Rock Excavation and Support Systems

Refer to Handout

Factors Unique to Tunnelling

• Uncertainty in the nature and variability of ground conditions (rock quality, ground water, gas, etc) - *need for adequate site investigations prior to and vigilance during tunnelling*

• Confined space of tunnel environment (limited access, escape, air quality control)

• Difficulty in communications (sound and signal barriers)

• Work in compressed air (soft ground)
Rock Excavation and Construction Methods

- Drill & Blast

- TBM – hard rock, feasibility use of TBM, type of TBM, cutter and backup equipment.

- NATM – construction involves special approach to both the construction and contracting method. Requires more comprehensive geotechnical data and analysis to predict behaviour, classify ground condition, support system based on the anticipated behaviour. Ground condition becomes part of construction contract for pay items and selection of support system.
Drill and Blast Method

- Most suitable for hard rock with complex layout and geometry
- Unique hazards due to need for blasting
- Work is carried out in a cyclic manner
Sequence of excavation

Drill Jumbo Machine

Drilling

Drilling of Charge Holes
The number of hole depends on the cross-section of tunnel

Swedish Rule:  
N = 37.6 + 1.36 S   (In tough rocks)  
N = 30.9 + 1.0 S   (In Medium tough rocks)  
Where S = Cross-section of tunnel.

For large underground caverns like Power house, Oil storage reservoirs etc.
Drilling

Drilling of Charge Holes
Arrangement of holes

Charging Explosive

1. Type of explosives used for tunneling blasting operations.
2. Blast design and selection of dia. & location of holes in compatible with the geology of strata, designed area of opening, Environment, existing laws etc.

Brief description of Emulsion explosives: Emulsion explosives are the intimate and homogenous mixer of oxidiser and fuels. It consists of micro droplets of Super – Saturated oxidiser solution in oil matrix. These are in the form of water – in – oil emulsion. The internal phase is composed of solution of oxidiser salts e.g. Ammonium Nitrate etc. dispersed as microscopically fine droplets, which are surrounded by a continuous fuel phase. The emulsion, thus formed, is stabilized against liquid separation by an emulsifying agent.
Charging Explosive

TYPE OF EXPLOSIVES (EMULSION EXPLOSIVES): Nitroglycerine based explosives have been the workhorse of hard rock blasting for more than 100 years. ANFO and Slurries, though easier to store, handle and use, fall far behind in performance as compared to Nitroglycerine based explosives. Years of research have led to development of emulsion explosives and now for tunneling operation, all over the world, Emulsion explosives have taken the lead in regard to its use.

Hazards
• accidental detonation by drilling into explosives
• being knocked over or crushed by drilling boom
• falling

Protection
• Only charge after the whole face has been drilled
• work can only be carried out under supervision of authorised blasting specialist
• use working platforms
• Bulk emulsion

Charging
Charging with Explosives

Holes drilled are next filled with explosives. This is done by miners standing on the ground and, if the rock face is high, by using another jumbo with booms to lift the miner.

Charging may be done using cartridge explosives, also known as stick powder or dynamite.

The cartridges are placed in the holes and pushed to the back using a wooden ramrod.

A waterproof detonator cord, or fuse, hangs out of the end of each hole.

The primer that starts the explosion is at the end of the fuse in the bottom of the hole.

Charging may also be done using bulk explosives.

This granular material, commonly ammonium nitrate fuel oil, is blown by air into the holes.

Again the fuse with a primer at the far end hangs from each hole.

During Charging

Shotfirer will check final charged face before leaving

Signs to warn and cordon off personnel from charged face
Types of Emergency
- Ground collapse (need we say more?)
- Support failure
- Flooding
- Gas explosion
- Oxygen deficiency
- Fire (encountering inflammable gas)
- Accidents: moving plants
- Plant and power failure
- Stoppage

Principal Causes of Accidents
- Falling from heights or falling on level (tripping/slipping)
- Materials falling from height or from stacks or vehicles
- Burial by fall of material (rock collapse or stacking collapse)
- Flooding or inrush of water
- Machinery related (cranes, excavators, etc)
- Vehicles (excavators, dump trucks)
- Electrical installations
- Fire and explosions (gas and explosives)
- Air pollution (oxygen deficiency, toxic fumes & radon gas)

Hazards Related to Blasting
-
Pre-Blasting
• Responsibilities of Shot-firer in Mandai
  – Connecting the explosive charges
  – Final checking before blasting
  – Work with Tunnel Foremen & Safety Supervisor to ensure adequate safety measures are taken.

Safety vehicle with light siren evacuating personnel in cavern
Ample warning (E.g. sirens) outside the caverns

Blasting
**Hazards**
• Blasting a “way of life” in hard rock tunnelling
• Fly rock
• Airblast and ground shock
• Toxic fumes
• Accidental explosions

**Protection**
• keep away from area
• switch off ventilation completely before firing
• switch on ventilation at full capacity after blasting
• evacuate team or provide shelter(containers or niches)
**Inspection of Blast Results**

- Check for Misfires, Dangerous and Loose Rocks Conditions
  – Shotfirer and Tunnel Foreman will inspect the area cautiously for dangerous signs

- Safety Supervisor to ensure SF/TF carry out inspection – Should there be no initiation of explosives, minimum re-entry time must not be less than 30 mins.
  – After initiation, minimum retry time must not be less than 15mins (after ventilation)
  – Blast inspection team shall enter tunnel with appropriate breathing apparatus.

**Use of Explosives**

On-site Storage
– Licensed magazine to store detonators and booster charges in temp cavern on site
– Reduced transport hazards to public

Use of Bulk Emulsion
– Non-explosives until being charged.
– Less toxic fumes
– Mechanised charging minimises human exposure at drilling face

Mobile Charging Unit
Control of Dust and Fumes
- Ventilation
- Gas/dust monitoring
- Minimum entry time after blasting (with ventilation)

Air Quality Underground
- Oxygen deficiency
- Dust
- Toxic gas (CO, CO2, NO)
- Heat and fire

Parameters for Air Monitoring
- Oxygen – 19.5 to 23%
- Nitrogen Dioxide – Less than 5ppm
- Lower Explosive Limit – Less than 10%
- Carbon Monoxide – Less than 25ppm
- Dust – Less than 10mg/m3 (Long term)

Mucking Out

Hazards
- Being struck or crushed
- Falling Material
- Dust and Noise
- Tripping and falling

Protection
- Do not enter into loading area
- Keep running surface in good condition
- Do not overload dumper
- Good lighting to work area
Mucking Out

Hazards
- Rock fall
- Collapse as result from instability of exposed rock surface

Protection
- Use machine for rock scaling
- Do not enter danger zone before scaling is completed
  - Lighting adequately

Hazards
- Rock fall
- Falling from heights
- Being crushed

Protection
- Only work from a safe area
- Use working platforms
- Light the area adequately
Shotcreting

Hazards
• Falling from heights
• Rebound & dust
• Chemical additives

Protection
• Use working baskets
• Use protective clothing
• Use shotcrete robot where possible
• Wear protective hardhat for shotcreting
• Wear respiratory protection

Installing Rock Bolts

Hazards
• Falling from heights
• Noise

Protection
• Use working platforms
• Use eye and hearing protection
Tunnel boring machines (TBM) excavate rock mass in a form of rotating and crushing by applying enormous pressure on the face with large thrust forces while rotating and chipping with a number of disc cutters mounted on the machine face (cutterhead)
Chipping Process between Two Disc Cutters (After Herrenknecht, 2003)

Classification of Tunnel Excavation Machines

Tunnel Boring Machine (rotational cutter head)

- Segment
  - Slurry Type (Closed)
  - Earth Pressure Balance Type (Closed)
  - Mechanical Excavation Type (Open)
- Gripper
  - Shield Type (Closed)
  - Beam Type (Open)

Soft Ground

Rock
Roadheaders

NATM
When NATM is seen as a **construction method**, the key features are:

The tunnel is sequentially excavated and supported, and the excavation sequences can be varied.

The initial ground support is provided by shotcrete in combination with fibre or welded-wire fabric reinforcement, steel arches (usually lattice girders), and sometimes ground reinforcement (e.g. soil nails, spiling).

The permanent support is usually (but not always) a cast-in-place concrete lining.

The NATM integrates the principles of the behaviour of rock masses under load and monitoring the performance of underground construction during construction.

The NATM is not a set of specific excavation and support techniques and has often been referred to as a "design as you go" approach to tunnelling providing an optimized support based on observed ground conditions but more correctly it is a "design as you monitor" approach based on observed convergence and divergence in the lining as well as prevailing rock conditions.
There are seven features on which NATM is based:

Mobilization of the strength of rock mass - The method relies on the inherent strength of the surrounding rock mass being conserved as the main component of tunnel support. Primary support is directed to enable the rock to support itself.

**Shotcrete** protection - Loosening and excessive rock deformation must be minimised. This is achieved by applying a thin layer of shotcrete immediately after face advance.

Measurements - Every deformation of the excavation must be measured. NATM requires installation of sophisticated measurement instrumentation. It is embedded in lining, ground, and boreholes.

Flexible support - The primary lining is thin and reflects recent strata conditions. Active rather than passive support is used and the tunnel is strengthened not by a thicker concrete lining but by a flexible combination of rock bolts, wire mesh and steel ribs.

Closing of invert - Quickly closing the invert and creating a load-bearing ring is important. It is crucial in soft ground tunnels where no section of the tunnel should be left open even temporarily.

Contractual arrangements - Since the NATM is based on monitoring measurements, changes in support and construction method are possible. This is possible only if the contractual system enables those changes.

**Rock mass classification** determines support measures - There are several main rock classes for tunnels and corresponding support systems for each. These serve as the guidelines for tunnel reinforcement.
NEW AUSTRIAN TUNNELING METHOD (NATM)

1 DIGGING PREPARATIONS
The crew first conducts a pre-support stage, or what Dominic Cerulli calls “one of the keys to this tunnel.” Using a machine called the “drill jumbo,” the team drills a double-rowed arch of steel pipes into the ground above where the tunnel will be excavated. The pipes are filled with grout, and the ends capped with foam. This pipe arch canopy will run the length of the completed tunnel, providing extra support.

2 EXCAVATION OF TOP HEADING
The excavator digs the top heading, or upper portion of the tunnel, in three-foot increments. The exposed earth is sprayed with a stabilizing substance called shotcrete. A steel lattice girder is placed in place to add support, and an additional 8-inch layer of shotcrete encases the girders. Sections 1 and 2 are removed and stabilized before the excavator works on the lower portion of the tunnel. Two-inch outer ring of steel lattice

3 EXCAVATION OF BENCH
The bench, or lower portion of the tunnel, is cut away in six-foot increments. Section 3 is also stabilized with shotcrete and lattice girders.

4 TUNNEL COMPLETION
Once fully excavated and stabilized, the tunnel is treated with a waterproof lining and fitted with a concrete tunnel liner. A concrete walkway is poured and the rail bed is installed.
SUPPORT SYSTEM

<table>
<thead>
<tr>
<th>Ground</th>
<th>Rock bolts</th>
<th>Rock bolts with wire mesh</th>
<th>Rock bolts with shotcrete</th>
<th>Steel ribs and lattice girder with shotcrete</th>
<th>Cast in-place concrete</th>
<th>Concrete segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong Rock</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Rock</td>
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<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soft Rock</td>
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<td></td>
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<tr>
<td>Soil</td>
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<td>0</td>
<td>0</td>
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</tbody>
</table>
Shotcrete

Shotcrete is a process where concrete is projected or "shot" under pressure using a feeder or "gun" onto a surface to form structural shapes including walls, floors, and roofs. The surface can be wood, steel, polystyrene, or any other surface that concrete can be projected onto. The surface can be trowelled smooth while the concrete is still wet.

PURPOSE

To provide an arch action in the crevices created as a result of blasting

To provide immediate support to rock mass and helping preventing the dilation of the rock and opening of discontinuities

To help in maintaining the intrinsic/parent shear parameters of the rock mass,

To prevent weathering of rock surface due to exposure

Shotcrete weak in tension ➔ combine with a layer of chain link

- Scaling of excavated rock surface
- 10 – 20 mm sprayed shotcrete
- Spreading and stitching a layer of chain link
- Sprayed shotcrete to make the design thickness

sprayed shotcrete to make the design thickness
# Shotcrete

**Wet Mix** - All ingredients, including water, are thoroughly mixed and introduced into the delivery equipment. Wet material is pumped to the nozzle where compressed air is added to provide high velocity for placement and consolidation of the material onto the receiving surface.

**Dry Mix** - Pre-blended dry or damp materials are placed into the delivery equipment. Compressed air conveys material through a hose at high velocity to the nozzle, where water is added. Material is consolidated on the receiving surface by the high-impact velocity.

<table>
<thead>
<tr>
<th>DRY SHOTCRETE</th>
<th>WET SHOTCRETE</th>
</tr>
</thead>
<tbody>
<tr>
<td>The equipment being lighter, the shotcreting can be done in poorly approachable areas as well</td>
<td>Proper approach is required for deploying the machine</td>
</tr>
<tr>
<td>Less power inputs is required</td>
<td>Greater power is required for the operation</td>
</tr>
<tr>
<td>Low initial cost, low maintenance and cheaper</td>
<td>Costlier process</td>
</tr>
<tr>
<td>The process is dusty</td>
<td>The process is much cleaner</td>
</tr>
<tr>
<td>Productivity is comparatively low</td>
<td>Higher productivity (about 10 to 16 cum/h)</td>
</tr>
<tr>
<td>Quality control is relatively poorer since addition of water is done by the nozzle man</td>
<td>Quality control is better</td>
</tr>
<tr>
<td>Accessibility of nozzle with the respect to surface is power</td>
<td>Accessibility is better in case of use of robot arm</td>
</tr>
<tr>
<td>Rebound is greater</td>
<td>Rebound is less</td>
</tr>
</tbody>
</table>
Shot-crete Equipment