EXCAVATION DESIGN IN STRATIFIED ROCK

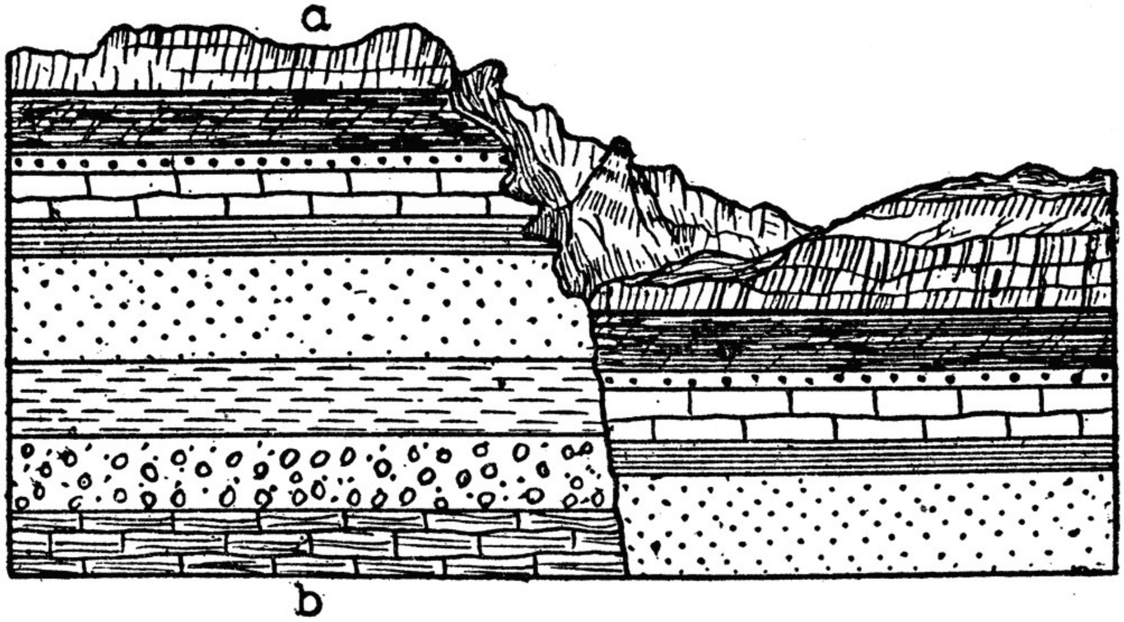
Md. Abdul Malek
Lecturer
Dept. of Geology and Mining

Ref. Book
Rock Mechanics for Underground Mining (3rd Edition)
B.H.G. Brady & E.T. Brown

Chapter-8

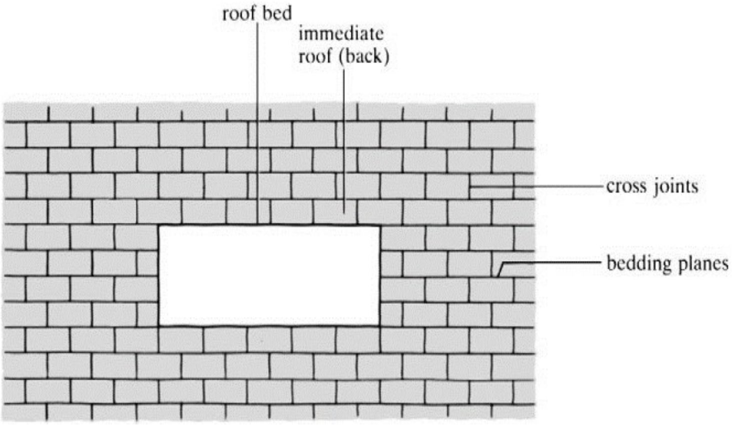
Stratified Rocks

Stratification, the layering that occurs in most sedimentary **rocks** and in those igneous **rocks** formed at the Earth's surface, as from lava flows and volcanic fragmental deposits. The layers range from several millimetres to many metres in thickness and vary greatly in shape.



Excavations in a stratified rock mass are usually mined to a cross-sectional geometry in which the immediate roof and floor of the excavation coincide with bedding planes. Factors to be considered in the design of such an excavation include:

- the state of stress at the excavation boundary and in the interior of the rock medium, compared with the strength of the anisotropic rock mass;
- the stability of the immediate roof;
- floor heave in the excavation.



Design factor

- ❖ Principal engineering properties of bedding planes
  - -Low or zero tensile strength in direction perpendicular to the plane
  - -Low shear strength of surface
- ❖ Features of excavations in a stratified rock mass
  - -Immediate roof and floor of the excavation coincide with bedding planes.
- ❖ Factors to be considered in the design of excavation in a stratified rock mass

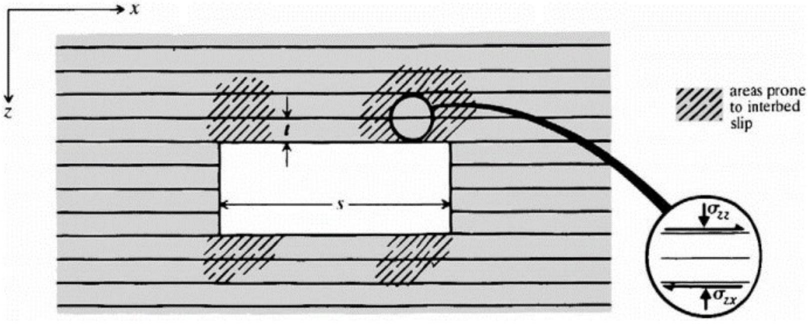
(a) State of stress compared with the strength of the anisotropic rock mass
    -Surface spalling and internal fractures
(b) Stability of the immediate roof
    -Detachment/deflection into the void
(c) Floor heave in the excavation
    -Weak rock under the excavation

Rock mass response to mining

Design process

1) Determining the elastic stress distribution around the excavation in plan
2) Define the zones of tensile/compressive stress exceeding the rock mass strength and a zone of slip on bedding planes.
3) Excavation shape is modified or support/reinforcement zone is defined.

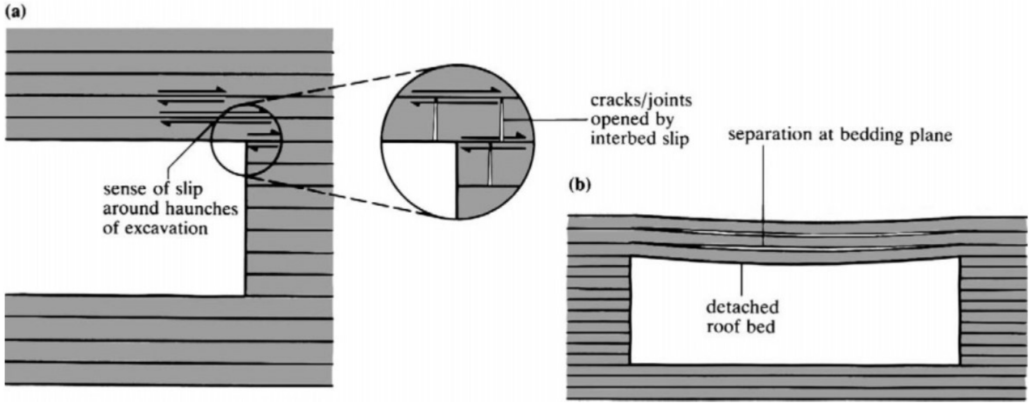
$$|\sigma_{zx}| \geq \sigma_{zz} \tan + c$$



General rules of potential slip on bedding planes

-Low span/bed thickness (s/t): slip occurs only in the haunch area with opening of cracks sub-perpendicular to bedding

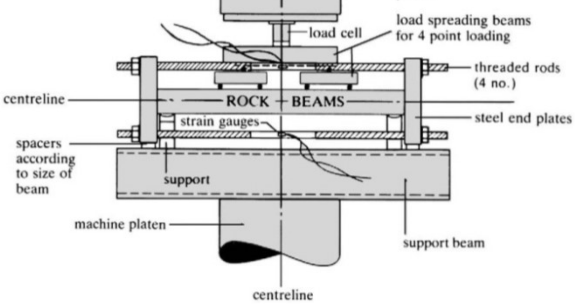
-High span/bed thickness (s/t): slip occurs throughout the whole span of immediate roof, and downward deflection /separation occur at the roof center.



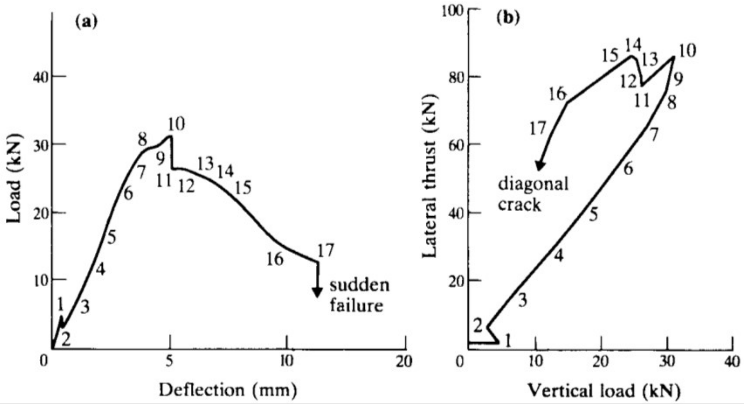
Roof bed deformation mechanics

The experimental studies by Sterling (1980) capture many of the key conclusions of the work by other researchers and provide insights into the deformation and failure modes of roof rock.

The experimental arrangement -as in Figure. A rock beam, of typical dimensions 660 mm ×75 mm ×75 mm, was constrained between steel end plates linked by strain-gauged tie rods. The beam was loaded transversely by a servocontrolled testing machine and a load spreading system. The experiment design provided data on applied transverse load, induced beam deflection, induced lateral thrust, and eccentricity of the lateral thrust.



From the small original thrust corresponding to lateral pre-stress, the initial response (0–1) is flat, corresponding to continuous, elastic behaviour of the beam. Central vertical cracking of the beam (1–2) with increase in lateral thrust, reflects the significance of induced thrust in determining the subsequent performance of the voussoir beam. The linear range of response (2–7) was reversible, and extrapolates downwards to the original loading conditions. Past the peak load capacity of the beam (10), the reducing lateral thrust caused by local spalling results in reduced vertical load capacity for the beam.



This and other tests conducted by Sterling allow formulation of the following principles concerning roof rock behaviour over mined spans:

a) roof beds cannot be simulated by continuous, elastic beams or plates, since their behaviour is dominated by the blocks (voussoirs) generated by natural cross joints or induced transverse fractures;

(b) roof bed behaviour is determined by the lateral thrusts generated by deflection, under gravity loading, of the voussoir beam against the confinement of the abutting rock;

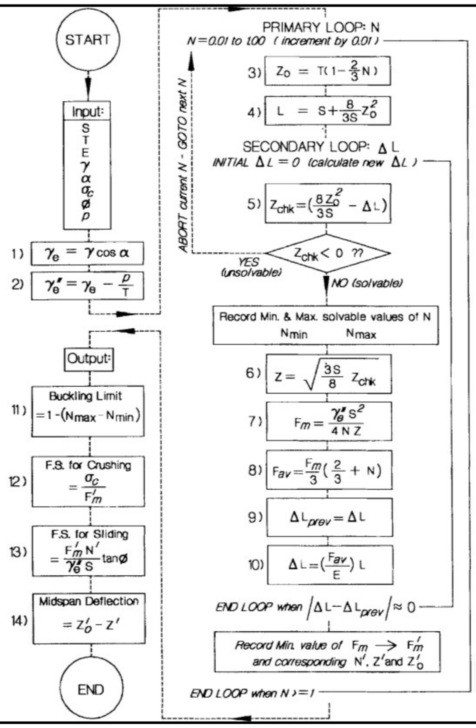
(c) a voussoir beam behaves elastically (i.e. the lateral thrust – vertical deflection plot is linear and reversible) over the range of its satisfactory performance, the upper limit of which approaches the peak transverse load capacity;

(d) for a voussoir beam with low span/thickness ratio, the most likely failure mode is shear failure at the abutments;

(e) for a roof with high span/thickness ratio, roof span stability is limited by the possibility of buckling of the beam, with no significant spalling of central or abutment voussoirs;

(f) a roof with low rock material strength or moderate span/thickness ratio may fail by crushing or spalling of central or abutment voussoirs.

Flow chart for the determination of stability and deflection of a voussoir beam (after Diederichs and Kaiser, 1999a).



Horizontally Layered Rock

Introduction to Rock Mechanics -**Goodman**

Chap-7

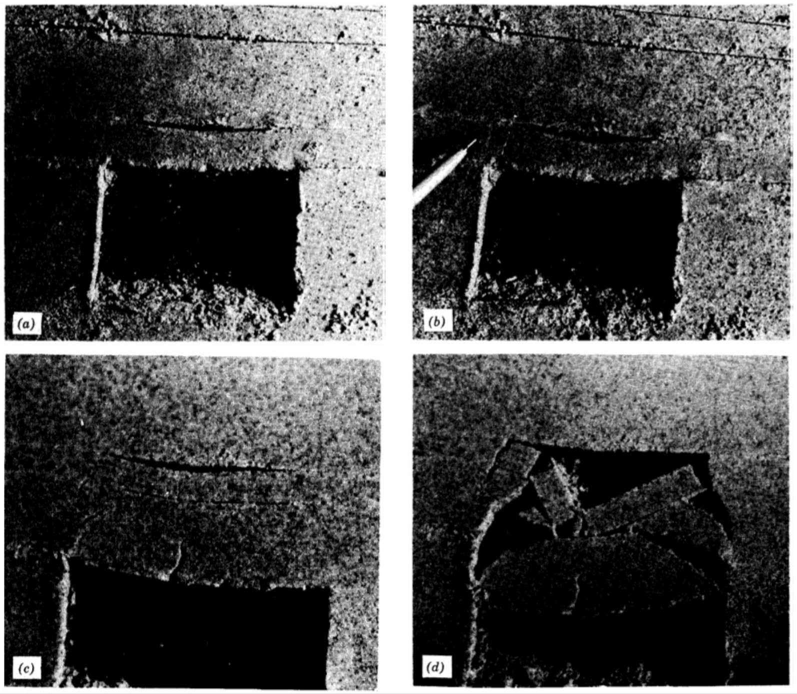
In an underground opinging, when horizontally layered rock lies above the roof-

- the thiner strata near the opening will tend to detach from the main rock mass, and
- Form separated beams

The stability of such beams is great

- If there is a horizontal stress, and
- the span-to-thickness ration is fairly small

In Fig. below shows models of progressive failure of the roof of an opening with horizontally bedded rock.



The beams are greatly strengthed by horizontal stress, up to about one-twentieth of the Euler Buckling stress-

$$\frac{\pi^2 E t^2}{3L^2}$$ Where E-Young's modulus, t-Beam thickness, L-Span

Assuming the roof acts like a clamped beam, the maximum tensile stress occurs at the top surface near the ends-

$$\sigma_{\max} = \frac{\gamma L^2}{2t} - \sigma_h \text{ with the constraint that } \sigma_h < \frac{\pi^2 E t^2}{60L^2}.$$

The maximum tensile stress in the center, at the bottom of the beam, is half the value obtained in above equation. To be conservative, σ_h can be assumed to be zero.

Visible deflection of the roof warns that a detached beam may have formed.

Miners have been known to force a stick into a bow between the roof and floor, and draw a string taut between the ends so that any relaxation of the tension in the string will indicate continued downward deflection of the roof (or heave of the floor).

A borehole periscope or television device should be used to inspect the roof for gaps between layers.

The maximum deflection of a clamped, elastic beam is

$$\mu_{\max} = \frac{\gamma L^4}{32Et^2}$$

For beams in a given rock type, where E and γ are constant from one layer to the next, load will be transformed from a thin beam into a thick beam if the thin beam lies above the thick beam.

The stresses and deflections of the lower beam can be calculated by assingning it an increased unit weight γ_a given by

$$\gamma_a = \frac{E_{thick} t_{thick}{}^2 (\gamma_{thick}\, tt_{hick} + \gamma_{thin}\, tt_{hin})}{E_{thick}\, tt_{hick}{}^3 + \gamma_{thin}\, tt_{hin}{}^3}$$

This equation can be generalized for n beams, in which thickness decrease progressively upward.

In case where a thin beam underlies a thicker beam, a separation tends to form. If rock bolt are used, the bolts will be to stretch to permit thr separation, and the load transference, which occurs naturally in the thin-over-thick case, will be achieved through the action of the rock bolts.

In this case, the bolts must be designed to supply a force per unit area equal to Δq. The load per unit of surface area of each beam is $\gamma_1 t_1 + \Delta q$ and $\gamma_2 t_2 - \Delta q$ for the stiffer and less stiff beam, respectively.

Substituting these loads in place of γt in max deflection equation, and equating deflections of each beam (for $\sigma_h = 0$), we get

$$\frac{(\gamma_1 t_1 + \Delta q)L^4}{32E_1{t_1}^3} = \frac{(\gamma_2 t_2 + \Delta q)L^4}{32E_2{t_2}^3}$$

Solving for Δq,

$$\Delta q = \frac{(\gamma_2 t_2 E_1{t_1}^3 - \gamma_1 t_1 E_2{t_2}^3)}{E_1{t_1}^3 + E_2{t_2}^3}$$