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## Tunneling in Difficult Ground

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## Module 8: Tunneling In Difficult Ground

### Learning Objectives

By the end of this section, you will be able to:

- **Identify** the four primary categories of difficult ground and their specific geologic triggers.
- **Calculate** the required tunnel working pressure in soft clays using the Stability Number method to prevent ground closure.
- **Evaluate** the technical requirements for TBM components, including cutterheads and propulsion systems, when operating in squeezing or swelling rock.

*Executive Summary:* "Difficult Ground" represents geologic conditions—such as instability, heavy loading, and hazardous physical environments—that actively resist standard mining or boring efforts. Success in these environments requires a transition from "ideal" material assumptions to specialized engineering approaches, including Sequential Excavation Method (SEM) principles, pressurized TBM systems, and yielding support structures.

### Conversion Factors

The following table provides approximate conversions for primary units used in civil engineering.

Approximate Conversions to SI Units			Approximate Conversions from SI Units		
When you know	Multiply by	To find	When you know	Multiply by	To find
(a) Length					
inch	25.4	millimeter	millimeter	0.039	inch
foot	0.305	meter	meter	3.28	foot
yard	0.914	meter	meter	1.09	yard
mile	1.61	kilometer	kilometer	0.621	mile
(b) Area					
square inches	645.2	square millimeters	square millimeters	0.0016	square inches
square feet	0.093	square meters	square meters	10.764	square feet
acres	0.405	hectares	hectares	2.47	acres
square miles	2.59	square kilometers	square kilometers	0.386	square miles
(c) Volume					
fluid ounces	29.57	milliliters	milliliters	0.034	fluid ounces
gallons	3.785	liters	liters	0.264	gallons
cubic feet	0.028	cubic meters	cubic meters	35.32	cubic feet
cubic yards	0.765	cubic meters	cubic meters	1.308	cubic yards
(d) Mass					
ounces	28.35	grams	grams	0.035	ounces
pounds	0.454	kilograms	kilograms	2.205	pounds
short tons (2000 lb)	0.907	megagrams (tonne)	megagrams (tonne)	1.102	short tons (2000 lb)
(e) Force					
pound	4.448	Newton	Newton	0.2248	pound
(f) Pressure, Stress, Modulus of Elasticity					
pounds per square foot	47.88	Pascals	Pascals	0.021	pounds per square foot
pounds per square inch	6.895	kiloPascals	kiloPascals	0.145	pounds per square inch
(g) Density					
pounds per cubic foot	16.019	kilograms per cubic meter	kilograms per cubic meter	0.0624	pounds per cubic feet
(h) Temperature					
Fahrenheit temperature(°F)	$5/9(°F - 32)$	Celsius temperature(°C)	Celsius temperature(°C)	$9/5(°C) + 32$	Fahrenheit temperature(°F)

Notes: 1) The primary metric (SI) units used in civil engineering are meter (m), kilogram (kg), second(s), newton (N) and pascal (Pa=N/m<sup>2</sup>).  
 2) In a "soft" conversion, an English measurement is mathematically converted to its exact metric equivalent.  
 3) In a "hard" conversion, a new rounded metric number is created that is convenient to work with and remember.

💡 **Design Tip:** Distinguish between "soft" conversions (exact mathematical equivalents) and "hard" conversions (rounded, convenient metric numbers) in project specifications.

## Introduction

Geology rarely presents the uniform, defined characteristics engineers desire. In "Difficult Ground," specialized arrangements are mandatory to safely stabilize the tunnel.

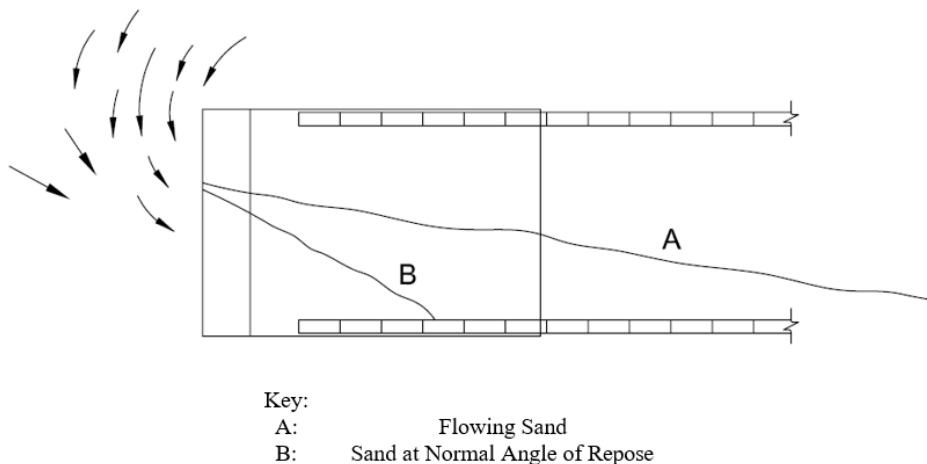
- **Instability:** Arises from a lack of stand-up time in non-cohesive or weak cohesive soils, blocky rock, adverse joint orientations, or water effects.
- **Heavy Loading:** Encountered in weak rock at depth (squeezing, popping) or swelling materials like anhydrite.
- **Obstacles and Constraints:** Includes natural boulder beds and caverns, or urban man-made obstructions like abandoned foundations and piles.
- **Physical Conditions:** Hazardous environments featuring tectonic/geothermal heat, noxious gases (methane, H<sub>2</sub>S), or contaminated ground.

## Instability

### Non-Cohesive Sand and Gravel

Sand stability is transient and highly moisture-dependent.

- **Apparent Cohesion:** Negative pore pressure provides temporary stand-up time in damp sand, but disappears as it dries.
- **Flowing Ground:** If groundwater is flowing, any amount can trigger a run leading to total collapse.



**Figure 8-1.** Flowing Sand in Tunnel

⚠ **Safety Constraint:** Do not overrate soil stability based on initial exposure; once cohesion is lost through drying, it cannot be restored by rewetting.

## Soft Clay

Soft clay behaves as a plastic material that closes on the excavation if overburden pressure at the spring line exceeds shear strength by a factor of three or more.

📊 **Calculation Note:** To maintain stability ( $N_{crit}$  below 5), determine the required tunnel working pressure.

**Equation 8-1:**

$$P_a = P_z - (N_{crit} \cdot S_u)$$

**Where:**

- **Pa** = Required working pressure (psi/psf)
- **Pz** = Overburden pressure at tunnel spring line
- **Ncrit** = Critical stability number
- **Su** = Undrained shear strength of the soil

## Blocky Rock

Blocky rock requires early support to preserve stability.

- **Seamy Rock:** Joints containing clay increase rock loads by a factor of approximately three.
- **Blasting:** Micro-fissures from explosives can cause overbreak extending a full tunnel diameter beyond the perimeter.
- **Support:** Use an initial 5 cm shotcrete layer in the crown followed by pattern rock bolts.

## Adverse Combinations of Joints and Shears

Assume shears and faults are continuous throughout the excavation. Large blocks can define unstable zones with no inherent support once excavated. Identify these locations via mapping to control drift size and round length.

## Faults and Alteration Zones

Fault zones may contain pulverized rock or inclusions of large native rock.

- **TBM Risk:** Loose material stalls cutterheads, while cohesive material binds the shield.
- **Mitigation:** Maintain a grout curtain ahead of the TBM. If water is running, a bulkhead is required to stop the flow before grouting.

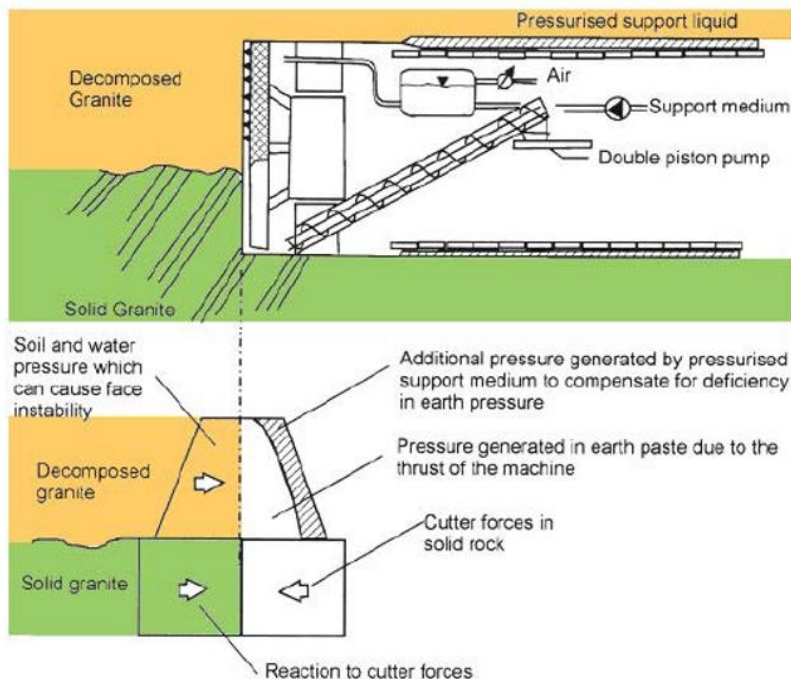
## Water

Terzaghi suggested doubling the design rock load on linings when below the water table (except for circular tunnels).

- **Clay:** Sensitivity in clays (ratio of undisturbed to remolded strength) can range from 2 to 1,000. Remolding during shield passage releases free water, causing rapid volume changes and surface settlement.

## Mixed Face Tunneling

Typically, this involves rock in the lower face and soil in the upper face.



**Figure 8-2.** Mixed Face Tunneling Example (Babenderede et al., 2004)

💡 **Design Tip:** Use consolidation grouting rather than compressed air for mixed face conditions with clean sands, as the ground becomes free-flowing once dried.

## Heavy Loading

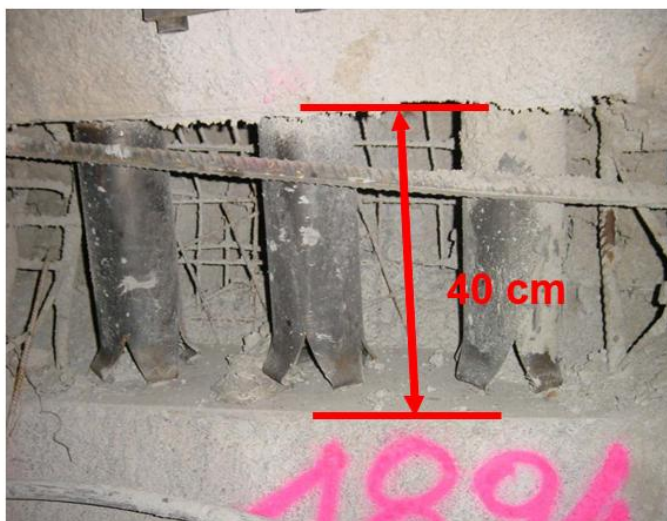
### Squeezing Rock

Squeezing occurs when the unconfined compressive strength of the rock is less than the increased tangential stresses (which can reach three times the overburden load).

- **Initial Elastic Movement:** Stress relief causes rebound that distorts the excavation shape, especially in laminated rocks.
- **Strength Reduction:** In brittle rock, this leads to rock bursting or "popping rock". In weak rock, the material enters a plastic regime where load-bearing capacity drops by two orders of magnitude.
- **Creep:** A time-dependent diameter decreases where weakened material moves toward the boundary.
- **Modeling Rock Behavior:** Mathematical models for elasto-plastic movement depend on experience derived from the specific tunnel.
- **Other Factors:** Pore water can provide temporary initial support via negative pore pressure but later increases loading through seepage pressure.
- **Monitoring:** Establish convergence point installations to monitor movement rates, which is central to SEM tunneling.

### Yielding Supports

Yielding joints (permitting up to 22 cm of closure) allow stress relief without damaging the shotcrete.



**Figure 8-3.** Yielding Support in Squeezing Ground



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