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

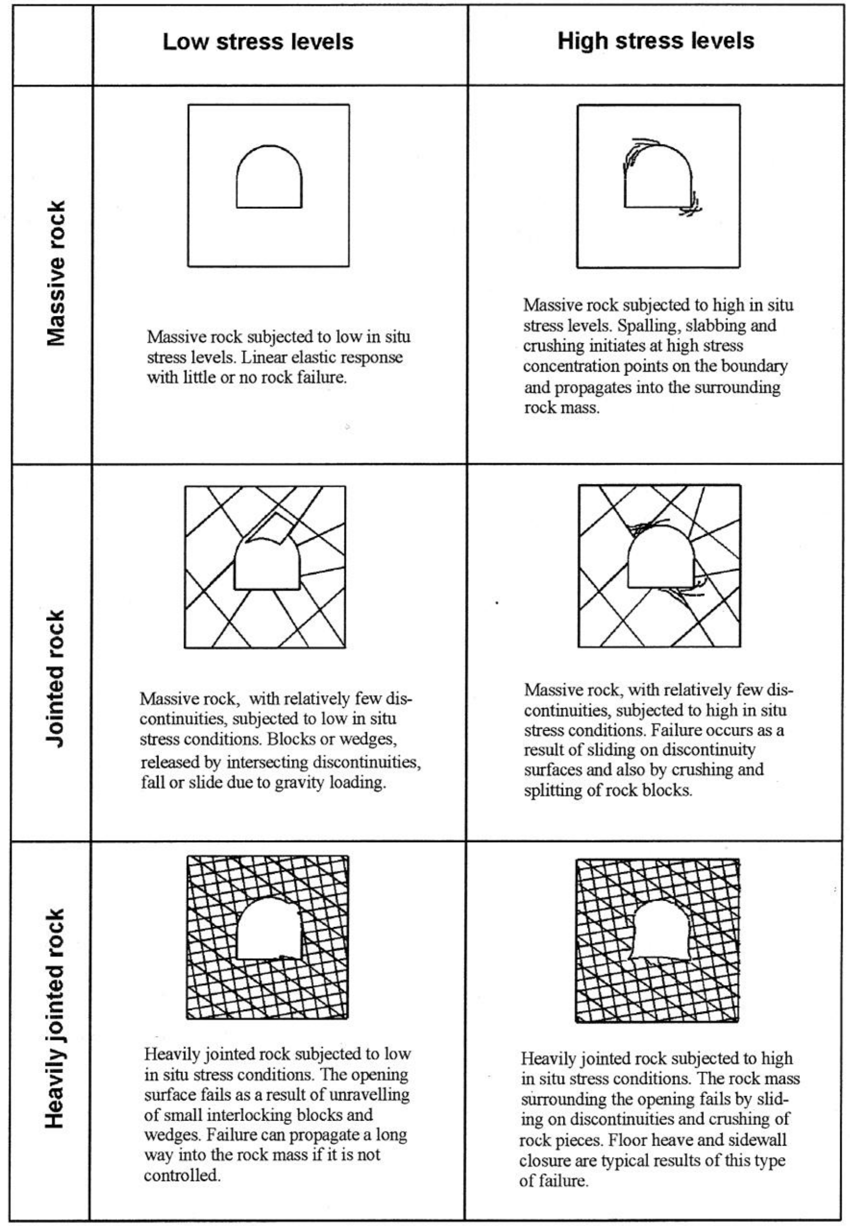


Figure 9.1: Types of failure which occur in different rock masses under low and high in situ stress levels.

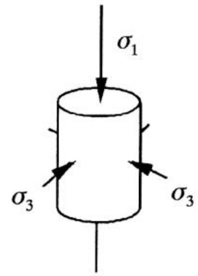
Support interaction analysis

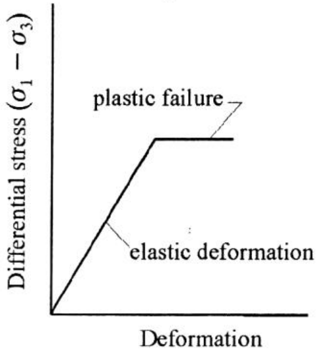
(1) A circular tunnel, hydrostatic stress field
(2) Elastic-perfectly plastic rock mass (no volume change)
(3) Support as an equivalent internal pressure (rockbolts
(4) Definition of failure criterion

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

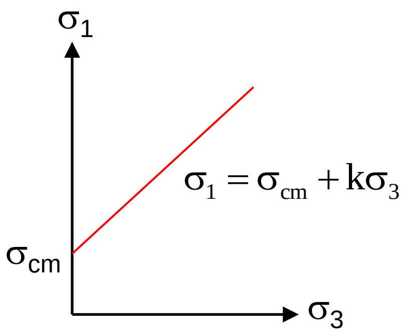
Uniaxial compressive strength of rock mass $\sigma_{cm} = \dfrac{2c \cdot \cos\phi}{1 - \sin\phi}$

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)

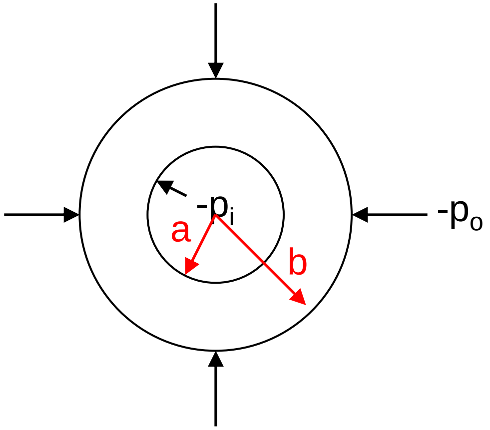
If $p_i > p_{cr}$, no failure occurs (elastic behavior)

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

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

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

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



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

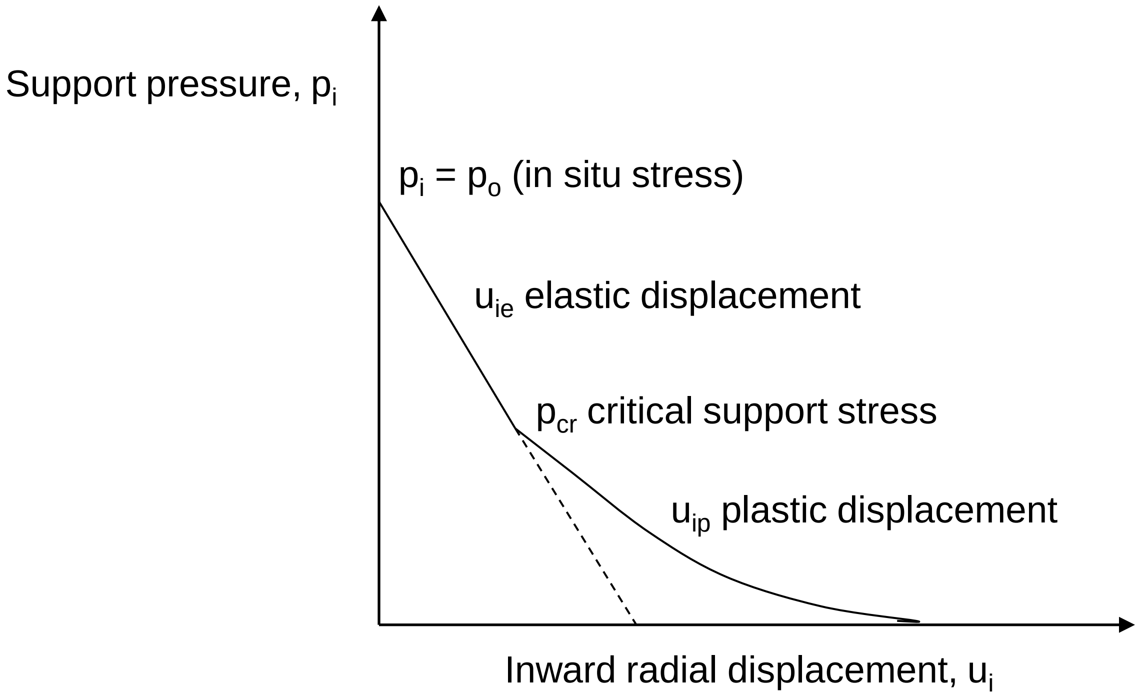
$$r_p = r_o\left[\frac{2\{p_o(k-1)+\sigma_{cm}\}}{(k+1)\{(k-1)p_i + \sigma_{cm}\}}\right]^{\frac{1}{k-1}}$$

The total inward radial displacement

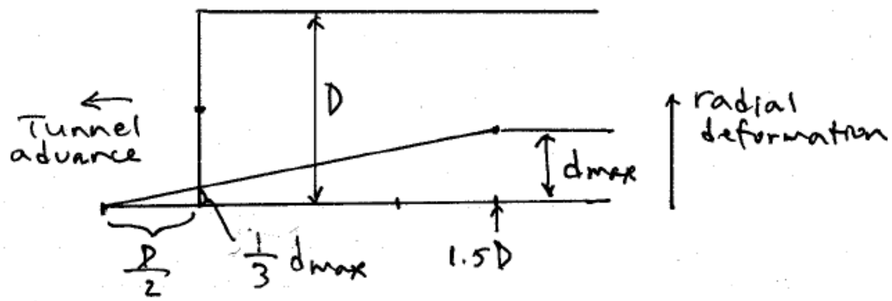
$$u_{ip} = \frac{r_o(1+\nu)}{E}\left[2(1-\nu)(p_o - p_{cr})\left(\frac{r_p}{r_o}\right)^2 - (1-2\nu)(p_o - p_i)\right]$$

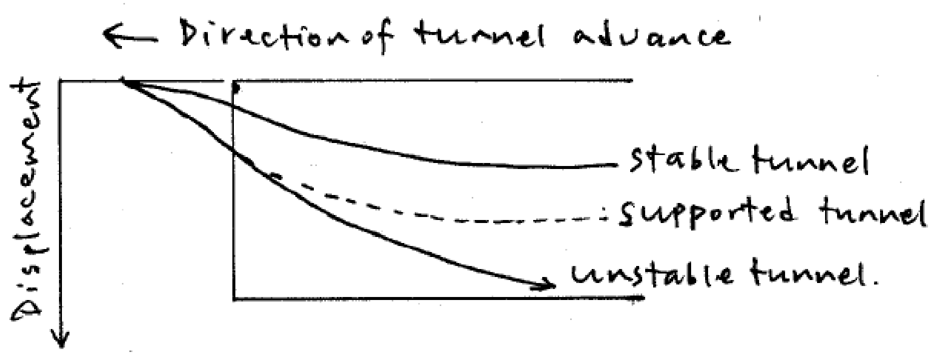
Support interaction analysis

(5) Analysis of tunnel behavior



(6) Deformation of an unsupported tunnel

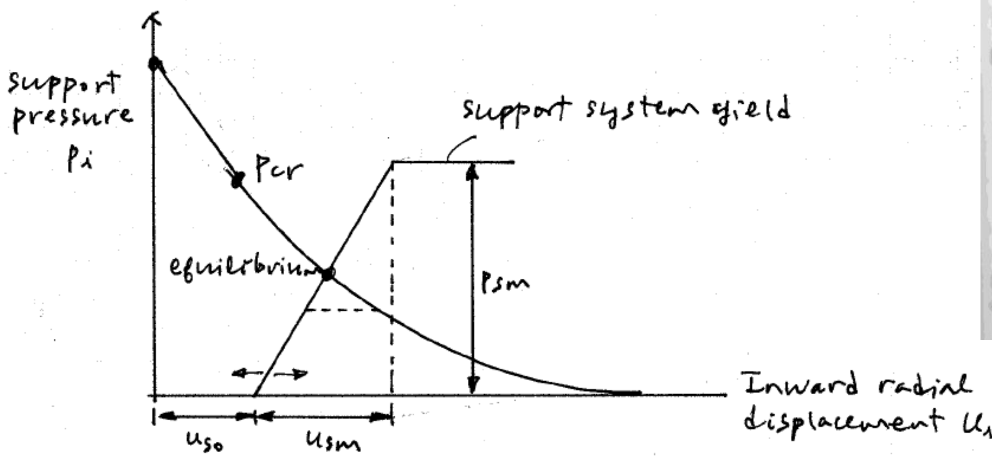




Support interaction analysis

(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. → further deformation.



AC - properly designed support: equilibrium at C
0D - radial deformation for stable unlined tunnel
AeE - support yields before stabilizing opening
AF - support too flexible
GH - support too delayed

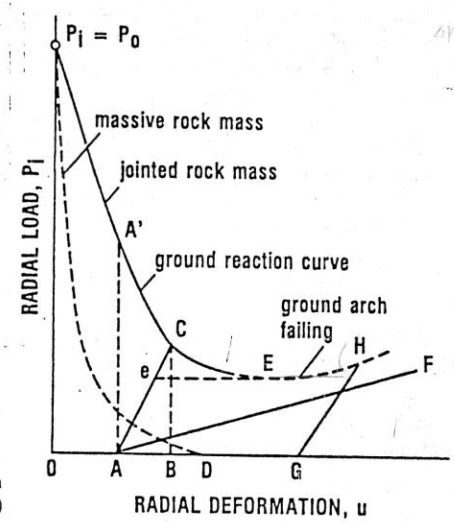


Figure 7.1. The concept of ground reaction curve for rock tunnels (after Deere et al., 1970)