Rock Tunnel Engineering

INTRODUCTION

• Tunnel – a hole in the ground to provide for desired movement or as mobility channel.

• Serves as highway, railroad, pedestrian passageway, water conveyance, waste water transport, hydropower generator, utility corridor, storage, etc.

• Tunnel shape: circular, multicurve, horseshoe, arched, flat-roofed.

• Location: under mountain, cities, river, lakes, straits, bays etc.

• Ground: soft ground, mixed face, rock, layered, wet, flowing or squeezing ground.

• Tunnel constructed; cut and cover method, drilling and blasting, mechanized; TBM, Roadheader, etc.
Example of Underground tunnel Layout

Trans – Tokyo Bay Tunnel.

Example of Underground tunnel Layout

Hampton Roads Bridge-Tunnel, Virginia. 1957
Example of Underground tunnel Layout

Soil tunnel - Ribbed support system

Pergau Dam Tunnel, Kelantan

Smart Tunnel - Tunnel Boring Machine

THE GREAT EXCAVATION
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2
3
4

Breaking through
Underground Nuclear waste storage

TYPICAL TUNNEL GEOMETRY

Typical box tunnel, single cell

Typical arch roof tunnel, single cell

Typical box tunnel, double cell
Geotechnical Investigations Challenges

- Vast uncertainty in all underground projects.
- The cost and feasibility of the project is dominated by geology.
- Every feature of geologic investigation is more demanding than foundation engineering projects.
- The regional geology must be known.
- Engineering properties drastic change with a wide range of conditions eg time, season, rate and direction of loading etc.
- Groundwater is the most difficult condition/parameter to predict and the most troublesome.
- It is guaranteed that the actual stratigraphy, groundwater flow and behaviour encountered during construction will be compared with the geotechnical team’s prediction.

Rock Classification

- Physical rock description- rock types, Intact strength, weathering state, Discontinuities.
- Rock mass classification system; RQD (core loss –indicate a weakness in the rock),RMR, Q-system.
The most important part of design to stabilize ground movement, not to carry ground load.

The most important part of tunnel lining is the ground that surrounds it.

The most important component of the ground is the groundwater.

Most important element of lining construction is to secure full, continuous contact between the lining and the ground.

The most efficient tunnel stabilization and lining system is one that mobilizes the strength of the ground by permitting controlled ground deformation.

Selection of type of lining depends on excavation methods that suited ground characteristics, of which ‘stand-up’ time is most significant. It affects the magnitudes of ground deformation and lining loads.

Axial stiffness of the lining permits it to distribute non-uniform ground loads by mobilizing passive pressure from surrounding ground, thereby modify ground deformation.

Flexural stiffness of lining is inefficient in modifying ground deformation.
**PRINCIPLE OF TUNNEL STABILIZATION AND DESIGN**

- Multistage lining can absorb large flexural deformation and redistribution of ground stresses.
- Dimension of lining are controlled by water sealing, constructability, facility usage rather than ground load.
- Load and pressures vary along the length of tunnel owing to variations in geology and construction proficiency.
- The largest loads on the lining may come from construction processes.

**MECHANISM OF FAILURE AND LOAD ANALYSIS**

Effect of joint orientation on crown stability

\[ P_1 = P_N \left(1 - \frac{\tan \theta}{\tan \phi}\right) + \frac{2b}{4\tan \phi} \]
Tunnel Load Analysis

Loading on tunnel support (Terzaghi, 1964)

Direction of movement during excavating operations.

Carried by arching

Approx. B + H1

Carried by wedge

Carried by roof support

Carried by wedge

Sand surface
Forces acting on tunnel; support in inclined strata. (Terzaghi, 1964)

E3: Load on 2-stage lining system
Load Analysis
- Reinforced rock arch loading

Width of rock wedge is:
\[ B_w = \left( B + 2 \left( \frac{B}{2} \cdot \frac{B}{4} \right) \right) = \frac{7}{15} B \]

Height of rock wedge is:
\[ H = \frac{B}{2} \cdot \tan \alpha = \frac{7}{15} B \tan \alpha \]

Assume average rock arch load is:
\[ p = \frac{11H}{2} = \frac{7}{25} \gamma B \tan \alpha \]

Thrust/ft = 
\[ N = \frac{21\gamma B \tan \alpha}{80} \]

Arch compression is:
\[ \frac{N}{B} = 2 \gamma B \tan \alpha \]

Circular Tunnel: deformation characteristics & behaviour of flexible rings

a) Unconfined ring - Uniform radial load

b) Unconfined ring - Concentrated load

c) Partially confined ring - Concentrated load

d) Fully confined ring - Random load
Example of analysis using numerical simulation method

TUNNEL LINING

• Unlined rock - massive and stable rock formation

• Rock reinforcement systems – sound rock but have structural defects (rock joints) eq: rock reinforcement to knit the rock mass together so that it is self-supporting short bolt, untensioned steel dowels, tensioned steel bolt,

• Dowel or bolts provide temporary stabilization

• Shotcrete; stabilization of rock tunnels excavated by drill-and-blast methods. Shotcrete provide early support in rock with limited ‘stand-up’ time.

• Ribbed system - timber, steel H-section in poor rock condition

• Segmental lining - soft ground tunnel

• Poured concrete – poured-in-place concrete in wet ground, water leakage, water proofing membrane
Ground-structure interaction – characteristics of lining behaviour

• Tunnel lining behaviour is a 4D problem

• During construction, ground conditions at the tunnel heading involve both transverse arching and longitudinal arching or cantilevering from unexcavated face.

• All ground properties are time-dependent, The timing of lining installation is an important variable.

EXAMPLE OF LINING

Steel Fiber Reinforced Concrete Precast Tunnel Segments
• Tunnel segments are precast and packaged in a precasting facility before delivery and placement on site. Steel fiber reinforced concrete is cast or pumped directly inside the formworks.
• With respect to design load conditions, it is possible to use 100% fiber reinforced concrete in precast tunnel segments.

Fiber reinforced concrete can be applied to precast concrete construction with excellent results and several key advantages:
• Better aesthetic quality of the product
• Higher mechanical strength in terms of toughness, flexural and shear stress
• Faster industrialized production process through the partial or total elimination of steel reinforcement cages
• Improved damage resistance during transportation and placing
• Reduced concrete thickness as no reinforcement cover depth is required
• Improved durability in aggressive environments