Engineers Association in Kurdistan

Construction of tunnel

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CHAPTER ONE

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Introduction

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1.1 Introduction to Tunnels:

The tunnel is geometric construction, artificial not natural and forms a passage or way underground, through water or through mountain.

The tunnel is build through rock soil or clayey soil, tunnels used to transport goods and persons, there are special tunnels used for carrying water or gas or to drain waters ...etc.

There are many shapes of tunnels; tunnel shape depends on what purpose it built for. There are many sections of tunnels but the most used section is rectangle one, as it preferred for service purposes.

In this project, we brought up historical development that goes along with tunnels evolution since first tunnel constructed in history until present time. It's already mentioned how to build tunnels through two kinds of soil (rocky and clayey) and used methods to construct these tunnels through these soils. It's also brought up how to drain water leaked and entered to tunnels, the sources of water and its quantity.

It's also recognized how to ventilating and lining tunnels with concrete blocks. Studying tunnels is very important matter as excavating tunnels considered one of most costly projects and most dangerous engineering project. Excavating tunnels needs before staring digging to geological inspections by certificated geologist to estimate geological circumstances undergrounds and representing them in maps and geological sections to enlighten the tunnels engineer about the expected geological *problems during digging the tunnel to avoid its danger by proper design of tunnel path or taking required geometric procedures that ensuring to face these problems and difficulties.*

This chapter presents the technical and constructional development of tunnel, and gives a clear idea about tunnels development stages in various countries further to details of some superior tunnels that existed in the world.

1-2 Egyptian Tunnels:

The first tunnel built by the Egyptians and Babylonians before 4000 years ago.

The tunnel of Babylon is built between two buildings was 3.6m width and 910m length.

*The first tunnel constructed underwater was under Tigris River and its internal dimensions are (5*4m) and length about 1km.*

Many tools used like (shovels, hammers, sculpture tools ... etc.) are used to construct theses tunnels but within limited applications and unlimited time.

They used many auxiliary factors to build tunnels represented by:

Using fire as auxiliary factor to break rocks.

Developing work manners in many points using ...

Using acids in waters as method to handling rocks chemically and mechanically.

1-3 Roman Tunnels:

*The first roman tunnel constructed before about 2700 years ago with dimensions: (3*1.8m) and length 5.2kms. It's built through* *limestone rock and takes about 11 years to be accomplished, 30000 workers participated in progress, and it's used for bringing waters from a spring under Salvino Mountain.*

In those days, working in tunnels considered punishment for prisoners and slaves, most of those tunnels are used for war purposes. Romans also built a tunnel before 2000 years ago (length 900m and width 7.5m) under Posilipo Mountain.

1-4 French Tunnels:

Until the 17^{th} century, there isn't any development in tunnels construction except using gunpowder. The gunpowder used in France during the years (1679 – 1681) to construct a tunnel ***Languedoc Caval*** *which was (170m) length and dimensions (9.6*7.3m). In years (1766 – 1777) a tunnel called* ***Harecastle*** *constructed, 2.4km length and dimension (3*4m), the first railway tunnel constructed in France on year 1826.*

The art of tunnels construction witnessed the greatest constructive development at construction of ***Mont Cevis*** *tunnel in France between Italy and France, It was 12kms long and many Italian machines are used to construct it in addition to explosion processes.*

1-5 American Tunnels:

*The first American tunnel constructed in Pennsylvania called **Auburn** on 1821; dimensions are (width 4.8m, height 6m and length 135m). **Portage** tunnel is considered the first railway tunnel in USA and constructed on year 1833 with dimensions (6m width, 5.7m height and 270m length).*

***Hoosace** tunnel in USA which connect states **Boston** and **Albany** was (7.6km length, 6m height and 7.2m width) constructed during years (1857 – 1875). In that period there are many constructive developments in tunnel construction like:*

Work was beginning from both ends of required tunnel

Using Nitroglycerine as explosive material and electricity as power source

Using pressured air as digging power.

***Washington** tunnel which constructed under **Chicago** River was the first tunnel for vehicles passage on 1866, many other tunnels are constructed like **Hollawd tunnel** 1927, **Lincoln** tunnel 1933.*

1-6 British Tunnels

*In London, the firs the railway tunnel was **Box-Hill** (length 3.2km, width 9m and height 7.5m) and constructed on 1814, the other tunnel is **Kilsby** (2.4km length) constructed on 1841.*

***Rotherhithe** tunnel construction based on using pressured air during 1908 (2km length and 9m diameter).*

Chapter Two

Types of Tunnels

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Types of tunnels

2.1 Tunnel Basics:

A tunnel is a horizontal passageway located underground. While erosion and other forces of nature can form tunnels, in this article we'll talk about man made tunnels -- tunnels created by the process of excavation. There are many different ways to excavate a tunnel, including manual labor, explosives, rapid heating and cooling, tunneling machinery or a combination of these methods.

Some structures may require excavation similar to tunnel excavation, but are not actually tunnels. Shafts, for example, are often hand-dug or dug with boring equipment. But unlike tunnels, shafts are vertical and shorter. Often, shafts are built either as part of a tunnel project to analyze the rock or soil, or in tunnel construction to provide headings, or locations, from which a tunnel can be excavated.

The diagram below shows the relationship between these underground structures in a typical mountain tunnel. The opening of the tunnel is a portal. The "roof" of the tunnel, or the top half of the tube, is the crown. The bottom half is the invert. The basic geometry of the tunnel is a continuous arch. Because tunnels must withstand tremendous pressure from all sides, the arch is an ideal shape. In the case of a tunnel, the arch simply goes all the way around.

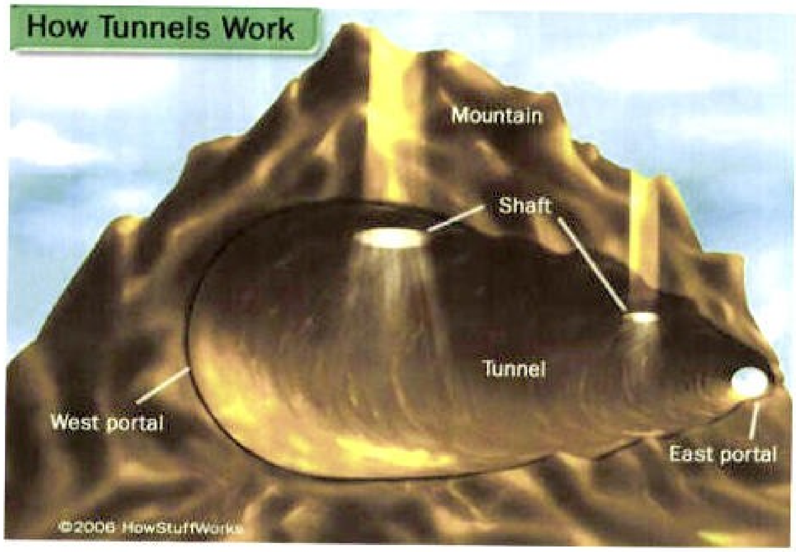


Figure (1) typical mountain tunnel

Tunnel engineers, like bridge engineers, must be concerned with an area of physics known as static's. Static's describes how the following forces interact to produce equilibrium on structures such as tunnels and bridges:

Tension, which expands, or pulls on, material

Compression, which shortens, or squeezes material

Shearing, which causes parts of a material to slide past one another in opposite directions

Torsion, which twists a material The tunnel must oppose these forces with strong materials, such as masonry, steel, iron and concrete.

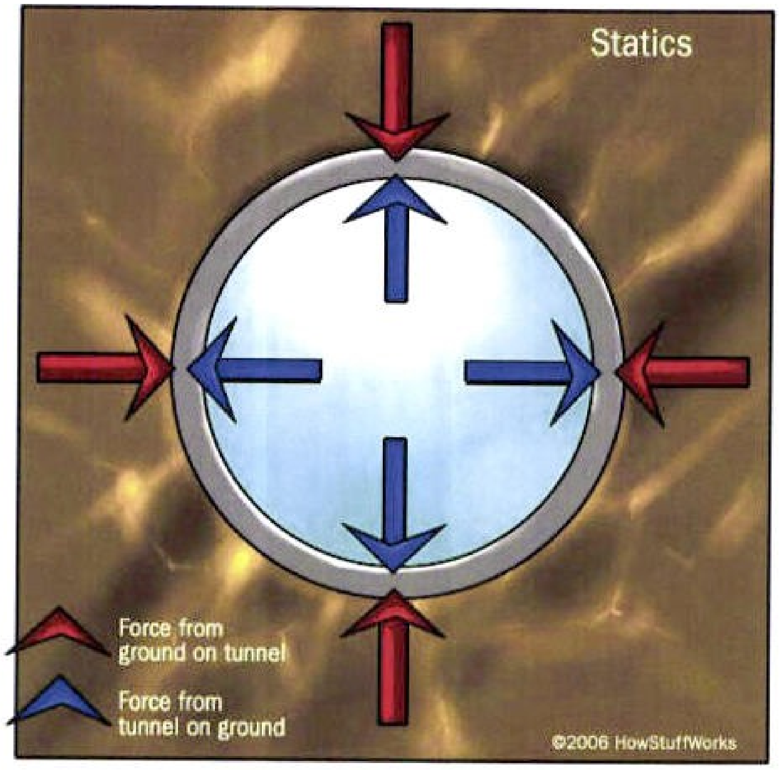


Figure (2) forces acting on tunnels

2.2 Types of Tunnels

There are three broad categories of tunnels: mining, public works and transportation. Let's look briefly at each type.

2.2.1 Mine Tunnels

Mine tunnels are used during ore extraction, enabling laborers or equipment to access mineral and metal deposits deep inside the earth. These tunnels are made using similar techniques as other types of tunnels, but they cost less to build. Mine tunnels are not as safe as tunnels designed for permanent occupation, however.

Figure (3) a coal miner standing on the back of a car in a mine tunnel in the early 1900s. Notice that the sides of the tunnel are shored up with timber

2.2.2 Public Works Tunnels

Public works tunnels carry water, sewage or gas lines across great distances. The earliest tunnels were used to transport water to, and sewage away from, heavily populated regions. Roman engineers used an extensive network of tunnels to help carry water from mountain springs to cities and villages. These tunnels were part of aqueduct systems, which also comprised underground chambers and sloping bridge-like structures supported by a series of arches. By A.D. 97, nine aqueducts carried approximately 85 million gallons of water a day from mountain springs to the city of Rome.

Figure (3) A Roman aqueduct that runs from the Pools of Solomonto Jerusalem

2.2.3 Transportation Tunnels

Before there were trains and cars, there were canals -- artificial waterways used for travel, shipping or irrigation Just like railways and roadways today, canals usually ran above ground, but many required tunnels to pass efficiently through an obstacle, such as a mountain. Canal construction inspired some of the world's earliest tunnels.

The Underground Canal, located in Lancashire County and Manchester, England, was constructed from the mid- to late-1700s and includes miles of tunnels to house the underground canals.

By the 20th century, trains and cars had replaced canals as the primary form of transportation, leading to the construction of bigger, longer tunnels. The Holland Tunnel, completed in 1927, was one of the first roadway tunnels and is still one of the world's greatest engineering projects. Named for the engineer who oversaw construction, the tunnel ushers nearly 100,000 vehicles daily between New York City and New Jersey.

Figure (4) Traveling through the Holland Tunnel from Manhattan to New Jersey

2.3 Tunnel Planning

Almost every tunnel is a solution to a specific challenge or problem. In many cases, that challenge is an obstacle that a roadway or railway must bypass. They might be bodies of water, mountains or other transportation routes. Even cities, with little open space available for new construction, can be an obstacle that engineers must tunnel beneath to avoid.

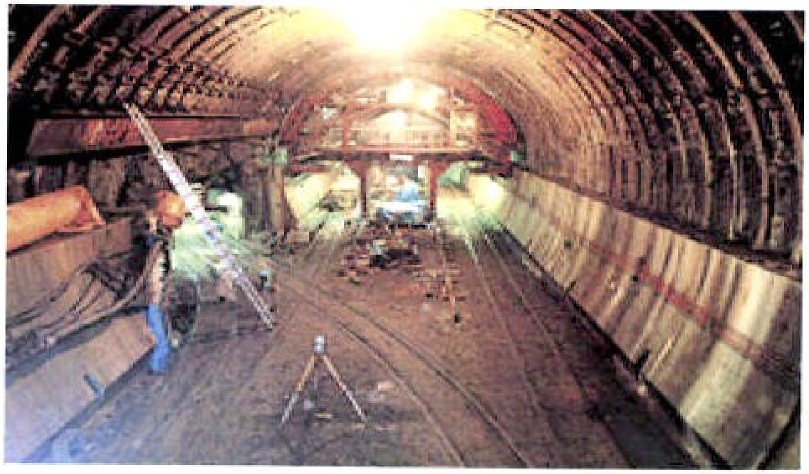


Figure (5) Construction of the Seikan Tunnel involved a 24-year struggle to overcome challenges posed by soft rock under the sea

In the case of the Holland Tunnel, the challenge was an obsolete ferry system that strained to transport more than 20,000 vehicles a day across the Hudson River. For New York City officials, the solution was clear: Build an automobile tunnel under the river and let commuters drive themselves from New Jersey into the city. The tunnel made an immediate impact. On the opening day alone, 51,694 vehicles made the crossing, with an average trip time of just 8 minutes.

Sometimes, tunnels offer a safer solution than other structures. The Seikan Tunnel in Japan was built because ferries crossing the Tsugaru Strait often encountered dangerous waters and weather conditions. After a typhoon sank five ferryboats in 1954, the Japanese government considered a variety of solutions. They decided that any bridge safe enough to withstand the severe conditions would be too difficult to build. Finally, they proposed a railway tunnel running almost 800 feet below the sea surface. Ten years later, construction began, and in 1988, the Seikan Tunnel officially opened.

2.4 How tunnels are built

Building of tunnels depends heavily on the material through which it must pass. Tunneling through soft ground, for instance, requires very different techniques than tunneling through hard rock or soft rock, such as shale, chalk or sandstone. Tunneling underwater, the most challenging of all environments, demands a unique approach that would be impossible or impractical to implement above ground.

That's why planning is so important to a successful tunnel project. Engineers conduct a thorough geologic analysis to determine the type of material they will be tunneling through and assess the relative risks of different locations. They consider many factors, but some of the most important include:

Soil and rock types

Weak beds and zones, including faults and shear zones

Groundwater, including flow pattern and pressure

Special hazards, such as heat, gas and fault lines

Often, a single tunnel will pass through more than one type of material or encounter multiple hazards. Good planning allows engineers to plan for these variations right from the beginning, decreasing the likelihood of an unexpected delay in the middle of the project.

Once engineers have analyzed the material that the tunnel will pass through and have developed an overall excavation plan, construction can begin. The tunnel engineers' term for building a tunnel is driving, and advancing the passageway can be a long, tedious process that requires blasting, boring and digging by hand.

In the next section, we'll look at how workers drive tunnels through soft ground and hard rock.

2.5 Tunnel Construction: Soft Ground and Hard Rock

Workers generally use two basic techniques to advance a tunnel. In the full-face method, they excavate the entire diameter of the tunnel at the same time. This is most suitable for tunnels passing through strong ground or for building smaller tunnels. The second technique, shown in the diagram below, is the top-heading-and-bench method. In this technique, workers dig a smaller tunnel known as a heading. Once the top heading has advanced some distance into the rock, workers begin excavating immediately below the floor of the top heading; this is a bench. One advantage of the top-heading-and-bench method is that engineers can use the heading tunnel to gauge the stability of the rock before moving forward with the project.

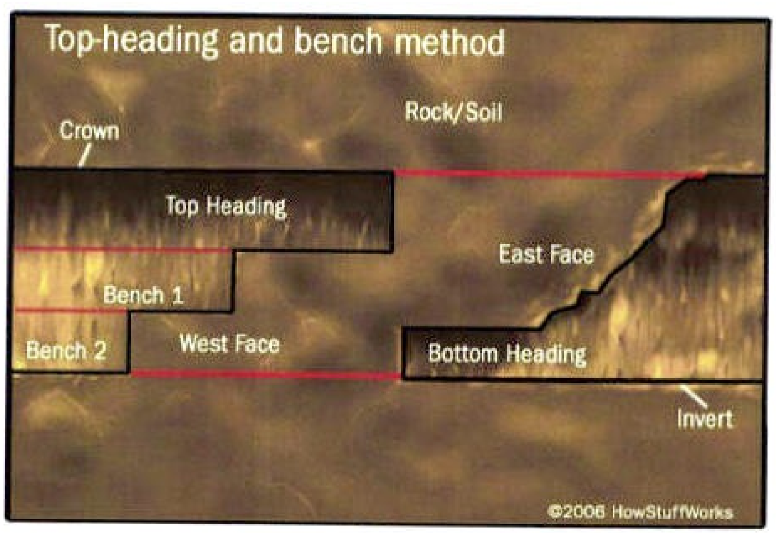


Figure (5) Top heading and bench method

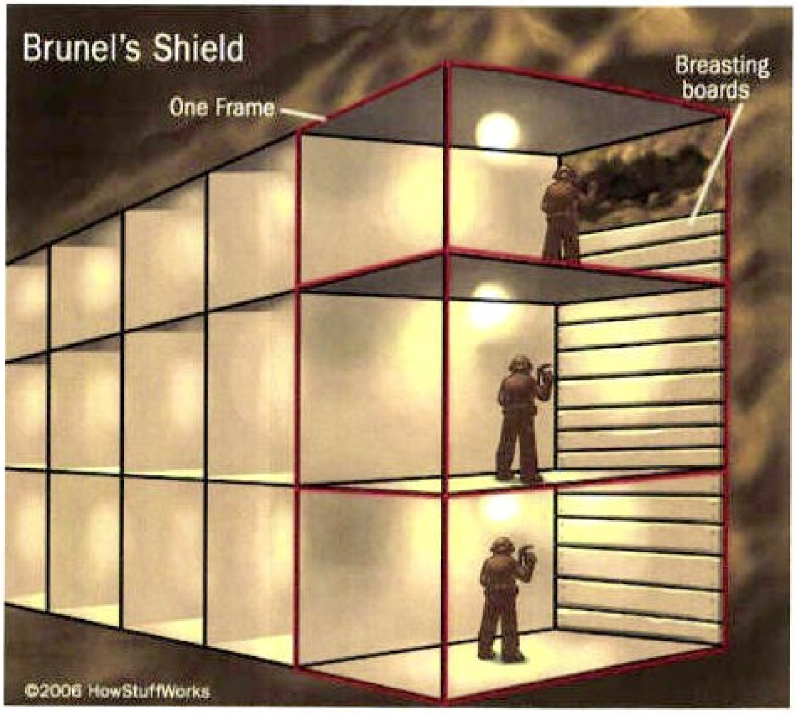
Notice that the diagram shows tunneling taking place from both sides. Tunnels through mountains or underwater are usually worked from the two opposite ends, or faces, of the passage. In long tunnels, vertical shafts may be dug at intervals to excavate from more than two points.

Now let's look more specifically at how tunnels are excavated in each of the four primary environments: soft ground, hard rock, soft rock and underwater.

2.5.1 Soft Ground (Earth)

Workers dig soft-ground tunnels through clay, silt, sand, gravel or mud. In this type of tunnel, stand-up time -- how long the ground will safely stand by itself at the point of excavation -- is of paramount importance. Because stand-up time is generally short when tunneling through soft ground, cave-ins are a constant threat. To prevent this from happening, engineers use a special piece of equipment called a shield. A shield is an iron or steel cylinder literally pushed into the soft soil. It carves a perfectly round hole and supports the surrounding earth while workers remove debris and install a permanent lining made of cast iron or precast concrete. When the workers complete a section, jacks push the shield forward and they repeat the process.

Marc Isambard Brunel, a French engineer, invented the first tunnel shield in 1825 to excavate the Thames Tunnel in London, England. Brunel's shield comprised 12 connected frames, protected on the top and sides by heavy plates called staves. He divided each frame into three workspaces, or cells, where diggers could work safely. A wall of short timbers, or breasting *boards, separated each cell from the face of the tunnel. A digger would remove a breasting board, carve out three or four inches of clay and replace the board. When all of the diggers in all of the cells had completed this process on one section, powerful screw jacks pushed the shield forward.*



In 1874, Peter M. Barlow and James Henry Greathead improved on Brunel's design by constructing a circular shield lined with cast-iron segments. They first used the newly-designed shield to excavate a second tunnel under the Thames for pedestrian traffic. Then, in 1874, the shield was used to help excavate the London Underground, the world's first subway. Greathead further refined the shield design by adding compressed air pressure inside the tunnel. When air pressure inside the tunnel exceeded water pressure outside, the water stayed out. Soon, engineers in New York, Boston, Budapest and

Paris had adopted the Greathead shield to build their own subways.

Hard Rock

Tunneling through hard rock almost always involves blasting. Workers use a scaffold, called a jumbo, to place explosives quickly and safely. The jumbo moves to the face of the tunnel, and drills mounted to the jumbo make several holes in the rock. The depth of the holes can vary depending on the type of rock, but a typical hole is about 10 feet deep and only a few inches in diameter. Next, workers pack explosives into the holes, evacuate the tunnel and detonate the charges. After vacuuming out the noxious fumes created during the explosion, workers can enter and begin carrying out the debris, known as muck, using carts. Then they repeat the process, which advances the tunnel slowly through the rock.

Fire-setting is an alternative to blasting. In this technique, the tunnel wall is heated with fire, and then cooled with water. The rapid expansion and contraction caused by the sudden temperature change causes large chunks of rock to break off. The Cloaca Maxima, one of Rome's oldest sewer tunnels, was built using this technique.

The stand-up time for solid, very hard rock may measure in centuries. In this environment, extra support for the tunnel roof and walls may not be required. However, most tunnels pass through rock that contains breaks or pockets of fractured rock, so engineers must add additional support in the form of bolts, sprayed concrete or rings of steel beams. In most cases, they add a permanent concrete lining.

Chapter three

Constructions of Tunnels

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Constructions of tunnels

3.1 Introduction:

Tunnels are constructed using many methods, depending upon the kind of soil and/or rock through which they will pass, how deep they need to be, and the obstructions that may be encountered along the route. These methods include tunnel boring with machines (TBMs), cut-and-cover construction, immersion of prefabricated tunnels, and sequential excavation method (SEM). These methods will be explained in the following sections.

3.1.1 BORED TUNNEL

This type of tunnel is circular and may be constructed with a Tunnel boring machine (TBM), which mechanically excavates soil or rock. A large-diameter reinforced steel cylinder, a TBM contains drive motors for a rotating cutter, which is mounted on one end, and hydraulic machinery for the thrusting jacks mounted along the Perimeter of the cylinder on the other end.

TBM moves forward by pushing with the jacks against the tunnel lining or against the Surrounding rock. The tunnel is lined with rings, usually made of concrete or steel, bolted together to provide integrity and water tightness to the lining. Each time there is space for another ring of lining, the TBM stops, the jacks are retracted, and the

ring is installed. In a rock tunnel, the TBM body moves forward until the jacks reach the end of their stroke. The jacks are then *retracted into the body of the machine before gripping the rock again and repeating the boring cycle.*

These are some of the technical terms associated with tunnel boring:

ADVANCE RATE: the amount of progress the tunnel-boring machine makes—the distance it covers in a day, usually measured in feet or meters.

FACE: the soil being excavated directly in front of the tunnel boring machine. A MIXED FACE is a condition with more than one type of material, such as clay, sand, gravel, cobbles, or rock.

LINING: a temporary or permanent structure, made of concrete

or other materials, to secure and finish the tunnel interior or to support an excavation.

The front of the TBM is made up of a CUTTER HEAD, which uses rotating cutting tools to break up rock and/or other materials. Immediately behind the head is the machine BODY, which remains stationary while the cutters rotate. The MUCK (excavated material) from the excavation is either dropped onto a conveyor belt (above right) or removed by a screw conveyor, which carries it to the back of the machine. As the material is cut by the cutter head, thruster JACKS maintain forward pressure, and the machine is advanced until the jacks reach the end of their stroke.

All TBMs contain these essential components, but designs differ according to the type of ground to be encountered (for example, soft soil, a mixture of soils, rock).

3.1.2 CUT-AND-COVER TUNNEL

In this method of tunnel construction, a deep trench is excavated, The tunnel is constructed within the trench, and then covered by soil. Sometimes a temporary deck is placed over the excavation at an early stage so that vehicular and pedestrian movements can be reinstated while construction continues below.

The following are some of the technical terms that apply to cut-and-cover tunneling:

BENTONITE: a clay mineral that can absorb large amounts of water. When mixed with water, it forms SLURRY used to support deep trenches or bore holes against collapse until they can be filled with concrete.

DECKING: a plank cover over a work area that serves as a temporary surface for pedestrian and vehicular traffic (including construction equipment); usually made of wood, concrete, or steel.

OPEN CUT: a method of construction in which the excavated trench is left uncovered while the tunnel is constructed.

BOTTOM UP: a method of construction in which a tunnel is built within an excavated trench in a conventional way.

Sequence: base slab first, then the walls and, finally, the roof. The completed structure is then backfilled and the ground surface reinstated. In TOP DOWN construction, the tunnel walls are built first, using special machinery, within a narrow trench. Next, the roof is built in a shallow excavation, and the ground surface is reinstated. The rest of the tunnel is then excavated and constructed underneath the roof.

3.1.3 IMMERSED TUNNEL

A tunnel below a body of water may be built using this method.

First, the individual elements of the tunnel, made of steel or concrete and designed to be buoyant, are constructed on land, usually in a shipyard or dry dock. The ends of the elements are closed with temporary bulkheads, making them watertight. Each element, which may be as large as a football field, is then floated to the tunnel site, sometimes on a barge. The tunnel element is readied for immersion, and then lowered into a trench that has been dredged under water. Each successive element is aligned with the previously placed element and joined underwater using a watertight seal. After the elements are joined, the bulkheads are removed from the inside. The completed tunnel is covered with fill material and topped with a layer of heavy stones or precast concrete castings.

These are some of the technical terms commonly used to discuss this method of tunnel construction:

BALLAST: a stabilizing weight (stones or concrete), Temporary or permanent, often added to the tunnel elements while floating, being immersed, or in their final position.

COFFERDAM: a temporary structure constructed in water and pumped dry; used to keep water out so that work can be performed in dry conditions.

QUAY (pronounced "key"): A wharf or reinforced bank where ships are loaded or unloaded, built parallel to the bank of a waterway. Tunnel elements under dry conditions, was then flooded so the completed sections could be floated out.

3.1.4 SEQUENTIAL EXCAVATION METHOD

(SEM) TUNNEL

SEM, also known as New Austrian Tunneling Method (NATM), was developed in Austria but is now used worldwide. This underground method of excavation divides the space (cross-section) to be excavated into segments, then mines the segments sequentially, one portion at a time. Whereas TBMs can only excavate a fixed (generally circular) shape, SEM permits a tunnel of any shape or size to be excavated. This makes it useful in areas where the tunnel shape or size needs to change, such as highway ramps and subway stations.

The excavation can be carried out with common mining methods and equipment (often a backhoe), chosen according to the soil conditions; tunnel-boring machines are not used.

Ground conditions are assessed at the face of the tunnel or from the side of a small tunnel, which helps to decide how to proceed in the best way and determines the choice of equipment and lining. SEM involves careful sequencing of the excavation as well as installation of supports. SHOTCRETE (a kind of concrete sprayed from high-powered hoses) may be used to line the tunnel or support the face, and GROUTING (the injection of a cementing or chemical agent into the soil) may be used to increase the soil's strength and reduce its permeability.

SEM requires extremely dry conditions; dewatering is often necessary before the excavation can proceed. Because of the requirements of this method, the rate of excavation is slow.

These are some of the technical terms associated with this type of tunnel construction:

DEWATERING: the removal of ground water from the area to be excavated.

DRAWDOWN: a lowering of the normal ground-water level (water table) as the result of dewatering.

HEADING: A smaller tunnel used when a larger tunnel is excavated in several stages. Smaller headings are used when full tunnel excavation at once would not be prudent. Sometimes multiple headings are used simultaneously to increase the number of excavation faces and compensate for SEM's slower excavation rate. Shotcrete, a pneumatically sprayed concrete, will be applied on these tunnel walls, which have been lined with waterproofing and a cage of wire-mesh fabric.

3.2 OTHER TUNNELING TERMS

CROSS-PASSAGE: *a short passage or tunnel connecting two adjacent tunnels, often used to allow people to escape from one tunnel to another in an emergency.*

CUT-OFF WALL: *an underground wall, either temporary or permanent, used in tunnel excavations to prevent the passage of ground water.*

GRADE: *a measure of the inclination of a road or slope.*

MOLE: *slang term for a tunnel engineer.*

PILE: *a long, slender, below-ground column, usually of steel, timber or reinforced concrete, serving as a foundation for a structure by transferring the structure's weight to bedrock or other subsurface materials more capable of withstanding the loads.*

PILOT TUNNEL: *an exploratory tunnel, usually smaller and driven ahead of the main tunnel.*

SANDHOG: *slang term for a tunnel worker.*

SHAFT: *a vertical excavation often used to provide access to a tunnel from the surface.*

UNDERPINNING: *the installation of new supports beneath the foundation of a building or other structure to protect it from settlement caused by adjacent tunneling or other construction; sometimes used in place of an old foundation that was removed.*

VENTILATION BUILDING: *a building that houses ventilation fans and other mechanical and electrical equipment necessary to ventilate, power, and light a tunnel.*

3.3 GEOTECHNICAL TERMS

BACKFILL: material such as sand, gravel or crushed stone used to fill the remainder of an excavation after a tunnel or other underground structure has been constructed within the excavation.

GLACIAL DEPOSITS: a mixture of geological debris (such as rocks, stones, gravels, silts and clays) carried, plowed and mixed by glacial ice and melt water.

ORGANIC SILT: a silt, highly compressible and with a low bearing capacity (strength), containing plant and occasionally animal remains.

OVERBURDEN: the soil between the ground surface and the roof of a tunnel.

SETTLEMENT: the movement or settling of soils.

SILT: soil whose grains are finer than sand but coarser than clay.

SOFT GROUND: soils and weak rock that can be easily removed.

TERMINAL MORAINE: an area where glaciers melted during their southward advance, leaving behind an accumulation of boulders, stones and other debris.

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