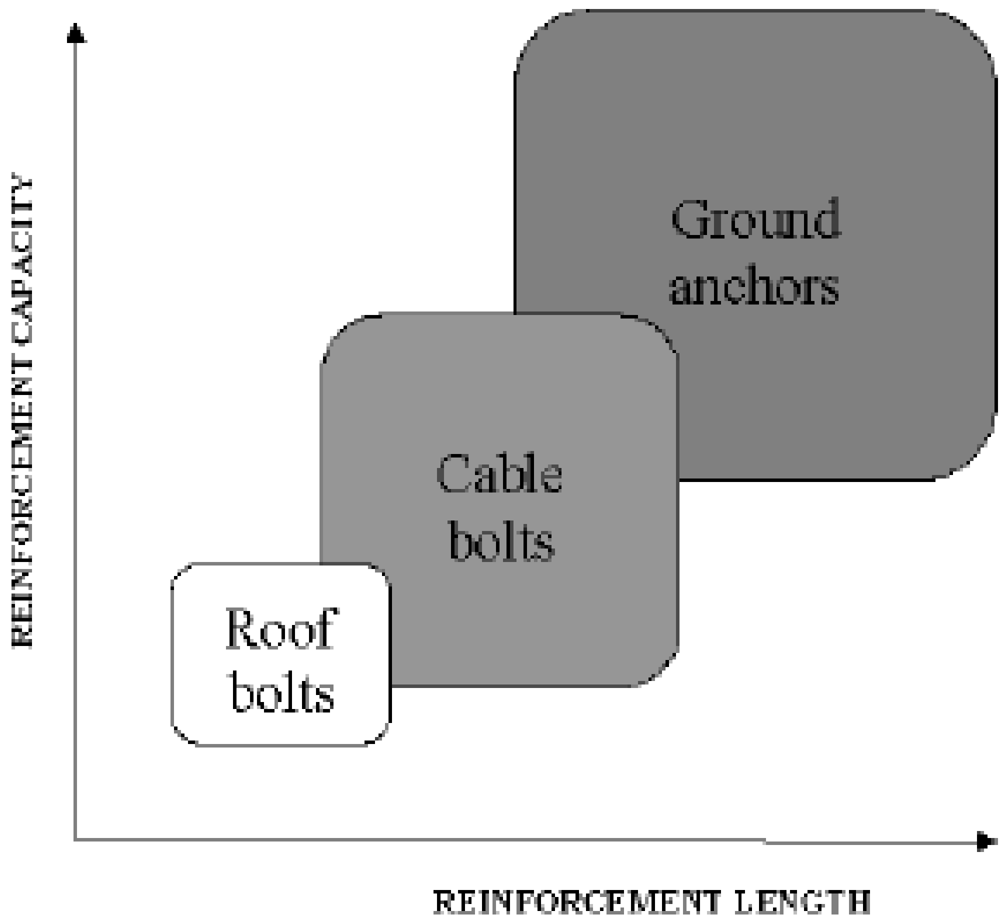
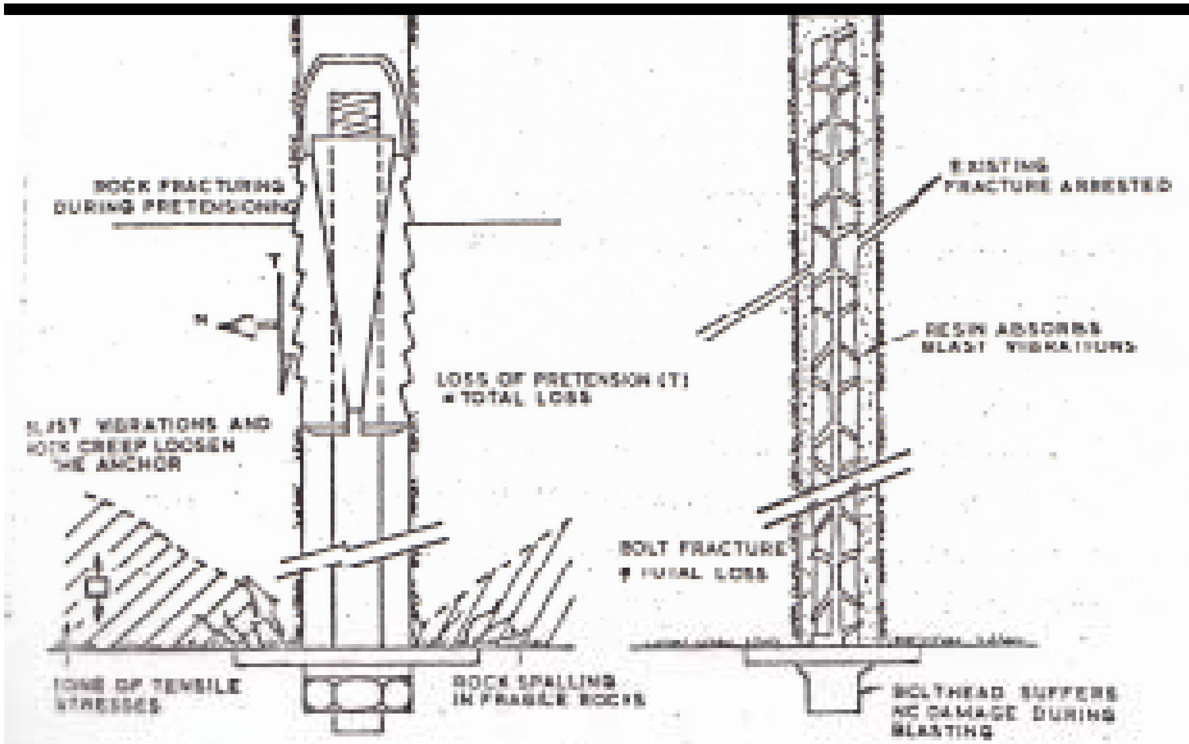
Rock Bolts



The length-capacity relationships that have evolved for roof bolts, cable bolts, and ground anchors (after Windsor and Thompson, 1997)



a. POINT-ANCHORED BOLT

b. FULL-COLUMN GROUTED BOLT

FIG-1 – COMPARISON OF POINT-ANCHORED AND GROUTED BOLTS

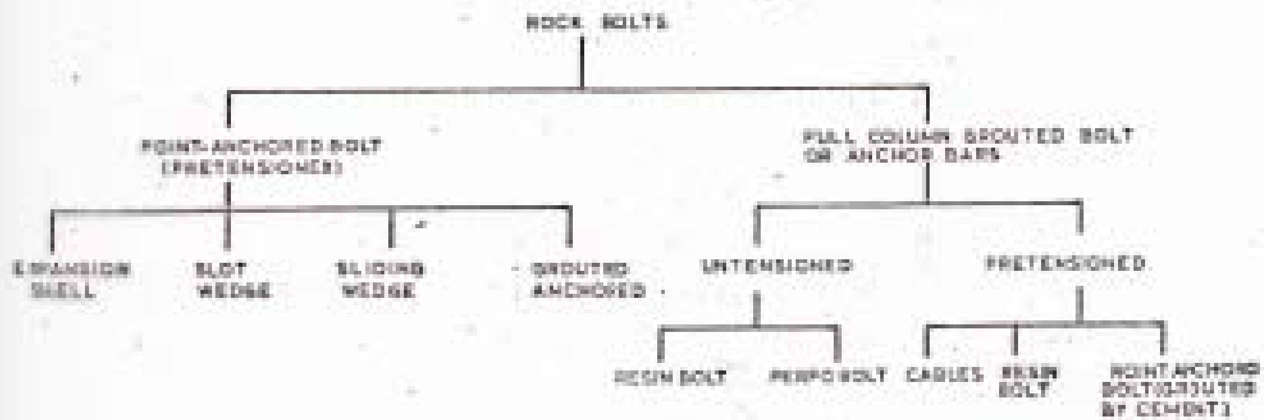


FIG. 2 – TYPES OF BOLTS

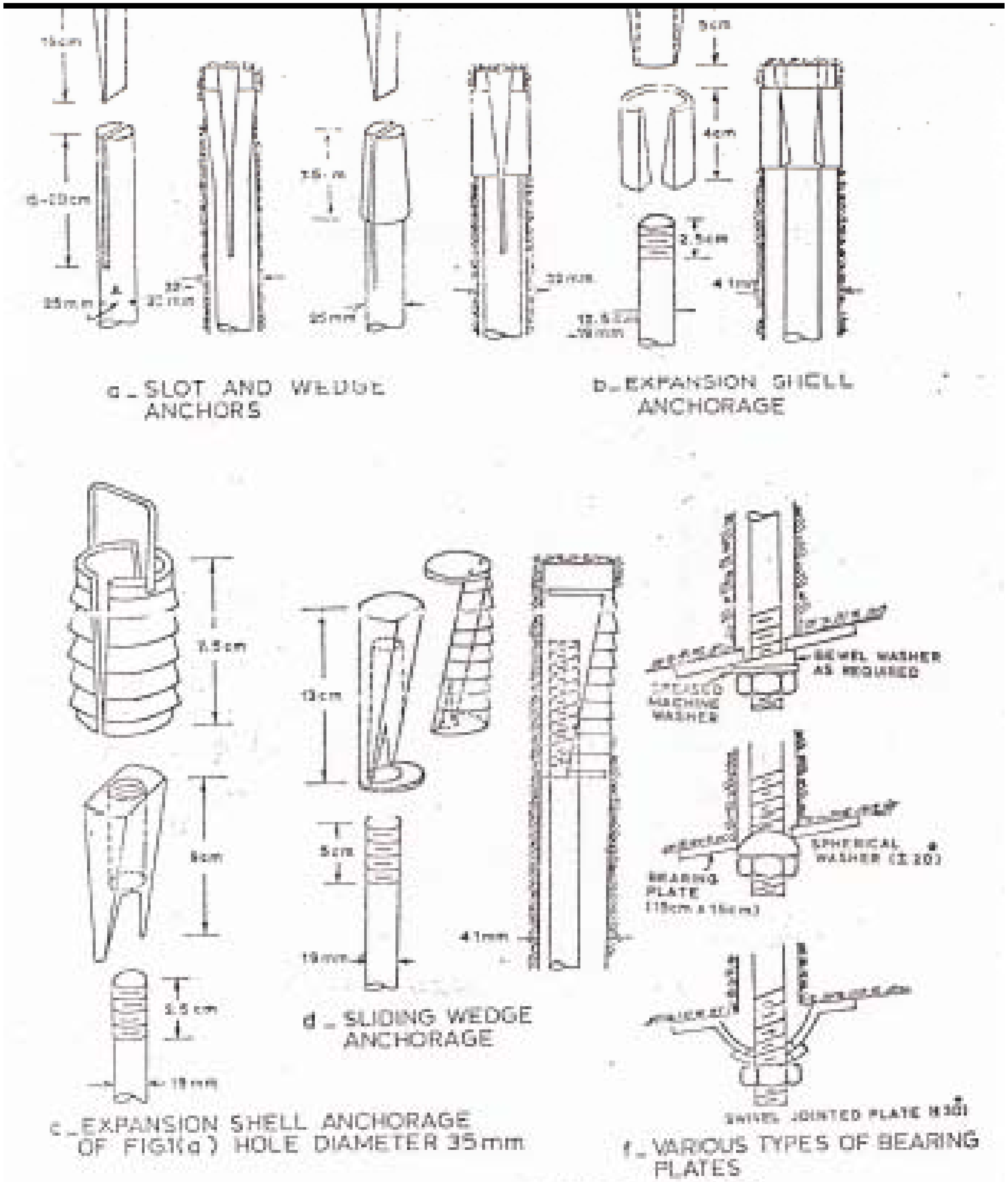


FIG.3 _COMPONENTS OF POINT-ANCHORED BOLTS

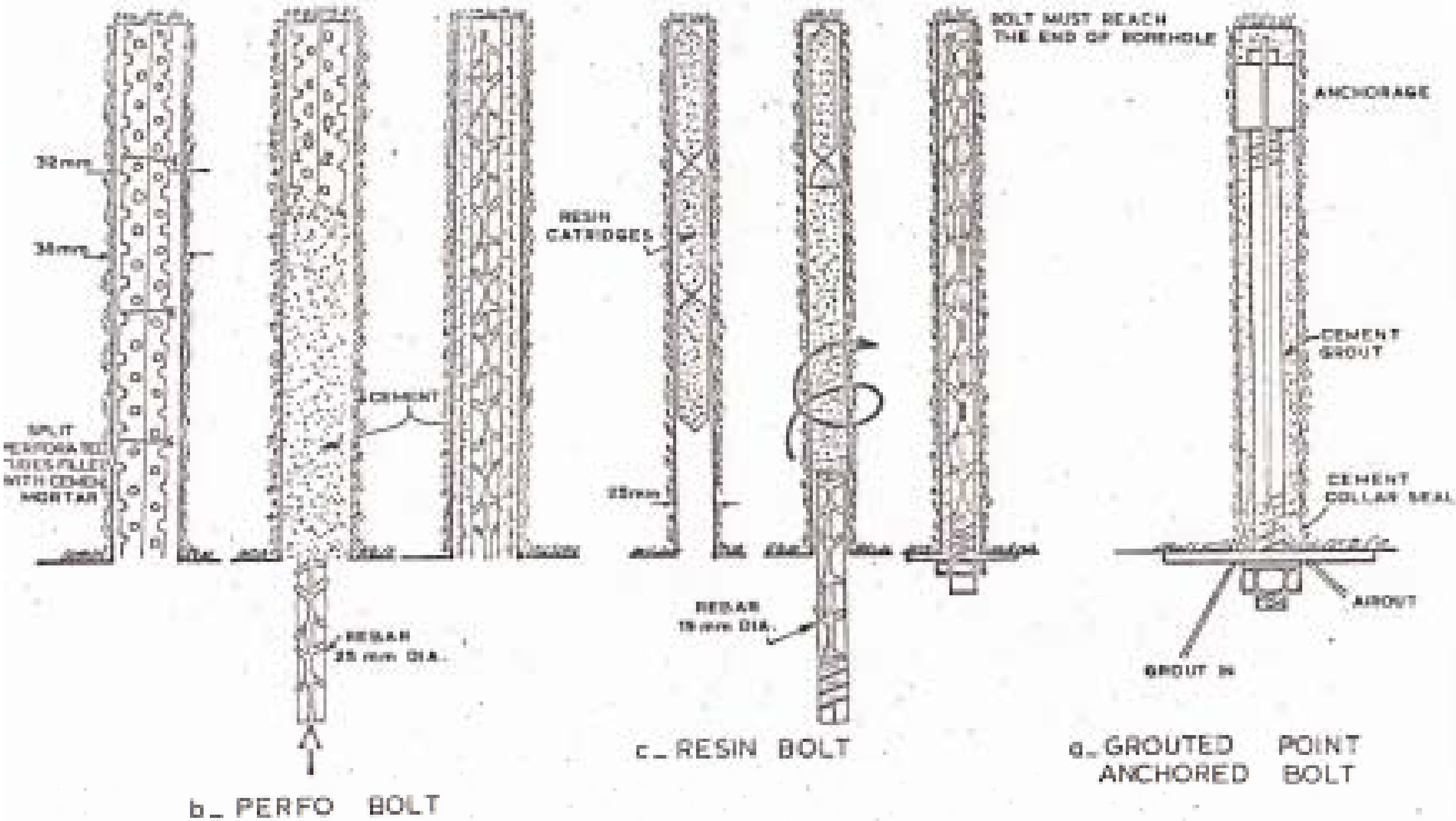


FIG. 4 _ PROCESS OF INSTALLATION OF GROUTED BOLTS

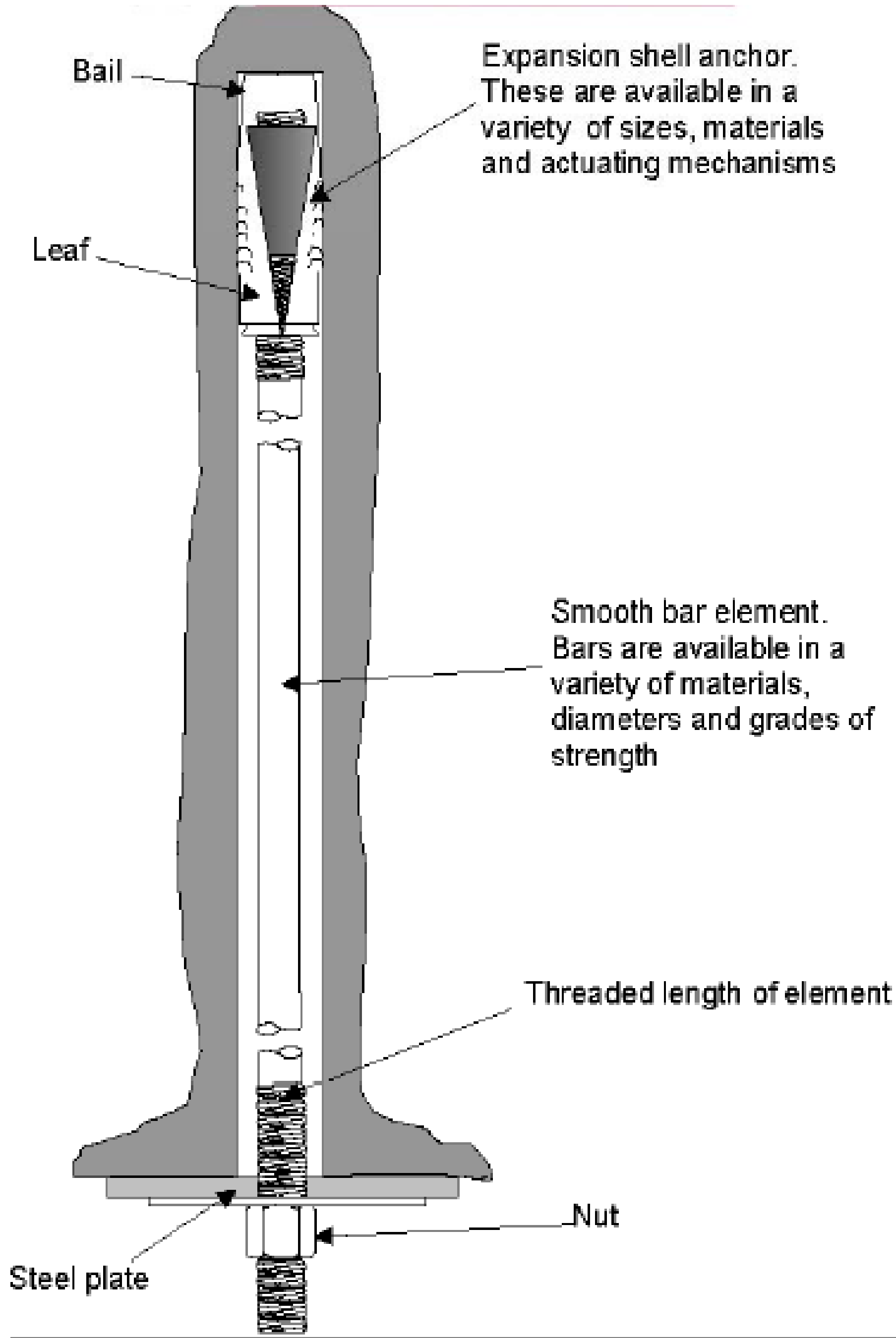
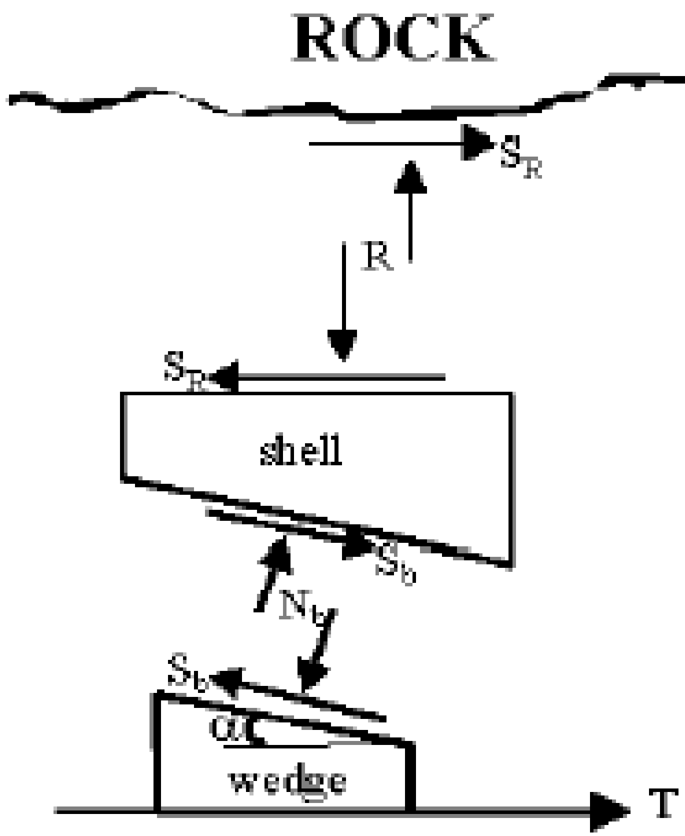


Figure 2-2 Mechanical anchor bolt



Forces acting on the components of an expansion shell anchor (after Windsor and Thompson, 1997)

The radial (R) and longitudinal shear force (S_R) at the interface between the shell and the rock can be converted to approximate equivalent normal (σ_r) and longitudinal (τ_r) stresses with the use of the following equations:

$$\sigma_r = \frac{T}{\pi DL \tan(\alpha + \phi_b)} \quad [2\text{-}1]$$

$$\tau_r = \frac{T}{\pi DL} \quad [2\text{-}2]$$

where D is the nominal diameter of the anchor or borehole

L is the length of the shell in contact with the rock

T is tension on the bolt

ϕ_b is the contact friction angle (degree)

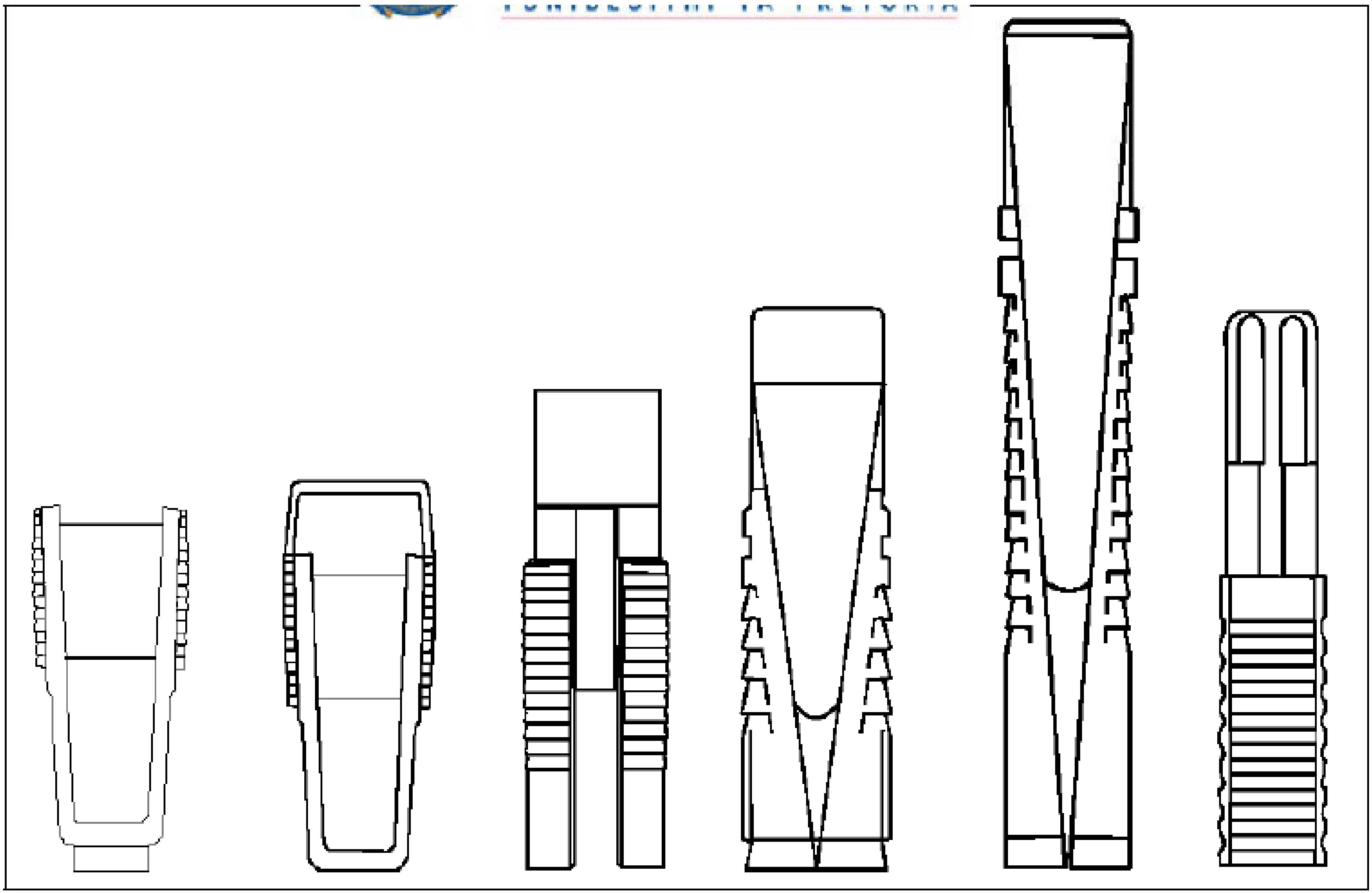


Figure 2-4 Various expansion shell mechanisms (after Windsor and Thompson, 1997)

Resin Point anchored bolt

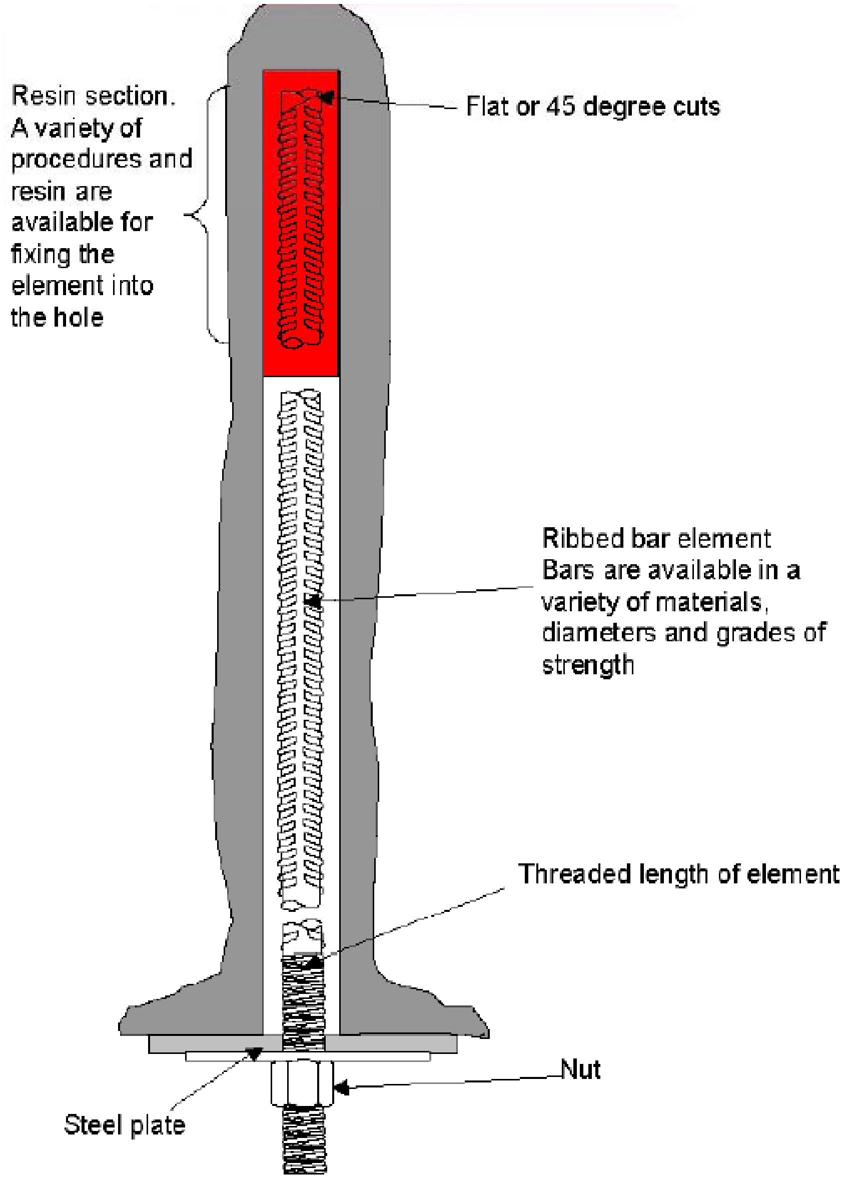


Figure 2-5 Point resin anchor

Advantages:

- The anchor resistance can be increased by making the anchorage length longer; and
- The changeover to full-column resin support, should it be required by changing conditions, is less traumatic because operators will already be trained in resin installation.

Disadvantage:

- Point resin anchors cannot be used in friable or burnt coal ribsides, because of difficulties in proper mixing of the resin.

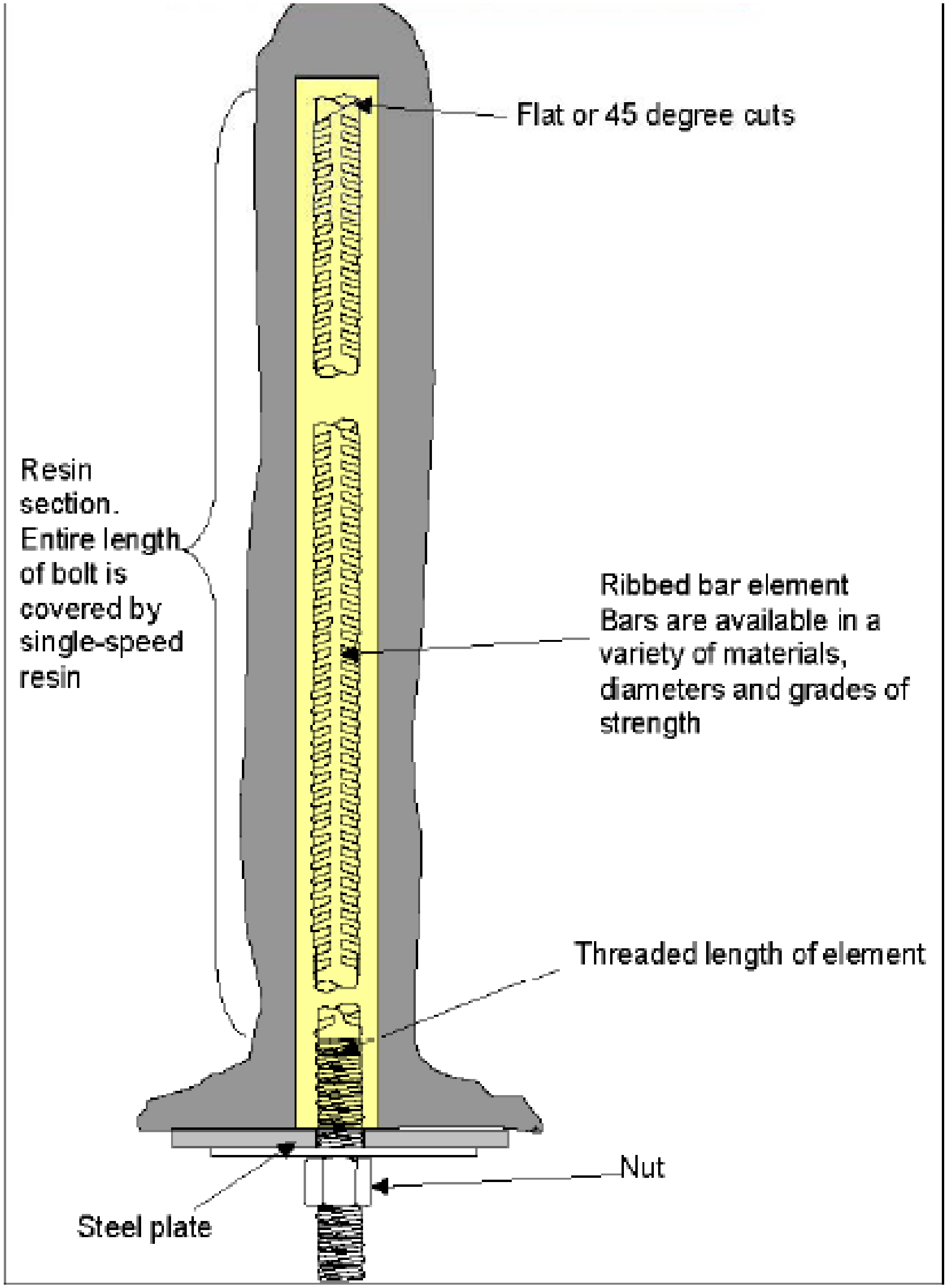


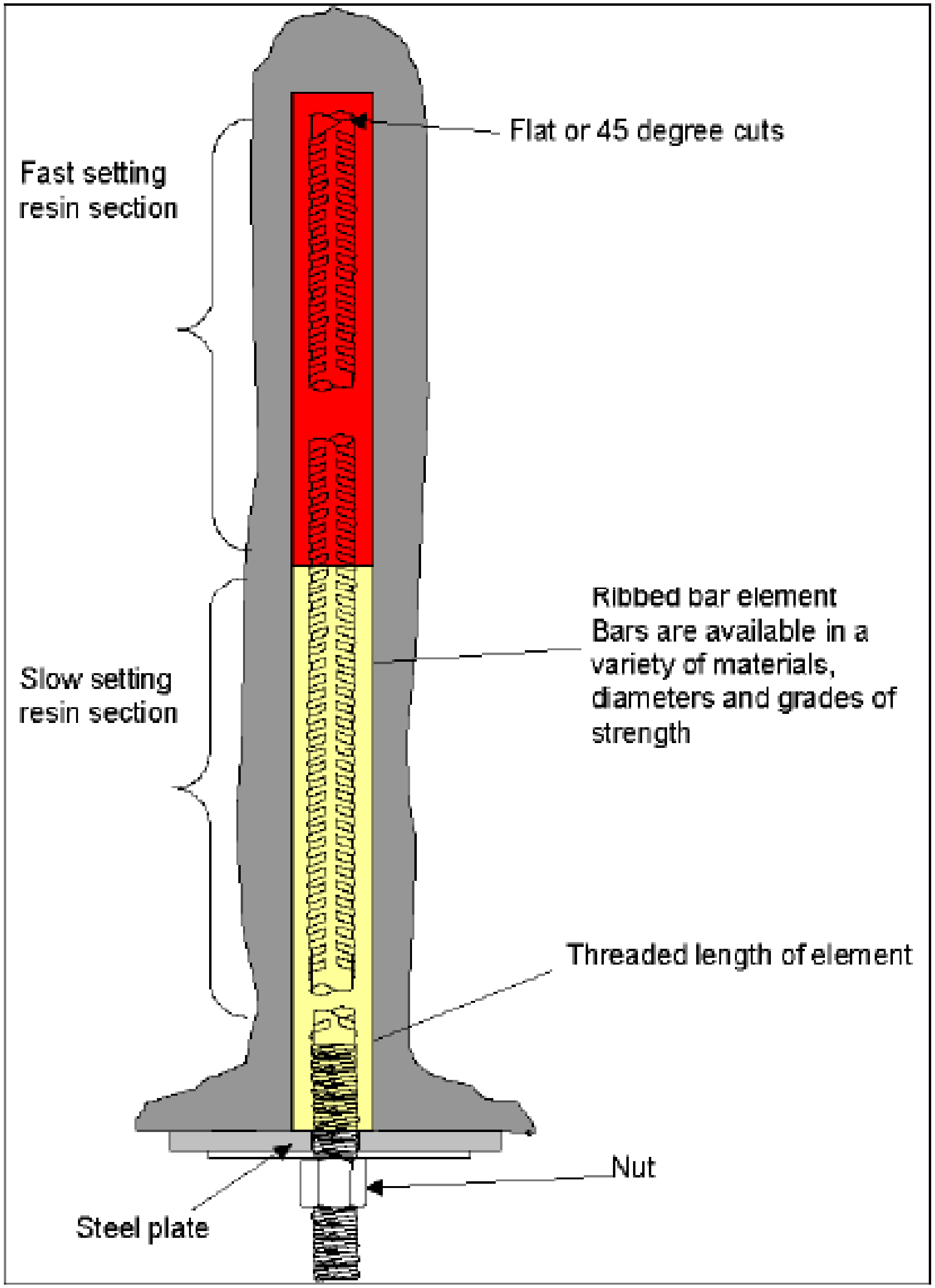
Figure 2-6 Full column resin bolt

Advantages:

- Full-column resin support can be used virtually anywhere;
- It is ideal for any long-term requirement like main developments, underground workshops, etc.;
- Full-column resin support is essential in beam-building mechanisms; and
- It is ideal for the support of laminated roofs.

Disadvantages:

- The support is relatively expensive;
- It requires care to install as operators have to be well trained; and
- Full-column resin anchors cannot be used in friable or burnt coal ribsides, because of difficulties in proper mixing of the resin.



Full-column slow/fast-resin combination bolts (the dual resin system)

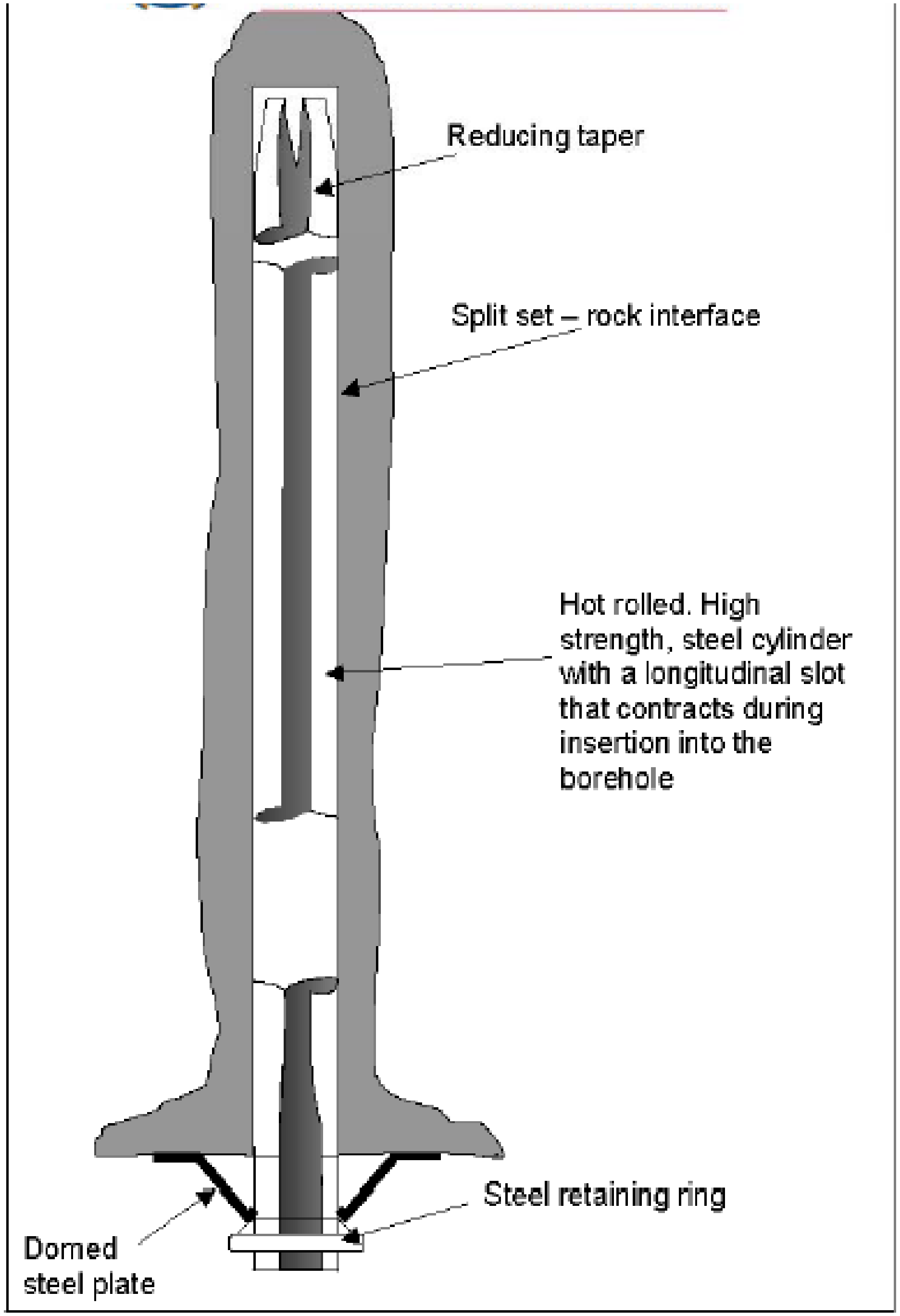


Figure 2-8 Split Set

Yassien (2003) made recommendations on the selection of bolt type. Mechanical bolts are recommended for:

- Hard and strong rock as they can resist bit biting and keep the anchorage force;
- Temporary reinforcement systems;
- Conditions where bolt tension can be checked regularly;
- Rock that will not undergo high shear force; and
- Areas away from blast sites where bolt tension may be lost.

Fully grouted bolts are recommended by Yassien (2003) for:

- Areas and conditions where mechanical bolts are not recommended;
- Rock without wide fractures or voids that will cause grout loss; and
- Long-term support of thinly bedded roof strata.

Table 2-1 Support system characteristics summary (after van der Merwe and Madden, 2002)

System	Active/ Passive	Stiff/ Soft	Corrosion resistance	Ease of installation	Pull-out resistance	Where to use
Mechanical Anchors	Active	Soft	Medium	Good	Medium	Short term, unlaminated roof, medium, light load
Resin point anchor	Active	Soft	Medium	Medium, requires training	Very good	Short term, unlaminated roof, medium, heavy load
Full-column resin (single-resin type)	Passive	Stiff	Good	Medium, requires training	Very good	Long term, laminated roof, heavy load, thick weak roof, close to face
Full-column resin-(slow/fast combination)	Active	Stiff	Good	Medium, requires training	Very good	Long term, laminated roof heavy load, beam building, thick weak roof
Friction rock stabilisers (Split Set in SA collieries)	Passive	Stiffish	Poor	Good	Poor	Burnt coal ribsides, wire mesh fill-in, thin laminated layers, short term, light load
Wooden dowels	Passive	Stiff but weak	Excellent	Easy	Poor	Longwall faces, ribsides in stooping
Fibreglass dowels	Passive	Stiff	Excellent	Easy	Good	Burnt coal, joint areas, friable roof, long term, densely populated areas

2.4 Roof bolting design

As in the design of other support systems, the design of a roof bolting system depends on: the nature of the discontinuities and the intact rock; the magnitude and distribution of the stresses induced; support requirements such as acceptable deformation and lifetime of the opening; and the size and shape of the openings. For a complete and appropriate roof bolting system design, the following parameters must be properly determined (Luo et al., 1998):

- Bolt type;
- Bolt length;
- Pattern and spacing of bolts;
- Bolt diameter and anchor capacity;
- Whether pre-tension should be applied or not. If pre-tensioned, the magnitude of the tension should be determined.

In order to achieve the best support system design, the mechanical behaviour of rock masses reinforced by full grouted bolts, i.e. the rock-bolt interaction, needs to be fully understood. The design methodologies for roof bolts can be classified into the following four categories:

- Analytical methods;
- Field testing;
- Numerical modelling;
- Geotechnical classification; and
- Physical modelling.

2.3 Theories of roof bolting support

The main function of roof bolting is to bind stratified or broken rock layers together to prevent roof falls. In order to achieve this objective four basic theories have been established for roof bolting (Wagner, 1985; Buddery, 1989; Peng, 1986; Van der Merwe and Madden, 2002; Mark, 2000).

The four theories are:

- Simple skin support;
- Suspension of a thin roof layer from a massive bed;
- Beam building of laminated strata; and
- Keying of highly fractured and blocky rock mass.

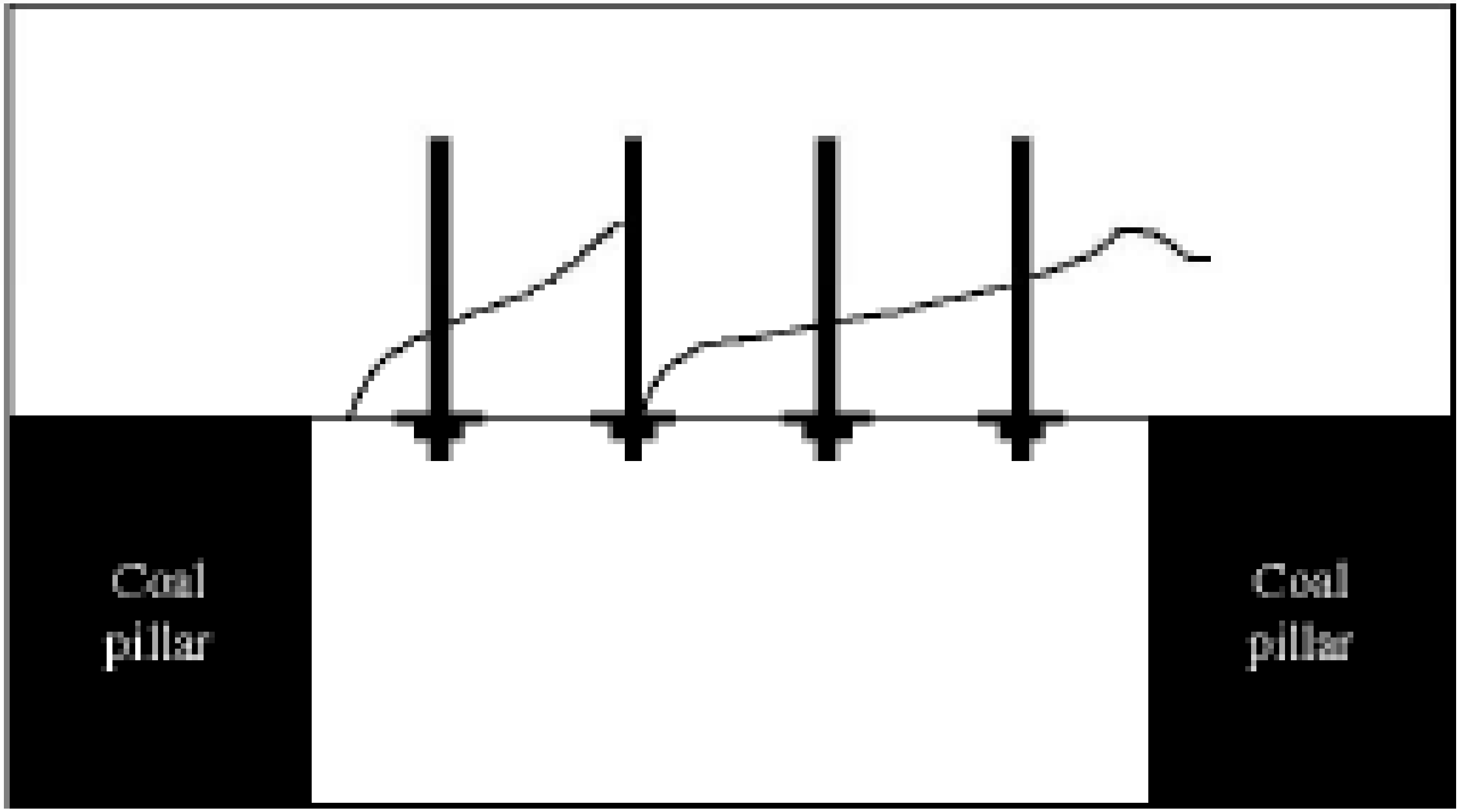


Figure 2-11 Simple skin support

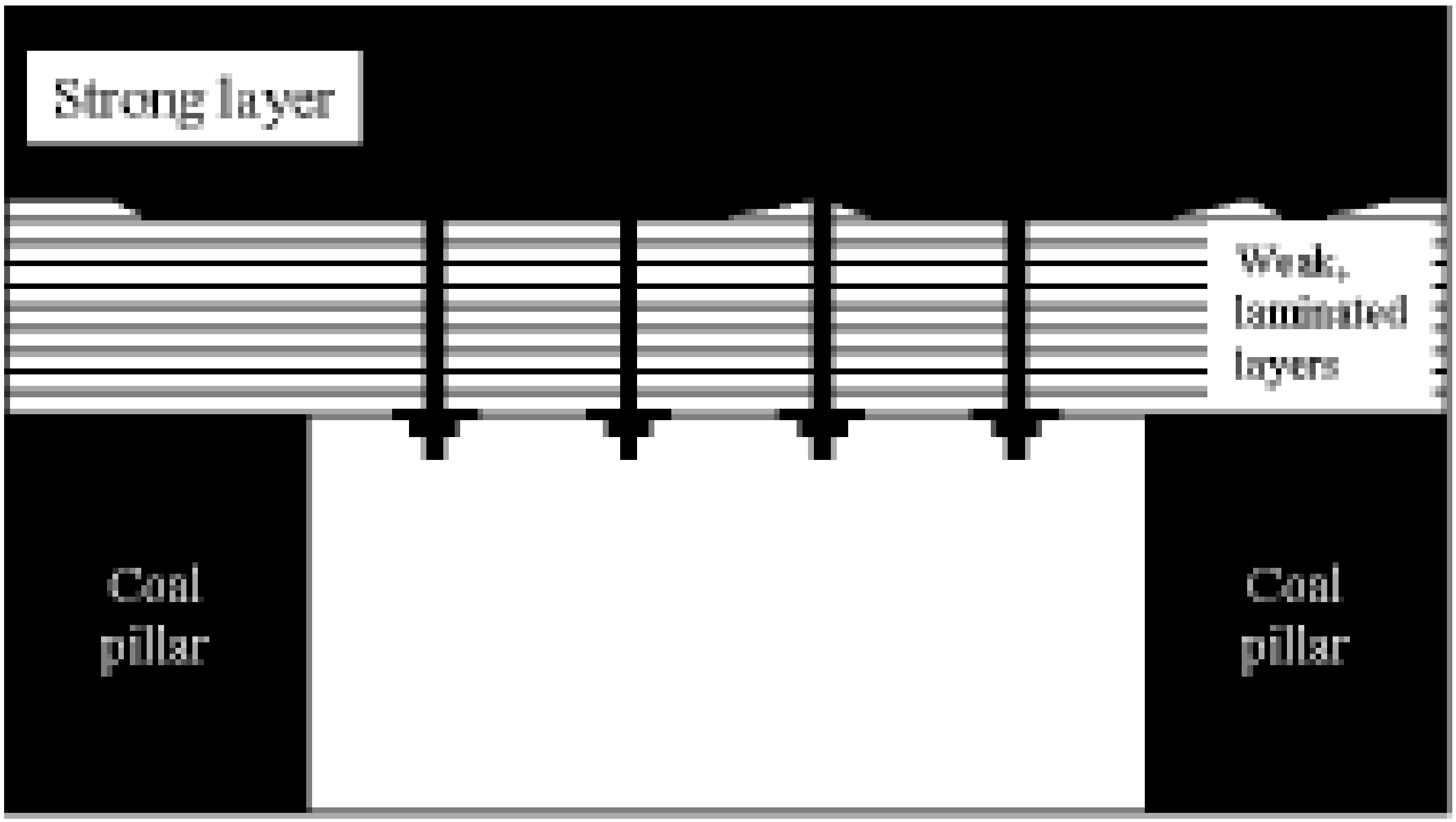


Figure 2-12 Suspension mechanism

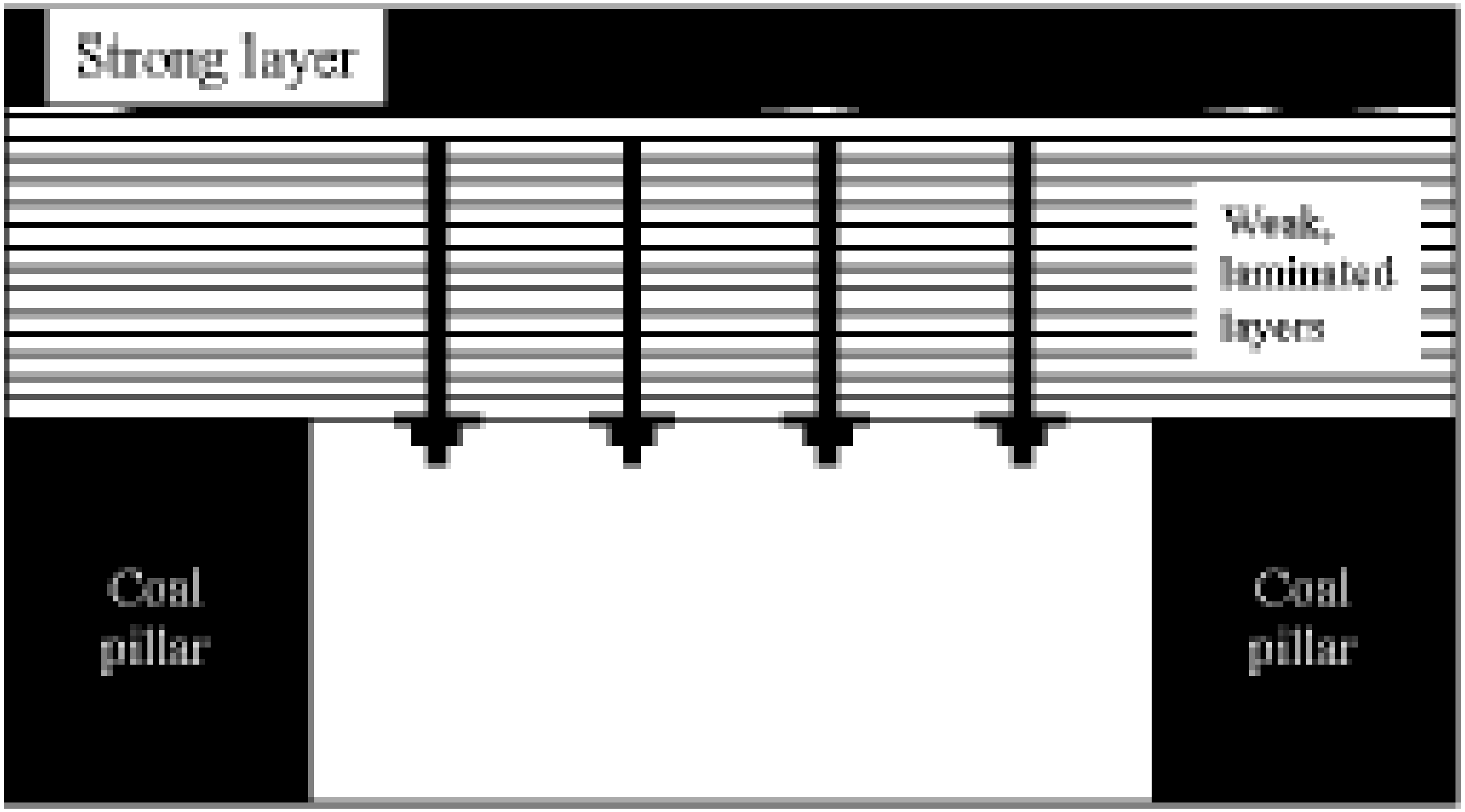


Figure 2-13 Beam-building mechanism

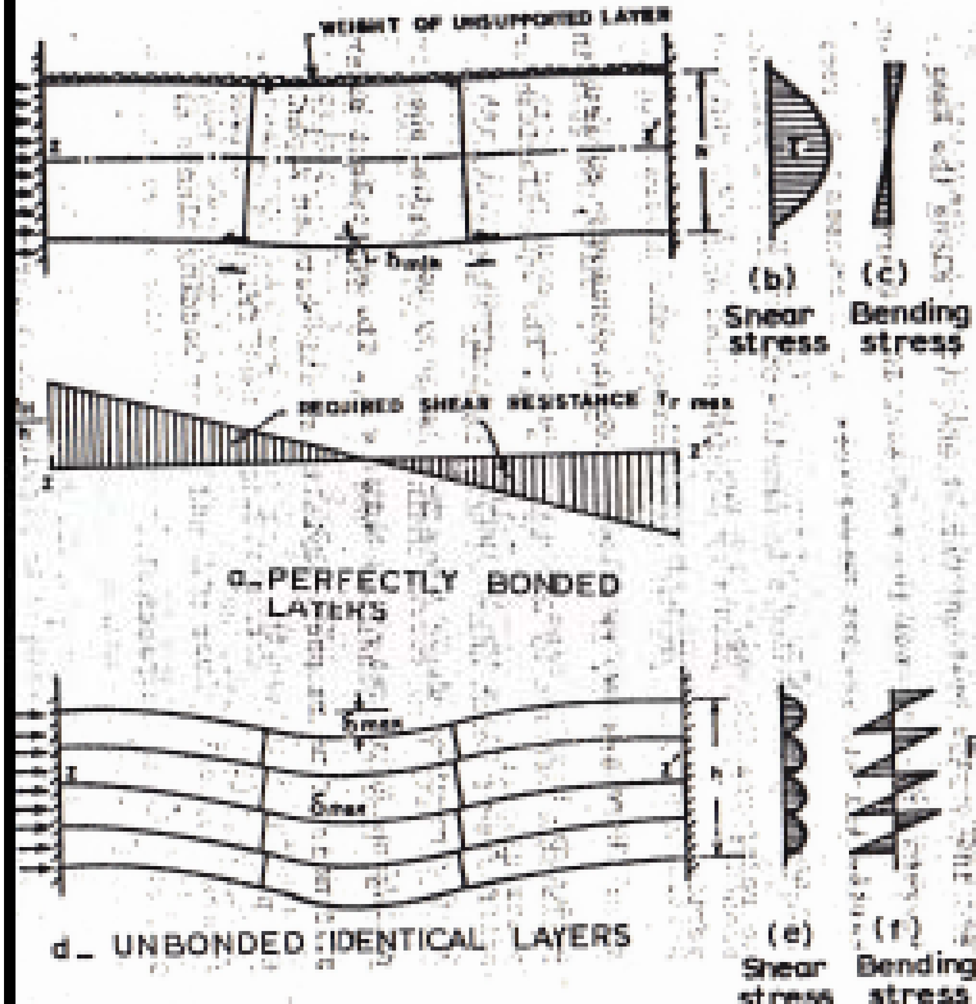


FIG. 7 _FLEXURE OF GRAVITY LOADED STRATA WITH BUILTIN ENDS (AFTER PANEK 1953)

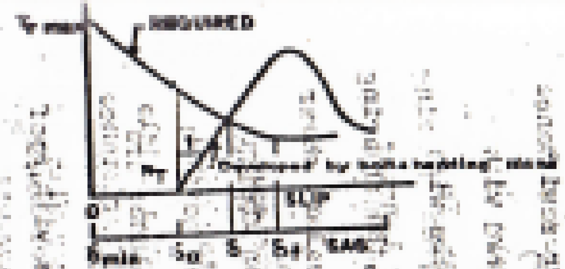


Fig.g _ Actual shear force that is developed by bolt and the middle bedding plane (δ_a, δ and δ_f are sag before and after bolting and at failure respectively)

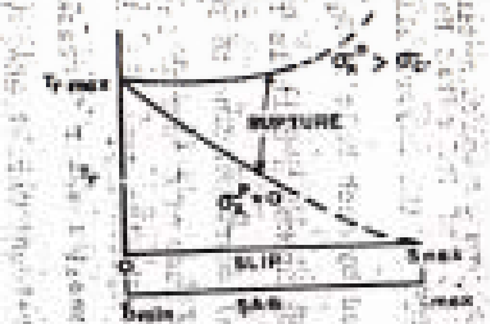


Fig.h _ Shear force (τ_r) that must be developed by sliding resistance of the middle bedding plane in order to maintain a given averege slip or sag δ (After Fairhurst and Singh 1973)

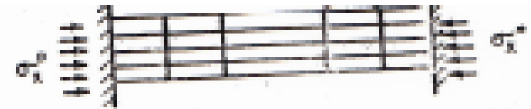


FIG-8a _MODEL OF BOLTED LAYERS

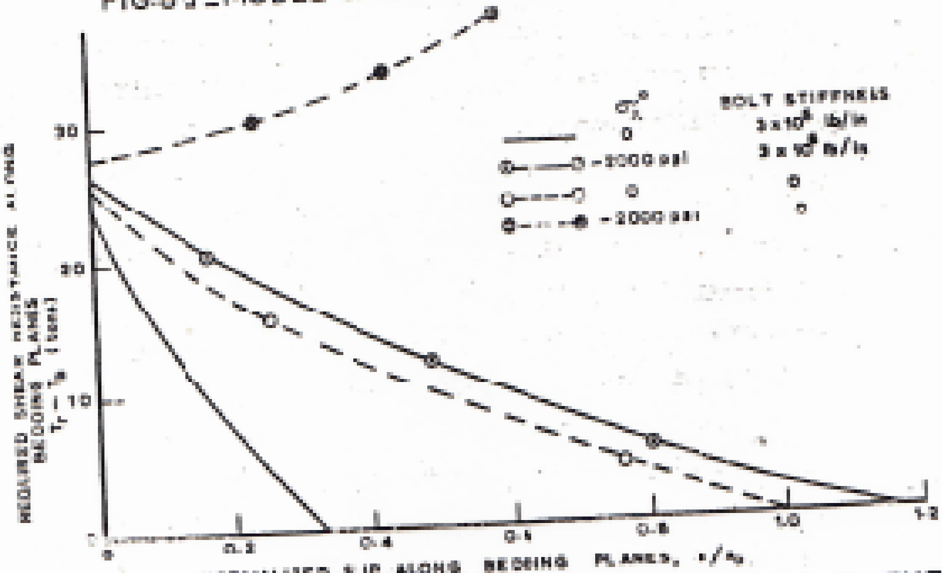


FIG-8b _ EFFECT OF INSITU - HORIZONTAL STRESS ON THE SHEARING RESISTANCE REQUIRED ALONG BEDDING PLANES FOR A GIVEN ROOF SAG.
(After Singh, Christiano and Fairhurst 1973)

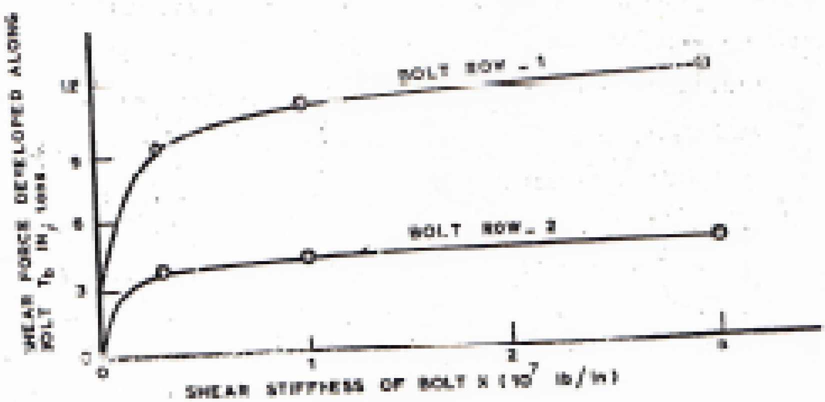


FIG. 9 _INFLUENCE OF SHEAR STIFFNESS OF BOLTS ON THE MAXIMUM SHEAR FORCE DEVELOPED IN GROUTED BOLTS (Fairhurst and Singh 1974)

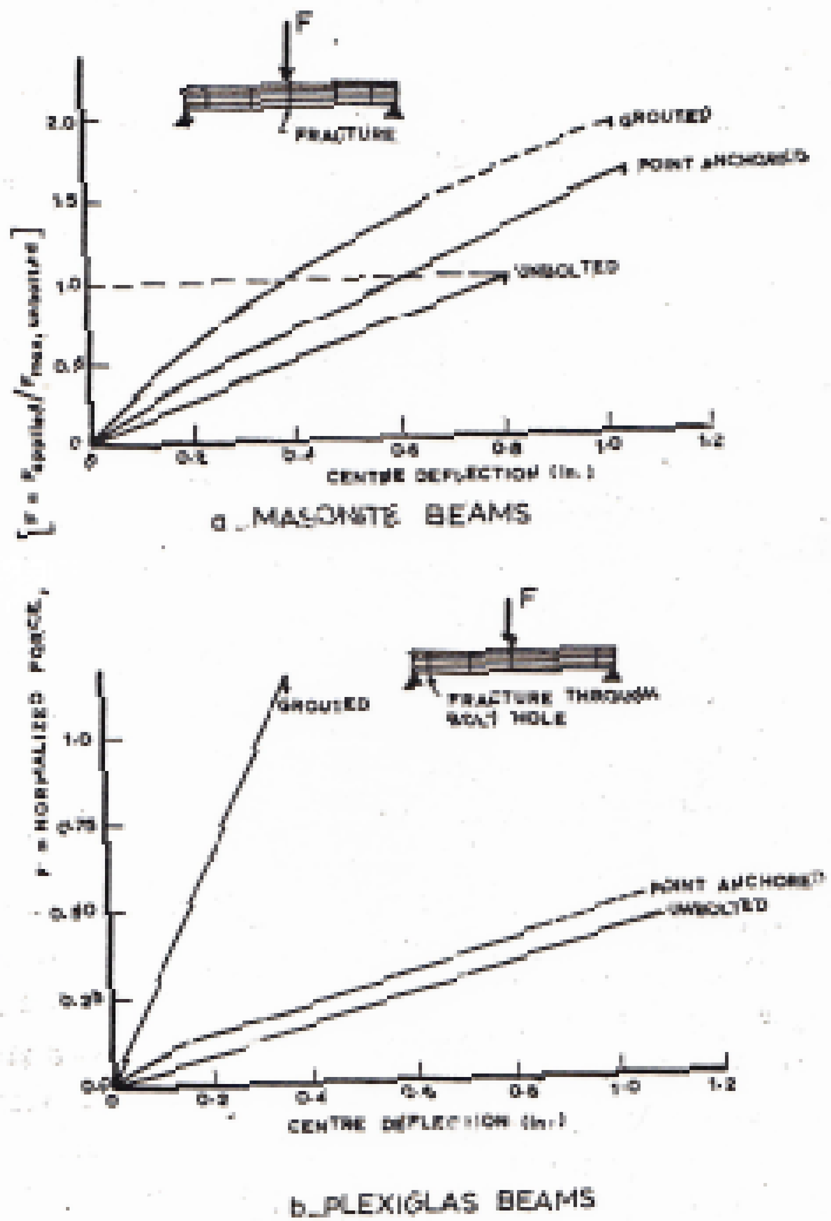
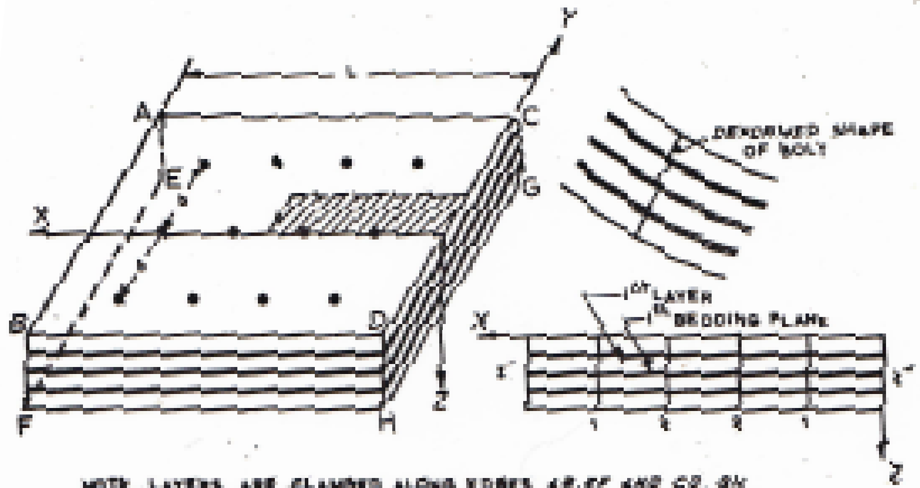


FIG. 10 – LOAD DEFLECTION RESULTS FROM MODEL ROCKBOLTING TESTS (After Fairhurst and Singh 1974)

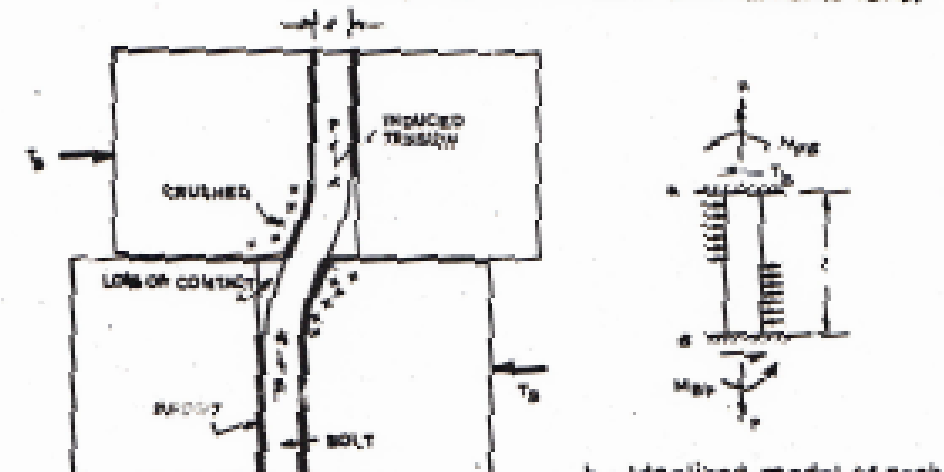


NOTE – LAYERS ARE CLAMPED ALONG EDGES AB, EF AND CD, GH RESPECTIVELY.

a – General view of bolted layers

b – Cross section through X axis

FIG. 11 – THEORETICAL MODEL OF LAYERS REINFORCED WITH GROUTED BOLTS (After Singh, Christiano and Fairhurst 1973)



a – Actual deformation of grouted bolts in thick layers

b – Idealized model of rock-bolt interaction

FIG. 12

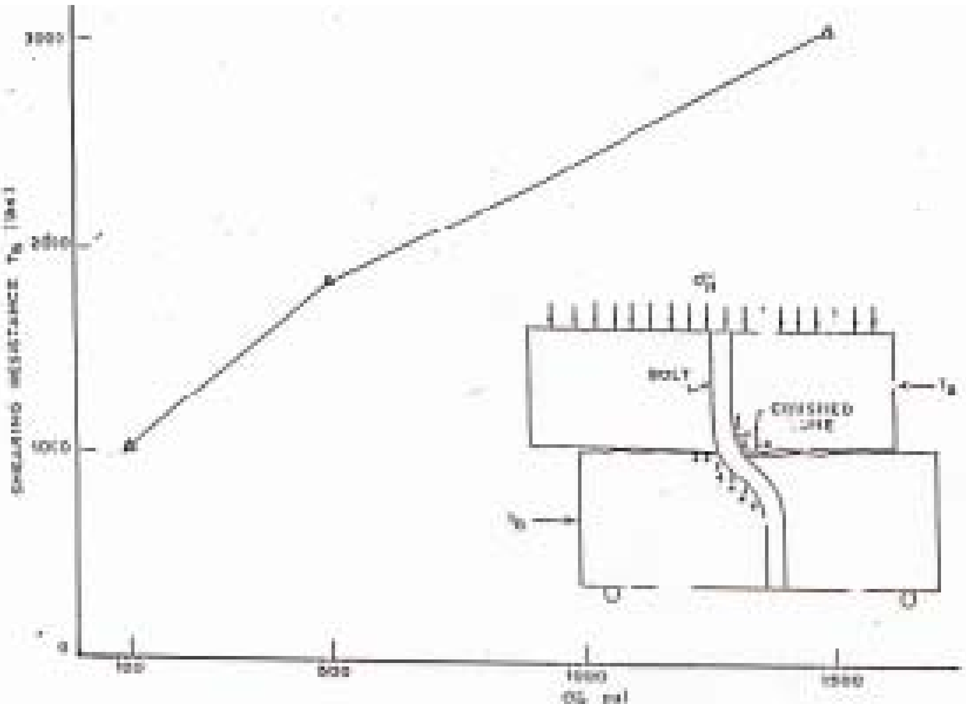


FIG. 13 _ INFLUENCE OF NO MAL STRESS ON SHEARING RESISTANCE OF GROUTED BOL'S

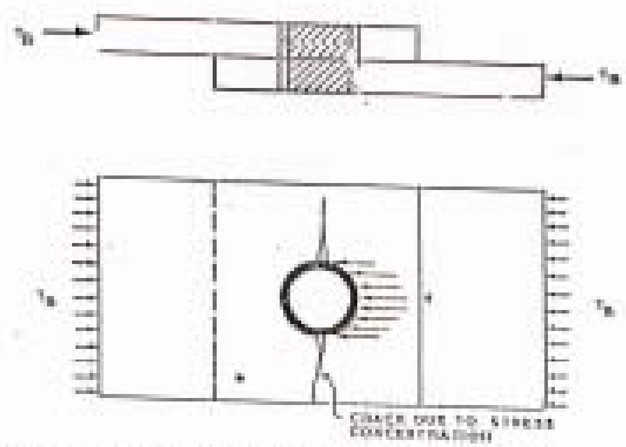
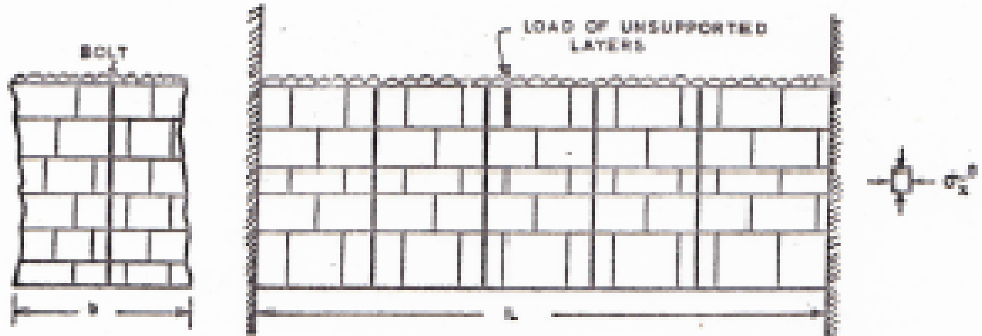
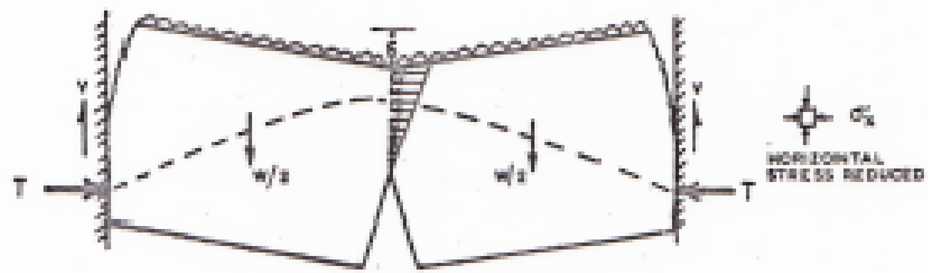


FIG. 14 _ MODE OF FAILURE OBSERVED IN THIN BRITTLE LAYERS BOLTED WITH GROUTED BOLTS

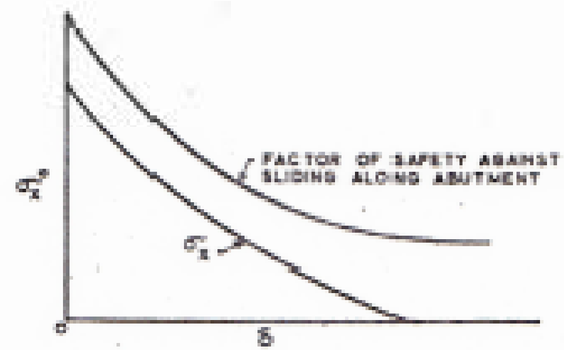


SIDE VIEW

a_ INITIAL STATE



b_ LINEAR ARCH



c_ RELAXATION OF HORIZONTAL STRESS DUE TO ROOF SAG AND ITS EFFECT ON THE STABILITY OF BOLTED ROOF

FIG. 15

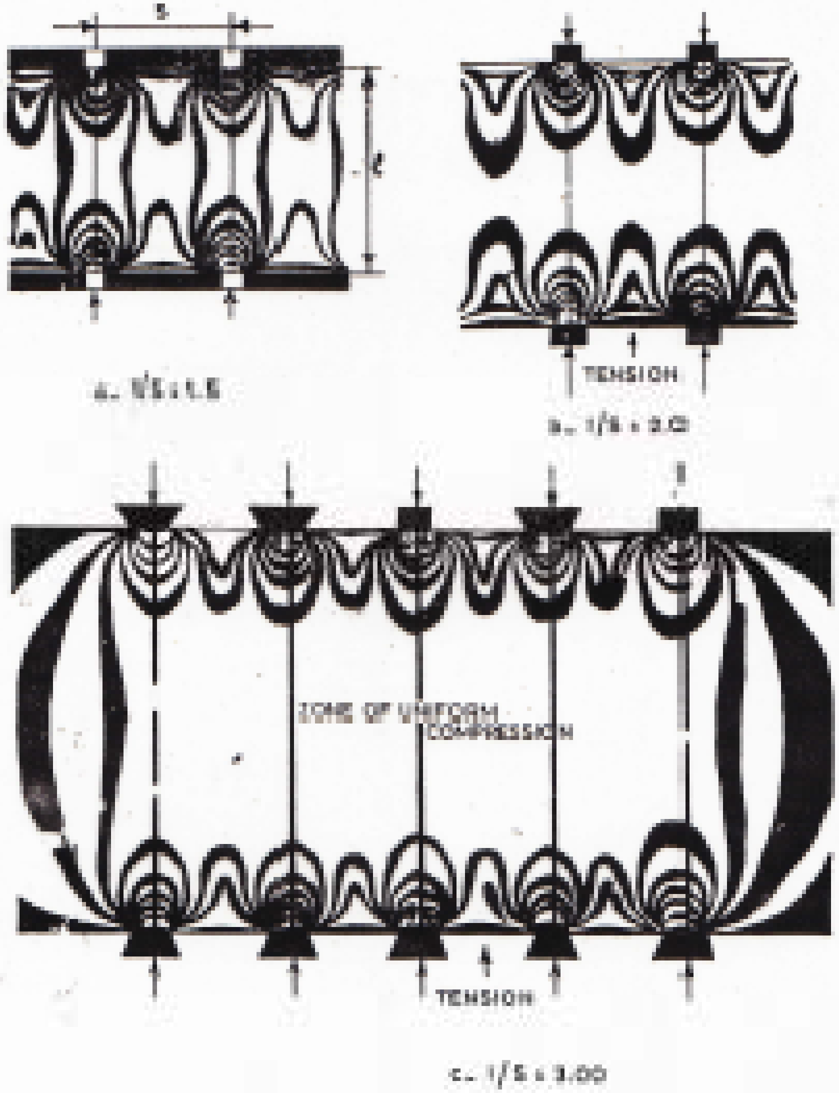


FIG.16 – ROCK BOLT–PHOTOELASTIC STRESS PATTERNS
(AFTER LANG 1961)

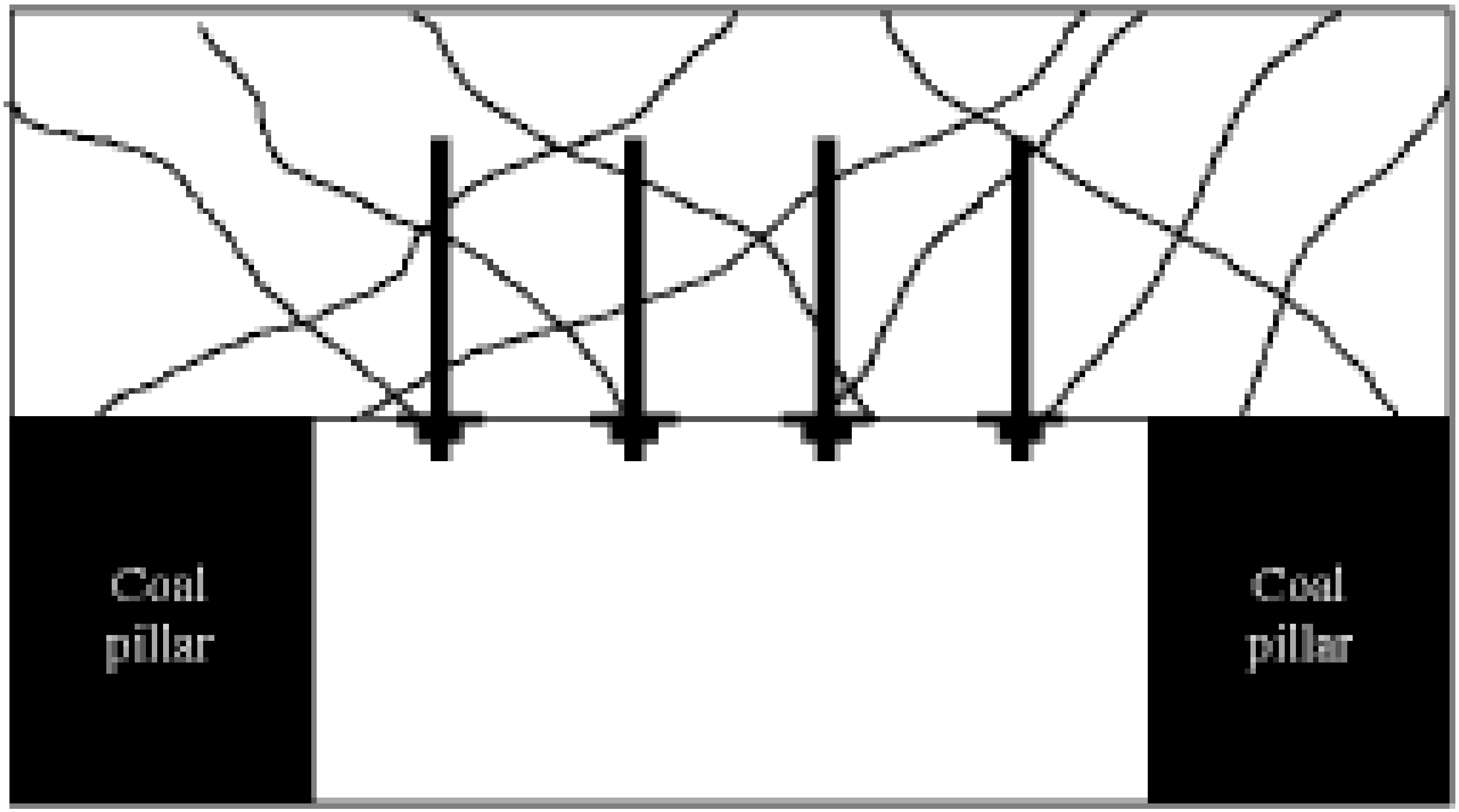


Figure 2-14 Keying effect of bolting

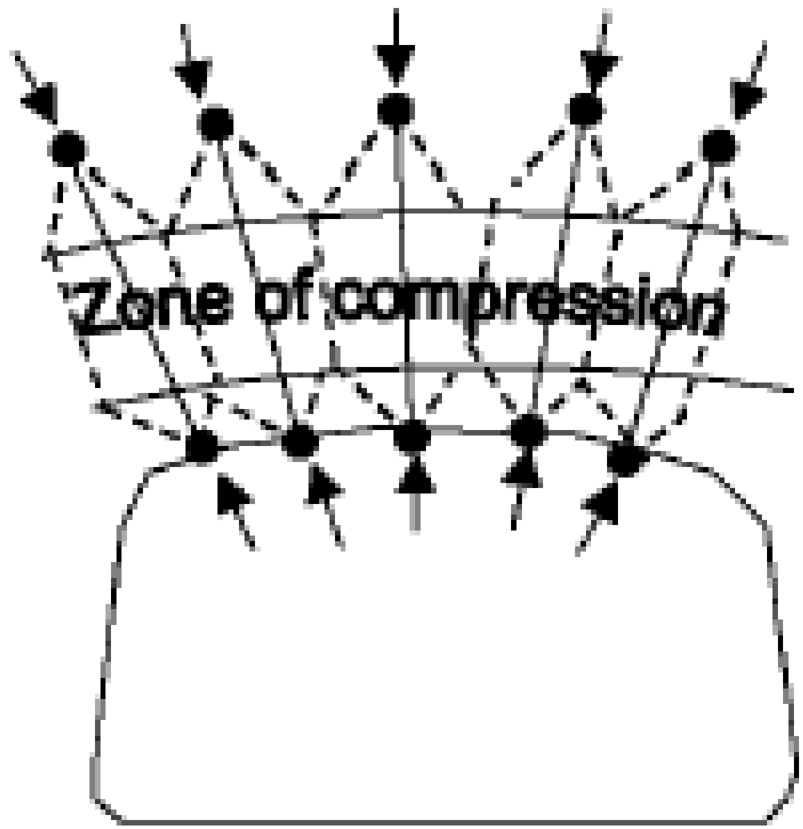


Figure 2-15 Compression zone created by keying (after Luo et al., 1998)

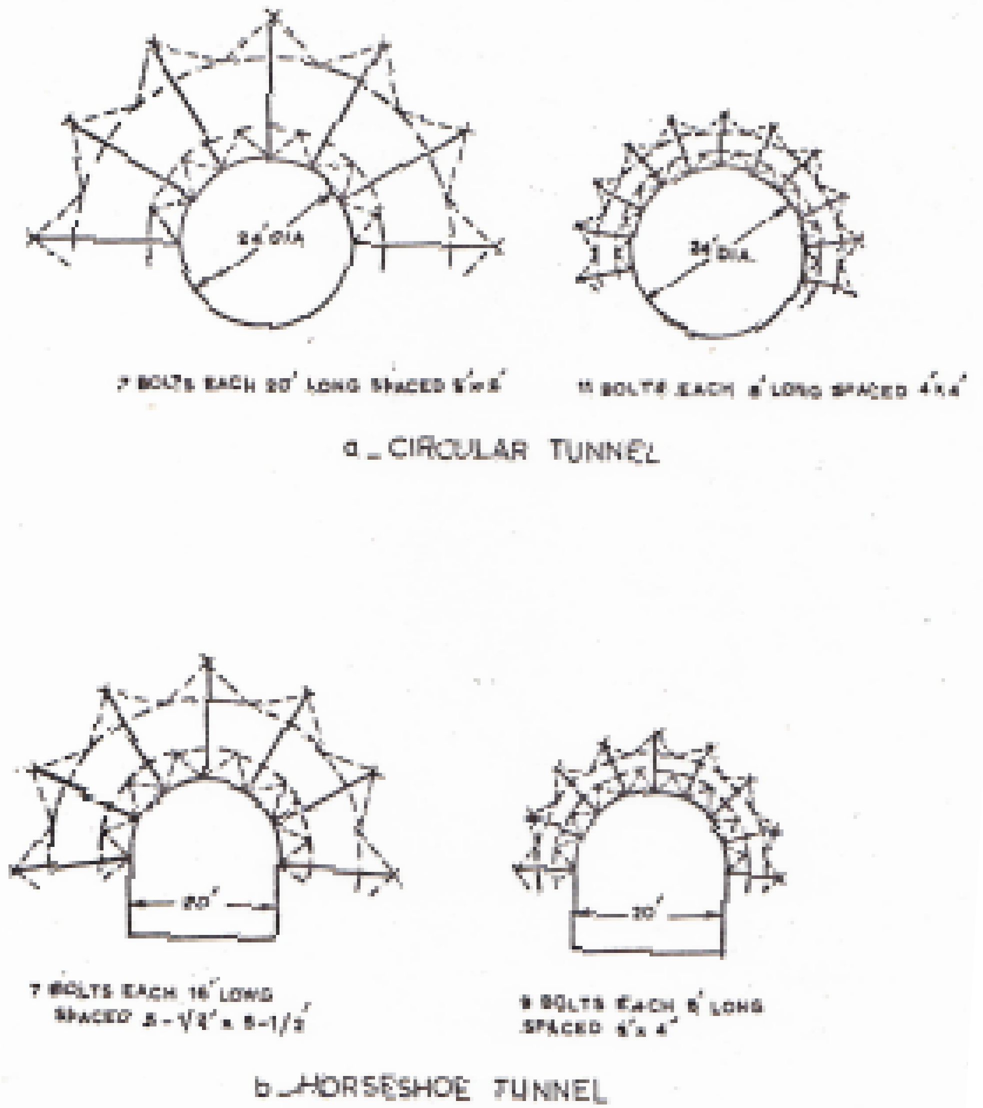
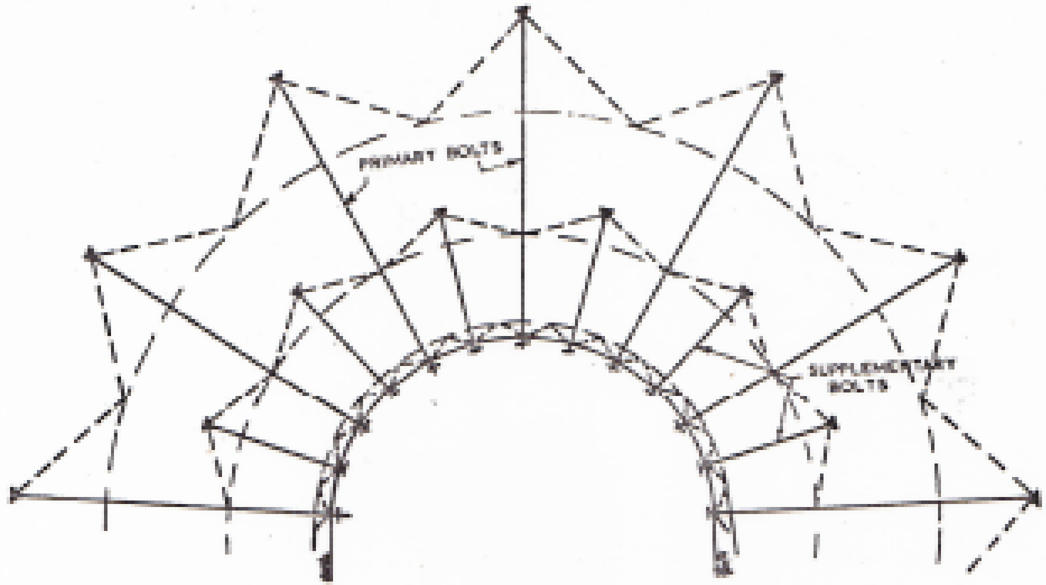
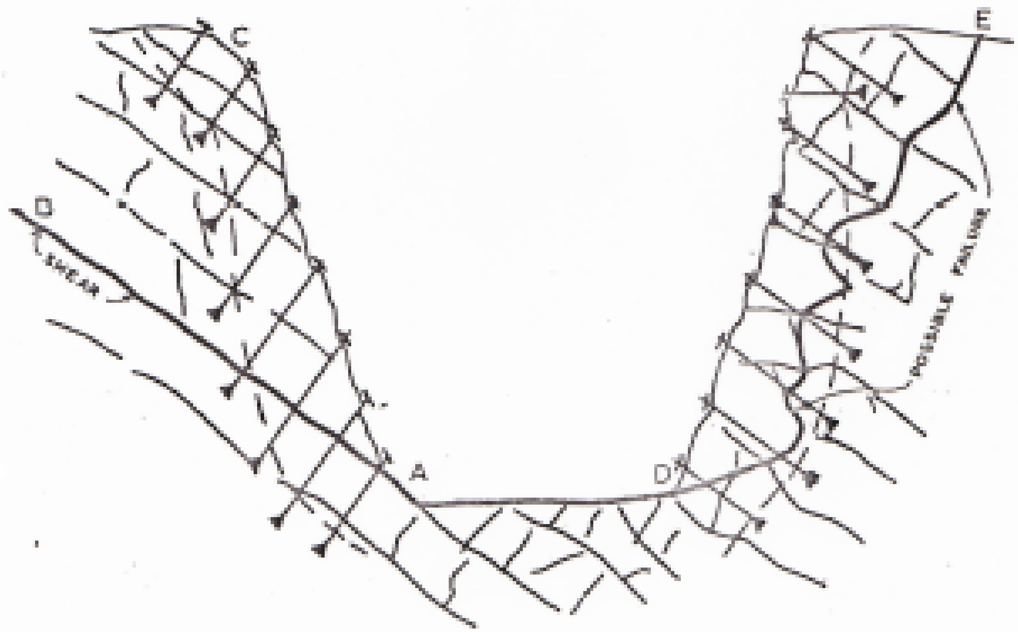


FIG. 7B _ ARCH CONCEPT OF ROCK REINFORCEMENT
(AFTER LANG 1961)



a_ SUPPLEMENTARY BOLTING



b _ROCK CUT- BOLTED

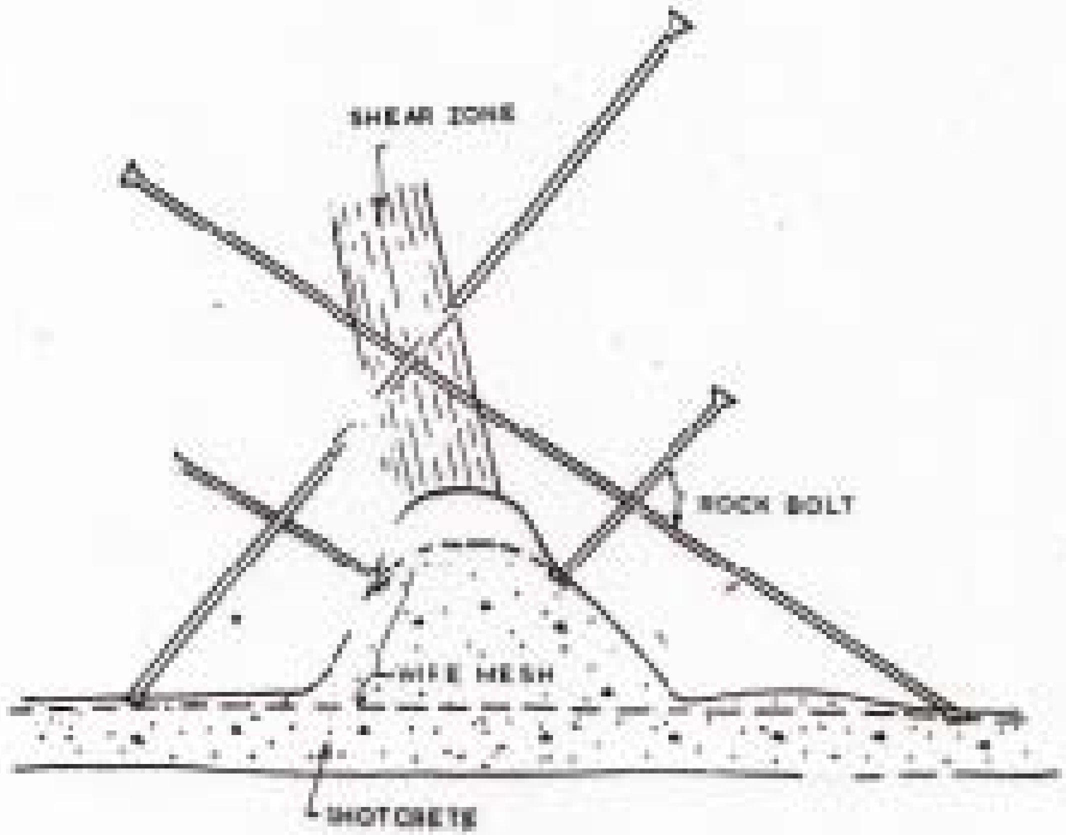


FIG. 5 – TYPICAL TREATMENT OF A NARROW SHEAR ZONE (After LANG 1964)

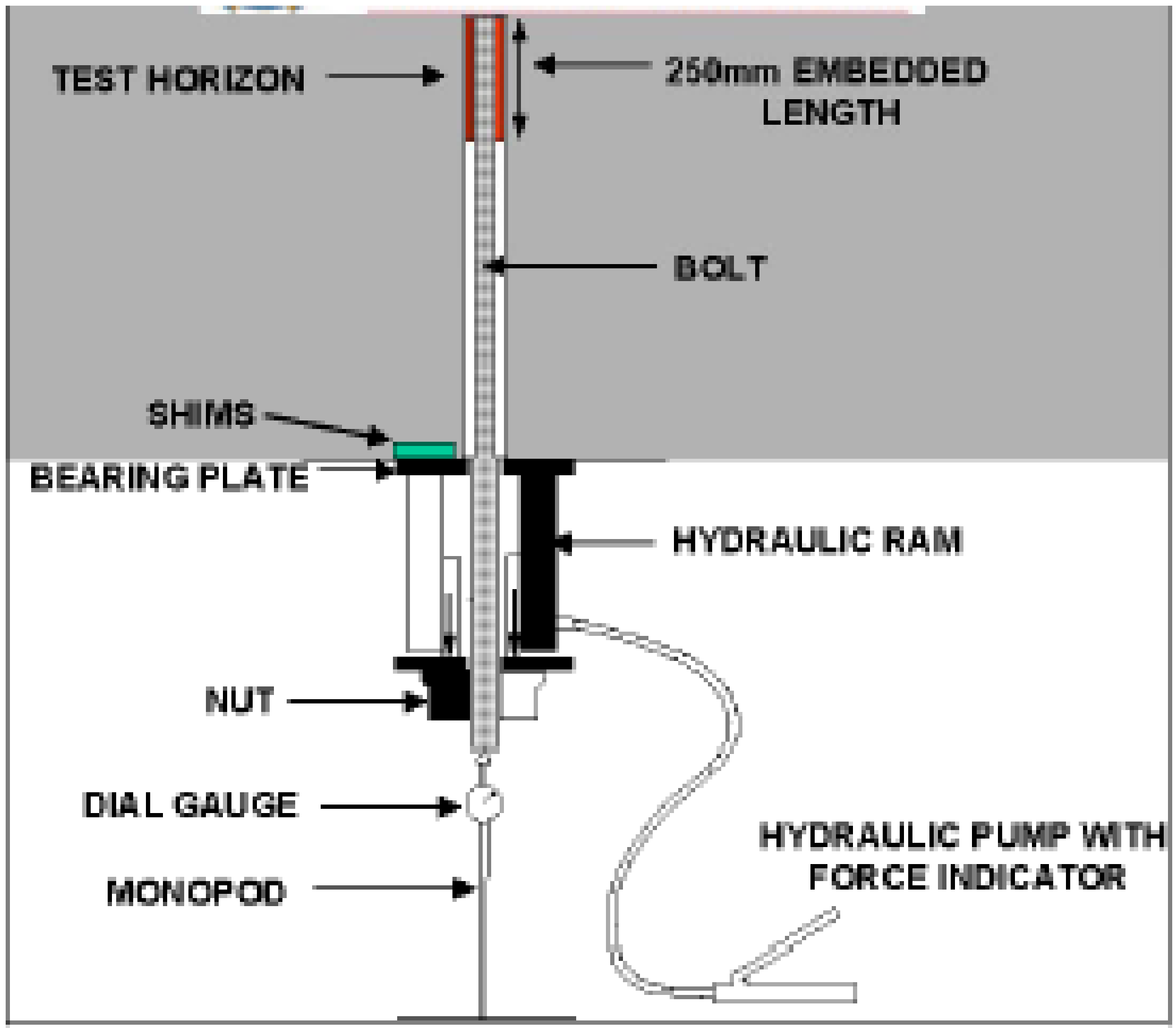


Figure 2-16 Short encapsulated pull test equipment (after DMCIDC, 1996)

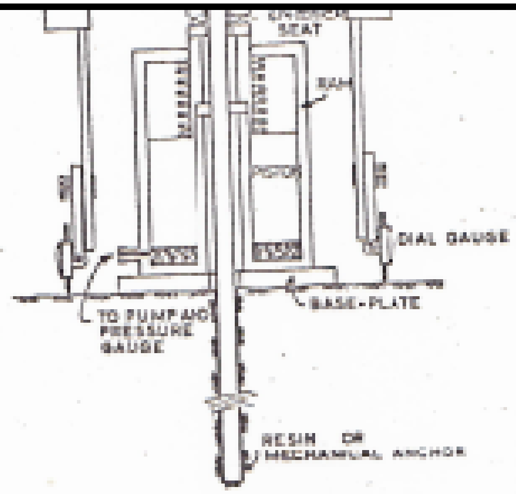


FIG. 6a _DIAGRAM OF ROCK- BOLT TESTING EQUIPMENT (AFTER FRANKLIN AND WOODFIELD 1971)

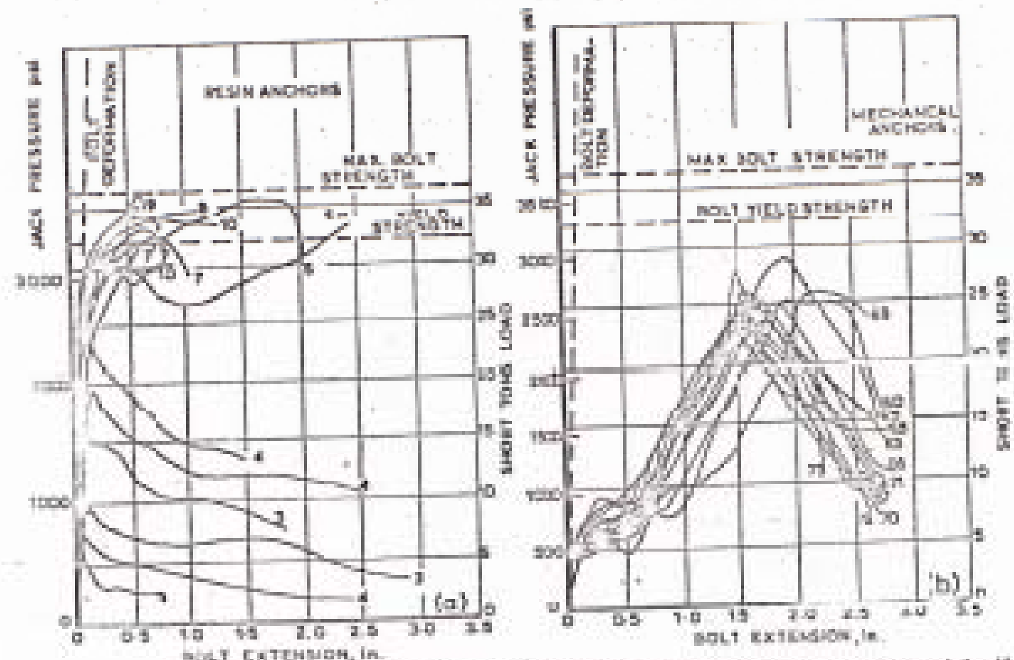


FIG. 6b_PULLOUT CURVES FOR GRANITE, SITE 1.(a) Resin-anchored bolts
- b) Mechanically anchored bolts. Yield and ultimate strengths of the bolt, and a line representing its deformation in the elastic range are plotted here and in later diagrams for comparison with curves for the combined bolt-anchor system

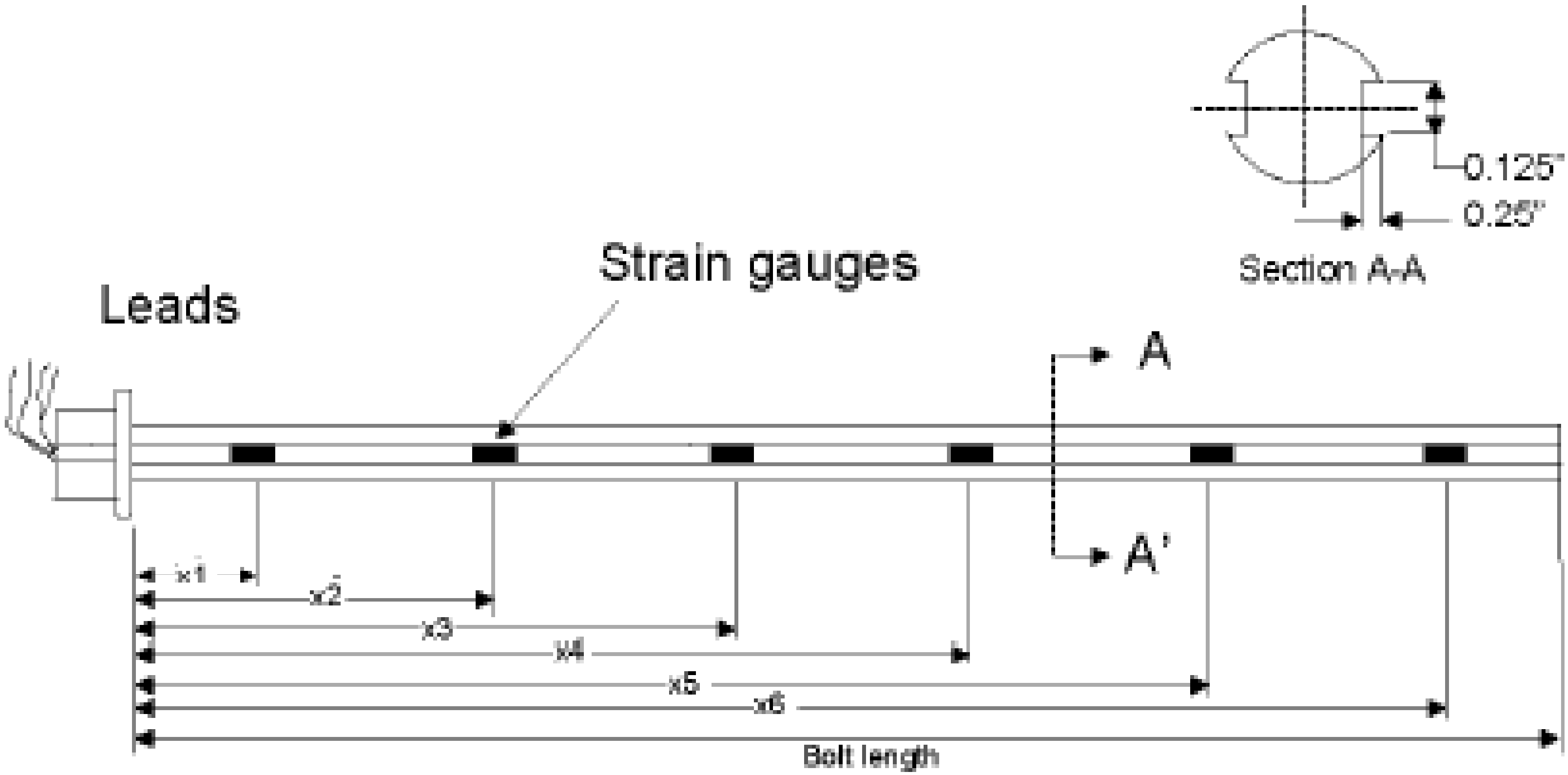


Figure 2-18   Instrumented roof bolt (after Signer and Jones 1990)

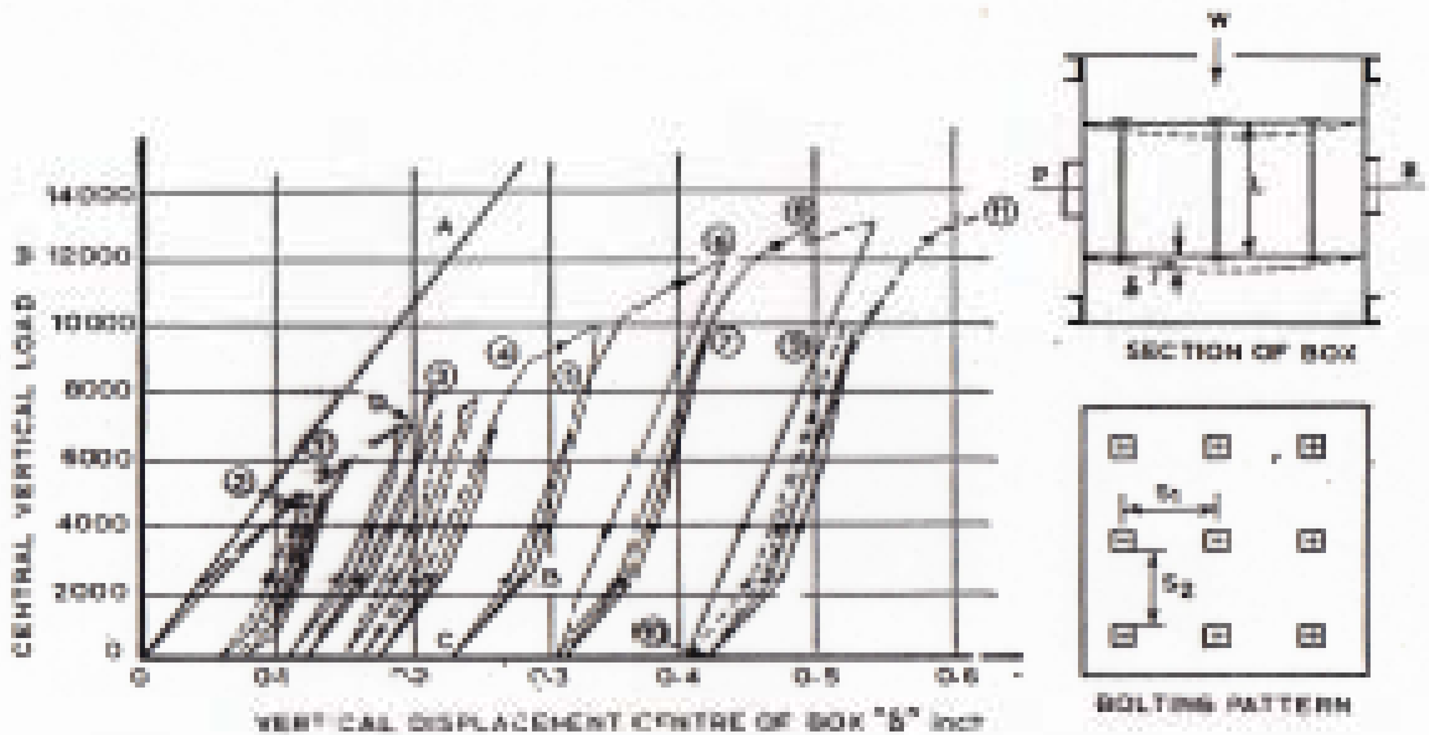


FIG. 17 _ BEHAVIOR OF CRUSHED ROCK MODLE

ROCK SIZE RANGE WAS 1½" TO 2½" THE MEAN (m) WAS 1.875 in. ($F = S_2/m = 4.3$) (AFTER LANG 1961)

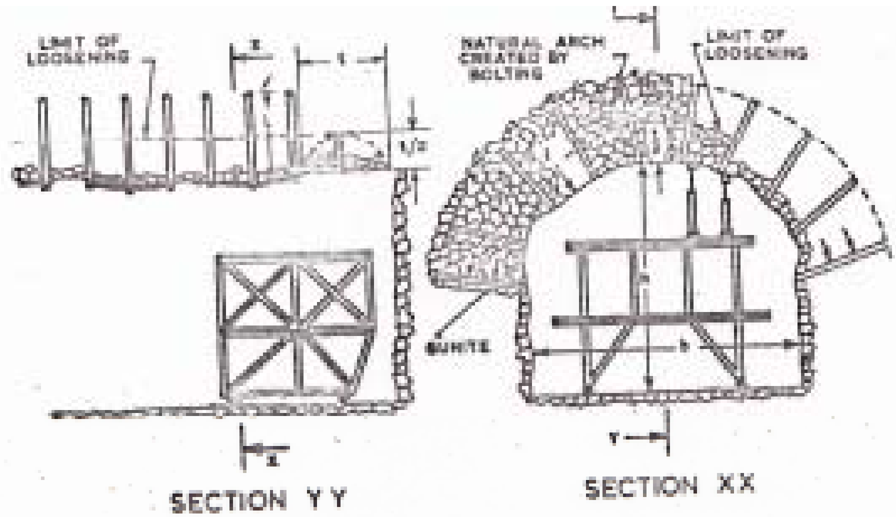


FIG. 20_ DIAGRAMMATIC SECTIONS DEMONSTRATING PRINCIPLES OF ROOF BOLTING

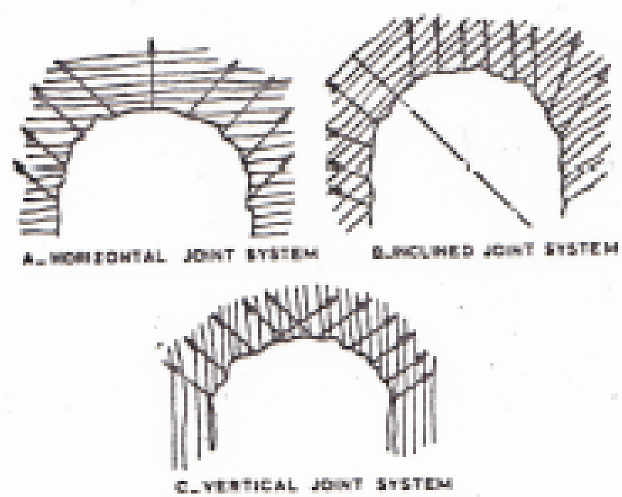


FIG. 21_ ROOF BOLTING IN STRATA RUNNING AT VARIOUS ANGLES OF DIP