

Chapter 9. Support design in overstressed rock

Rock mass failure?

- Depends on (1) in situ stress level,
 (2) characteristics of the rock mass,
 (3) geometry of the excavation

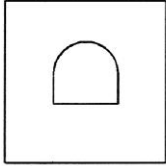
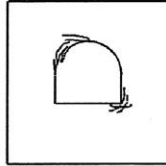
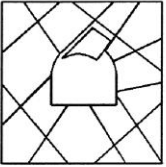
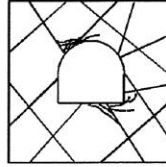
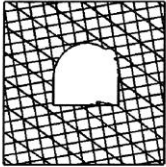
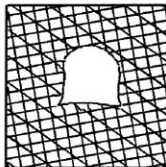
	Low stress levels	High stress levels
Massive rock	 <p>Massive rock subjected to low in situ stress levels. Linear elastic response with little or no rock failure.</p>	 <p>Massive rock subjected to high in situ stress levels. Spalling, slabbing and crushing initiates at high stress concentration points on the boundary and propagates into the surrounding rock mass.</p>
Jointed rock	 <p>Massive rock, with relatively few discontinuities, subjected to low in situ stress conditions. Blocks or wedges, released by intersecting discontinuities, fall or slide due to gravity loading.</p>	 <p>Massive rock, with relatively few discontinuities, subjected to high in situ stress conditions. Failure occurs as a result of sliding on discontinuity surfaces and also by crushing and splitting of rock blocks.</p>
Heavily jointed rock	 <p>Heavily jointed rock subjected to low in situ stress conditions. The opening surface fails as a result of unravelling of small interlocking blocks and wedges. Failure can propagate a long way into the rock mass if it is not controlled.</p>	 <p>Heavily jointed rock subjected to high in situ stress conditions. The rock mass surrounding the opening fails by sliding on discontinuities and crushing of rock pieces. Floor heave and sidewall closure are typical results of this type of failure.</p>

Figure 9.1: Types of failure which occur in different rock masses under low and high in situ stress levels.

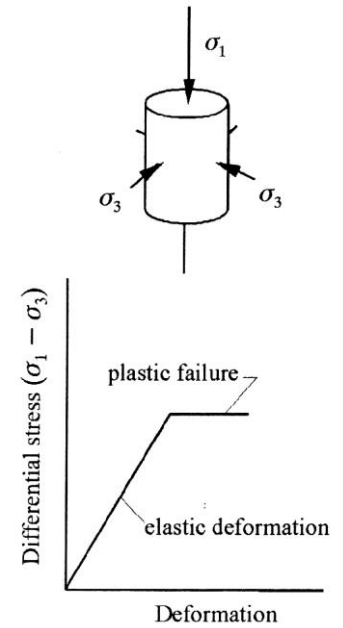
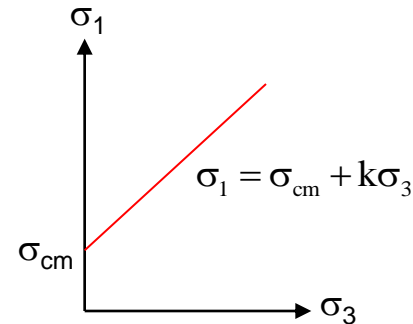
Support interaction analysis

- (1) A circular tunnel, hydrostatic stress field
- (2) Elastic-perfectly plastic rock mass (no volume change)
- (3) Support as an equivalent internal pressure (rockbolts)
- (4) Definition of failure criterion

Onset of plastic failure $\sigma_1 = \sigma_{cm} + k\sigma_3$

Uniaxial compressive strength of rock mass $\sigma_{cm} = \frac{2c \cdot \cos \phi}{1 - \sin \phi}$

where, σ_1 = axial stress at which failure occurs,
 σ_3 = confining stress,
 c = cohesive strength,
 ϕ = angle of friction of the rock mass



Stress-deformation curve for a constant confining pressure

Support interaction analysis

(5) Analysis of tunnel behavior

$$\sigma_1 = \sigma_{cm} + k\sigma_3$$

$$2p_o - p_{cr} = \sigma_{cm} + k \cdot p_{cr}$$

$$p_{cr} = \frac{2p_o - \sigma_{cm}}{1+k}$$

(p_{cr} : critical support pressure)

If $p_i > p_{cr}$, no failure occurs (elastic behavior)

Inward radial elastic displacement

$$u_{ie} = \frac{r_o(1+\nu)}{E}(p_o - p_i)$$

If $p_i < p_{cr}$, failure occurs

Radius of the plastic zone, r_p

$$r_p = r_o \left[\frac{2\{p_o(k-1) + \sigma_{cm}\}}{(k+1)\{(k-1)p_i + \sigma_{cm}\}} \right]^{\frac{1}{k-1}}$$

The total inward radial displacement

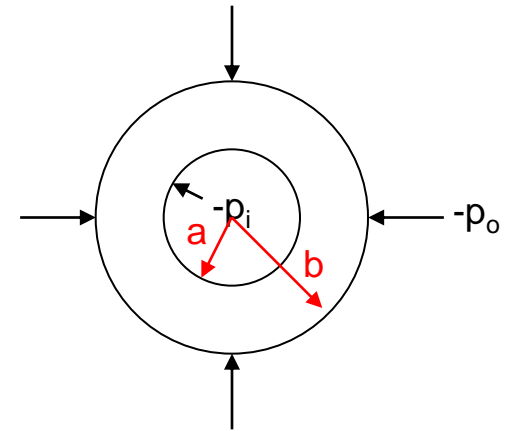
$$u_{ip} = \frac{r_o(1+\nu)}{E} \left[2(1-\nu)(p_o - p_{cr}) \left(\frac{r_p}{r_o} \right)^2 - (1-2\nu)(p_o - p_i) \right]$$

$$u = \frac{1+\nu}{E} \left[\frac{p_i a^2 - p_o b^2}{b^2 - a^2} (1-2\nu)r - \frac{a^2 b^2 (p_o - p_i)}{(b^2 - a^2)r} \right] - \nu \varepsilon_z r$$

$$\varepsilon_z = 0, b \rightarrow \infty, r = a$$

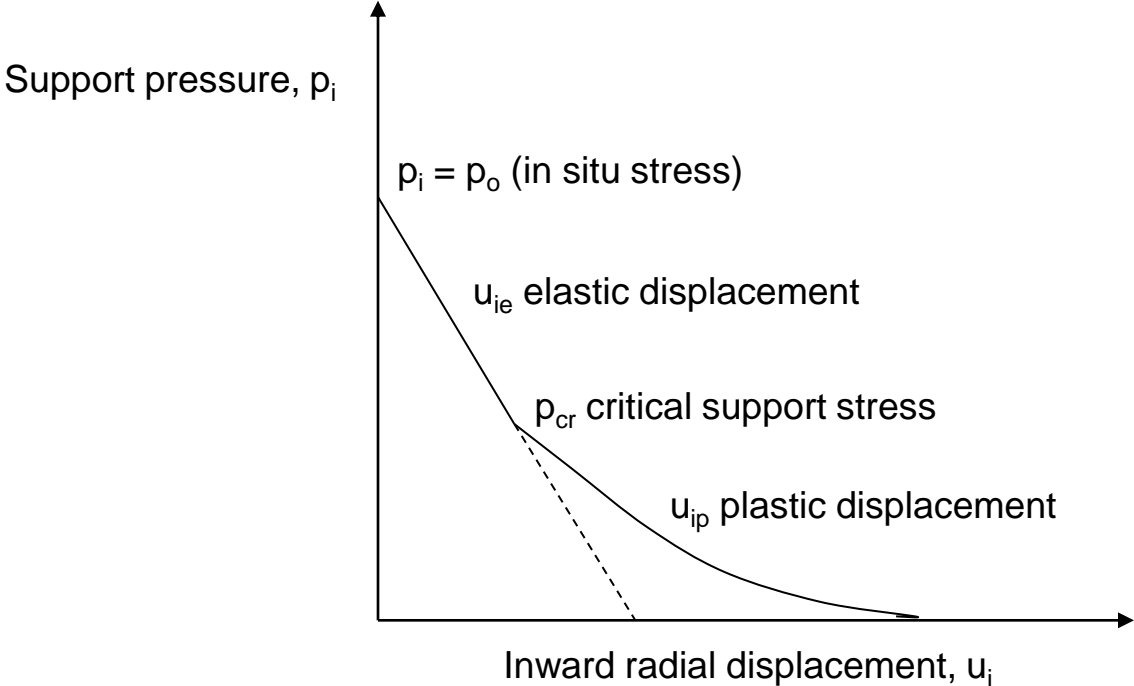
$$u = \frac{1+\nu}{E} [-p_o(1-2\nu)a - a(p_o - p_i)]$$

$$\approx \frac{-a(1+\nu)}{E}(p_o - p_i)$$



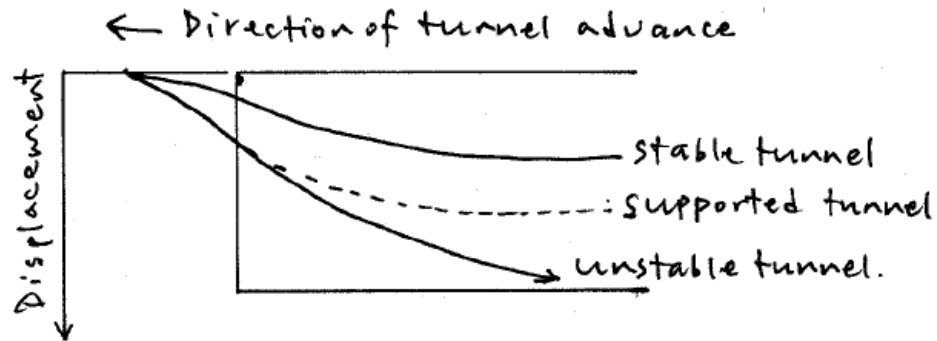
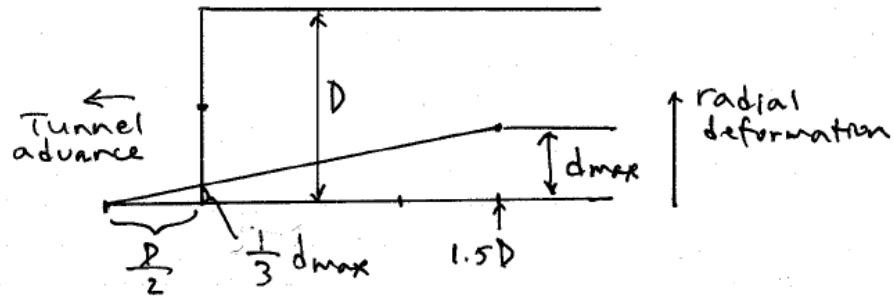
Support interaction analysis

(5) Analysis of tunnel behavior



Support interaction analysis

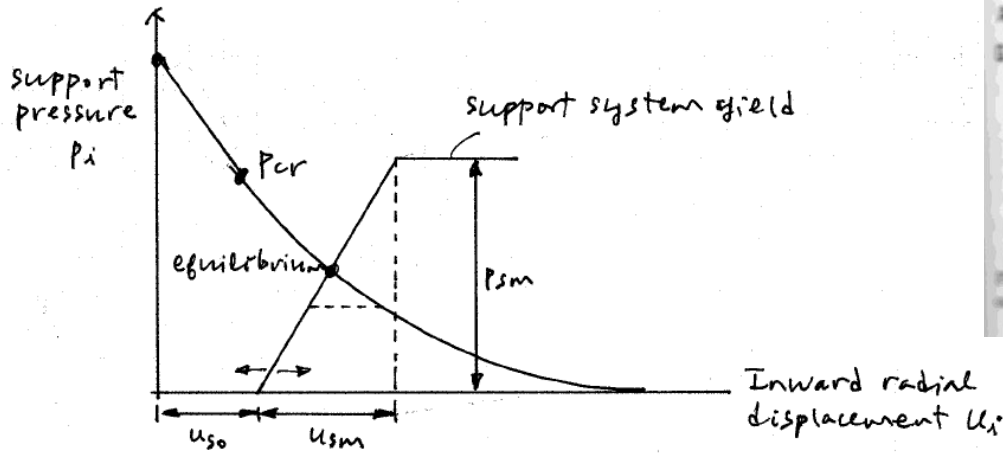
(6) Deformation of an unsupported tunnel



Support interaction analysis

(7) Deformation of characteristics of support

- At the face, approximately $\frac{1}{3}$ of the total deformation occurs. This can not be recovered.
- There is always a stage of the excavation cycle. There is a gap between the face and the closest installed support element. \rightarrow further deformation.



- AC - properly designed support: equilibrium at C
- OD - radial deformation for stable unlined tunnel
- AeE - support yields before stabilizing opening
- AF - support too flexible
- GH - support too delayed

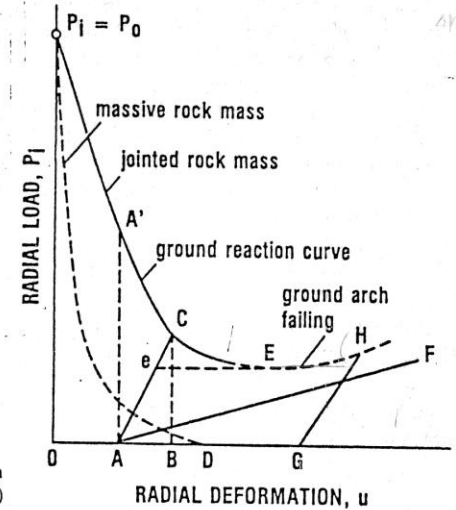


Figure 7.1. The concept of ground reaction curve for rock tunnels (after Deere et al., 1970)