DI04006071: Railway, Harbour & Tunnel Engineering

Lecture 5.39: Drill and blast method, Tunnel Boring Machines (TBMs) (types like EPB, Slurry, Hard Rock TBMs, and their components/selection)

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Introduction to Tunnel Excavation Methods I

Tunnel excavation methods are broadly classified into conventional and mechanized methods. The Drill and Blast (D&B) method is a highly versatile conventional technique suitable for a wide range of rock conditions and irregular profiles. In contrast, mechanized tunneling using Tunnel Boring Machines (TBMs) offers higher advance rates, improved safety, and continuous excavation, but is generally restricted to circular cross-sections and requires significant upfront capital investment. The choice between D&B and TBM depends heavily on geological conditions, tunnel length, diameter, and environmental constraints.

Key Points

- Conventional method: Drill and Blast (D&B)
- Mechanized method: Tunnel Boring Machines (TBM)
- D&B: Highly adaptable to varying ground conditions
- TBM: High initial cost but faster advance rates for long tunnels

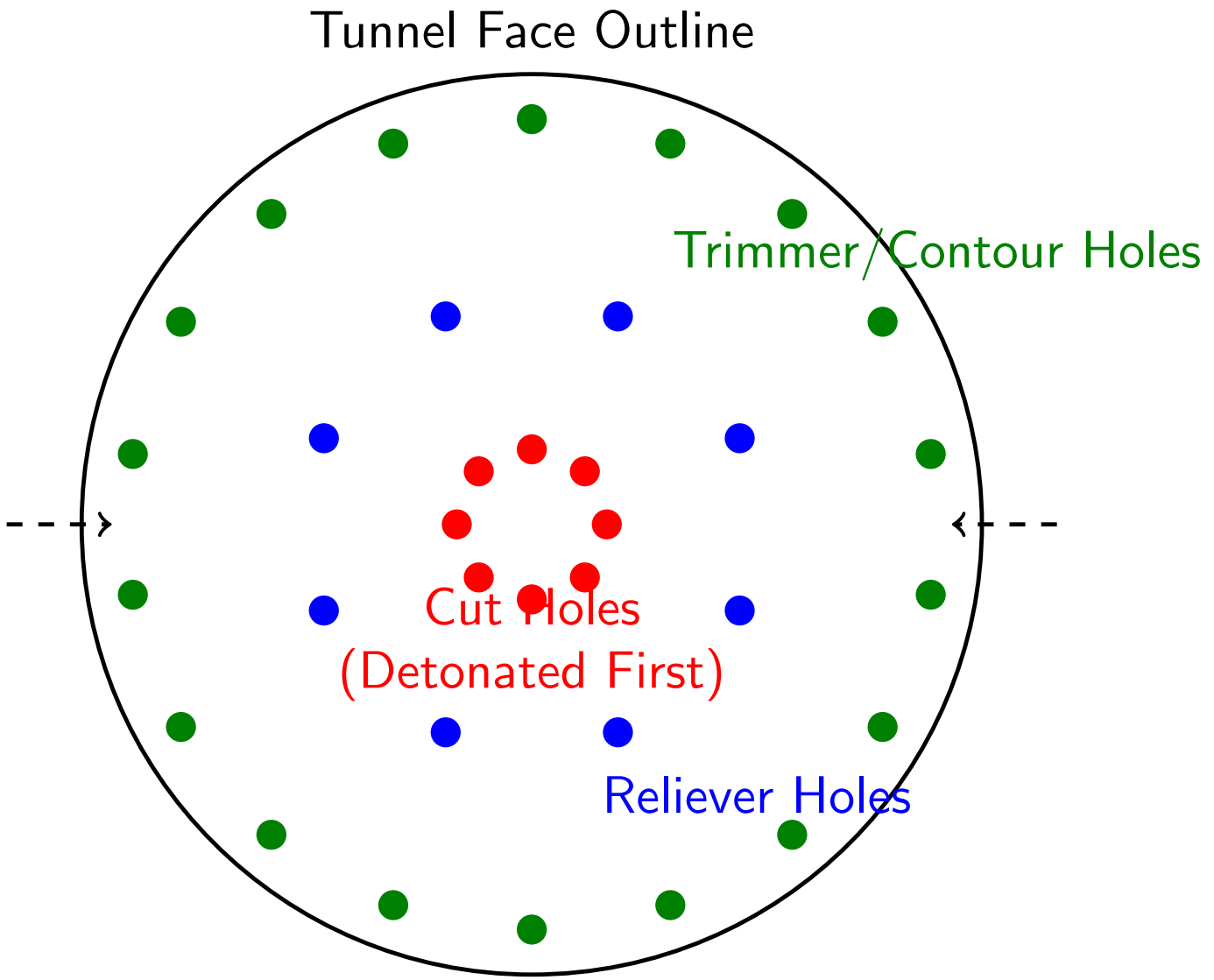
The Drill and Blast Sequence I

The Drill and Blast method follows a cyclical sequence of operations. First, blast holes are drilled into the tunnel face according to a specific pattern. These holes are then charged with explosives and detonated. Following the blast, ventilation is required to clear toxic fumes and dust. The fractured rock, known as muck, is then removed (mucking). Finally, the newly exposed rock surface is scaled to remove loose rock fragments, and initial ground support (such as rock bolts, shotcrete, or steel ribs) is installed before the cycle repeats.

Key Points

- Drilling blast holes according to a designed pattern
- Charging with explosives and controlled blasting
- Ventilation to remove toxic fumes
- Mucking (removal of excavated rock)
- Scaling and installation of initial support

Typical Blast Hole Pattern I



Typical Blast Hole Pattern II

Key Points

- Cut holes: Create an initial free face at the center
- Reliever holes: Expand the initial cavity outwards
- Trimmer/Contour holes: Define the final shape and minimize overbreak

Introduction to Tunnel Boring Machines (TBMs) I

A Tunnel Boring Machine (TBM) is a massive, complex machine used to excavate tunnels with a circular cross-section through a variety of soil and rock strata. The primary components of a TBM include a rotating cutterhead equipped with cutting tools, a main bearing that supports the cutterhead, thrust cylinders that propel the machine forward by pushing against the tunnel walls or previously installed segments, and a muck transport system. TBMs can also erect precast concrete segments to form the final tunnel lining continuously as they advance.

Key Points

- Used for continuous excavation of circular tunnels
- Main components: Cutterhead, thrust cylinders, and muck transport
- Reduces disturbance to the surrounding ground
- Can simultaneously excavate and install the final tunnel lining

Hard Rock TBMs I

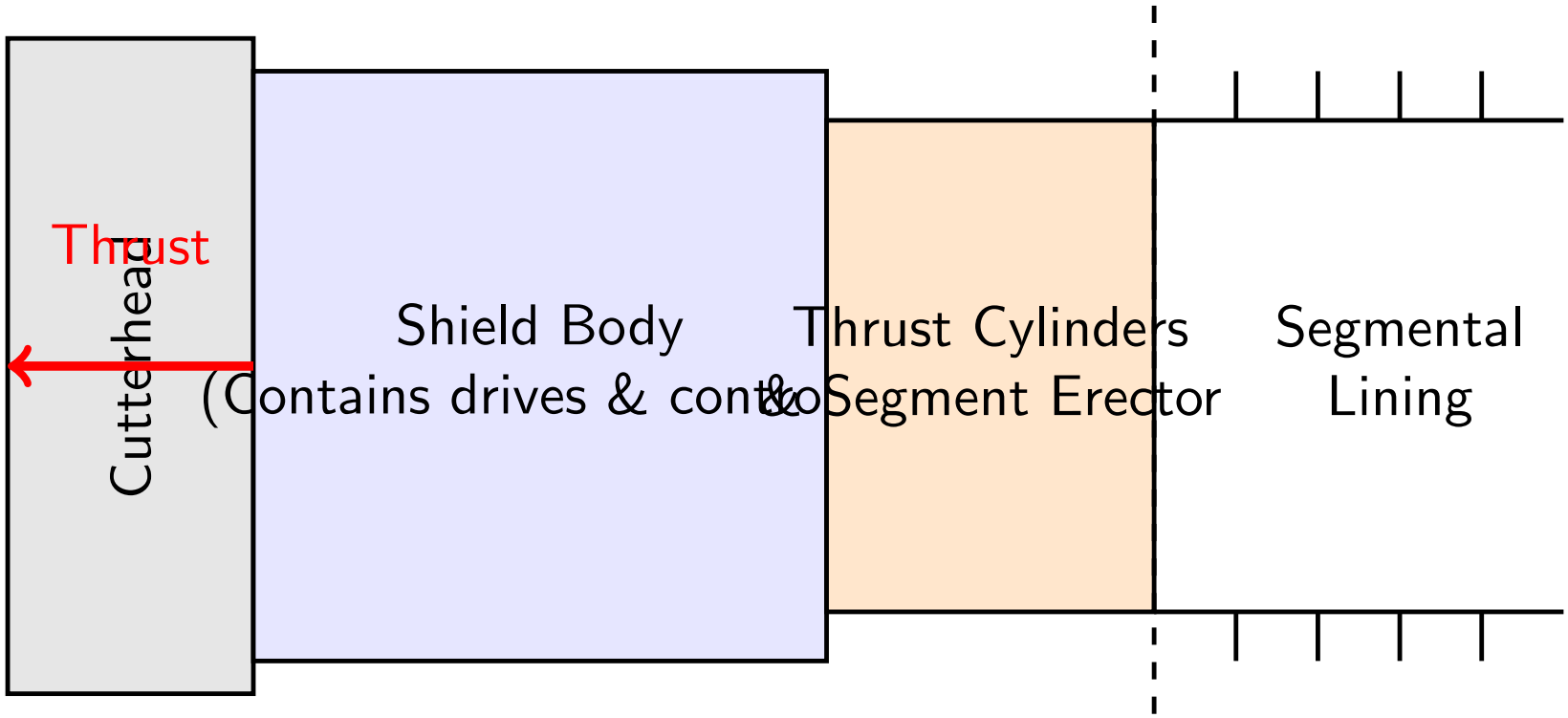
Hard Rock TBMs are designed to excavate through solid, stable to moderately fractured rock. They primarily use disc cutters mounted on the cutterhead, which roll against the rock face, inducing high contact stresses that cause the rock to spall and fracture. Open-type TBMs (or Main Beam TBMs) grip the tunnel walls to provide thrust and are used in competent rock. Shielded TBMs (Single or Double Shield) provide continuous support to the excavated opening and are utilized in more fractured or unstable rock conditions, erecting segmental lining immediately behind the cutterhead.

Hard Rock TBMs II

Key Points

- Utilize disc cutters to induce rock spalling under high pressure
- Open-type TBMs rely on gripper shoes against competent rock
- Shielded TBMs are used for unstable or highly fractured rock conditions
- Double Shield TBMs offer high advance rates by simultaneous boring and lining

Schematic of a Shielded TBM I



Schematic of a Shielded TBM II

Key Points

- Cutterhead rotates to break the face material
- Shield body protects workers and internal equipment from ground collapse
- Thrust cylinders push off installed segments to propel the TBM forward
- Segment erector mechanically installs the precast concrete lining rings

Earth Pressure Balance (EPB) TBMs I

Earth Pressure Balance (EPB) TBMs are specialized soft-ground machines used primarily in cohesive soils with high clay or silt content. The core principle of an EPB TBM is to use the excavated soil itself as a support medium to balance the earth and groundwater pressures at the tunnel face. The excavated muck enters a pressurized extraction chamber behind the cutterhead. A screw conveyor, which allows for controlled pressure dissipation, is used to extract the muck from this chamber to a belt conveyor operating at atmospheric pressure. Soil conditioning agents are often injected to improve muck flowability and impermeability.

Earth Pressure Balance (EPB) TBMs II

Key Points

- Designed for cohesive soils like clay and silt
- Uses excavated muck in a pressurized chamber to support the tunnel face
- Face pressure is regulated by controlling the discharge via a screw conveyor
- Soil conditioning agents (foams/polymers) optimize muck properties

Slurry Shield TBMs I

Slurry Shield TBMs are employed in granular soils (sands and gravels) or mixed faces with high groundwater pressures. In this system, a pressurized bentonite slurry is pumped into the excavation chamber to stabilize the tunnel face. The slurry creates an impermeable filter cake on the soil surface, preventing groundwater inflow and face collapse. The excavated soil mixes with the slurry and is hydraulically pumped out of the tunnel through pipes to a surface separation plant, where the soil particles are removed, and the cleaned slurry is recirculated back to the TBM.

Key Points

- Ideal for highly permeable granular soils and high groundwater pressure
- Uses pressurized bentonite slurry to stabilize the face via a filter cake
- Muck is transported hydraulically via a closed-loop pipe network
- Requires a large and complex surface slurry separation plant

Comparison of TBM Types I

| Feature | Hard Rock TBM | EPB TBM | Slurry Shield TBM | | :— | :— | :— | :— | | **Ideal Ground** | Competent to fractured rock | Cohesive soils (clays, silts) | Granular soils (sands, gravels) | | **Face Support** | Unnecessary or partial shield | Pressurized excavated muck | Pressurized bentonite slurry | | **Muck Extraction** | Belt conveyor/muck cars | Screw conveyor | Hydraulic pumping (pipes) | | **Additives Used** | Water (for dust control) | Foams, polymers | Bentonite, polymers | | **Surface Footprint**| Small (mostly muck storage) | Moderate | Large (requires separation plant) |

Comparison of TBM Types II

Key Points

- Hard Rock TBMs are suited for stable geology without massive groundwater pressure
- EPB is standard for urban tunneling in soft, clayey grounds to control settlements
- Slurry shields are necessary for highly permeable soils below the water table

TBM Selection Criteria I

Selecting the appropriate TBM is a critical decision that influences project success and safety. The primary factor is the geological and hydrogeological profile of the alignment, requiring thorough geotechnical investigations. For rock, the Unconfined Compressive Strength (UCS), abrasivity, and jointing dictate cutter design and TBM type. For soft ground, particle size distribution and groundwater pressure determine if an EPB or Slurry TBM is required. Other vital criteria include the tunnel length and diameter, alignment constraints (such as minimum curve radii), allowable surface settlements (especially critical in urban areas), and available surface space for site installations.

TBM Selection Criteria II

Key Points

- Geological profile: Rock strength (UCS), soil gradation, abrasivity
- Hydrogeology: Expected groundwater pressures and inflow rates
- Project constraints: Tunnel length, required diameter, and alignment curves
- Environmental constraints: Strict surface settlement limits in urban settings

Summary I

Tunnel excavation relies heavily on choosing the right method for the prevailing ground conditions. The Drill and Blast method provides unmatched flexibility for variable rock profiles and irregular shapes but operates on a slower, cyclic basis. Conversely, TBMs offer continuous, rapid excavation for circular tunnels but require specific machine types tailored to the geology. Hard Rock TBMs employ disc cutters for solid rock, whereas soft-ground machines like EPB and Slurry Shields actively support the tunnel face to prevent collapse and control groundwater. Proper geotechnical investigation remains the cornerstone for the optimal selection of TBM technology, ensuring safe and efficient project delivery.

Summary II

Key Points

- Drill & Blast is highly versatile but involves slower, cyclic operations
- TBMs provide rapid, continuous excavation but require high initial capital
- Hard Rock, EPB, and Slurry TBMs address distinct ground conditions
- Accurate geotechnical data is essential for safe and successful TBM selection