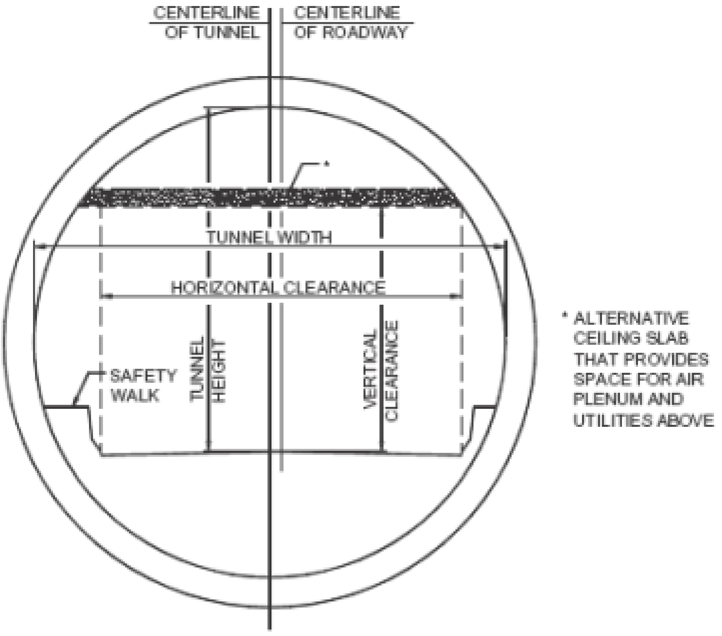
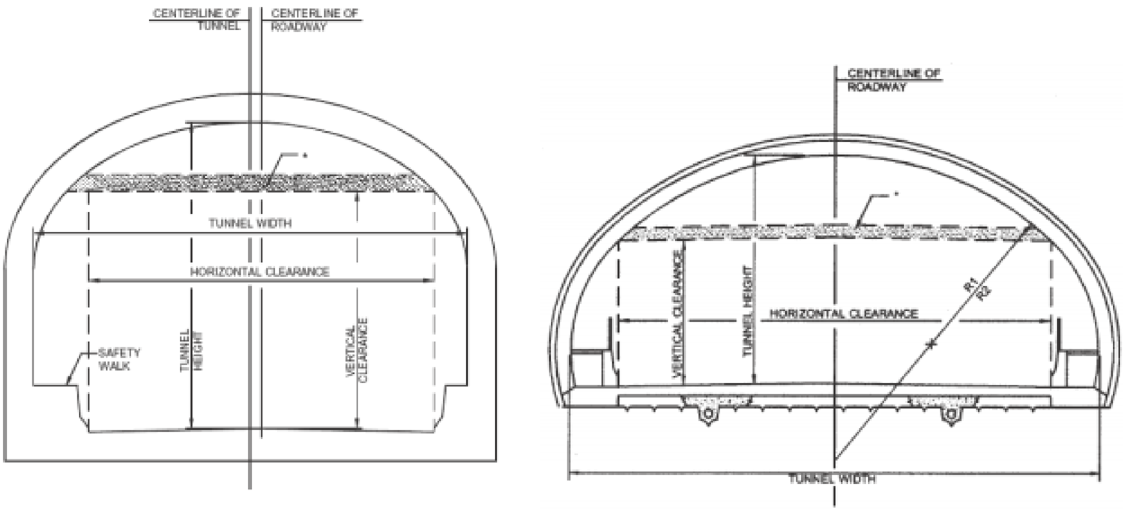


Fig.4.2. Circular profile[12]



* Alternate Ceiling Slab that Provides Space for Air Plenum and Utilities Above

Fig.4.3. Horseshoe and Curvilinear (Oval) Tunnels [12]

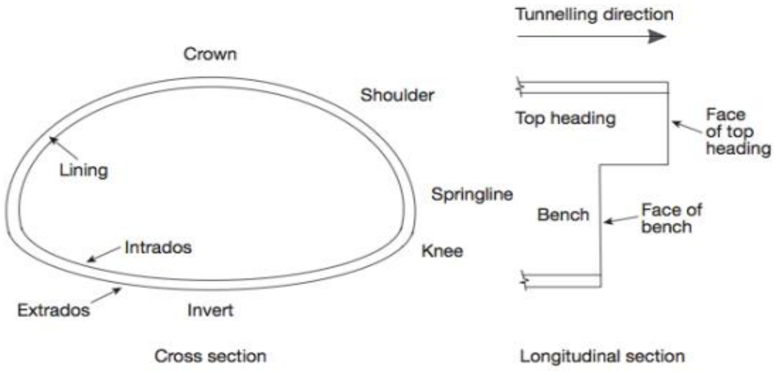


Fig.4.4. Cross section and longitudinal section of tunnel heading [12]

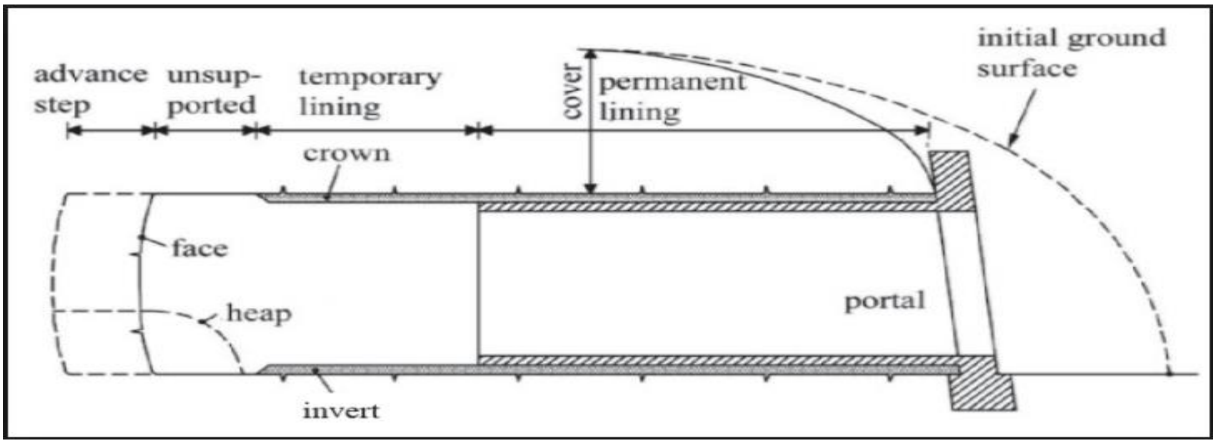


Fig.4.5. Longitudinal section of heading [12]

4.1. Cut and cover tunnel

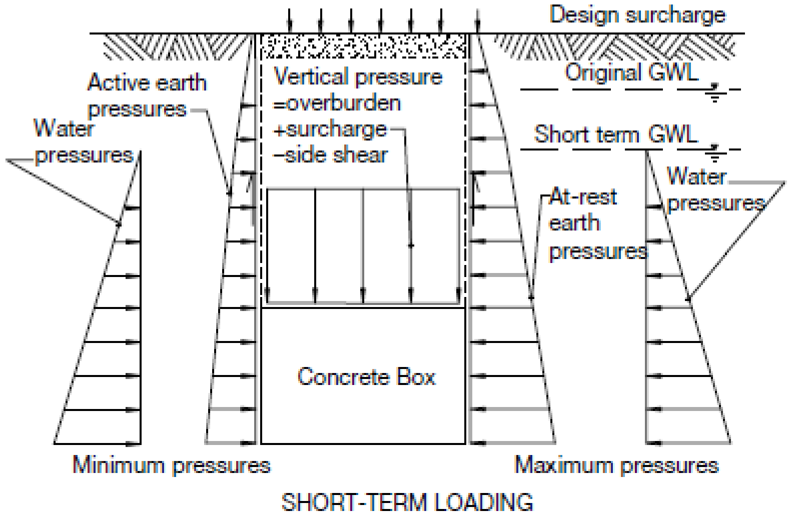
In a Cut and Cover method the tunnel structure is finalized within the excavated ground and muck is reused to cover the structure. This method are normally performed to constructed a tunnel in a shallow (depth of 12 to 18 meters) and the excavation from the surface is possible, economical, and acceptable (FHWA-NHI-09-010- Road Tunnel Manual,2009). A construction of tunnel in Czech Republic employing a cut and cover method (fig.4.6).

However, it is important to mention that this technique has a great impact of interference with the Surface and it is not possible to construct a tunnel with this technique without The change of surface, particularly in urban areas.

The excavation of the tunnel with this method employs two technique procedure, the bottom up and top down and both are uniquely selected depend on the tunnel project. Load bearing aspect in the tunnel (fig.4.7).

Fig.4.6. Blanka tunnel in Prague, Czech Republic, a section constructed with cut and cover method [12]

Design to withstand the load



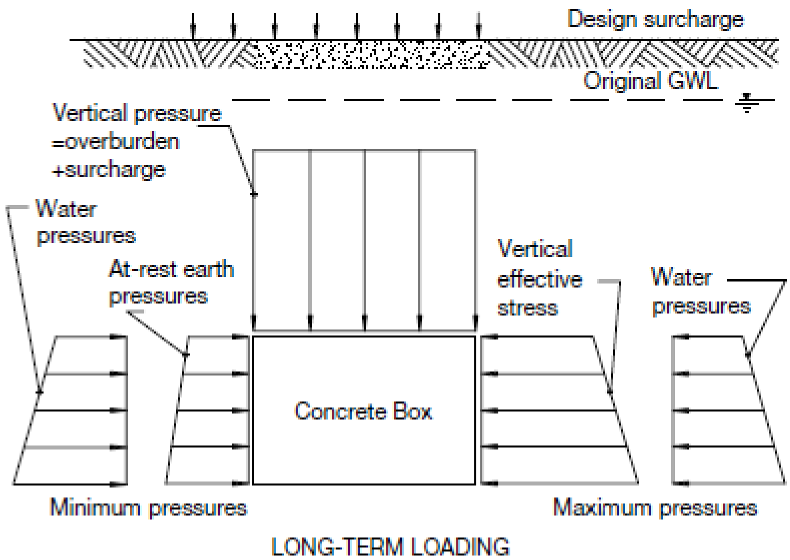


Fig.4.7. Example of design loadings in the short- and long-term for a concrete box structure [10]

4.1.1.**Bottom up**

The method Bottom Up the trench is excavated from the surface till the planned depth of the tunnel (fig.4.8). The next section, the constructed tunnel foundation, framework and reinforce, and subsequently the refill of the trench with soil once the structure support can loads.

<u>Shoring system (support system)</u>

- Soldier plies
- Steel sheet piles
- Lagging walls

The procedure for Bottom Up excavation

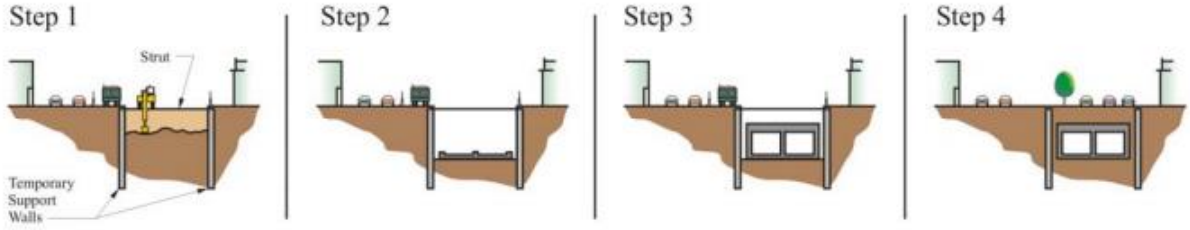


Fig.4.8. Bottom Up method[12]

Bottom Up sequences constructions:

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: Compete construction of the walls and then the roof, apply waterproofing as required;
Step 4: Backfilling to final grade and restoring the ground surface.

Bottom-up 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.

Bottom – up disadvantages

- Somewhat larger footprint required for construction than for top-down construction.
- The ground surface cannot be restored to its final condition until construction is complete.
- Requires temporary support or relocation of utilities.
- May require dewatering that could have adverse effects on surrounding infrastructure.

4.2.2.**Top down**

The top-down methods sequences are done oppositely compare to the Bottom (fig.4.9). The Top-Down construction requires the built of a walls or columns, which can be slurry walls or either a secant pile walls, the roof which is tied into the support excavation walls, 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. The surface is then reinstated before the completion of the construction. The remainder of the excavation is completed under the protection of the top slab. Upon the completion of the excavation, the floor is completed and tied into the walls. The tunnel finishes are installed within the completed structure. For wider tunnels, temporary or permanent piles or wall elements are sometimes installed along the center of the proposed tunnel to reduce the span of the roof and floors of the tunnel.

The procedure for Bottom Up excavation

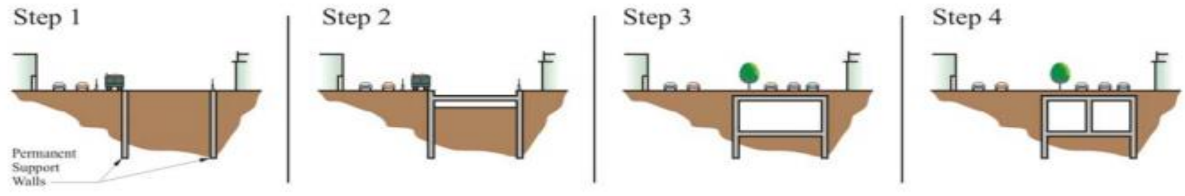


Fig.4.9. Top-Down method [1]

Top-Down sequences constructions:

Step 1a : Installation of excavation support/tunnel structural walls, such as slurry walls or secant pile walls

Step 1b: Dewatering within the excavation limits if required

Step 2a: Excavation to the level of the bottom of the tunnel top slab

Step 2b: Construction and waterproofing of the tunnel top slab tying it to the support of excavation walls

Step 3a: Backfilling the roof and restoring the ground surface

Step 3b: Excavation of tunnel interior, bracing of the support of excavation walls is installed as required during excavation

Step 3c: Construction of the tunnel floor slab and tying it to the support of excavation walls; and Step 4 Completing the interior finishes including the secondary walls.

Top-down advantage:

- It allows early restoration of the ground surface above the tunnel
- The temporary support of excavation walls are used as the permanent structural walls
- The structural slabs will act as internal bracing for the support of excavation thus reducing the amount of tie backs required
- It requires somewhat less width for the construction area
- Easier construction of roof since it can be cast on prepared grade rather than using bottom forms
- It may result in lower cost for the tunnel by the elimination of the separate, cast-in-place concrete walls within the excavation and reducing the need for tie backs and internal bracing
- It may result in shorter construction duration by overlapping construction activities

Top - down disadvantages

- Inability 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

4.2. Drill and Blast

Before the invention of tunnel boring machines, drilling and blasting was the efficient method to excavate long tunnels through hard rock, where digging if man's labor was difficult and impossible (fig.4.10). The method currently is used to excavate a short tunnel in harder layers. The decision whether to construct a tunnel using a TBM or using a drill and blast method includes a number of factors such as:

- Tunnel length
- Managing the risks of variations in ground quality
- The required speed of construction
- Required shape of the tunnel

Procedure drill and blast construction

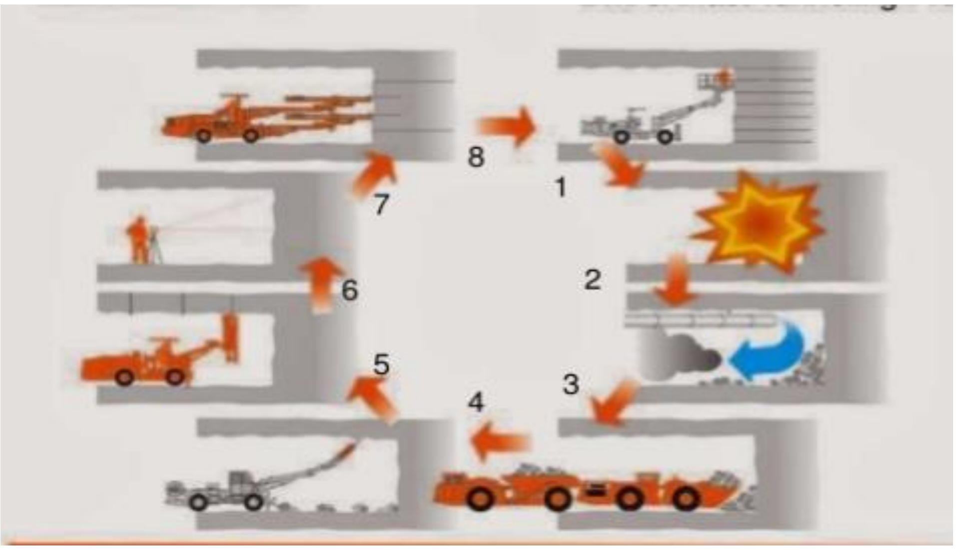


Fig.4.10. Cycle of excavation drill and blast. Source [12]

Excavation technique

The hydraulic rock drill penetrated the ground/rock layers equipped with an automatic drilling system, angle sensor and hydraulic sensor to ensure parallel drilling, and positioning and setting an angle (fig.4.12). This allows the release of dynamite in drilled hole and blast of the rocks. This excavation techniques were more used until the development of the tunnel boring machines. Illustrate the rubber tyred drilling carriage jumbo (fig.4.11).

Fig.4.11. Example of a rubber tyred drilling carriage ‘jumbo’ as used on the second tube of the Katschberg Tunnel, Austria[10]

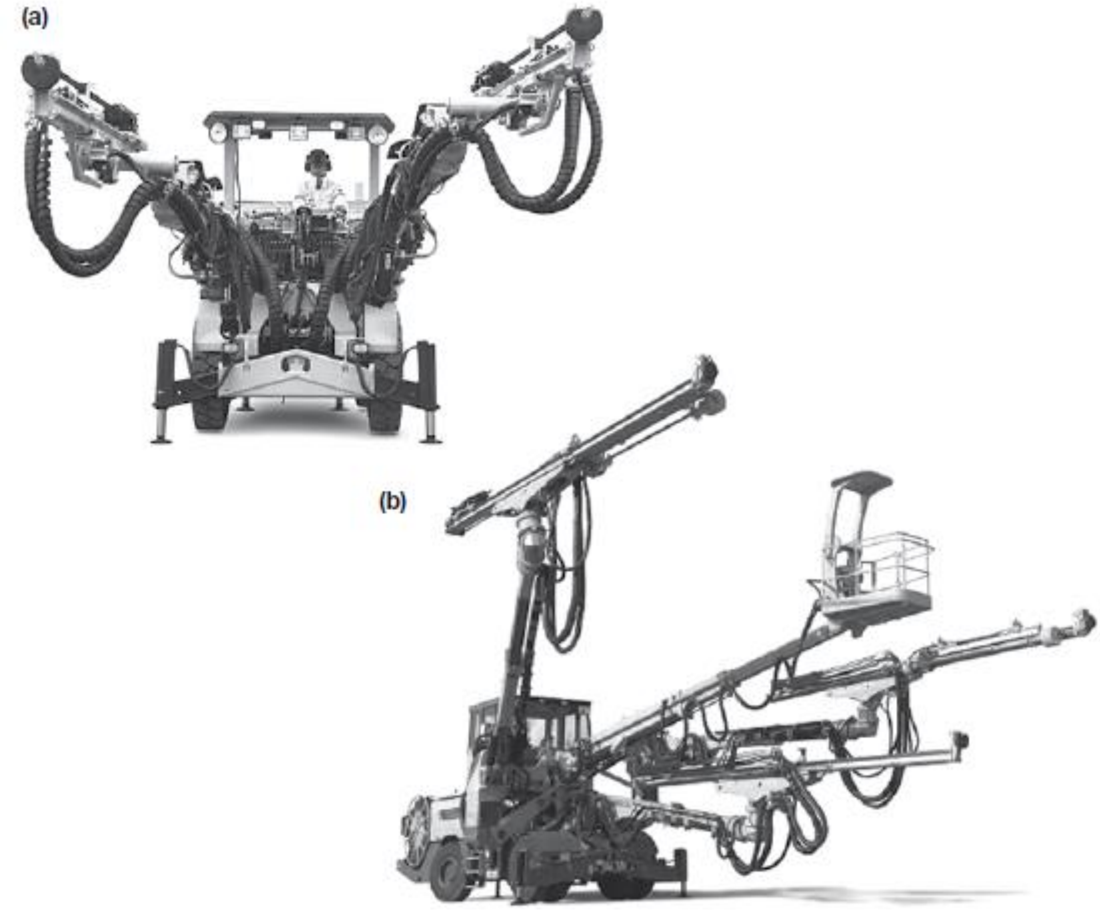


Fig.4.12. a) Twin-boom hydraulic drill rig and (b) four-boom hydraulic drill rig[10].

Support cavity and muck transport technique

The support cavity techniques were performed by means of wooden material in an excavation of tunnel to support its cavity, and new generation used steel which can support more stress and are more durable. Illustrate a timber support for a tunnel maintain its stability (fig.4.13).

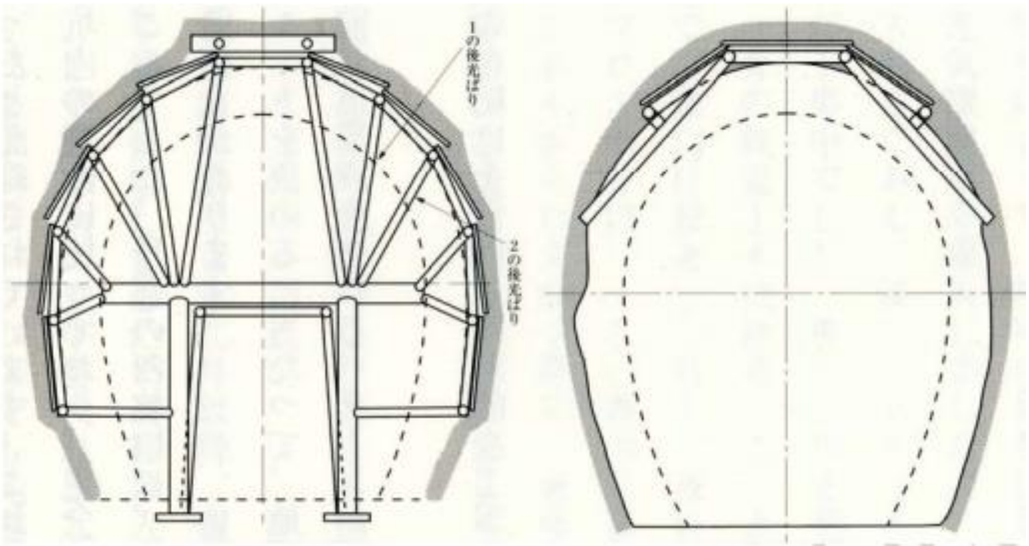


Fig.4.13. timber support of tunneling [10]

Muck transport

On this excavation method the debris (muck) or excavated material are removed out tunnel by the help of the large trucks and belt conveyors. The locomotive for muck transport are illustrated on (fig.4.14-fig.4.16).

Fig.4.14. SHIN CATERPILLAR MITSUBISHI [21]

Fig.4.15. large dump trucks or containers [21]

Fig.4.16. Belt conveyors [16]

Drill and blast construction sequence

a. Drilling blast holes and loading them with explosives.
b. Detonating the blast, followed by ventilation to remove blast fumes.
c. Removal of the blasted rock (mucking).
d. Scaling crown and walls to remove loosened pieces of rock.
e. Installing initial ground support.
f. Advancing rail, ventilation, and utilities

Advantages:

a. Potential environmental impacts in terms of noise, dust and visual on sensitive receives are significantly reduced and are restricted to those located near the tunnel portal;
b. Compared with the cut-and-cover approach, quantity of C&D materials generated would be much reduced;

c. Compared with the cut-and-cover approach, disturbance to local traffic and associated environmental impacts would be much reduced;
d. Blasting would significantly reduce the duration of vibration, though the vibration level would be higher compared with bored tunneling;

Disadvantages:

a. Potential hazard associated with establishment of a temporary magazine site for overnight storage of explosives shall be addressed through avoiding populated areas in the site selection process.

4.3. New Austrian method – NATM (projektowanie i budowa tuneli

The sequential excavation method, also known as NATM (New Austrian Tunneling Method), "New Austrian Method of Tunnel Construction" concept based on the behavior of the rock mass when excavating it. This technique aims at using the geological stress of the surrounding rocks mass to support the tunnel structure in order to maximize resources, that is, decrease the number of immediate support and decrease spending. Meanwhile, it is of extreme importance that when excavating The ground to keep the disturbance as low as possible, so that it maintains its Characteristics as close as possible to their initial characteristics. This techniques requires after each of excavation to immediate provide a lighter and flexible support to take advantage of the ground support capacity. This technique requires after each of excavation for immediate provide a lighter and flexible support to take advantage of the ground support capacity. After the entire tunnel has been opened, the final support is then placed in order to satisfy the Purpose of the tunnel and monitoring the performance of underground construction during construction.[1]. The in Austria excavated with NATM (fig.4.17).

The sequential excavation method (SEM) was developed between 1957 and 1965 by Ladilaus Von Rabcewicz , Leopold Muller and Franz Pacher to distinguished it and shows a cross section used in the NATM (fig.4.18) .From the old Austrian method. "…A new method consisting of a thin sprayed concrete lining, closed at the earliest possible moment by an invert to a complete ring –called an "auxiliary arch"- the deformation of which is measured as a function of time until equilibrium is obtained" (Prof L.V Rabcewicz). It is currently used in soft-ground and rock, in urban or rural areas. The ability of the method to adapt to various geometries while maintaining safety and economy has led to this being one of the most widely used techniques in World. For a clear picture of the process refer to (fig.4.19).

Fig.4.17. Example of a NATM crown and bench excavation during the construction of the Katschberg Tunnel, Austria[10].

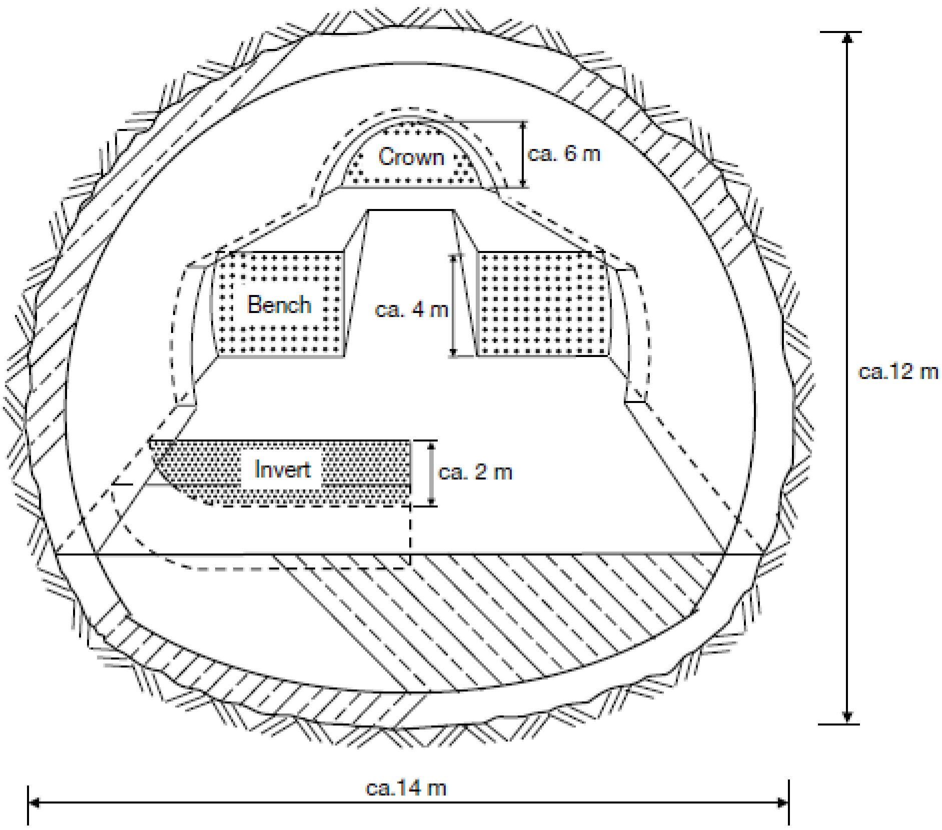


Fig.4.18. Example cross section through a tunnel constructed using NATM [10].

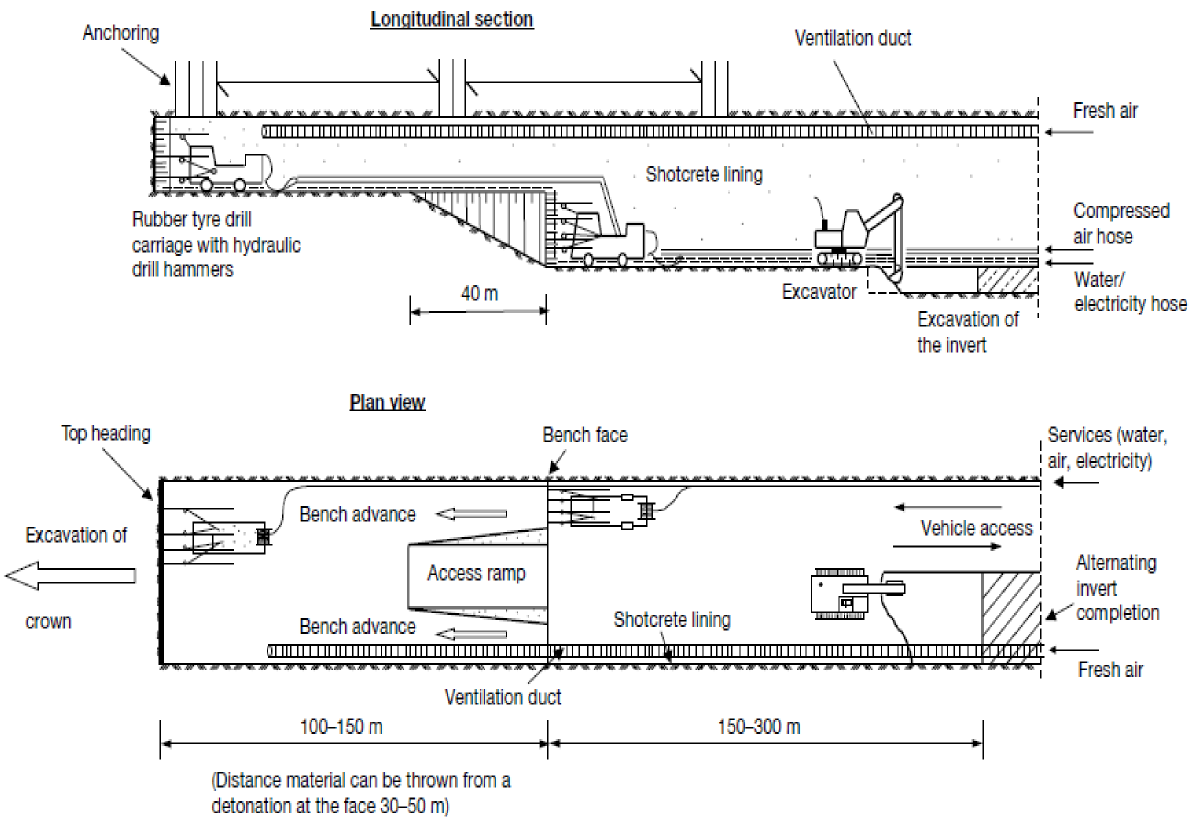


Fig.4.19. Construction activities using NATM for large cross section tunnels in stable ground conditions (no mandatory ring closure) [10]

Principl conceipts

These principles of NATM were summarised by Prof. Muller as follows:

I. The surrounding rock mass is the main load bearing component and its carrying capacity must be maintained without disturbance of the rock mass.

II. The support resistance of the rock mass should be preserved by using additional support elements

III. The lining must be thin-walled and necessary additional strengthening should be provided by mesh reinforcement, tunnel ribs and anchors rather than thickening the lining.

IV. The ring closure time is of crucial importance and this should be done as soon as possible.

V. Preliminary laboratory test and deformation measurements in the tunnel should be carried out to optimize the formation of the ground ring.

Possible excavation sequential NATM illustrate on the below sequence of figures: (Fig.4.20-fig.4.23) illustrate the process of planning a cross section view of the tunnel. The illustration the describe the section used to plan the cross section of the tunnel.

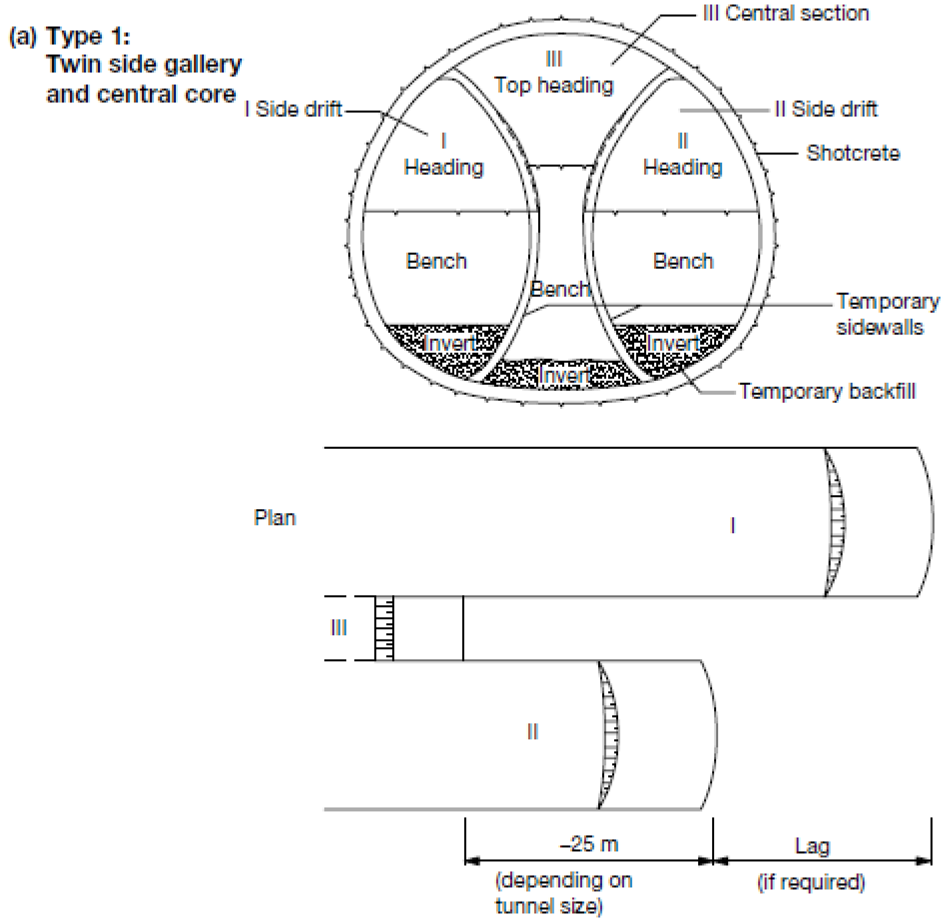


Fig.4.20. Twin side gallery and central core[10]

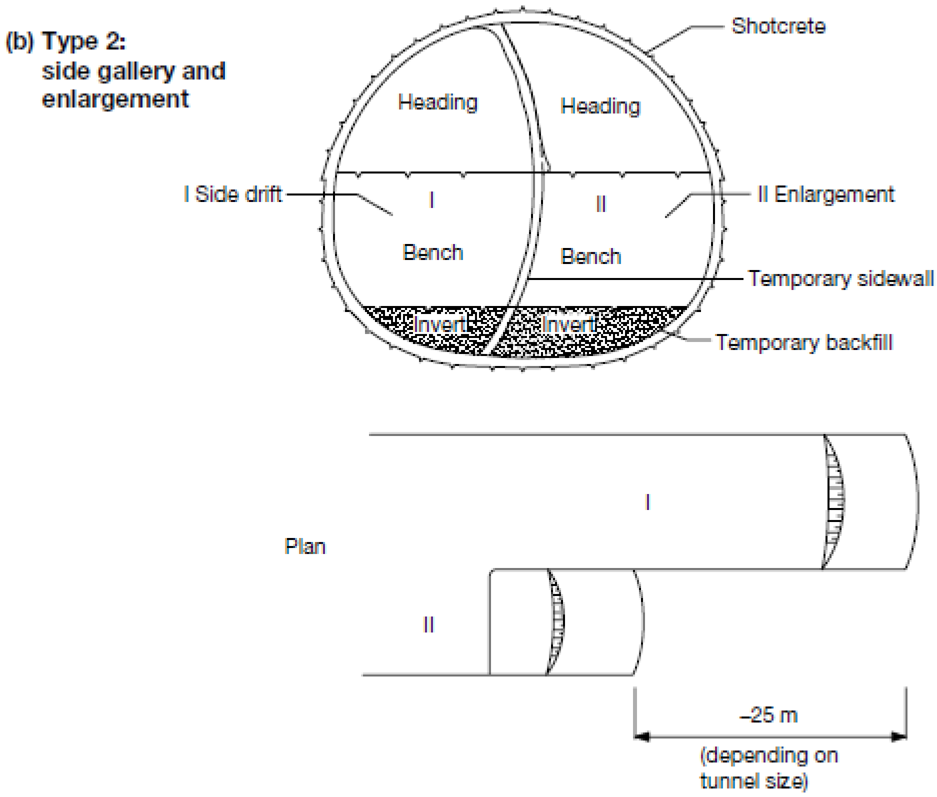


Fig.4.21. Side gallery and enlargement [1o]

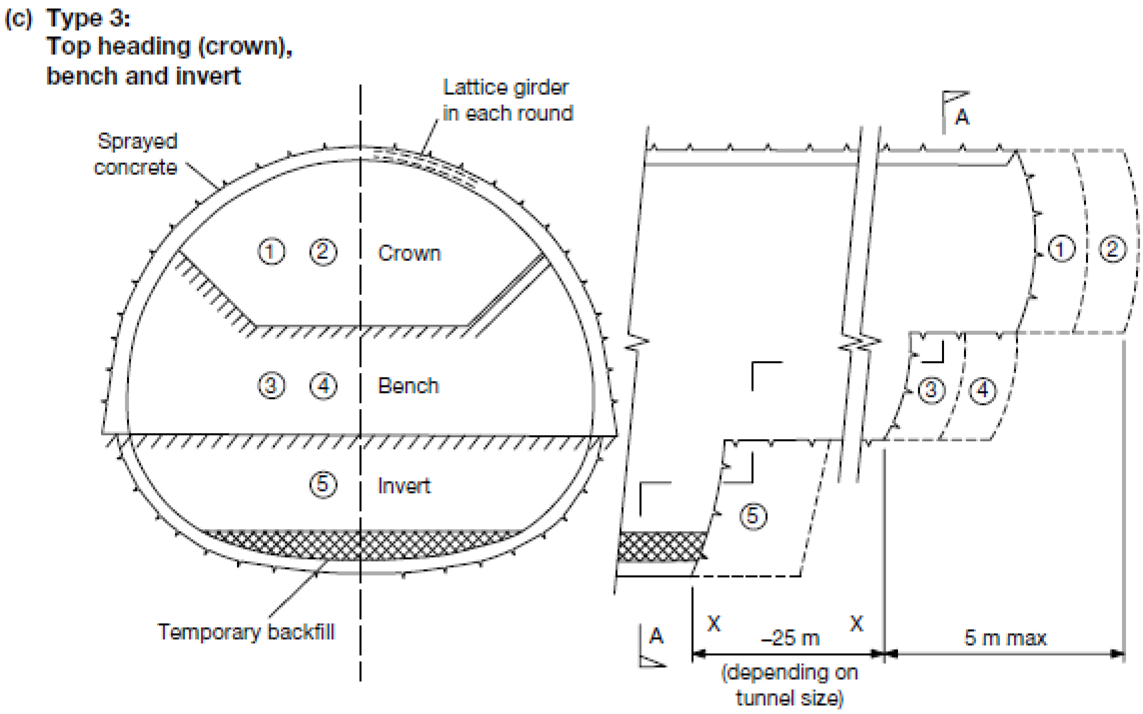


Fig.4.22. Top heading (crown).bench and invert [10].

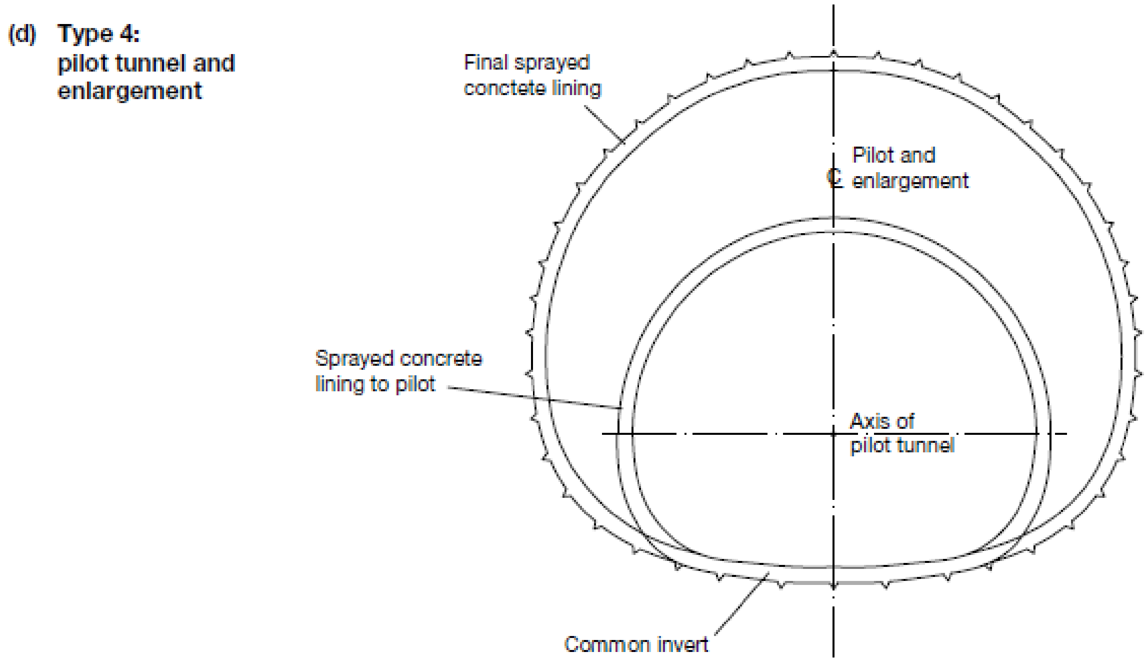


Fig.4.23. Pilot tunnel and enlargement[10] .

Figure.4.24 illustrate a general design aspects of the NATM. According to the OEGG the below listed steps are needed to be considered and executed in the planning and construction phase of a NATM tunnel to ensure a successful application:

Phase 1 - Design

- Step 1 – Determination of Ground Types
- Step 2 – Determination of Ground Behavior
- Step 3 – Selection of a Construction Concept
- Step 4 – Assessment of System Behavior in the Excavation Areas
- Step 5 – Determination of Excavation and Support and Evaluation of the System Behavior in the Supported Areas
- Step 6 – Geotechnical Report – Excavation and Support Requirements
- Step 7 – Determination of Excavation and Support Classes

Phase 2 - Construction

- Step 1 – Identification of the Encountered Ground Type and Prediction of Ground Conditions
- Step 2 – Assessment of the System Behavior in the Excavation Area
- Step 3 – Determination of Excavation and Support
- Step 4 – Verification of System Behavior in the Supported Area

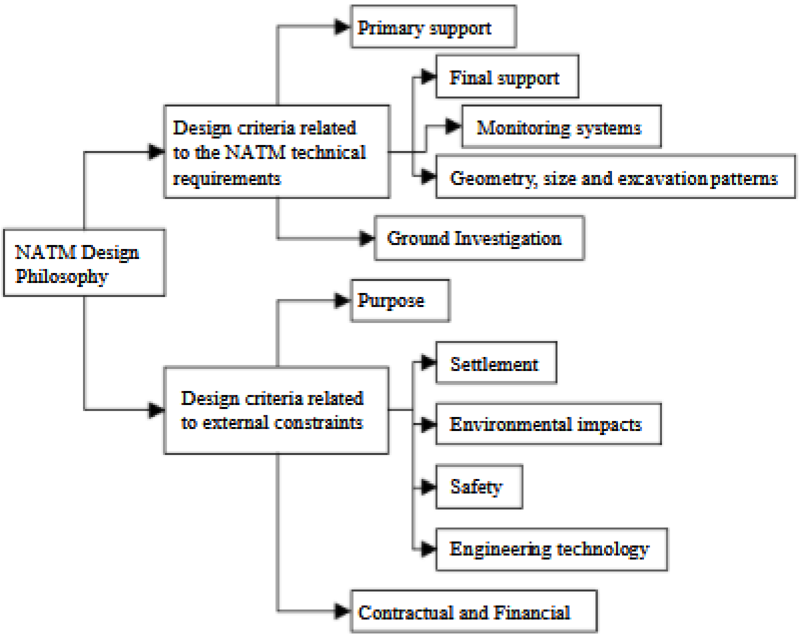


Fig.4.24. General design aspects for NATM [10]

Advantages

a. Flexible – support provide as required by the ground conditions.
b. Safe – able to deal with locally unexpected ground condition, minimizing claims
c. Economical –support provides as required by the encountered ground conditions, in contrast to TBM segments, which are designed for worst load case – if needed or not, therefore overdesigned.
d. Adaptable –optimizing equipment and crews, allowing multiple heading operations concurrent.

Disadvantages

a. High level of coordination, cooperation and communication.
b. Lower production rates.
c. Interruptions in excavation and support works have to be avoided as much as possible.

(Fig.4.25) the transport of the excavation residuals of the tunnel needs to excreted as fast possible to give a space to process itself. This mucks are vehicles of different capacities.

Fig.4.25. Example of mucking equipment used during the construction of one of the emergency cross-passages of the Katschberg Tunnel, Austria.[10]

4.4. Introduction to mechanized tunnel construction – TBM technology

The need to excavate tunnels through more complex geological layers, the Level of safety, both for workers inside the tunnel and at the surface when Excavations proceed under urban areas, and issues that are predicted with the viability of Entrepreneurship, in particular economic issues, led to the creation of machines that TBMs.[1]

The techniques of excavation with tunnel boring machines are diverse, depending Off the ground in which the excavation is to be carried out and whether it is under a Urban area or not. These two important factors influence the choice of technique And thus the need to design a machine Specifically, since there are specific characteristics of each, such as the example Evidence of the presence or absence of a shield, which provides immediate peripheral support, or Propulsion, which characterize each machine, as will be explained in this chapter.

This technique can be discussed for tunneling in soft-grounds and rocks. which after are subdivided into the various excavation techniques. tunneling machine, differing in the type of shield used, type of frontal support, shape of advance among other factors intrinsic to each technique. It should be noted that only front-loading excavation machines, some of them be used for partial excavation. These techniques are presented in

figure.4.26. Type of ground for which they are appropriate, type of immediate support provided, categories, Types of shield possible in each category.

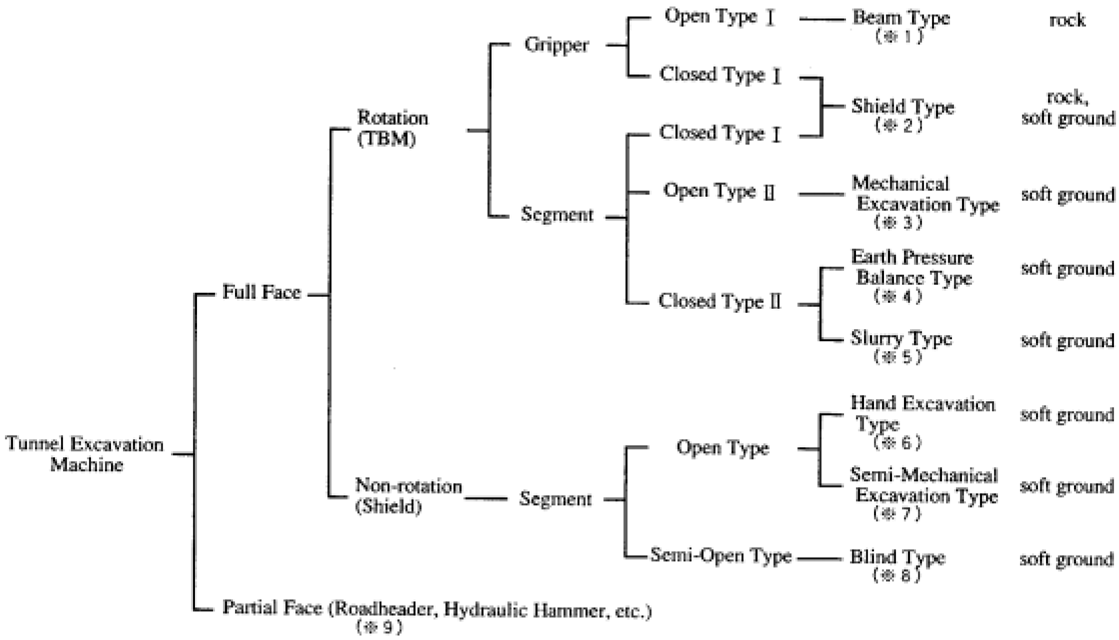


Fig.4.26. Classification of Tunnel Excavation Machines. [17]

General operation principle

The operation concept of a boring machine bases on the tunneling shield developed by the French engineer Sir Marc Isambard Brunel and the rotary cutter head created by James S. Robbins. (Fig.4.29) illustrate the TBM arrive on the retrieval shaft São Bento, Porto

The tunnel is excavated with circle profile and depending on the type of boring machine used an immediate support to cavity is provided. The cutting head of the machine is pushed against the excavation front with the aid of hydraulic jacks, while Rotating and excavates the rock mass, making use of the cutting tools installed in it. After the jack reaches their maximum extent, the cutting head stops and the jack are retracted to its original position. These jacks act directly on the Immediately behind the machine, still inside the machine shield**.** (Fig.4.28) illustrate the excavation circle of the TBM machine.

The principle operation is similar on all boring tunneling machines, with their evolution, these presents changes on system composition and functions. For each technique, the changes processed are detailed discussed in the following chapter. Shield tunnel boring machine schematic (courtesy of Herrenknecht AG)[5] is presented in (fig.4.27).

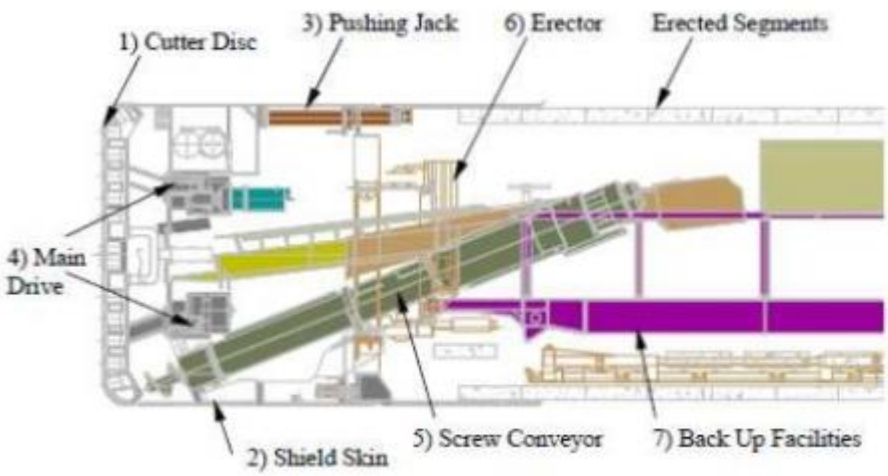


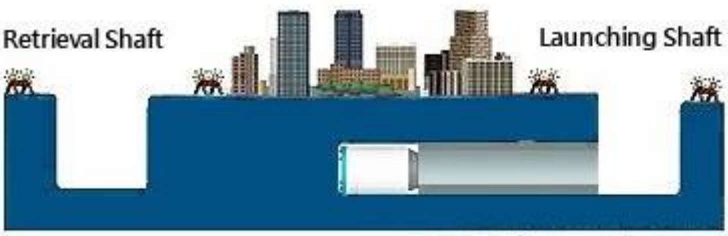
Fig.4.27. Typical layout of TBM [5]

Stage of tunnel construction using a TBM

1- Excavate launching shaft and retrieval shaft

2- Assemble the TBM on launching shaft

3- Cut and excavate the tunnel



4- The TBM arrive on the retrieval shaft to be dismantled for transportation

Fig.4.28. Stage of tunnel construction using TBM [12]

Fig.4.29. The TBM arrive on the retrieval shaft São Bento, Porto[5]

The advantages of machine boring compared to conventional drill and blast are:

1. Greater safety
2. Less over-break and consequently less support
3. Decrease in size of labor crew
4. More uniform size of muck for disposal
5. Better direction control
6. Higher rates of advance

Disadvantages are:

1. High capital outlay
2. Limit of rock hardness which can be excavated
3. Time for manufacture of machine for a given job
4. Assembly time
5. Dismounting time
6. Reliability
7. Tunnel profile limited to circular
8. Ventilation and dust problem
9. High power requirements
10. Experience and advance conditions

Operating problems:

I. Boring and cutters must be improved
2. Hard rocks require high thrusts
3. Collecting system for sticky materials

Main drive

The purpose of driving a TBM is to drive the machine in accordance with the Tunnel alignment. The driving of the machine with an efficient penetration, cutting and chipping requires an optimum cutter pressure, and these are directly related to the machine thrust and the number of cutters. The upper limits of pressure between the cutter and rock are determined by limitations on the cutter bearings and the machine power. The TBM components and the thrust system are detailed discussed in the following chapters. It is important to bear in mind that driving a machine through the geological is not accurate, and a need of steering adjustment depends on excavation tolerance range. Gripper Cylinder and Gripper Shoes is presented in (fig.4.30).

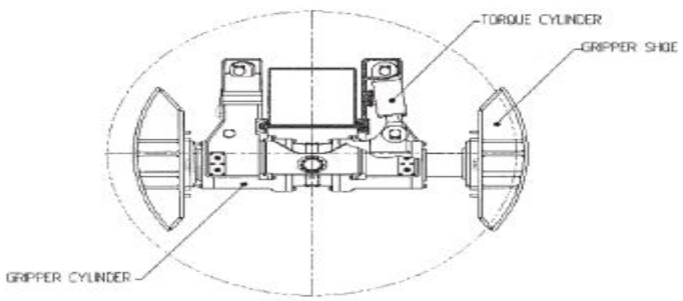


Fig.4.30. Gripper Cylinder and Gripper Shoes [18]

Segment lining

This is prefabricated concrete elements reinforced with a metallic fiber and installed into the tunnel as final support, with the help of a mechanical system. (Fig.4.32) illustrate a prefabricated concrete segment. The Annular space between the excavated rocks and external part of the segment should be filled with sand. (Fig.4.33) illustrate an erector which install the segment ring into the excavated cavity. This segment are carried into the tunnel by means of multi-service vehicle shown on (fig.4.34).

(Fig.4.31) illustrate a scheme of a segment placed into the tunnel. The segment consists of several keys components which allows to support according through the measured geological layers and the diameter to be employed for the planned tunnel.

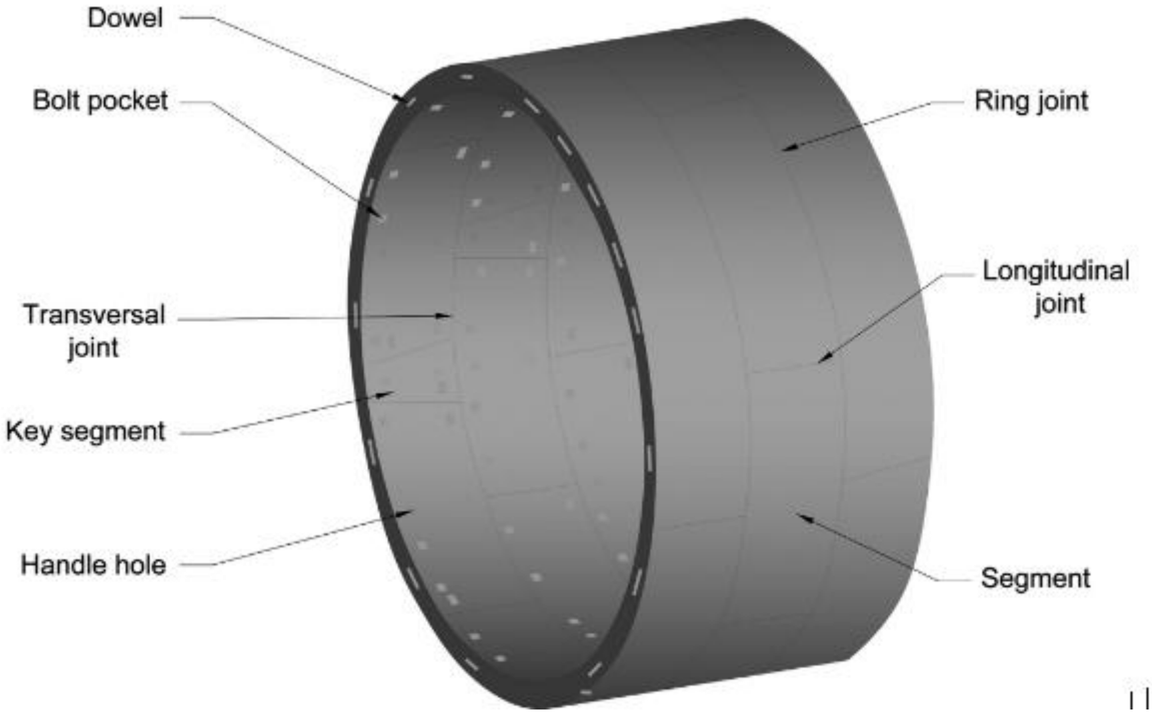


Fig.4.31. Segment ring schematic [16]

Fig.4.32. Segment characteristics [16]

Fig.4.33. Segment erector [16]

Fig.4.34. Techni-Métal multi-service vehicles are extremely all-terrain mobile and can be loaded in different ways [16]

Excavation tools for rock

This subject is vast and the selection of cut disc is important for a correct and productive excavation. The cut disc was adapted from the drilling oil and gas technology and, over time, they were sized for use in the tunneling of mechanized tunnels in the TBMs. As in drilling bit the cut disc is measured in inches and the first used disc of 10 inches (254mm) was altered to bigger size due to a need to increase the cutting power on mechanized excavation process. On nowadays cutting disc 8 "(203mm) to 15", 17 "and 19" diameters, respectively 394mm, 432mm and 483mm are being used on the cutter head to excavate the tunnel. These large diameters have led to a considerable increase in the load capacity to be applied, but as well for the lifetime of the cutters and since it can easily wear out are throughout an excavation, there is a need to be replaced with some frequency, this increase also promoted the performance of the excavation.

These discs are placed on the cutting head together with the bearings and in a certain position so as to ensure that on high pressures these continue to roll along with the movement of the cutting head. The way these are coupled to the cutting head depends greatly on the manufacturer. It should be noted that, as a disposable tool, its replacement must be simple and quick. Typically in tunnel borers with a diameter greater than four meters, this replacement is feasible from the back of the cutting head. Type of cutting disc presented on (fig.4.35 -fig.4.37).

a) Single cutting disc b) Double cutting disc
Fig.4.35. Cutting disc [11]

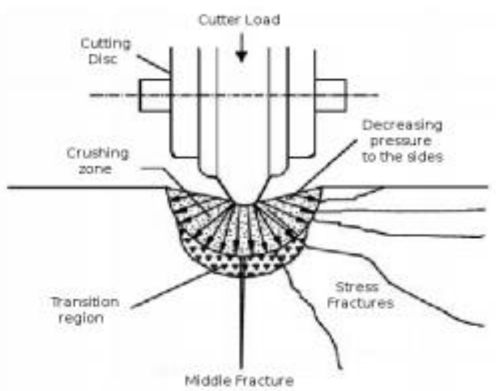


Fig.4.36. Rock fracture with a single cutting disc [11]

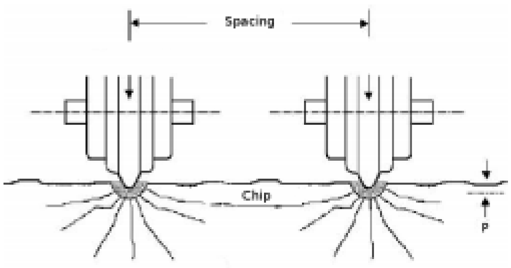


Fig.4.37. Rock fracture with two cutting discs [11]

Excavation tools for soft-ground

cutting tools for soil are essentially static cutting tools, also applicable in combination with discs when the excavation ground is composed of soft rock or some degree of change. These tools are extremely important because they allow break down of the rock if it is altered, cut if the rock is soft, up to about 80 MPa of compressive strength, and remove from the face of excavation rock already excavated in its passage, making it possible to optimize the excavation, and the cutting discs during its passage will cut only hard rock, for which purpose they were designed. This cutting tools are manufactured only in steel and it can be molded in different shapes, and the strength requirements depend from the producer. A sensor intend to be adapt in the cutting disc to provide information about the physical state of the tool to the cab operator. Types of cutting disc for soft ground presented in (fig.4.38).

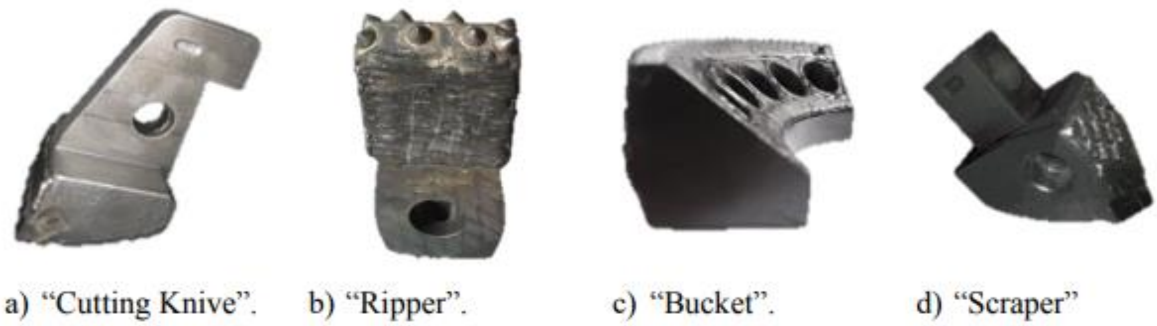


Fig.4.38. Excavation tools for soft soil [11]

Back Up Facilities

The components of the backup system of a TBM for Hochberg tunnel construction in Switzerland. The system employs mechanism components to increases the boring process, providing extra safety, minimizing the labor force, monitoring of the excavation process and the efficient of excreted mucks outside the tunnel (fig.4.39).

Fig.4.39. Gripper TBM and backup system for Hochberg tunnel construction Switzerland [16]

2. Separating material flows

 • Illustration of the disposing of the excavated material mucking with conveyor installations for loading the trains or dumpers, or for feeding the gate (fig.4.40).

Fig.4.40. Belt conveyer system [16]

 • Material supply—base invert segments, support arches, shotcrete, roof bolts, provision of rail/tracks, utility pipes, lighting, tools, spare parts, and power.

3. Separating working areas
   • Bottom invert construction,
   • Ground support work, and
   • Ceiling membrane installation. These should be separated from the transportation flow and back-up infrastructure to enable concurrent work activities.

4. Carrier for the electric and hydraulic installations needed to drive the machine and operate supporting functions—These would include electric transformers, main electric motors, and grout injection pumps.
5. Intermediate storage for ground support elements and other supplies
6. Carrier for mechanical equipment used when installing ground supports, shotcrete, erectors for steel support arches, and hoisting devices power winches
7. Operator and control cab with regulating and steering units for controlling the cutter head and transport installations, the hydraulic and electric installations, and necessary pumps as well as monitoring and alarm equipment. (Fig.4.41) illustrate control cab.

Fig.4.41. Control cab [6]

8. Carrier for ancillary equipment such as fire extinguishing, first-aid, and rescue equipment; toilets; telephone; survey; spare parts; extension tubes; cables; and track storage with hoisting devices

9. (Fig.4.42) illustrate carrier for the dust control system with electric fans, and storage of ventilation duct material used to extend. (Fig.4.43) illustrate Back-up areas for typical gripper.

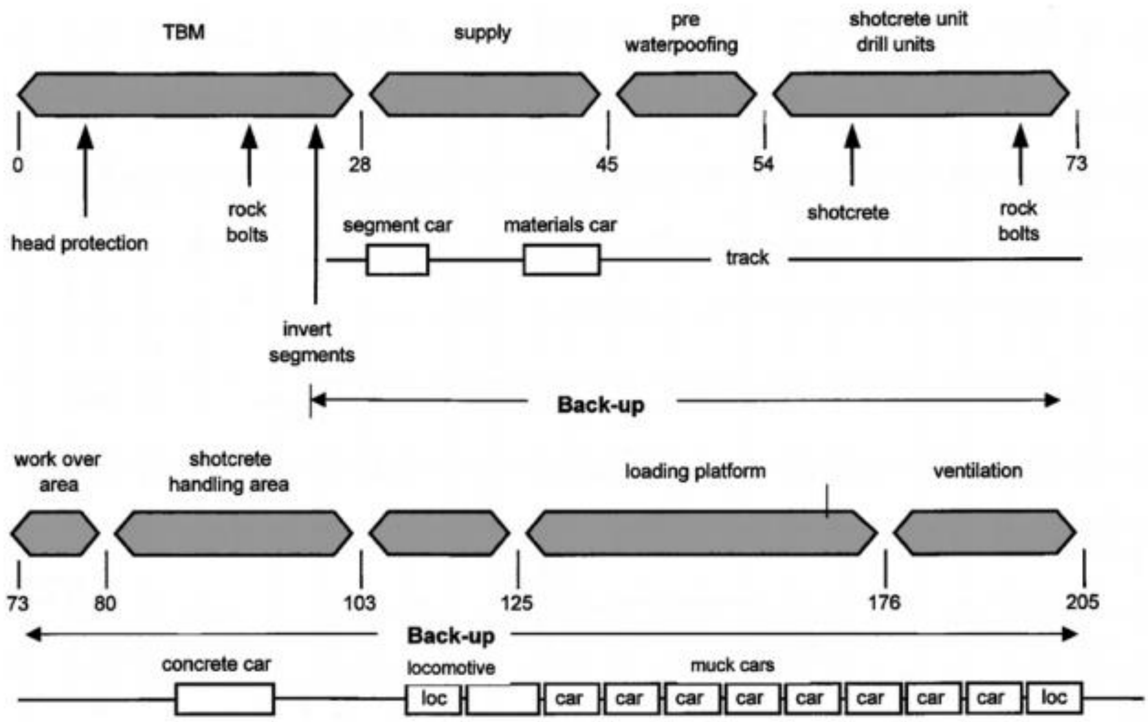


Fig.4.42. Backup functional areas for typical grippers TBM [11]

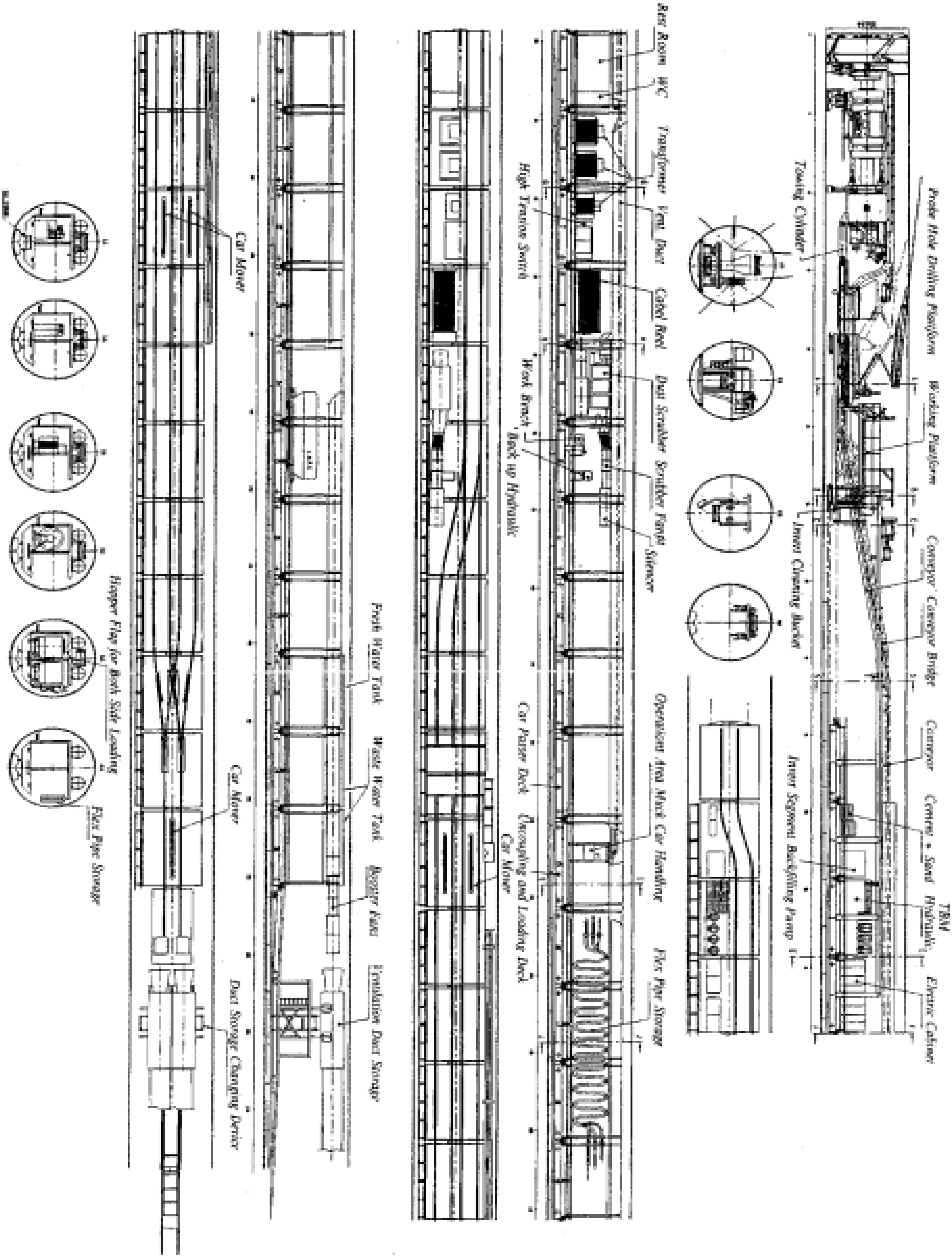


Fig.4.43. Back-up areas for typical gripper [11] odwrócić rys.

5.Techniques procedure in hard rocks

Tunneling in hard rock using the TBM, with good geomechanically behavior and without the presence of water, do not provide immediate support or only final support to the excavated ground, which usually happens only for safety reasons, in order to protect workers from falls of blocks of rock or due to the intended use of the tunnel, thus leading to the placement of the crankshafts and/or metallic grids and/or projected concrete which will give the final support to the tunnel.

5.1. Open TBM

This type of boring machine is usually used in hard, healthy or very low-grade rock massifs with no water presence, these geological conditions being favorable to the propulsion mode of this type of equipment and the need for immediate support after excavation. Full face excavation the tunnel face is excavated entire by the cutting head at each full rotation complete. The Thrust is made by hydraulic jacks attached to claws (Grippers) that act on the walls of the excavated tunnel providing the necessary traction. The progress of the TBM is done in sequence, excavation/propulsion, retraction of the traction claws, retraction of the propulsion monkeys, actuation of the traction claws in the mass, extension of the propulsion jack and again propulsion or excavation (fig.5.2).

This TBM usually has a cutting head equipped mainly with cutting discs and may have a smaller number of other cutting tools. The tunnel support is independent of the machine, being placed later or with the aid of additional equipment to be coupled to the TBM. Muck is usually removed by scrapers and buckets found in the cutting head and then transferred to belt conveyors at the rear of the TBM and taken out. This type of boring machine comprises diameters between 2 and 12.5 meters, and below 3.8 meters the design of the TBM becomes very complicated. Open TBM used to excavated the world's largest hard rock TBM used to excavated the Niagara hydroelectric power project in Canada presented on (fig.5.1).

Fig.5.1. Open TBM [18]

Features components of Open TBM

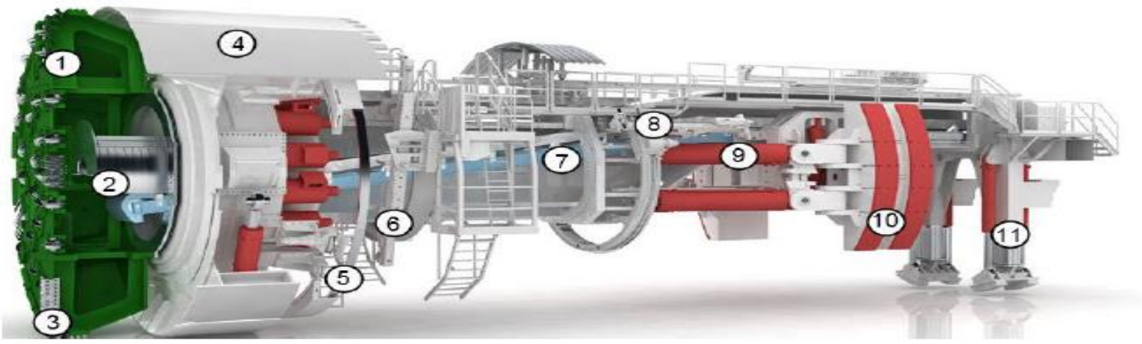


Fig.5.2. Three-dimensional schema of an Open TBM [16]

Where:

1- Cutting head
2- Muck ring
3- Bucket
4- Ceiling shield
5- Erector
6- Unloading unit
7- TBM conveyor belt
8- Drilling unit
9- Hydraulic jack
10- The gripper thrusting system
11- Static support

Immediate support

This type of TBM does not offer any type of immediate support except the one that its own mechanism offers, or as presented, if a shield is attached to it. With this possibility, which does not drastically alter its operating mode, this machine has a wide area of use within the excavation of tunnels in rocky. These shields are used in order to protect the integrity of the equipment and those of the maneuver, from occasional falls of mucks from the excavated ground, also conferring some stability to the tunnel boring machine itself. (Fig.5.3) illustrate a TBM supportive system.

Nowadays three types of shields are used, the Roof Shield, a combination between this shield and the side shield and the cutter head shield. The ceiling shields offers only protection for possible falls from mucks, which is considered a static protection. The TBMs equipped with a roof and side shield plus the static component of the protection inherent to the existence of shields have the possibility through the lateral shields to support the mass with the cutting head during the excavation and during the propulsion. The cutting head shield serves only to protect the machine that maneuvers the machine when it is advanced.

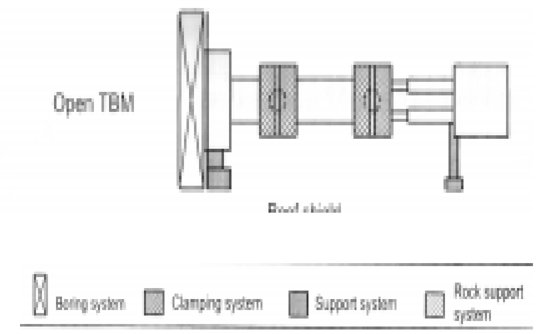


Fig.5.3. Immediate support [18]

Thrusting components

The required thrusting force depends on the type of rock to be excavated, with each TBM being usually built for a particular rock type. This type of TBM is used in hard or very hard rock, thus making it necessary to predict that during the excavation the appearance of rock less capable in Geomechanics occurs, to consider the entire support system in order to deal with the problems that comes from it.

The total thrusting force in this type of boring machine axially released. Applied through the system thrust / thrust jack that acts radially into the mass. In soft rock, it is necessary to take care of the forces applied to the walls of the tunnel, since if this force is too high this can lead to rupture of the rock and consequent deformation. In very hard rocks the opposite happens, since there is limit of expansion, created by the mass, this can create a massive increase of the tensions as well. These forces are about twice the driving force to be applied. This system consists of grippers that act directly against the walls of the tunnel with the aid of hydraulic arms and another set of hydraulic arms that after the "Clamping" push the TBM and all the equipment that makes it pull the face of the tunnel, thus generating the necessary force on the cutting head to excavate the rocks. TBM grippers presented on (fig.5.4) and (fig.5.5).

Driving on tunnel boring machines with this thrusting system is performed before each advance, and cannot be changed during the excavation phase. TBM guidance is performed horizontally and vertically using the rear gripper unit that positions Outer Kelly and the entire TBM. It is necessary to take into account that the during the excavation process the cutting head has to rotate all time to redirect the TBM in order to avoid damage in this and Outer Kelly.

Fig.5.4. Gripper X thrusting system [26]

Fig.5.5. Simple gripper thrusting system [26]

Cutting head

the cutting head, besides being the element to which the excavation tools are coupled, described below, has as functions the removal of the excavated material (Muck) of the excavation front through "pails" implanted in it, make the support of the front of excavation in case of overturning until the rock is properly supported and allow to perform maintenance tasks in normal situations of interruption of the excavation, such as the maintenance of the cutters.

The cutting head, in this type of TBM, can be opened if the rock to be excavated is hard or closed if the rock is fractured or likely to explode. Within these sections there are several types of cutting heads in which the number of muck removal buckets vary, whether they are internal or external and with or without adjustable "lips", the position, type and number of cuttings, and the existence of holes for injection of grouts to consolidate the excavation front, that is, depending on the project plan, and a different cutting head suitable for that project will be obtained. Open and closed cutting head presented on (fig.5.6)(fig.5.7).

Fig.5.6. Cutting head with open cutting tools [18]

Fig.5.7. Cutting head with close cutting tools [18]

- Muck removal

  The mucks is initially removed from the excavation front by "buckets" implanted in the cutting head and dumped into a muck ring, which then transfers the mucks to a belt conveyor. After the mucks is deposited on these conveyors, they are transferred to other belt conveyors, wagons or vehicles so as to be removed out of the tunnel

5.2. Reamer TBM

Concept of Reamer TBM

The Reamer TBMs, also known as Tunnel Boring Extender (TBEs), are in the chute tunneling machines, that is, they are machines used to widen a pre-existing or pre-built hole with the intuition of them being used.

Its operation is similar to the operation of the TBM discussed above except that its cutting head is drawn against the excavation face rather than being pushed. This movement is performed through a traction unit with grippers acting in a pilot hole in the front of excavation, to be excavated previously by a common Open TBM. The cutting head is, similarly, as in the previous machine, rotated with the aid of electric or hydraulic motors. The support of the excavation is also similar to the previous one, except in the pilot hole where in the case of use of temporary support it must be destructible or removable so as not to damage the cutting head that will widen the hole. The removal of mucks is again performed in the same way as in the Open TBMs. (Fig.5.8) illustrate a Reamer TBMs.

Fig.5.8. Reamer TBMs [2]

Thrusting system

The movement of the TBE against the excavation face in order to apply the axial force required to excavate the rock is generated from hydraulic jacks that pull the Outer Kelly, this in turn pushes the cutting head that rotates around the Inner Kelly. The gripper system is placed in the Inner Kelly inside the pilot hole. These gripper, like the conventional Open TBMs, act on the wall of this tunnel by giving the stability necessary for the excavation process to take place

Cutting head (undercutting techniques)

The cutting head, similar to conventional Open TBMs, also has the immediate supportive function in front of excavation and debris removal through conventional "buckets" of an open TBM for a belt conveyor. In this particular TBE the cutting head has a particularity, besides the positioning of the cutters, which are the rails where they meet. These rails slide axially allowing the cutters to run all over the face to dig in its spiral path. These cutting heads have the advantage of reducing the energy required to excavate, since the rock is excavated in the free face. The construction of the cutting head, which is simple with regard to the machinery behind it, allows the rapid restoration of the tunnel walls immediately behind it. (Fig.5.9) shown a cutterhaead.

Fig.5.9. Cutterhead "*Undercutting*" [2]

Undercover technique

This technique, used by the TBE manufactured for the Uetliberg Tunnel, Zurich, Switzerland, consists of the reorientation of the cutting discs. (Fig.5.10) illustrate the undercover in a cutterhead. These instead of acting perpendicular to the excavation face are placed angularly thus allowing the rock to be applied for traction rather than compression, with the understanding of all that the energy required for such is much smaller.

Fig.5.10. Undercover technique [2]

Cutting tool and muck removal

Being a suitable boring machine for hard rock the cuttings are discs, taking into account that if the "Undercutting" technique is used the discs have to be simple cut. As far as mucks removal adaption is mechanical construction of the mucks removal.

6. Technique procedure in soil/rocks

The tunneling machines used in rock with possibility of their conditions vary in terms of change or geomechanically capacity (soft rock) and without the presence of water, they need to provide immediate peripheral support to the excavated cavity so that the excavation goes without serious security problems. This is the only way to limit deformation of the tunnel walls before the final support is placed. Its thrusting mechanism system, in the case of soft or heavily altered rock, also has to be different since an ordinary gripper system would penetrate the ground without it providing the necessary resistance to stabilize the tunnel boring machine and redirect the force to the head cutting. Thus, these tunnel boring machines, which can be equipped with grippers, also have a thrusting system through hydraulic jacks that act on the staves that make up the final support of the tunnel, to be installed immediately behind the TBM and installed by TBM.

6.1. Single Shield TBM

This Single Shield TBMs are used to excavate soil and hard rock layers, and provide immediate peripheral support to the tunnel cavity. Its thrusting system composed by hydraulic jacks that act on the final support placed in behind on the machine. (Fig.6.2) illustrate the components of the single shield TBM.

However, single shield is equipped with a cutting head composed by different cutting tool or cutting disc and its component combination makes it suitable to excavate different geological ground. Robin Single Shield used in Spain’s AVE high-speed rail link (tunnel connects Asturias to the Madrid-Valladolid high-speed link) presented in (fig.6.1).

Fig.6.1. Robin Single Shield TBM [14]

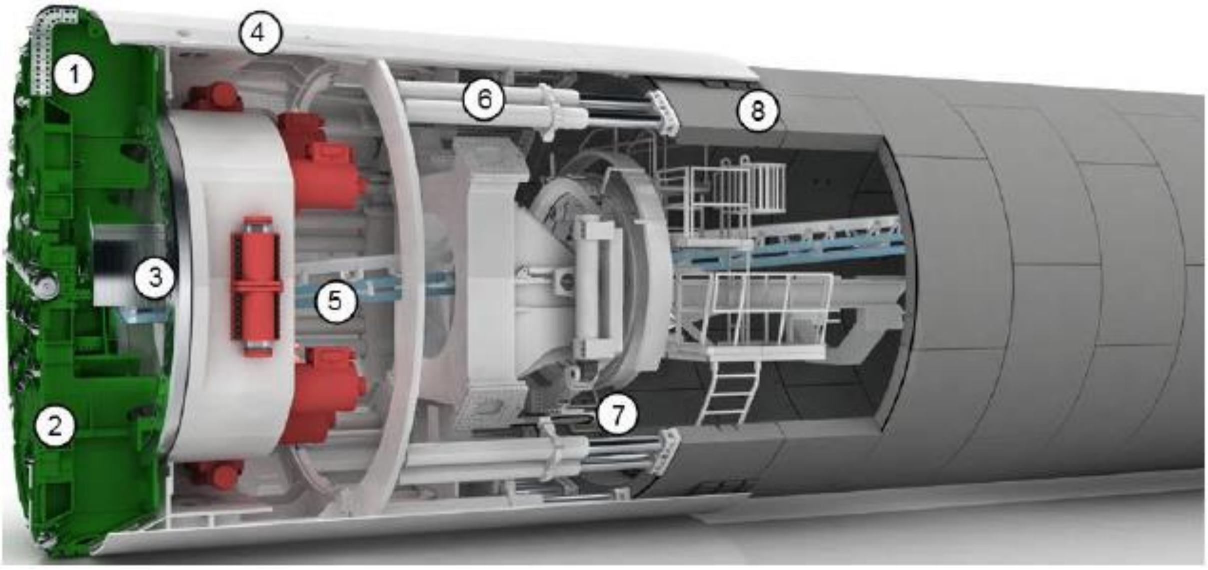


Fig.6.2. Tridimensional Single Shield TBM scheme.[16]

Where:
1-Buckets
2-Cutterhead
3-Muck ring
4-Mkin shield
5-Machine belt
6-Mhrust cylinders
7-Mrector
8-Backfilling

Supportive System

This type of TBM is equipped with a single shield that protects and supports the open ground cavity. Some manufacturers of these equipment's provide optional shields to be coupled to TBM for various uses, such as protecting the placement of staves. This shield consists of a metal ring to which the cutting head is attached. The metallic ring rotates over bearings giving addition a peripheral support, to ensure safety at the back of the cutting head by separating it from the rest of the TBM body.

Boring System

The cutterhead of a Single Shield TBM particularly operates as TBMs for hard rocks, the most obvious possible change may arise depending on the geology, mass on the ground. the excavation tools may be only cutting discs or a combination cutting disc and other excavation tools. (Fig.6.3) illustrate robin Cutterhead for Single.

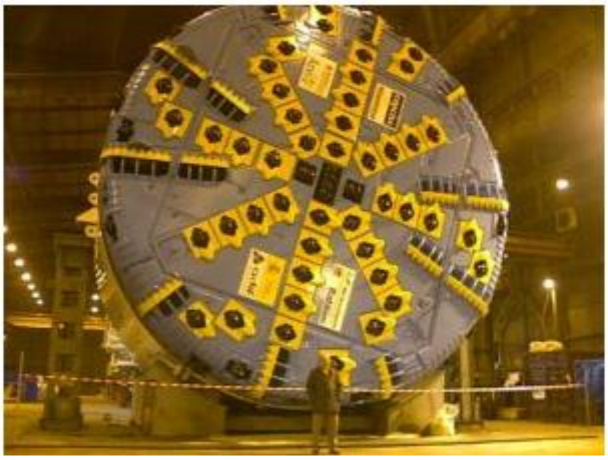


Fig.6.3. Robin Cutterhead for Single TBM [14]

Thrusting system

The driving of tunnel boring machines with this thrusting system is carried out exclusively by the hydraulic jacks. These are organized into groups that exert distinct pressures and depend on their location. In the lower part of the shield, due to the friction generated between this and the mass, there are in standard two groups of hydraulic jacks that will apply an upper pressure in relation to the groups placed laterally, usually one on each side, and in the upper part of the shield also a group. The pressure that each group exerts depends on the friction, which relays on the weight of the tunneling machine and the geology ground mass, and the direction of the machine. Being this directed according to the intended alignment, the different pressures generated by each group of jacks should translate into an equal pressure at the level of the machine axis.

Mucks removal system

Mucks is removed from the excavation front by "buckets" embedded in the cutting head and dumped into the mucks ring that transfers the excavated material to a belt conveyor.

6.2. Double Shield TBM

Double-shielded TBMs are considered by many to be the most technically sophisticated TBMs for tunneling rocky masses. (Fig.6.4) illustrate the double shield TBM. This TBM possesses principle operation of the Open TBMs with those of the Single Shield TBMs. The Double Shield TBM that is equipped with both thrusting systems and in masses of good geomechanically behavior, excavate without the need to stop and additionally allows placement of the final tunnel support. (Fig.6.5) illustrate the components of the double shield TBM.

Fig.6.4. Double Shield TBM [16]

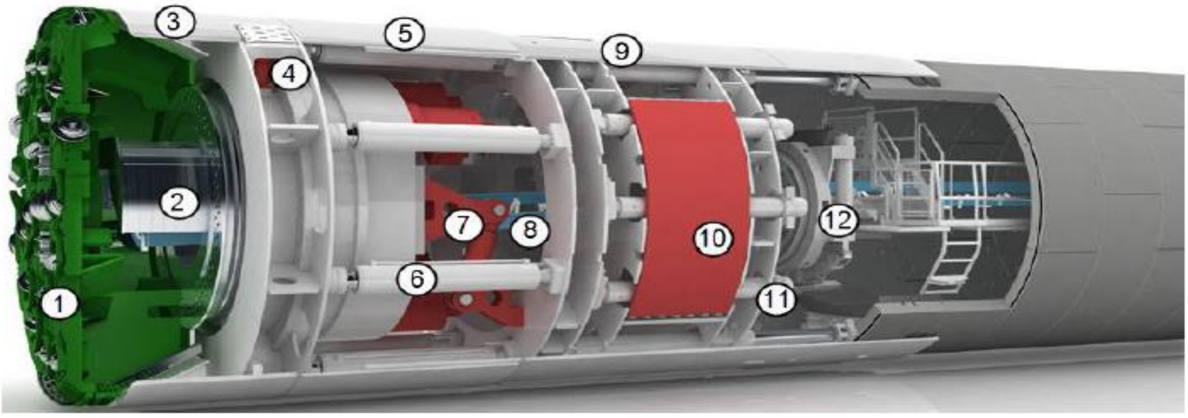


Fig.6.5. Tridimensional Double Shield TBM scheme [16]

Where:

1- Cutterhead
2- Muck ring
3- Front shield
4- Stabilizers
5- Telescopic shield
6- Main thrust cylinders
7- Torque cylinder
8- Machine belt
9- Gripper shield
10- Gripper shoes
11- Auxiliary thrust cylinder
12- Erector

Supportive system

The immediate support to the excavation offered by this TBM is carried out by two shields formed by metallic hoops to which the cutting head is attached, similar to the Single Shield TBM. (Fig.6.6) illustrate a support system for a double shield TBM. This partitioning allows, in addition to the peripheral support, to guarantee the safety at the rear of the cutting head by separating it from the rest of the TBM body. (Fig.6.7) illustrate a bearing for the double shield TBM.

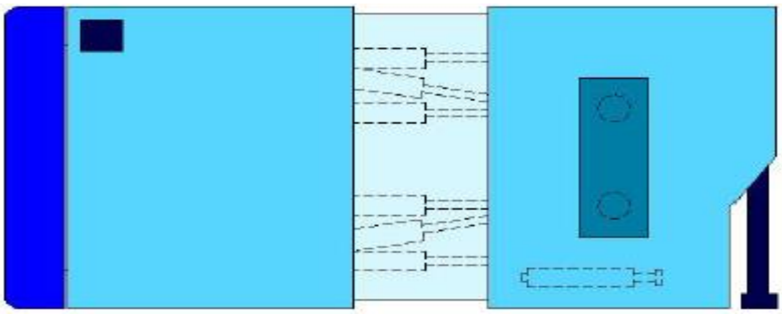


Fig.6.6. Supportive system Double Shield TBM [18]

Fig.6.7. Shield and Bearing for Double Shield TBM [16]

Thrusting system

This technique the driving force is provided by a hydraulic jacks system or a griper system or both alternately. (Fig.6.8) illustrate the thrusting system. The hydraulic jack system provide thrusting force with the assemble jacks installed under the telescopic shield, an auxiliary assembly also radially distributed but less dense behinds the gripper unit, acting on the final support staves simultaneously with the hydraulic jacks mounted on the first shield, the purpose of which is to stop the rotational movement of the machine caused by the rotation of the cutting head against the mass.

Fig.6.8. thrusting system [16]

7. Technique Procedure in Soil

The excavation of tunnels in soft soil or even heavily altered rock masses is one of the most complex tasks within underground works. Soft ground is unstable differently to hard rock and excavating this soil requires support of the cavity due to weakness soil to support itself. Furthermore, in soft ground may contain constant of ground water and this soil offer low supportive capacity, and may not sustain the cavity for a long time, this may difficulty the excavation in soil and a need to adapt a machine to perform the digging. In addition to the difficulties of performing an underground excavation in a mass of this kind, such as the possibilities of the soil pasting on the cutter head of the TBM, the existence of gases, when the mass is rich in organic matter, the need to provide the excavation support both peripheral as front before the final support is placed, there are still other difficulties related when performing tunnel in urban areas which needs more attention. Failure of cut and cover tunnel construction of Nicoll Highway presented in (fig.7.1).

Fig.7.1. Nicoll Highway Collapse [25]

7.1. Earth Pressure Balance TBM

The excavations of soft masses or cohesive soils must be ensured, for safety reasons and executability, to provide immediate support on all excavation process, a peripheral and frontal face support. (Fig.7.2) illustrate EPB TBM used in high ground water content.

The technology of EPB TBMs, also known as EPBMs (Earth Pressure Balance Machines), makes use of the excavated material, making it into a dense and malleable soil by injecting water and pressure additives into the plenum immediately behind the cutting heads, to support the excavation front. The name of this boring machines derived from the use of pressure generated in the front of the excavation by the water/soil mixture maintained in the plenum. This pressure is guaranteed/controlled by varying the amount of mixture withdrawn from the plenum by the "worm" as well as by the pressure exerted by the propulsion system on the front of the excavation. However, it is of utmost importance to continuously monitor this pressure in order to ensure both the stability of the excavation face and the absence of surface subsidence. Tridimensional EPB machine scheme presented in (Fig.7.3).

Fig.7.2. EPB TBM used in high ground water content[16]

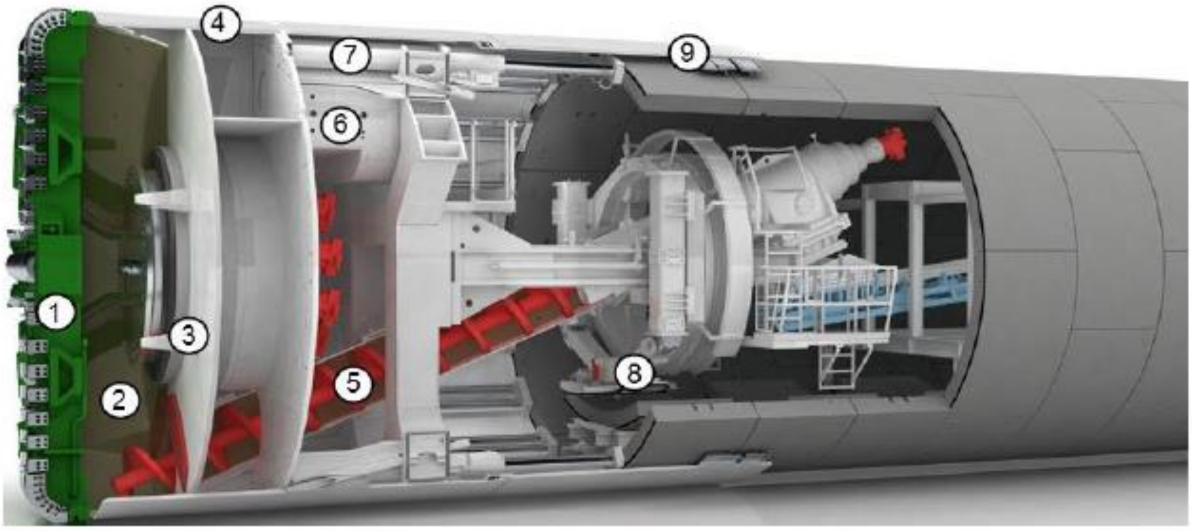


Fig.7.3. Tridimensional EPB machine [16]

Where:

1- Cutting wheel
2- Excavation chamber
3- Mixing arms
4- Bulkhead
5- Screw conveyer
6- Hyperbaric chamber
7- Hydraulic jack
8- Erector
9- Tailskin

Support system

This technique is intended to generate a pressure field that attempts to completely replace the excavated material These pressures are obtained by maintaining and controlling the amount of material excavated within the plenum as well as the pressure exerted on the front of the excavation generated by the thrusting system of the TBM. The body structure of the EPB TBM is similar to the previously discussed, however, a slight difference that it uses water and foams under pressure and keeping the material excavated inside the excavation chamber to ensure the support of the excavation face. The final support is still placed inside the shield, with a membrane that ensures the seal between the exterior and the interior of the tunnel and the machine. This seal is made by elements called "Wire Brushes" that are attached to the shield of the machine and acting between this and the staves. Schema of supportive system presented in (fig.7.4).

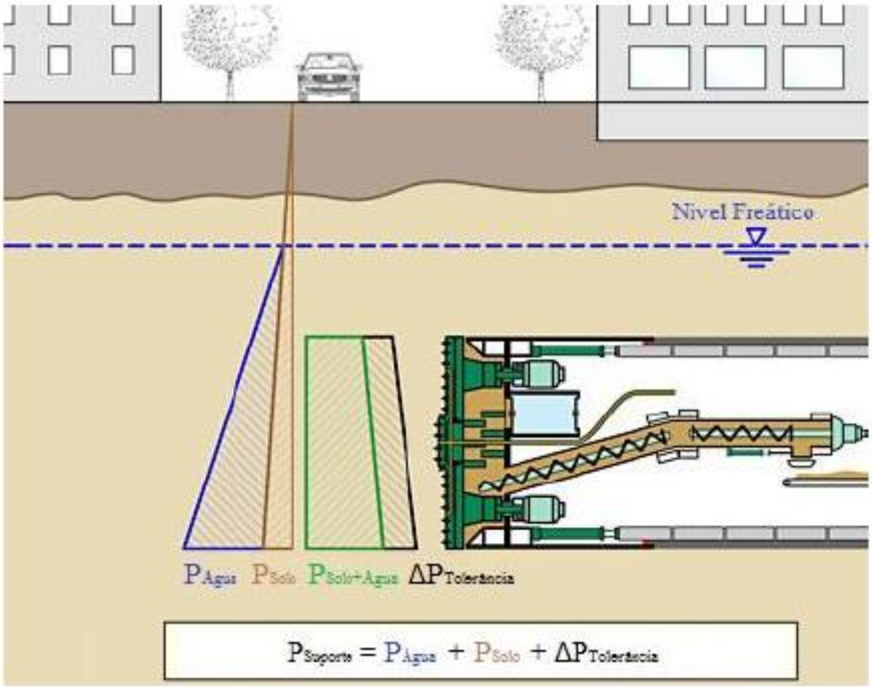


Fig.7.4. EPB TBM scheme [25]

Final support

The placing of final support is also a mandatory element in this technique, not only to provide a zone of action to the thrusting system, but also as a constituent element of the technique itself. The placement of staves inside the EPBM shield allows the waterproofing of the interior of the tunnel, thus guaranteeing the safety of the workers, but also preventing the collapse of the massif which is considered to be less peripherally and frontally competent, because if this waterproofing were not guaranteed, it was not It is possible to pressurize the excavation front causing all fluids due to pressure to converge into the tunnel and the EPBM. (Fig.7.5) illustrate a finalized final support and an engineer making a survey.

Fig.7.5. Final support [10]

Removal muck system

The removal mucks system performs its functions as previously mentioned, part of the immediate frontal support system generated by the EPBM. (Fig.7.6) illustrate The screw conveyor for EPB Shield. The amount of material removed from the excavation chamber is directly related to the pressure exerted on the excavation face. Thus, this system is more complex than those presented for the previous TBMs, so there is a need both to control the amount of accurate material removed from the front as well as maintain the pressure in the chamber. This system consists of a helicoid, commonly known as a "worm screw".

Fig.7.6. The screw conveyor for EPB Shield [16]

Thrusting system

The driving force required for the penetration of the EPBM cutterhead into the excavation face is generated by hydraulic jacks acting directly on the staves placed at the end of each excavation machine. These jacks are part of the TBM body, being positioned radially within the peripheral support shell immediately behind the excavation chamber. Following the line of EPBM components mentioned above, here again the thrusting force does not have the unique function of pushing the machine forward. The pressure exerted on the front of the excavation also depends on the thrusting system of an EPBM, which system has to be continuously monitored in order to avoid uncontrolled penetration into the ground or excessive soil ingress due to excessive in the excavation chamber which may generate some accidents.

Cutter head

The cutting head of an EPBM is slightly different from the other tunnel boring machines, this is due to the necessity of using pressure sensors in front of excavation being absolutely necessary and not optional. The existence of foam injectors and additives are also mandatory here as they are an essential part of the EPBM technique, and in the open TBMs the use of water and additives is optional, making use of these essentially for dust control or in the attempt to reduce wear cutting tools. The cutting tools are either cutting knives, ripper, bucket or scrapper inputted into the cutterhead and types of cutterhead presented in (fig.7.7).

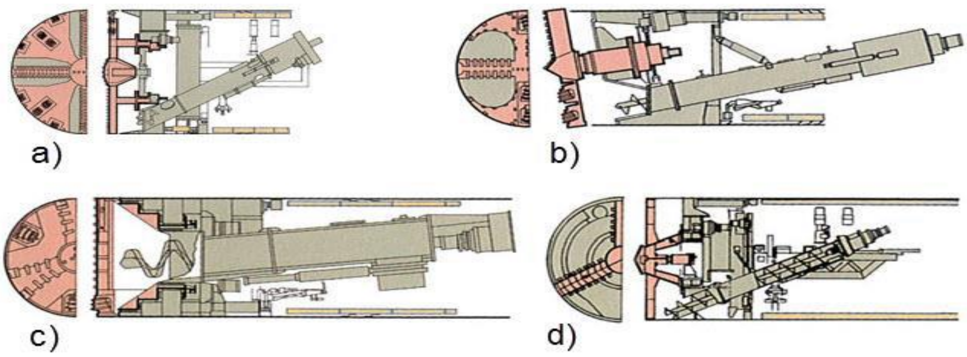


Fig.7.7. Cutterhead [18]

7.2. Slurry Shield TBM

Slurry Shield TBMs or Slurry Face Machines (SFM) or Hydro Shield TBMs, as well as EPBMs, are the most commonly used types of tunnel boring machines in Earthmoving tunnels, varying their applicability with the type of soil to be excavated, as will be explained. This type of boring machine is however more complex to operate and construct than EPBMs due to its excavation face pressurizing system. This system consists of injecting and pressurizing bentonite into the excavation chamber by providing the necessary support both for the stabilization of the excavation face and to prevent uncontrolled penetration of the TBM. The system of supply and removal of bentonite and bentonite / mucks mixture is complex since it is necessary to guarantee the pressurizing of the excavation chamber at all times and requires the construction of a large tubular network as well as a plant for the preparation of bentonite as for the treatment of the mixture withdrawn from the excavation front. (Fig.7.8) illustrate the slurry shield TBM scheme.

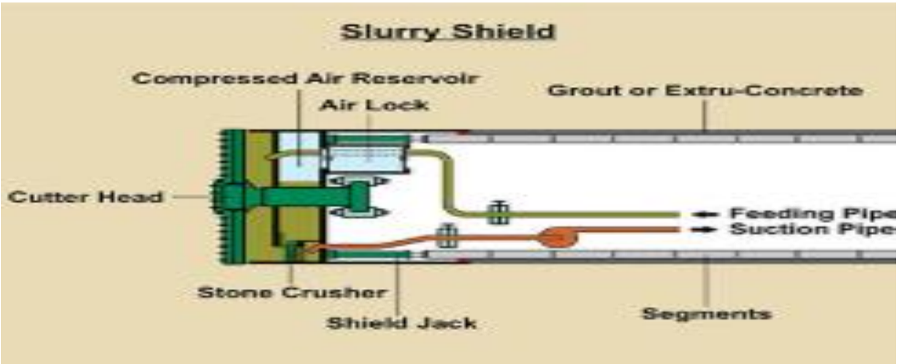


Fig.7.8. Slurry Shield TBM scheme [25]

Support system

The immediate peripheral support generated by an SFM is due to its circular shield that supports the rods and roof of the excavation, thus promoting the safety of both the machine and the personnel that works on it. Like the EPBMs, due to the front support due to the front pressurization, also in the SFMs there is a sealing mechanism, functioning between the shield and the final support, which waterproof the interior of the TBM.

Cutterhead

The cutterhead of SFM is similar to that of an EPBM, and there is also a need to be more open than a boring machine that does not provide front support. (Fig.7.9) illustrate the sslurry shield cutterhead. However, the ratio between the open section of the cutting head and the excavation section is substantially higher. (Fig.7.10) illustrate type of cutterhead system employed soft soil.

Fig.7.9. Cutterhead used on the water lee tunnel excavation London, UK [16]

The SFM TBM used a three types of cutting heads system as described below:

A) Intermediate cutting support system
B) Central cone cutter support system
C) Central Axle Cutting Support System

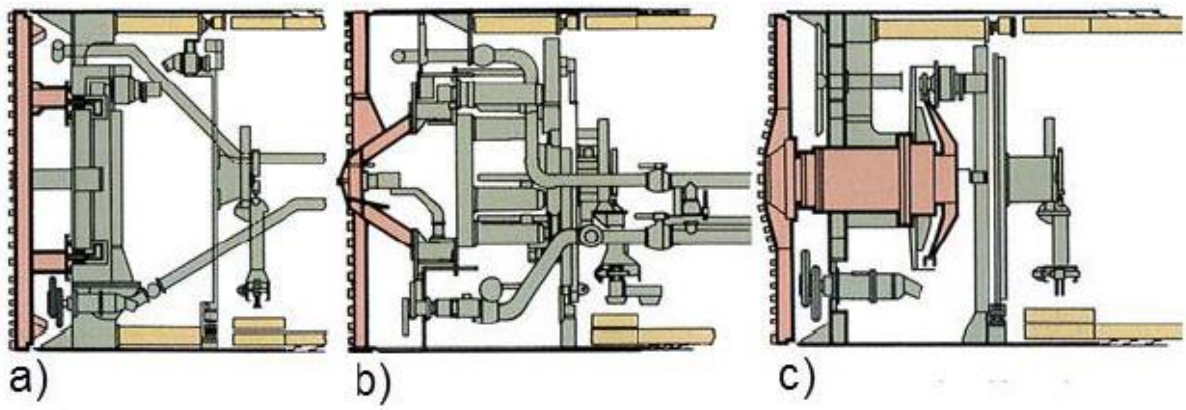


Fig.7.10. The three cutting head system [18]

Mucks system

Removal of mucks from the excavation chamber is carried out by pumping the mucks/ mud mixture to the outside, following the supply network and removal of sludge to the sludge treatment plant.

As on drilling borehole for gas and oil the mud extracted or provide should reguarly monitorized to have the accepatble standard.

Thrusting system

The driving force of the SFM is provided by hydraulic jacks that performed its works by acting axially on the final support plced by the erector of the tunnel boring machine inside the tunnel.

7.3. Mixed Shield TBM

The mixed shield TBX are combination of the slurry TBM and open TBM in more advance manner. The technology applied on this boring machines allows to excavate a ground with much content of groundwater presence and even with a much larger diameter of the borehole. The frontal is filled mud/mucks to provide the frontal support to the excavation.

The submerged wall provides the links between the parts through an open on the low part of the wall. This combination provide more stability on the excavation and the removal of the mucks to allow the better perform of the cutting head. A mixed shield TBM illustrated in (fig.7.11). there are more of this combination which shall not be discussed in this thesis, but the read can obtain on referring to biography[1],[2] and [3].

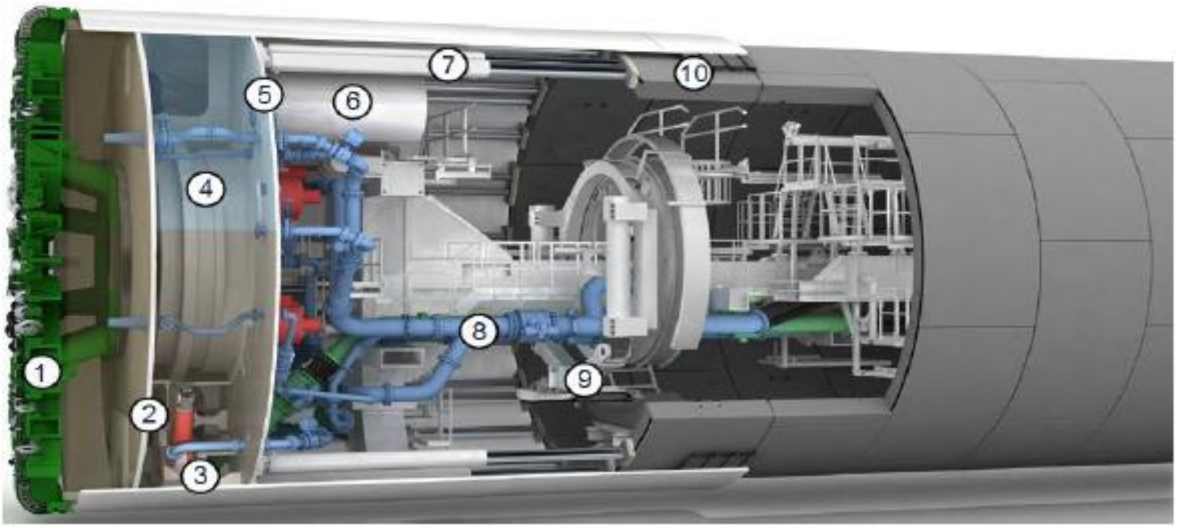


Fig.7.11. Combined SFM and OF TBM[16]

Multi-mode TBM (EPBM,SFM and Open TBM)

This technology combined the system of three TBM which were previously on this thesis. The tridimensional characteristics of the multi-mode boring system presented in (fig.7.12).

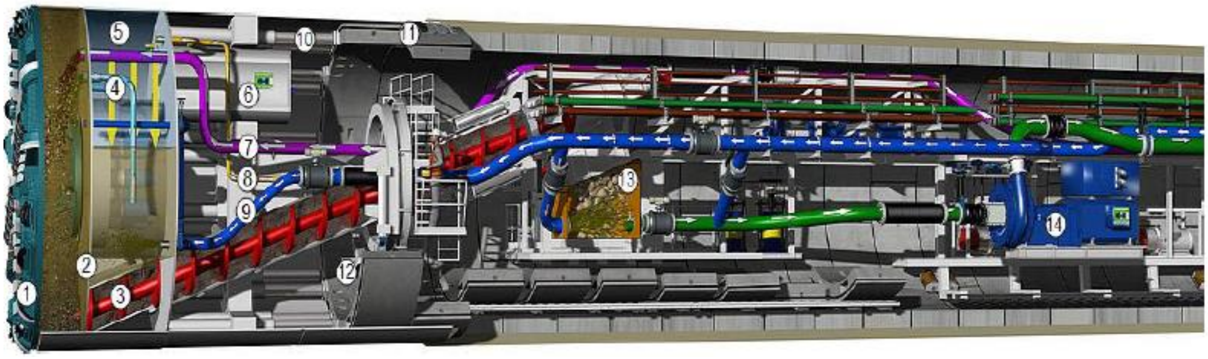


Fig.7.12. Multi-mode TBM [16]

These technology are not thoroughly discussed all the components of boring machines due to information provide on the previous chapter discussing the mechanizing of the ground open through tunneling boring machines. However, the advance of tunneling construction techniques have made a great impact not only provide safety to labor force, surrounding environment or stability and life expectance of tunnel, but more fast mechanism to perform the excavation of the ground.

8. Gotthard base tunnel case study

Introduction

The gotthard base tunnel is tunnel excavated in the heart of the swiss alps and consider to be the world's longest railway tunnel and the excavation plan on (fig.8.1). This tunnel consist of 57 km length for the two parallel tunnel connected with a passage away safety and the total length of tunnel and shafts is 151.84 km, linking the northern to the southern Europe and a ceneri tunnel which is rail route connecting Bellinzona and Lugano will shorten the travelling distance by a hour between Milan and Zurich, expected to be opened by 2020.

The excavation of the mega tunnel was divided in five section and base site excavation were introduced to minimize the construction time. The two main site are portals at the Erstfeld in the north and Badio in south, and three immediate attacking site are shafts in the Sedrun, Amsteg and faido.

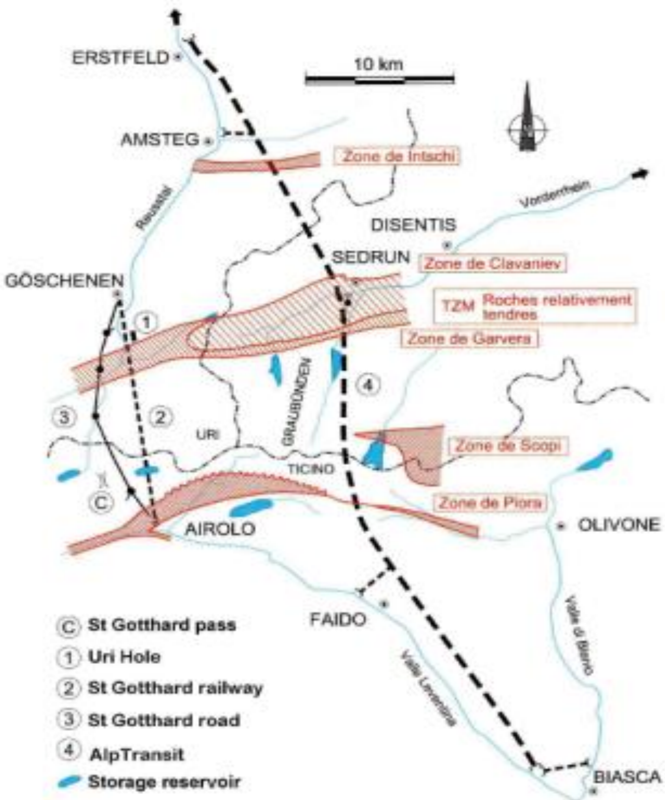


Fig.8.1. Key elements of the basis tunnel layout [15]

Tunneling safely through the "ordeal" of the Piora Basin

A further difficult zone awaited the tunnel builders on this stretch - the Piora Basin – a funnel-shaped formation filled with sugargrained dolomite and water, which reaches deep into the rock of the mountain range. (Fig.8.2) illustrate gotthard tunnel overview. Its existence was long known, and hardly any other part of the Gotthard had been investigated as intensely prior to the construction work. Since no one knew how far into the mountain the funnel reached, a decision was taken to make exploratory drills. A horizontal tunnel with a length of around 5.5 kilometers was driven from the cantonal road to the disturbance zone. In 1996, this zone was penetrated. The loose grains of rock turned out to be exposed to the enormous pressure of around 150 bar. A thick jet of water mixed with dolomite shot out of the mountain and flooded the road. The media called it 'D-Day at Piora Beach. [15]

.

The light S structure design of the tunnel was decisive due to:

- To avoid the facing of the overburden, especially when excavating the alpine crest
- To avoid the concrete dam
- To avoid poor soil conditions and mainly the Piora syncline in the south part and the Tavetsch mass layers in the centre of the tunnel.

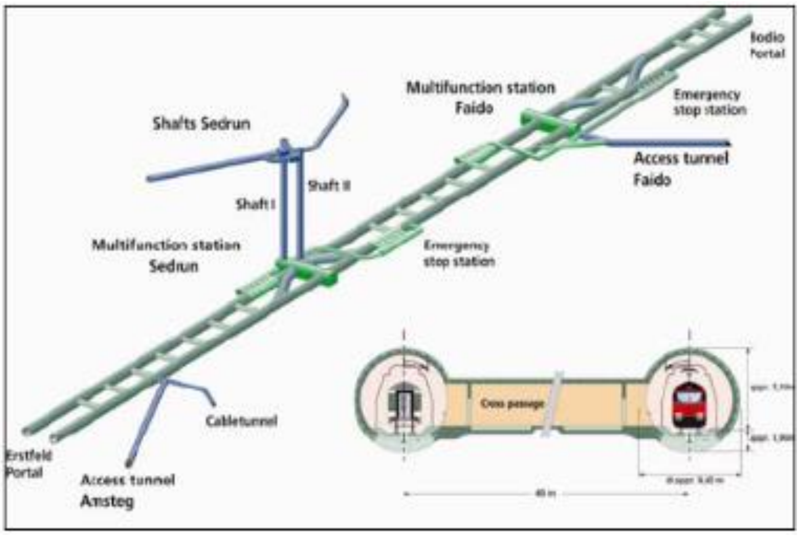


Fig.8.2. Gotthard Base Tunnel: Overview [15]

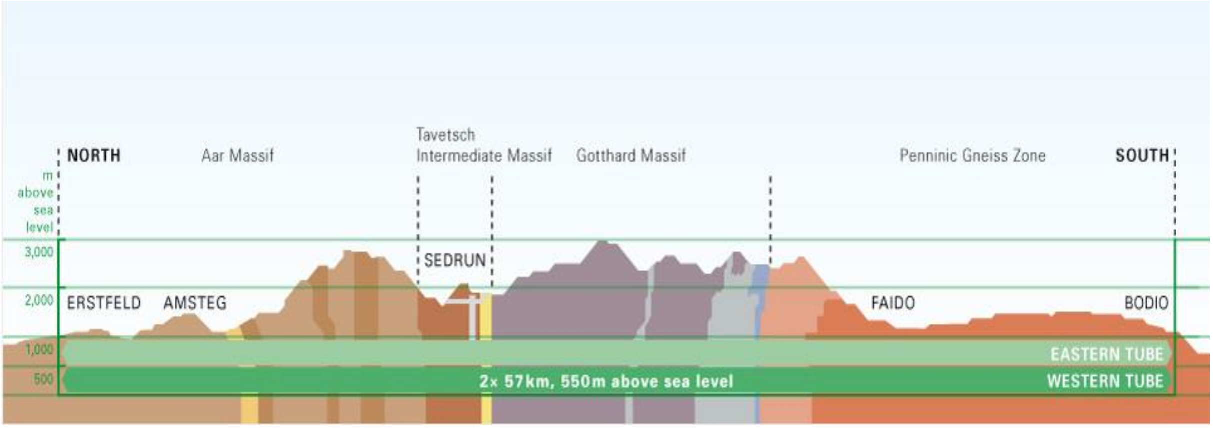


Fig.8.3. Gotthard Base Tunnel: general longitudinal profile with excavation methods [16]

In the gotthard base tunnel, with about 151,84 km, a 96km is excavated by TBM representing about 80% of total length, and "drill and blast" technology to excavated the Sedrun region. (Fig.8.4) illustrate the used excavation methodology. The excavated rocks were recycled and reuse to lining of the tunnel walls, and the pure contained water of the gotthard mountain were treated by the treatment plant created on each site. The access tunnel were constructed to allow labor force and needed materials to complete the project. To avoid the break of the lining of the walls, laboratory was constructed to test the rocks strengths, testing explosive to break the hard formation and training the labor force to respond to the accidents.

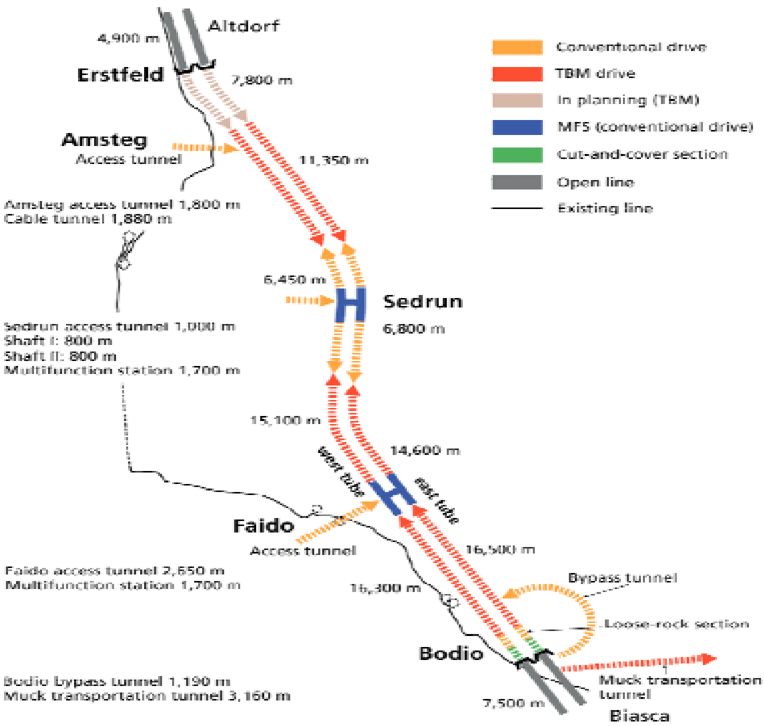


Fig.8.4. The excavation methodology layout [15]

The project were required the use of the big machines "boring machines", but the geological conditions of the underground of the mountains at some point required an alternative method "drill and blast". The soil presents facture, presence of water or soft which resulted on the S shape of the projects.

The site of the Faido and Bodia at one point had to be connected due to weaker layers and the excavation had to change the direction. The combination requires for both system to work along, and transportation mucks, dewatering the Faido station due to high volume of water and provide the safety into the tunnel were major challenge to the project itself. (Fig.8.5) illustrate the concept used to over the difficulties.

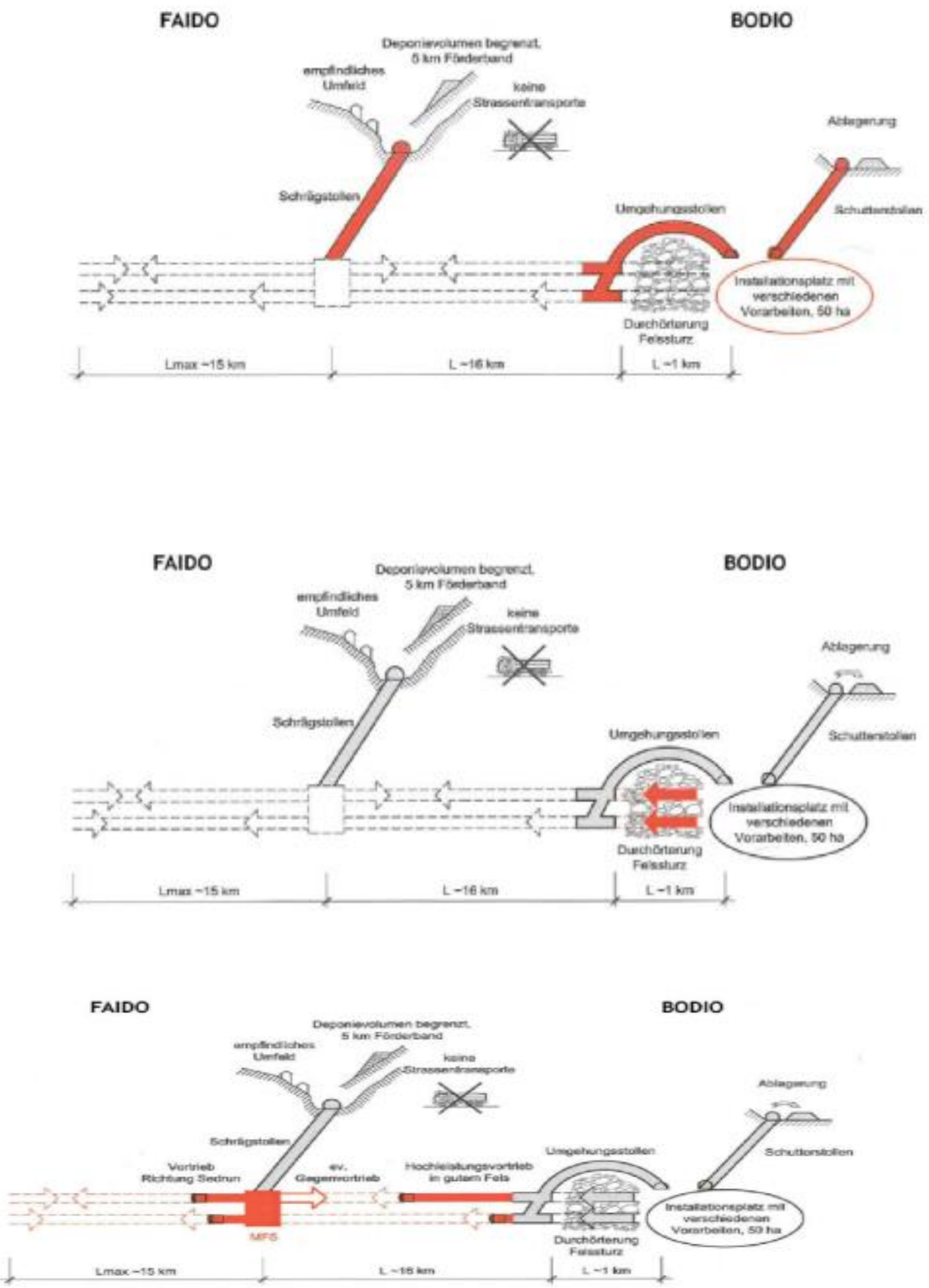


Fig.8.5. Gotthard base tunnel South, key elements of the heading concept [15]

This point were the used for the drill and blast presenting on the figure.8.6 below. The construction faced a major fault zone and engineers needed grouted the zone to allow the continuation of the excavation, and were noticed that the use of the :drill and blast" were relevant to use and in deep depth of the mountain represented a major risks to labor force. The excavation through difficult site illustrate on (fig.8.7).

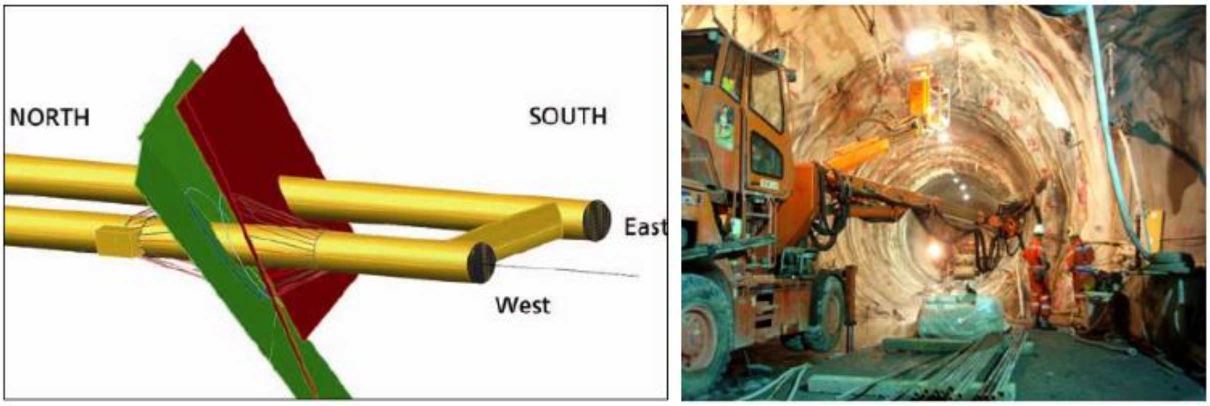


Fig.8.6. Grouting of a fault zone [15]

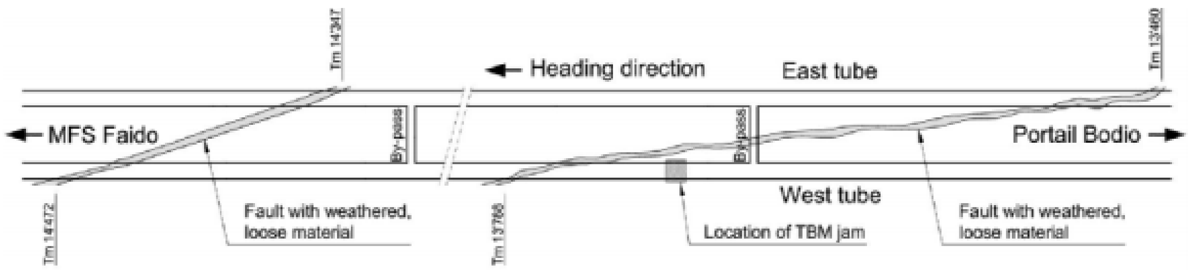


Fig.8.7. TBM progress through the faults [15]

These TBMs were operated 24 hours a day, 7 days a week for more than 10 years to constructed the world's longest tunnel. The cutterhead modified to excavated the geological layers between Faido and badio (fig.8.8).

Fig.8.8 Cutterhead used to excavated Faido and Bodio [16]

9. Conclusion

1. The construction tunnels techniques employs different types of excavation technologies, its complex and multidisciplinary aspects, and this methods always have been in constant evolution as discussed in the history chapter. This development seeks to respond to the rapid accessibility of various type transportation and the balance of this used technique to the between economic, environmental safety, labor force safety and some other aspects which may influence the application of chosen excavation technology.

2. Chapter discuss some of the main engineering consideration parameters which allows the analyzes of the rock mechanics and through this analyzes engineering are able to estimate support system, and the life expectancy of the tunnel. This parameters are geology, material properties, geotechnical parameters and the construction process. To obtain the optimal peak rock load to avoid the unwanted disaster of the construction such as failure of the tunnel resulting from excavating the weak site of the rock formation geological a geological collect data, properties and parameters are used to estimate withstand weight at each point along the construction process. The unstable loose wedges are caused by weak discontinuity planes and at this point site a support system need to avoid failure of the construction, and at point site where peak load exceed the bolt capacity. The tunnel are secure with a permanent support which is a support of rock mass by the wire mesh reinforced shotcrete lining and reinforced concrete lining. The estimation of performance include that the tunnel should accessible to service and economically wise affordable to be constructed.

3. The history of tunnel marks the existence of tunnel into human lives. The earlier tunnel were used for the drainage, links routes to the royal compound comparing to today tunnels that are more far used to better the human lives. The earlier tunnel were dug by men labor , support by wooden material and losses of lives. The revolution of tunnel by digging trench, tunnel used during wars battle. The drilling tunnel by blasting the structure of the mass rock by the invention of the explosive, but, the tunneling boring machines are more convenient which are currently used to excavate long tunnel. The evolution was base from failure and difficulties to excavate the tunnel at some point. The French engineer develop the base components of this machines, where they were used safety structure and along the years the full boring machines components connected to each other and optimizing the construction process at all aspects.

4. Tunnel excavation impacts the ground and the surrounding environment. The excavation impacts the ground both at the surface of the soil and at the subsoil affecting the natural in-situ stability, and environment impacts causing traffic

jams, relocation of people, affecting businesses in the surrounding of the site construction and this may lead to extra cost to the project.

Thus, to avoid the extra cost or the failure of the project due to in-situ instability the technologies and techniques employs have been into constant development. This thesis focused on the most currently technologies used to constructed such as the "cut and cover" , "drill and blast" , New Austrian Method and mechanized technology. The "cut and cover" used for short length tunnel due to its disturbance ways of executing the process excavating by providing lateral walls and cover support and the constructed is done in this structure. The "drill and blast" which may be disturbance to the urban areas due to noise of the explosive blasting and vibration due to drilling. Therefore, the mechanized technologies technology is the most optimal method, characterized to perform excavation in soft soil, mixture structures and hard rock by means tunneling boring machines. The tunneling boring machines provide safety of both soil and surrounding environment, excavate faster minimizing the excavation time length and adequate to use in the urban areas. This tunneling boring machines are assembly of the cutterhead which excavate the layers of mass rock, the body serve as a temporary support of the cavity, the combination of hydraulic jacks and grippers provide the driving force needed to excavate the rock mass, the cab unit and the mucks transport system to carry out debris out the tunnel.

Thus, to avoid the failure. Failure results from stress redistribution, stress relaxation and deformations around the tunnel. Ultimately, tunnel failure occurs when the loads exceed the value of the bearing resistance. Therefore, a support system comprising unique structural components is needed to resist the weight of unstable rock wedges thereby ensuring that the tunnel does not fail. Nevertheless, stability depends on an effective rock support interaction, specifically with the rock bolt which is the main support member. In order to assess and improve stability conventional methods to design are borrowed from geology which assesses material properties by visual observation, physical identification, using rudimentary geological handy tools, charts and graphs to estimate tunnel support ranges. For stability, the specific value of the required capacity to prevent failure should be established. This paper presents the background to the engineering design of an adequate tunnel support based on the peak rock load which must be resisted to ensure the tunnel remains stable.

5. Tunneling in hard rock using the TBM, with good geomechanically behavior and without the presence of water, do not provide immediate support or only final support to the excavated ground, which usually happens only for safety reasons, in order to protect workers from falls of blocks of rock or due to the intended use of the tunnel, thus leading to the placement of the crankshafts and/or metallic grids and/or projected concrete which will give the final support to the tunnel.

Hard rocks can be as well excavated by "drill and blast" method for a shorter length which is economically. But the process of excavation not seeing as environmental due to the explosive, noise pollution, safety of the labor force and time length to constructed a tunnel.

6. The tunneling machines used in rock with possibility of their conditions vary in terms of change or geomechanically capacity (soft rock) and without the presence of water, they need to provide immediate peripheral support to the excavated cavity so that the excavation goes without serious security problems. This is the only way to limit deformation of the tunnel walls before the final support is placed. Its thrusting mechanism system, in the case of soft or heavily altered rock, also has to be different since an ordinary gripper system would penetrate the ground without it providing the necessary resistance to stabilize the tunnel boring machine and redirect the force to the head cutting. Thus, these tunnel boring machines, which can be equipped with grippers, also have a thrusting system through hydraulic jacks that act on the staves that make up the final support of the tunnel, to be installed immediately behind the TBM and installed by TBM.

7. The excavation of tunnels in soft soil or even heavily altered rock masses is one of the most complex tasks within underground works. Soft ground is unstable differently to hard rock and excavating this soil requires support of the cavity due to weakness soil to support itself. Furthermore, in soft ground may contain constant of ground water and this soil offer low supportive capacity, and may not sustain the cavity for a long time, this may difficulty the excavation in soil and a need to adapt a machine to perform the digging. In addition to the difficulties of performing an underground excavation in a mass of this kind, such as the possibilities of the soil pasting on the cutter head of the TBM, the existence of gases, when the mass is rich in organic matter, the need to provide the excavation support both peripheral as front before the final support is placed, there are still other difficulties related when performing tunnel in urban areas which needs more attention

8. Throughout this thesis, the different excavation methods were discussed, but with more focus to mechanized construction of tunnels, which in tunnels of considerable length, becomes an economically viable option, with high safety conditions, both inside the tunnel and at the surface. To perform works that were once inaccessible. The use of these boring tunneling machines in a way, replace the so-called conventional techniques, eliminating in large number the limitations of this method.

   However, the tunneling boring machines present limitations regarding to types of subsoil being excavated. This was seeing in the construction of the Gotthard tunnel, facing different type of rock formation, the water presence and the time to perform the construction. The project used "drill and blast" method to secure excavation at setting point, but the TBM increased the rapid of the excavation and decreasing the time length of construction.

The tunnel construction employs different site to analyzes the techniques point for safety training issues, laboratories to analyze the contexts material of the excavation, techniques to recycle the mucks and this allowed the reuse of almost 70-80% to build the tunnel. Today the tunnel provide link transport is consider as an important route for the Europe with two lines running side each other and middle providing safety or evacuation in case of an accident between the lines.

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