A Review of Metro Station Construction Projects

Kumar Ashish,Vaibhav Dubey, Satish Parihar
Faculty of Engineering & Technology, Rama University, Kanpur 209217, INDIA
Email Id: vaibhavdubey890@gmail.com

ABSTRACT

To maximize efficiency, metro construction projects should be optimized both economically and technically.

In this sense, choosing an excavation technique is crucial to avoiding encroachment on currently provided municipal services and incurring extra costs. The development of several novel construction techniques, including Cover and Cut, Cut and Cover, and the novel Austrian Tunneling Method (NATM), has given design engineers a favorable environment in which to choose the best excavation choice. The most widely used techniques for building subterranean metro stations are covered in this paper. Additionally, several ground pre-supporting system techniques are described in order to control the instability of excavated subterranean space (convergence) and subsidence in metropolitan areas.

Keyword: Metro construction, Excavation, NATM

I. Introduction

Metro, which has benefits including minimal pollution, low energy consumption, great transit capacity, and acceptable resource costs, is an essential part of a metropolitan city's infrastructure. Additionally, it adheres to the sustainable development concept. There are already more than 100 metropolises functioning around the globe.

Iran's metro building industry has experienced exceptional growth in recent years. Numerous cities, including Tehran, Isfahan, Mashhad, Shiraz, Tabriz, and Ahvaz, are now seeing extensive metro development.

The building process used to build metro stations is highly sensitive to the surrounding environment, therefore choosing the right construction approach is crucial for projects of this nature.

Building stations and their entrances and the tunnels that connect the stations are the two main components of building a subway system. In general, there are three ways to build a metro station:

1. New Austrian Tunneling Method (NATM)
2. Cut and Cover method
3. Cover and Cut method

The aforementioned approaches are covered in full in this paper, along with an explanation of their respective benefits and drawbacks. Additionally, a presentation is given on the use of the NATM in challenging underground metro station excavation situations.

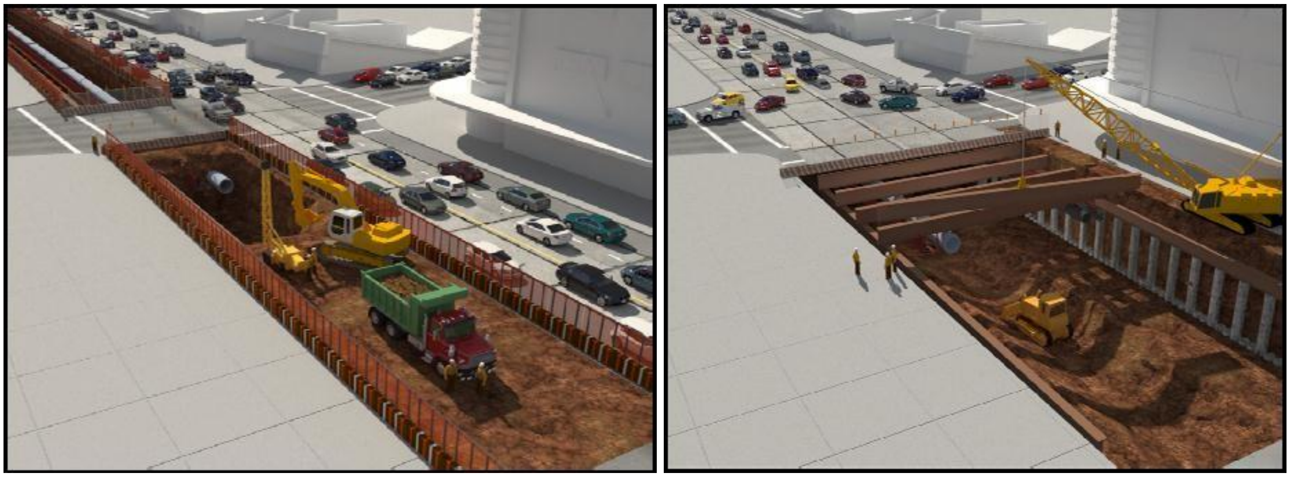


Figure 1: The effect of metro construction operation on the surface traffic.

2. UNFORESEEN GROUND BEHAVIOR

By 1) conducting a thorough site and laboratory research during the design phase and 2) by monitoring throughout the building phase, the danger of unanticipated ground behavior has been reduced. Risk management during the building phase includes technical monitoring.

This novel strategy is particularly beneficial in reducing the dangers that arise from unanticipated ground behaviour [1].

2. 1. Site- and Laboratory Investigation

The purpose of the site- and lab-based investigations is to specify the environmental, geotechnical, and geological elements. The goal of any inquiry is to get as much information as possible in order to reduce the hazards below the surface.

Establishing the design criteria for building is another objective. Even with these efforts, the information gathered might still include some doubt. Monitoring the subterranean and surrounding structures' behavior throughout the building phase mitigates the remaining hazards of unanticipated ground behavior [1].

Geotechnical parameter calculations ought to, in some way, follow mathematical (analytical) models. The geotechnical parameters are ascertained by means of mathematical models. Different geotechnical parameters are needed for advanced numerical techniques using second order material models. Determining the geotechnical parameters begins with a thorough selection of mathematical models, determining the necessary degree of safety (risk analysis), and conducting site assessment.

2. 2. Monitoring

A highly thorough set of monitoring specifications is created throughout the design phase. An essential component of the contract are the specifications. In addition to the comprehensive monitoring standards, a series of danger alert levels are presented. The contractor must utilize these stages to manage the building process. One can distinguish between two levels: (1) a warning level and (2) an intervention level. At the warning level, the contractor adjusts the construction process, notifies the customer, and increases monitoring frequency.

The warning levels also operate as a wake-up call for the customer and contractor. Following notice, the contractor must cease operations right once and take the required precautions to avert any potential risks.

Table 1: some of the most important types of monitoring with related hazard warning levels [1]

Object	Type of monitoring	Hazard warning levels	Aim
Metro tunnel	Tachymetric deformation	Based on rail track and tunnel deformation criteria	Prevention of tunnel damage and unobstructed exploitation of metro traffic
Surrounding buildings	Vibration and sound measurements	Based on hindrance and damage criteria from building codes	Preventing hindrance (where possible) and damage
Groundwater	Open standpipe piezometers	As dictated by groundwater extraction permits	Working within permits

3. DESIGN PHILOSOPHY

The goal of the station buildings' design is to strike a reasonable balance between building costs and safety regulations. During the design stage, the anticipated alterations in the nearby building foundations are utilized. The following variables affect the deformations:

a. The behavior of geotechnical parameters

b. Analytical or numerical calculation models

c. Design for construction

Determining the ideal geotechnical parameters enables the determination of the soil behavior. Since it is typically impossible to determine the geotechnical characteristics precisely from laboratory or in-situ testing, a safety margin of some kind must be included.

The amount to be spent increases with the safety margin.

4. OVERVIEW OF DESIGN AND CONSTRUCTION METHODS

Tunnel and underground metro station construction should use techniques that guarantee project safety and timely completion. The building techniques can be applied singly or in combination. The nearby geological and in situ circumstances should be taken into consideration while choosing the right approach.

- Use of the New Austrian Tunneling Method (NATM).
- Use of the Cut and Cover method.
- Use of the Cover and Cut method

4. 1. Station Construction using the Underground Conventional Boring Method

The second (in terms of choice) construction technique used globally for the building of tunnels utilizing the underground boring method is the conventional underground tunnel boring method, often known as the NATM method or New Austrian Tunneling technique. For tunnel building, the method that is most commonly utilized is the Tunnel Boring Machine (\\M). TMB is not appropriate for the excavation of an underground metro station since the cross-sectional area of the station and the tunnel are not the same size. Therefore, a specific procedure must be used. On the other side, an entry and exit shaft has to be ready for TBM operation. Consequently, the NATM technique is frequently applied to the excavation of deep metro stations.

It is crucial to oversee the project in metropolitan areas to minimise any disruption. It is avoided to use subterranean building techniques, occupy surface areas (squares, streets, private plots, etc.), relocate PUO pipelines (water, electricity, telephone supply, etc.), divert traffic, and conduct archaeological excavations (Fig. 2).

NATM Construction Methodology

The fundamental idea behind this approach is to keep the tunnel strong in close proximity to the surrounding surface. The application of flexible retaining has a beneficial impact on controlled soil deformation, allowing for safe advancement. The following is the design/construction technique for the project:

Figure 2: Using of NATM method for station construction

1. To identify the features of the soil in the region where the tunnel is proposed to be bored, geotechnical and geological studies and testing are carried out (both on site and in a laboratory). Based on the geotechnical properties of the soil that emerged from the previous phase, plans for the excavation and temporary retaining of the tunnel are now being developed, including calculations and drawings. In addition, the tunnel's permanent (final) lining design is ready.

2. Depending on the soil condition, the excavation is carried out using standard mechanical tools (road header, typical excavator, etc.). Occasionally, the excavation front is directly held at different stages of the process.

3. There is a system of interim retention consisting of shotcrete lining, rockbolts, steel frames, etc. after the excavation is finished, which is done progressively based on the peculiarities of the rocks and the project. Before excavation, forepoling beams are erected throughout the tunnel crown in the shape of an umbrella to protect the excavation front in the event that the soil has bad qualities. Excavation is often done in two stages: the bottom semi-section (invert) and the top semi-section (vault). The excavation can be done in many phases, depending on the subsurface and the tunnel's shape.

4. During the construction process, a systematic monitoring of the subsurface behaviour and the temporary retaining structure is carried out. This includes measuring the settling of the soil at the soil surface and surrounding structures, any convergence within the tunnel, and changes in the ground water level. One especially important concern is the safety of the structures that are situated along or above the tunnel's alignment. This is monitored continuously using the right equipment. It is important to compare the measurement findings with the design's assumptions and outcomes. If adjustments to the support system or the work schedule are required, they should be implemented.

5. When the system of the first support reaches conditions of balance, the final (permanent) lining of the tunnel is built. The permanent lining increases water tightness, unifies the interior surface, and increases safety during the project's lifetime. Concrete reinforced by in situ casting is used to create the permanent tunnel lining. Unique segmented metal shapes that are often self-sustaining. A few views of the NATM building process are shown in Figure 3.

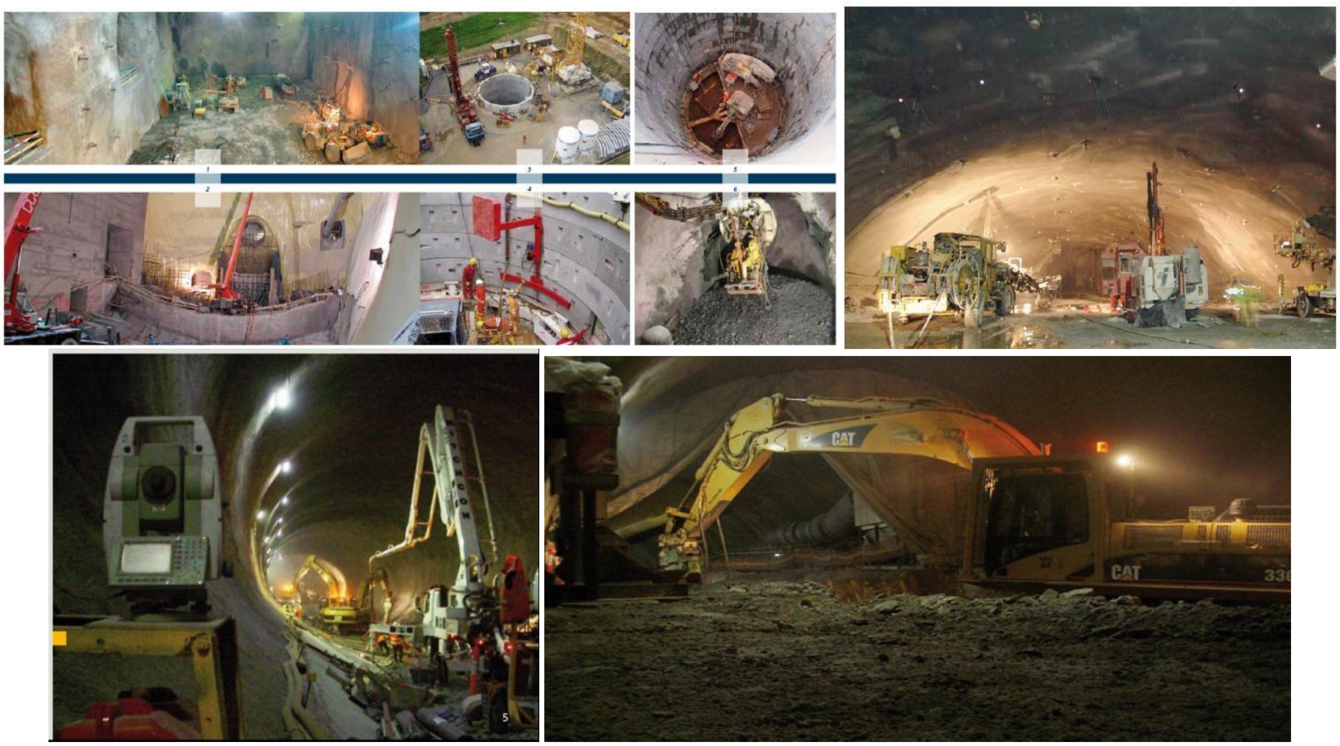


Figure 3: Some view of NATM construction method
Fig. 4: Cut and cover construction method

4. 2. Construction of Stations using the CUT & COVER Method

Although the cut and cover approach is substituted for underground tunnel drilling in regions of the city distant from the centre, this is still the preferred method (Fig. 4). If there is sufficient room, this approach is also utilised. This occurs as a result of the cut and cover method's greater simplicity, safety, and economy.

The following are the method's drawbacks:

a) Every PUO pipe found in the region where excavation work is planned is to be taken out,

b) In order to find any antiquities, particularly in old cities, an archaeological study should be conducted, and

c) Every necessary traffic diversion is impacted.

Even though the technique is just referred to as "open cut," it is actually a "cut & cover" technique since the structures are backfilled when they are finished.

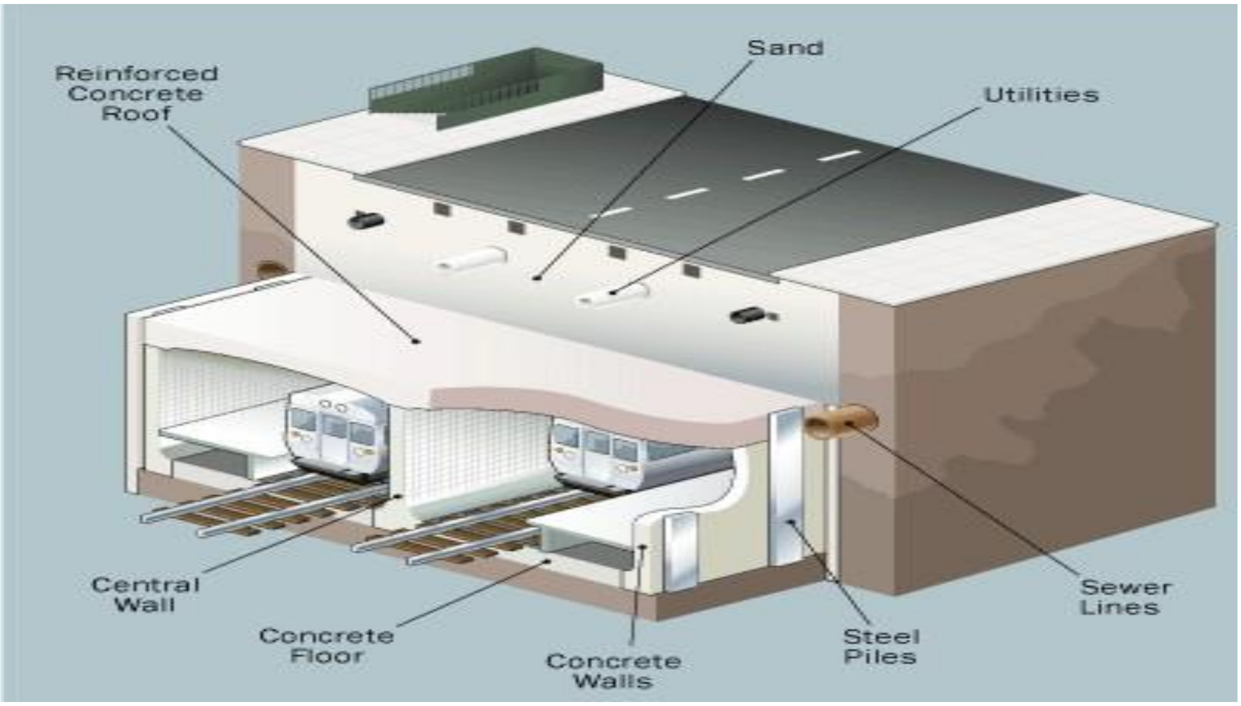


Fig. 5: In a cut-and-cover excavation, crews dig a trench and cover it with a temporary or permanent road surface.

Construction methodology

The cut and cover is a basic technique. Initially, a trench with steep sides is dug out. The second phase involves building a permanent bearing structure from the foundation up. The structure is then backfilled to its original place all the way to the surface. The following are the steps in the method:

1. In order to determine the soil qualities in the location where our construction is to be built, a geotechnical/geological investigation and tests—both on site and in a lab—are conducted.

2. Using the soil's geotechnical properties as a consequence of the preceding step, a plan (including calculations and drawings) for the excavation and temporary retaining is created. Additionally, the permanent bearing structure's design is completed.

3. All PUO pipelines (connected to water supply, electricity supply, telephone connection, etc.) and the necessary archaeological excavations are completed prior to the start of the major works, as are the necessary traffic diversions.

4. Round concrete piles with a diameter of around 0.80 to 1.00 metres are typically used as the temporary retaining structure for excavations. These piles are positioned 1.50-2.50% apart around the perimeter of the planned excavation. At the pile crown, a robust concreting beam connects the pile row.

5. The structure's water proofing system, which is made up of water stops, waterproofing membrane, and geotextile, is often installed at the invert and on the periphery of the trench.

6. The bearing structure is built in stages, beginning with the foundation and continuing with the walls and, in the event of an underground station, the roof slab. Concerning the stations, the building of barriers and flat slabs in between. As specified by the design, the foundation slab's (also known as the general lean concrete slab's) steel reinforcement is installed to mark the start of construction. Class C25/30 concrete is then injected gradually over the whole length of the structure, making sure to provide the proper joints.

4.3. Construction of the Stations using the COVER & CUT Method

The "top-down" or "cover & cut" approach is not the same as the cut & cover method. These building methods go through the following phases:

1. The surface of the excavation is dug to reveal the vertical retaining panels (piles, diaphragm walls, etc.) around the excavation.

2. The first step in the excavation process is to reach the structure's roof slab. It could be necessary to lightly maintain the slopes depending on the depth of the excavation.

3. The bottom of the excavation has a concreted roof slab. The slab is joined to the outside retaining wall.

4. The soil's surface is restored and backfilling is done over the slab.

5. Using a ramp that has been set aside for this purpose, the station's excavation work begins beneath the roof slab. Phases of excavation are carried out in parallel with the progressive installation of the necessary retaining components (struts, anchors, etc.).

The process of building the permanent bearing structural elements begins once the trench has been completely excavated. These components typically comprise of the lateral walls and the foundation slabs. No other permanent barriers are built if diaphragm walls are utilised as a lateral retaining mechanism. This approach has the benefit of shortening the building period. Conversely, the growing expenses and complexity are the drawbacks of this approach. The cover and cut method's construction steps are shown in Figure 7.

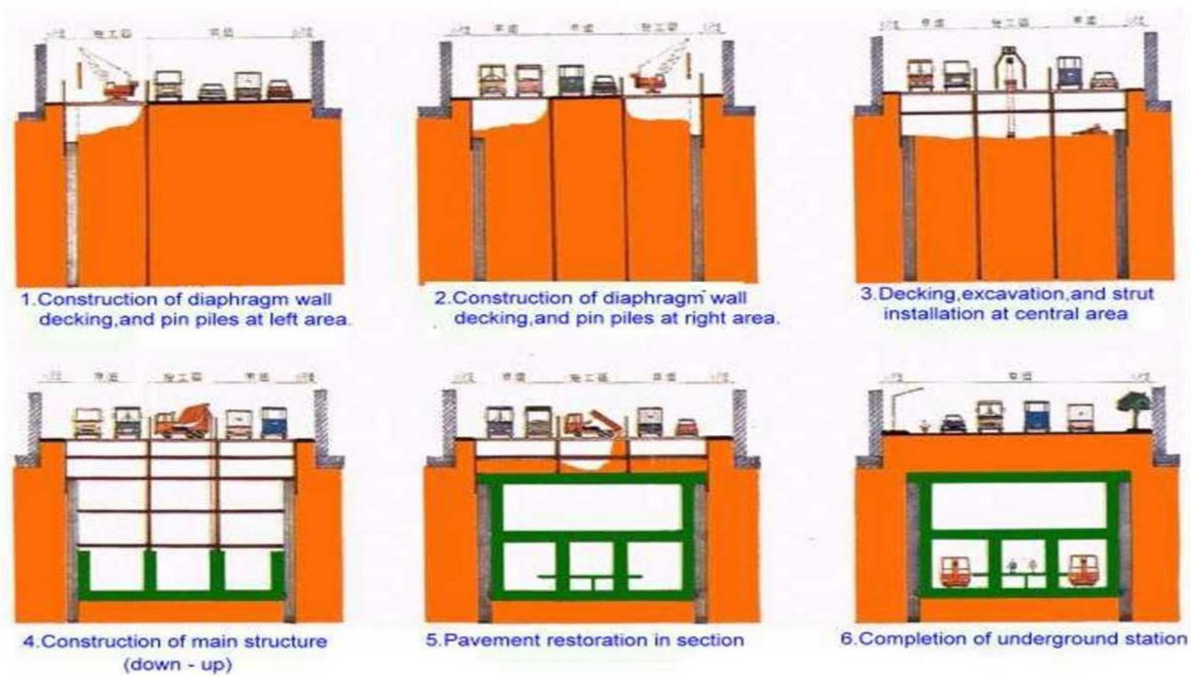
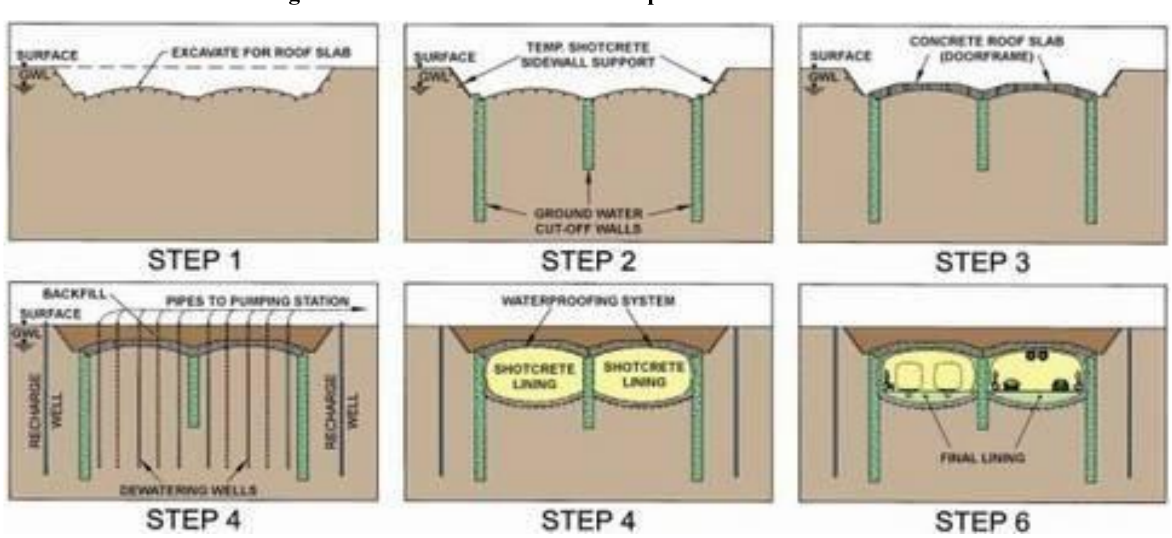


Figure 6: Illustration of construction phases in cut and cover method

Figure 7: Illustration of construction phases in cover and cut method



5. CONSTRUCTION OF NATM UNDERGROUND STATION IN DIFFICULT CONDITIONS

Infrastructure in urban regions has to be upgraded in tandem with the growing population. Most facilities are found underground in densely populated metropolitan areas. Owing to the pre-existing buildings on the surface, new project execution is constrained by certain requirements, such sinking and/or noise levels during construction. The ground in metropolitan areas is typically made up of heavily worn rock masses and/or sedimentary soil. When tunnelling, both kinds of grounds may cause significant displacements.

In these situations, the project constraints dictate every step of the design process since adhering to the specifications might need expensive and time-consuming extra support systems like pipe jacking, jet grouted columns, or ground freezing.

5. 1. Ground improvement

The "Pipe Roof Umbrella" System, also known as "Steel Pipe Umbrella" [2], "Umbrella Arch Method" [3], "Pipe Fore-Pole Umbrella" [4], "Long-Span Steel Pipe Fore-Piling" [5], or "Steel Pipe Canopy" [6,] is an alternate support system. The pre-support systems that were previously discussed are stiffer than this system, however pipe roof systems need less money and time to install. The pipe roof approach is being used more frequently as a result of these facts.

Iran has used a revolutionary pre-supporting technology for the building of wide span metro subterranean stations.

5.2. Some of underground metro station construction

1. Building the NATM subterranean station tunnel for Athens Metro under challenging circumstances by employing the forepoling technique.

This technique was applied at the Agios Savas subterranean complex, which is a part of the recently completed Line 3 metro expansion in Athens. The tunnel beneath the station has an overburden thickness of around 18 metres. The station tunnel's geological composition is made up of marl and conglomerates with a few tiny layers of clay and sand. The hydro-geological circumstances are advantageous for the undertaking. The top heading and bench have a width of 20.2 m, the tunnel's overall height (with maximum expansion) is 14.25 m, and the top heading's excavated height is higher than 8 m (Fig. 8) [7].

The following serves as the foundation for the excavation and temporary support system [7]:

• 1.00 m is the round top heading length.

• 12 m long,]193.7/179.5 mm forepoling tubes St37, arranged at axial average distances of 0.60 m for every 6 round lengths of top heading.

• A minimum structural thickness of 40 cm for the shotcrete shell, C25/30. To provide a superior structural system with smooth geometrical corners and to prevent stress concentrations, the structural thickness requirement increases at the junction regions of temporary invert and elephant feet.

• Steel sets, HEB 180, St37, positioned at every round length.

• Pairs of rock bolts for steel set security and rock bolts of 6 m length, S500, 25 mm in diameter, put at a grid of 1 m (each top heading round length) (cross axial spacing) at the sidewalls of the bench (except from the final and temporary inversion).

• The exterior, intermediate, and interior reinforcement layers of T188 mesh type are placed.

• Temporary invert with two layers of T188 steel mesh and 35 cm thick C25/30 shotcrete, together with prefabricated steel reinforcing cages for quicker construction.

• Final invert reinforced with two steel meshes (T188), shotcrete with a minimum thickness of 40 cm (C25/30).

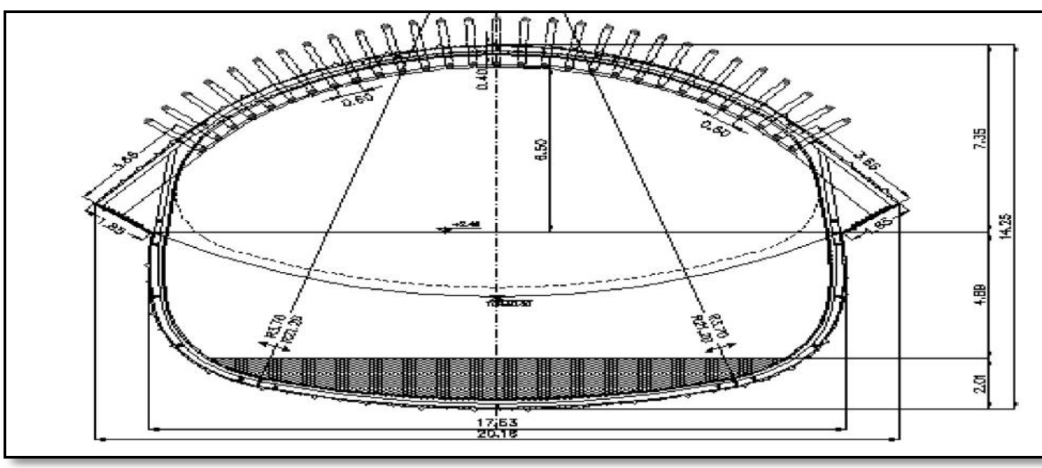


Figure 8: Excavation geometry of the typical cross section (maximum enlargement) [7]

Figure 9: Installation of the forepoling tubes at the top heading of thestation tunnel [7].

Figure 10: Top heading excavation of the station tunnel. Installationof the HEB 180 steel arches

2. Using the pipe ramming technology to construct the NATM underground station tunnel under challenging circumstances for Athens Metro

An additional technique that Athens Metro employed to enhance the state of the ground and regulate surface movement might maximise project time and expense. Additionally, this technique helps reduce surface settling. The diameter of the pipe that protrudes horizontally out of the ground is approximately 1.2 metres (figure 11). This technique, commonly referred to as pipe ramming, can ram high-diameter pipe up to 120 metres. The pipes may be pushed about the whole length of the station in this manner.

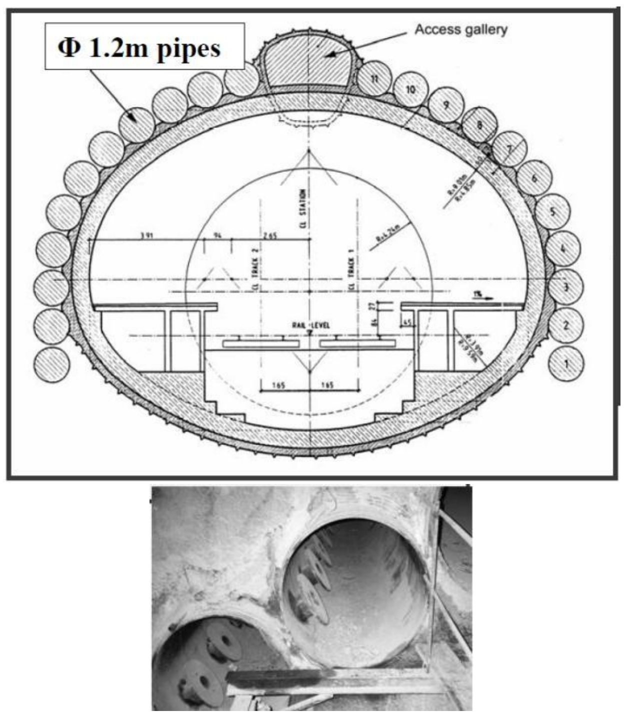


Figure 11: Athens Metro, Monastiraki Station (18m wide span), micro-tunnel pipe arch

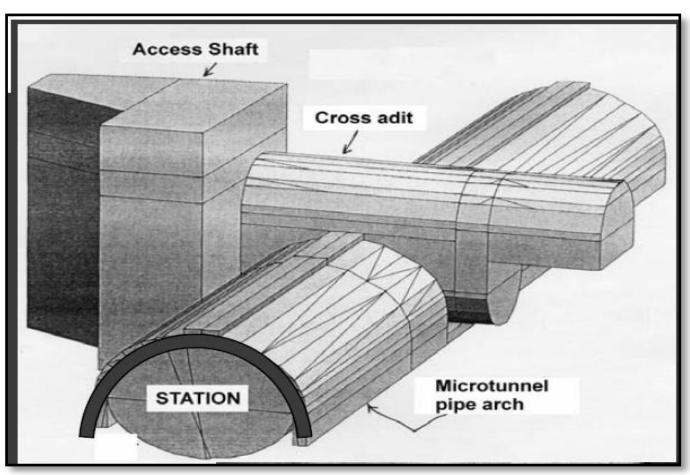


Figure 12: Sketch of Monastiraki Station, Athens Metro.

3. *Construction of NATM underground station tunnel by using of Concrete Arch Pre-supporting system (CAPS) in difficult conditions in Iran*

Large span subterranean structures can be made safer by using the Concrete Arch Pre-supporting technology (CAPS), a rib-shaped ground pre-treatment technology. This approach has resemblance to Bengt and Stillborg's (1979) [8] Rib in Roc Pre-reinforcement approach. Small horizontal tunnels were built using this pre-supporting system before the main tunnel was excavated for the Mount Baker Tunnel near Seattle, Washington, in the United States [9]. The CAPS construction method is based on the traditional Iranian "Kariz" water subterranean gallery, which is made up of little semi-horizontal adits and wells. Caps are made out of tiny vertical piles and semi-horizontal and horizontal arch beams that are attached to galleries that were manually dug out all around the vast subterranean station [10]. Figure 13 depicts the Rib-shape pre-supporting structure (CAPS).

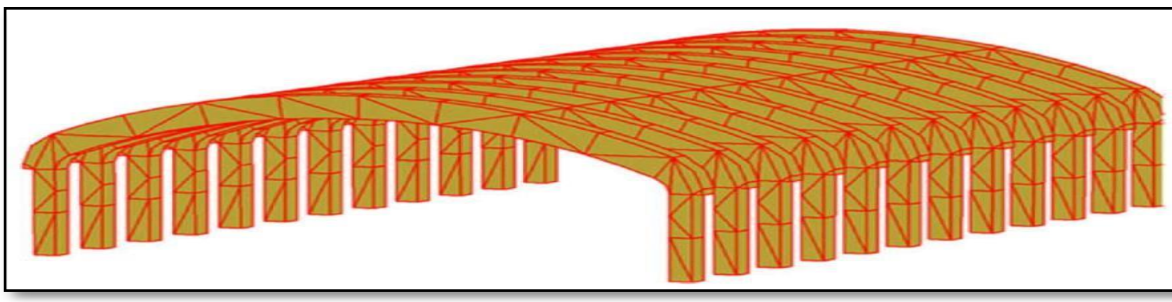


Figure 13: Rib-shape pre-supporting structure (CAPS) constructed prior to main excavation [10].

The previously mentioned approach has several technical drawbacks. Because of the outdated technique and its slow adoption of technological automation, labour is still needed for excavation even at this rapid pace of innovation. Additionally, there is no control over the quality of the reinforced concrete ribs in this procedure, therefore safety is unsatisfactory.

6. CONCLUSION

In tunnelling projects, choosing the right excavation technique is essential.

- Before starting any projects, a complete site and laboratory research is necessary to reduce the hazards associated with the building construction phase.
- Various data, including geological, geotechnical, geo-hydrological, and environmental factors, should be gathered for this inquiry.
- One may think of deformation monitoring as an integral component of tunnelling projects.

- The implementation of the NATM is essential given the vast cross section of metro stations, particularly given the unfavourable geological ground conditions.
- When using NATM in extremely bad ground conditions, complementary ground treatment techniques including grouting, fore-poling, and pipe ramming should be taken into account.
- The cover and cut approach is the best option for cutting down on building time, but being difficult to apply.
- Underground drilling can be used in place of the cut and cover approach when relocating from a crowded region.

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