Learning objectives

- Develop an overall understanding of rock support types
- Learn some specs about rock bolts and shotcrete

Common support types and their function

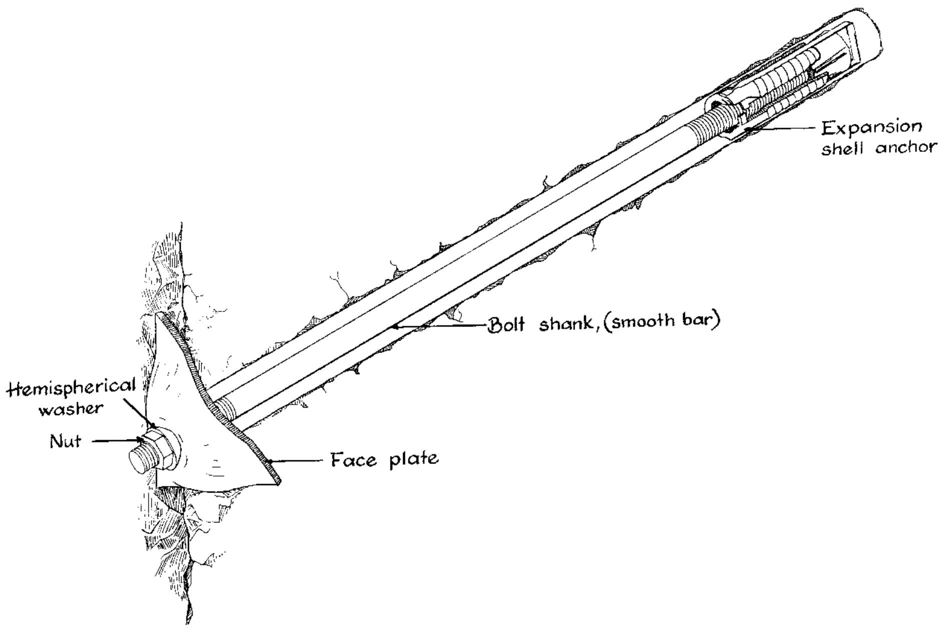
Support Type	Function
Bolt	Fastening individual blocks, forming rock arch and ring, taking stress
Shotcrete	Providing reactive pressure, locking block movement, protecting rock surface
Steel sets	Providing reactive pressure, limiting convergence
Wire mesh	Protecting block falling, reinforcing shotcrete
Concrete lining	Providing reactive pressure, limiting convergence
Jacking pipe	Providing reactive pressure, limiting convergence
Pillar	Providing reactive pressure, limiting roof movement

Rock bolt types and their features

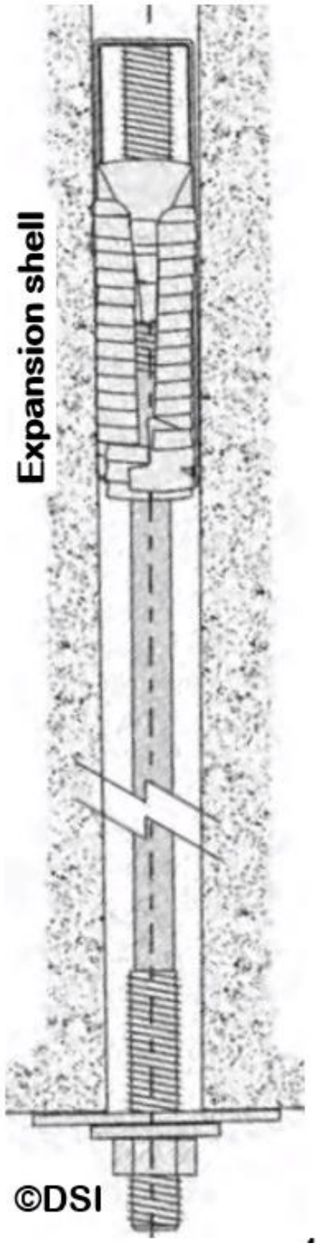
Rock Bolt Type	Characteristics and Function
End anchored	Fixed by two end, mainly for hard rock and block anchoring
Side frictional	Bolt skin in contact with rock, quick installation
Fully grouted	Fully integrated into rock, protected
Cable	Long length, flexible installation
Yielding	Large deformation, energy absorption
GRP	Cuttable, face stabilisation for excavation

End-anchored bolts

- Bolt body: rebar typically D 16-25 mm.
- Anchoring: at two end, (i) mechanical anchor a inside end by conical expansion shell, (ii) threaded end and nut, or forged head, plus face plate and tapped washer, at face end
- Functioning: provide active pre-stress, anchoring blocks

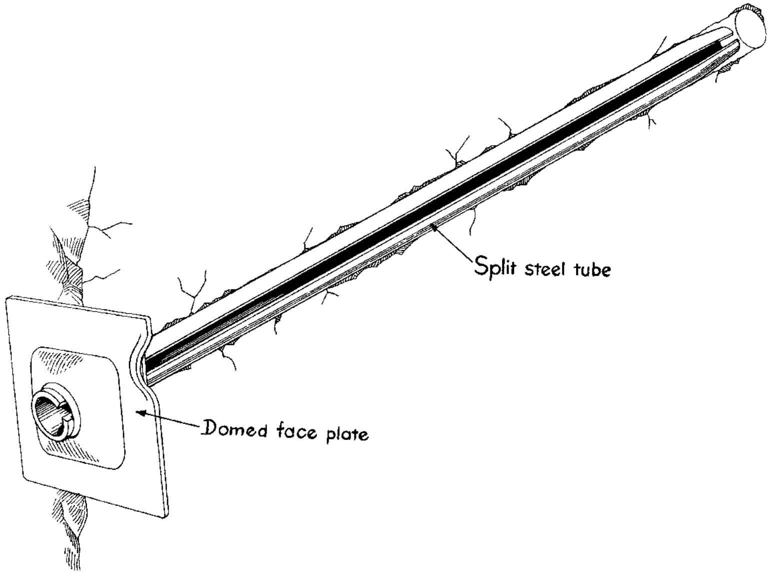


Typical technical data	SI-unit	Metric	U.S.
Steel quality designation:	700 N/mm^2	70 kp/mm^2	102 kpsi
Steel diameter:	16 mm	16 mm	5/8 in
Yield load, steel:	140 kN	14 tons	15.5 tons
Ultimate load, steel:	180 kN	18 tons	20 tons
Ultimate axial strain, steel:	14%	14%	14%
Weight of bolt without face plate and nut:	2 kg/m	2 kg/m	1.34 lb/ft
Bolt lengths:		any length required	
Recommended borehole diameter:	35 – 38 mm	35 – 38 mm (critical)	1 3/8 in

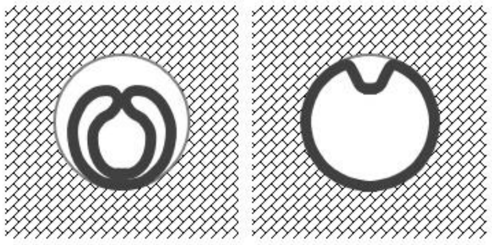


Side frictional bolts

- Bolt body: steel tube, split or folded
- Anchoring: by skin friction between steel tube and borehole wall rock
- Functioning: joint rock mass together
- Advantage: Rapid installation



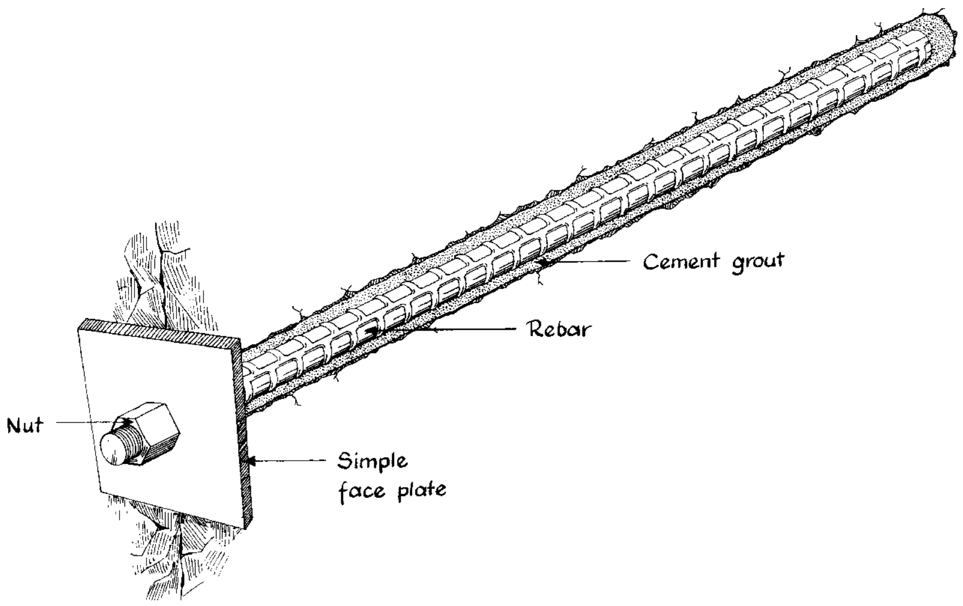

Swellex bolt ©atlas copco



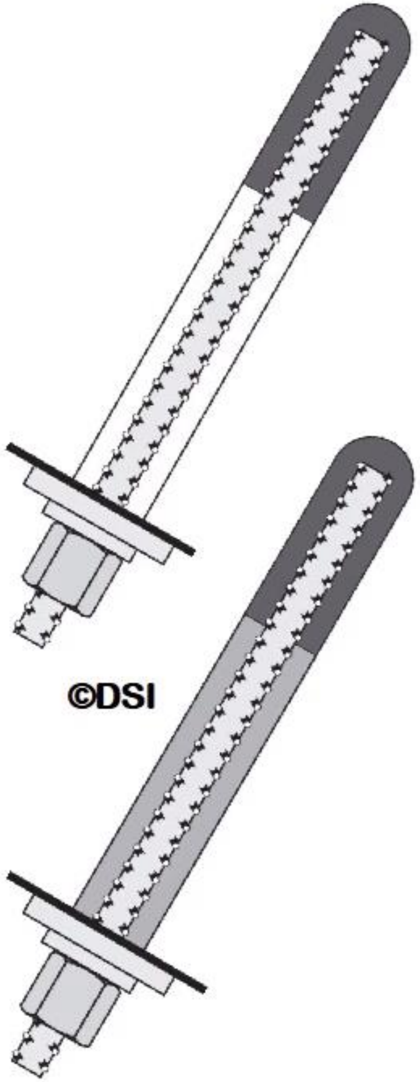
Typical technical data on SS-39/SS-46	SI-unit	Metric	U.S.
Tube diameter:	39/46 mm	39/46 mm	11/2 / 17/9 in
Yield load, steel tube:	90/135 kN	9/13.5 tons	10/15 tons
Ultimate load, steel tube:	110/163 kN	11/16.3 tons	12/18 tons
Ultimate axial strain, steel tube:	16/16%	16/16%	16/16%
Weight of bolt without face plate:	1.8/2.8 kg/m	1.8/2.8 kg/m	1.2/1.9 lb/ft
Bolt lengths:	0.9-3/0.9-3.6 m	0.9-3/0.9-3.6 m	3-10/3-12 ft
Recommended borehole diameter:	35-38/41-45 mm	35-38/41-45 mm (critical)	13/8-11/2 / 15/8-13/4 in

Grouted bolts

- Bolt body: rebar and anchored bolt
- Anchoring grout: resin/cement grout at inside end
- Full grout: full grout only with rebar
- Functioning: anchor and joint rock mass together, long-life full protection to bolts

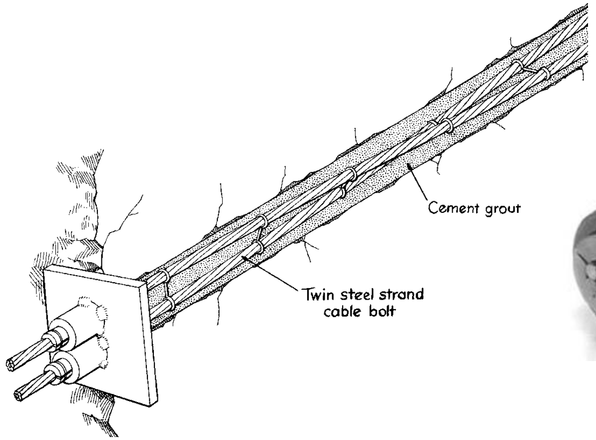


Typical technical data	SI-unit	Metric	U.S.
Steel quality designation:	570 N/mm^2	58 kp/mm^2	83 kpsi
Steel diameter:	20 mm	20 mm	7/9 in
Yield load, steel:	120 kN	12 tons	13 tons
Ultimate load, steel:	180 kN	18 tons	20 tons
Ultimate axial strain, steel:	15%	15%	15%
Weight of bolt without face plate and nut:	2.6 kg/m	2.6 kg/m	1.75 lb/ft
Bolt lengths:		any length required	
Recommended borehole diameter:	35 ± 5 mm	35 ± 5 mm	1 3/8 in

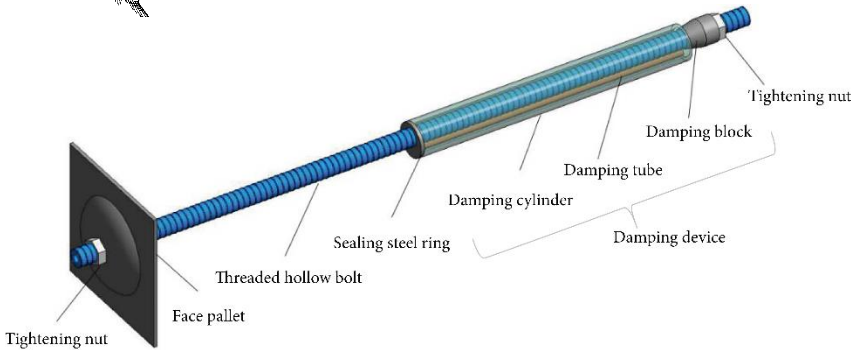


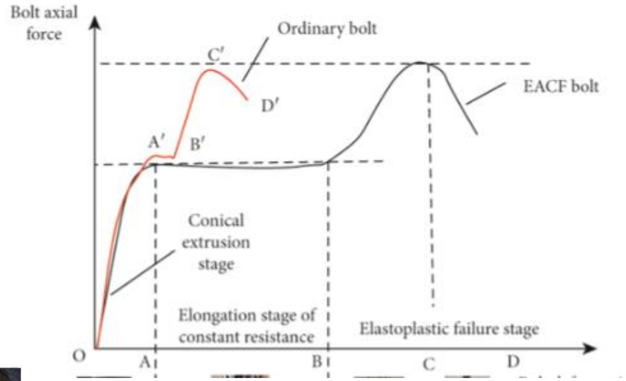
Cable bolt, yielding bolt and GRP bolt

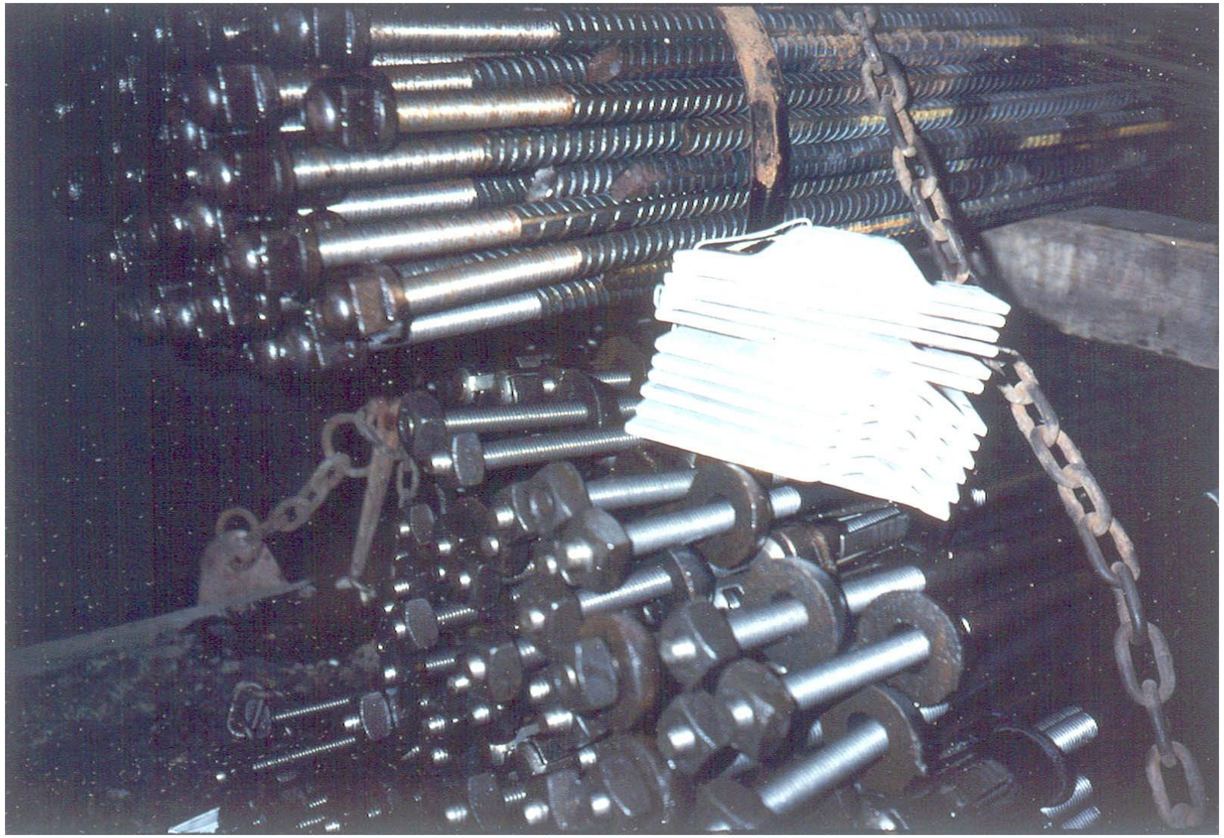
- Cable bolt: mainly for long bolting, can be end-anchored/full grouted
- Yielding bolt: for anticipated large deformation , spalling and rock burst
- Glass-reinforced plastic bolt – cuttable, suitable for temporally stabilizing the face for mechanical excavation



Typical technical data	SI-unit
Steel quality designation:	1950 N/mm^2
Cable diameter:	2 x 15.2 mm
Yield load, cable:	500 kN
Ultimate load, cable:	500 kN
Ultimate axial strain, cable:	4.8%
Weight of cable:	2.1 kg/m
Cable lengths:	
Recommended borehole diameter:	48 – 64 mm

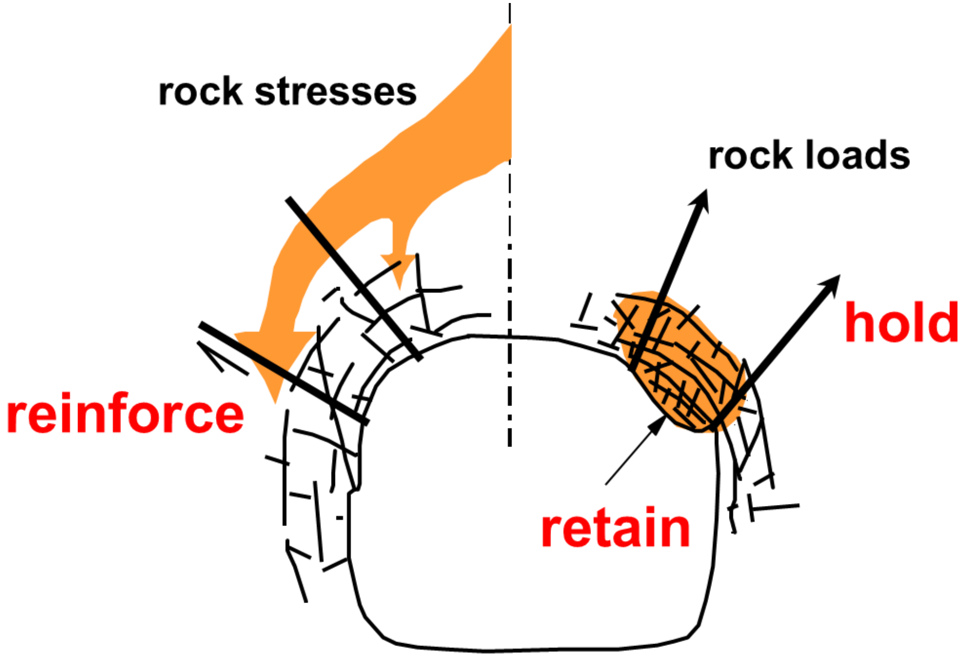






Considerations for support design

- Experience indicates that rock bolts have little influence on the failure zone developed around an excavation
  - This is not surprising in view of the high induced stress levels, 30-100 MPa, in the surrounding rock and the fact that the support pressure generated by the rock bolt pattern is usually less than 0.3 MPa
- The purpose of ground support is to control the deformations in the fractured rock mass
- Early installation of ground support systems that are too stiff, results in over stress and support failure
  - The support must be compliant enough to accommodate the rock mass dilation and strong enough to support the dead weight of the broken rock



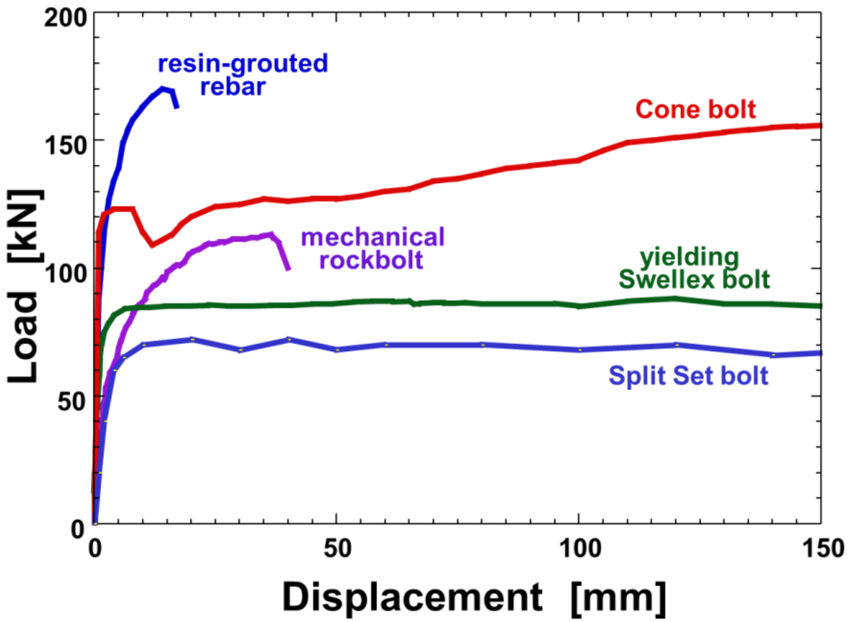
Support properties (capacity)

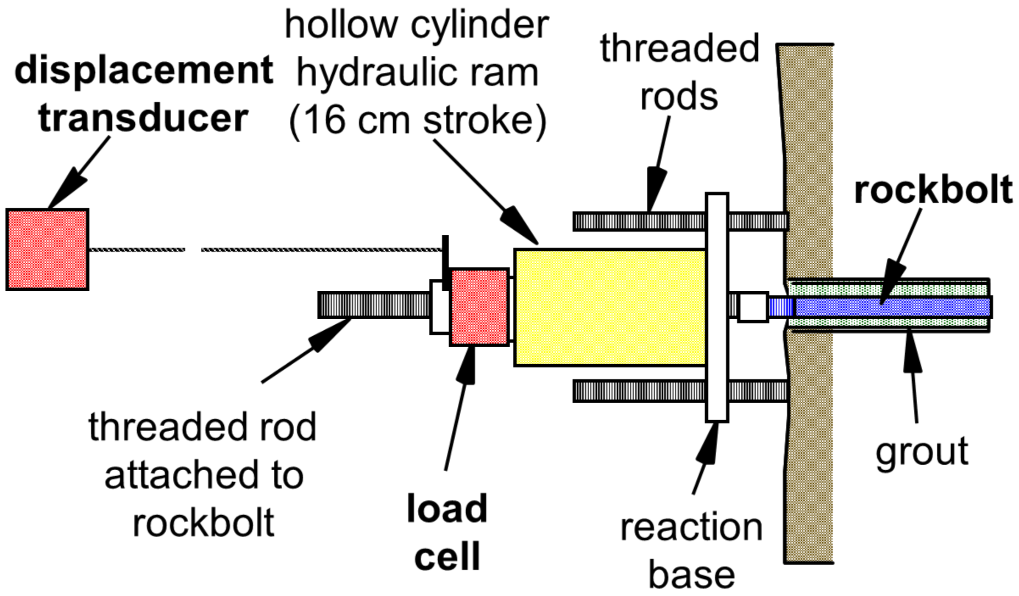
Description	Peak load [kN]	Displace. limit [mm]	Energy absorption [kJ]
19 mm resin-grouted rebar	120 - 170	10 - 30	1 - 4
16 mm cable bolt	160 - 240	20 - 40	2 - 6
16 mm 2 m mechanical bolt	70 - 120	20 - 50	2 - 4
16 mm 4 m debonded cable bolt	160 - 240	30 - 50	4 - 8
16 mm grouted smooth bar	70 - 120	50 - 100	4 - 10
Split Set bolt	50 - 100	80 - 200	5 - 15
yielding Swellex bolt	80 - 90	100 - 150	8 - 12
yielding Super Swellex bolt	180 - 190	100 - 150	18 - 25
16 mm cone bolt	90 - 140	100 - 200	10 - 25
#6 gauge welded-wire mesh	24 - 28	125 - 200	2 - 4/m^2
#4 gauge welded-wire mesh	34 - 42	150 - 225	3 - 6 /m^2
#9 gauge chain-link mesh	32 - 38	350 - 450	3 - 10 / m^2

note: these are design values

Rock bolt pull test

- typically performed in tunnels/caverns to assess the anchorage or pull-out capacity of rock bolts by measuring the pull-out load vs deformation
- Reflect the effective anchorage and bond strength between bolts & rock mass.

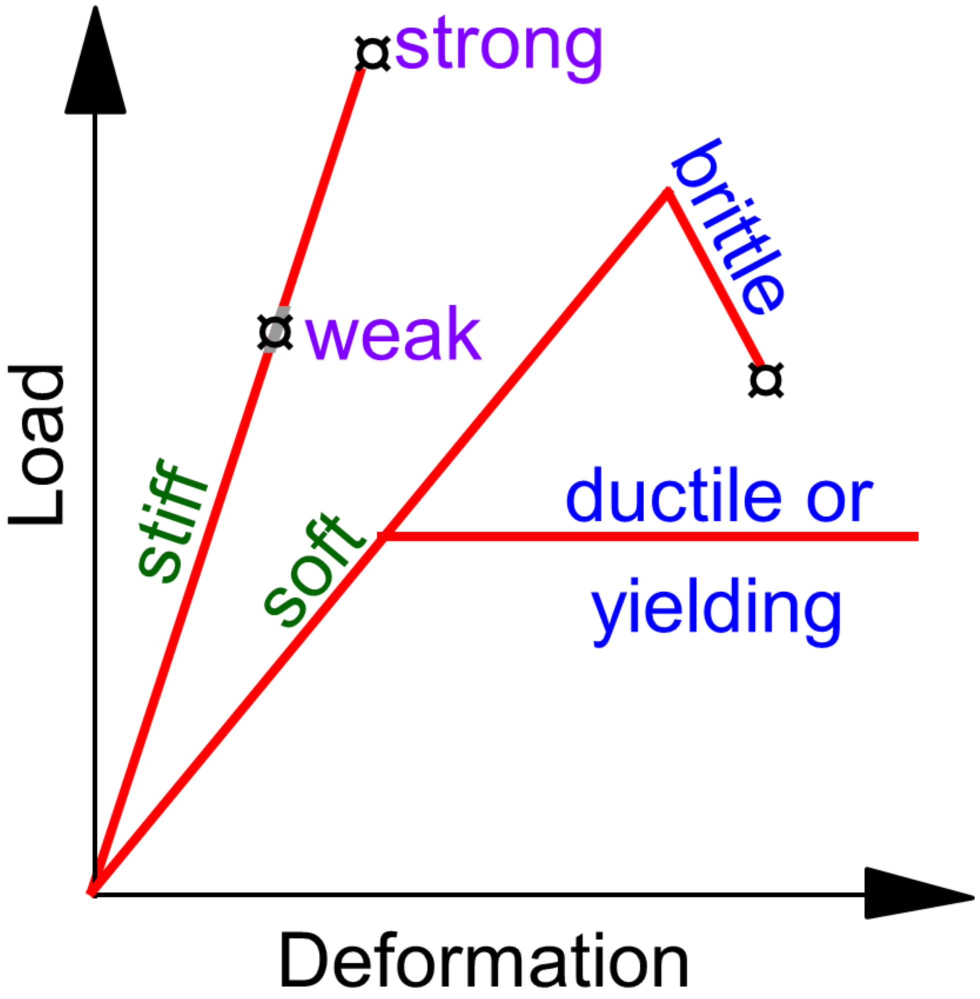




General support characteristics

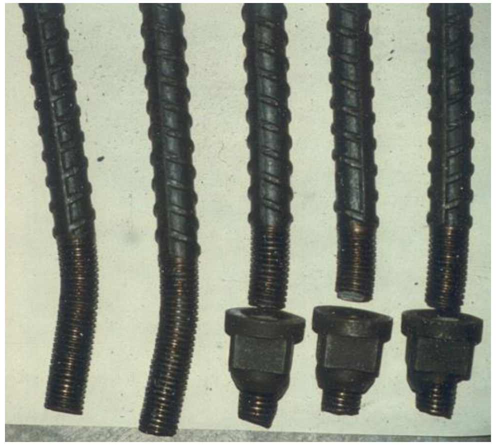
- Think about the following scenarios:

1. For brittle rock at high stress
2. For weak rock at high stress
3. For weak rock at low stress



Bolt failure modes

- Bending (bending moment)
  - equipment hitting bolt
  - installed at large angle to rock face
- Tensile (axial load or pull)
  - excessive load
  - inappropriate support design
- Shear (non-axial load)
  - equipment hitting bolt
  - excessive deformation
- Corrosion
  - sulphide rocks
  - wet conditions



notched profile

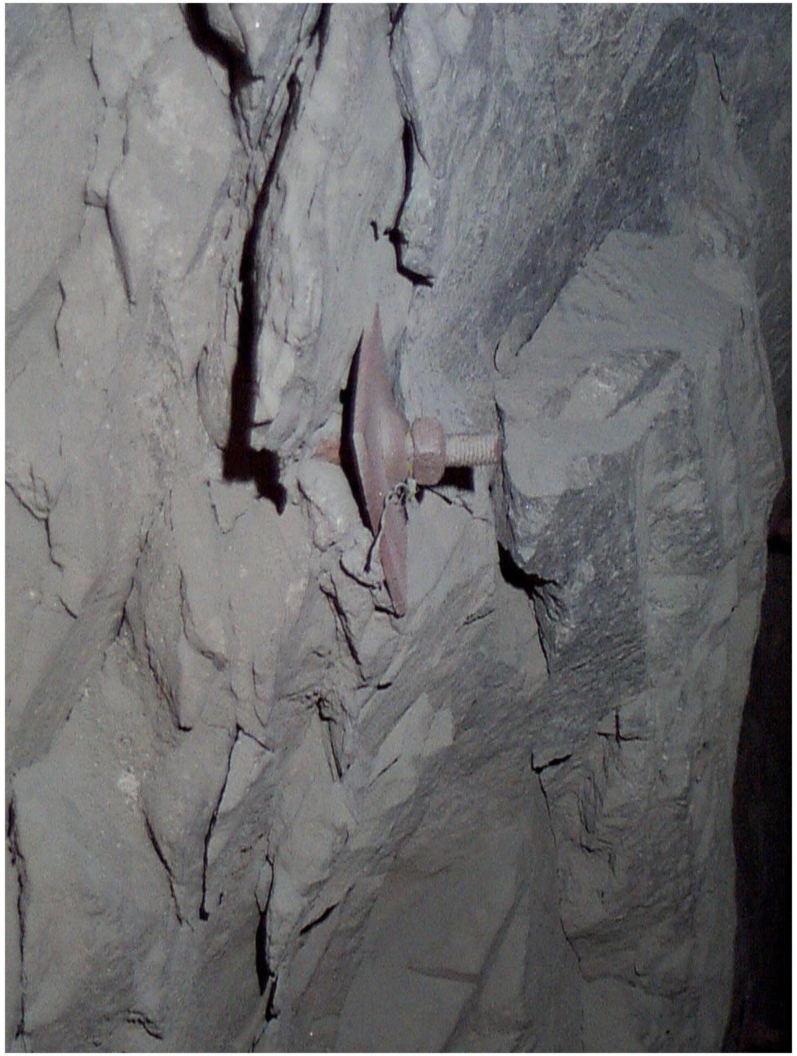
irregular profile
smooth surface
smeared

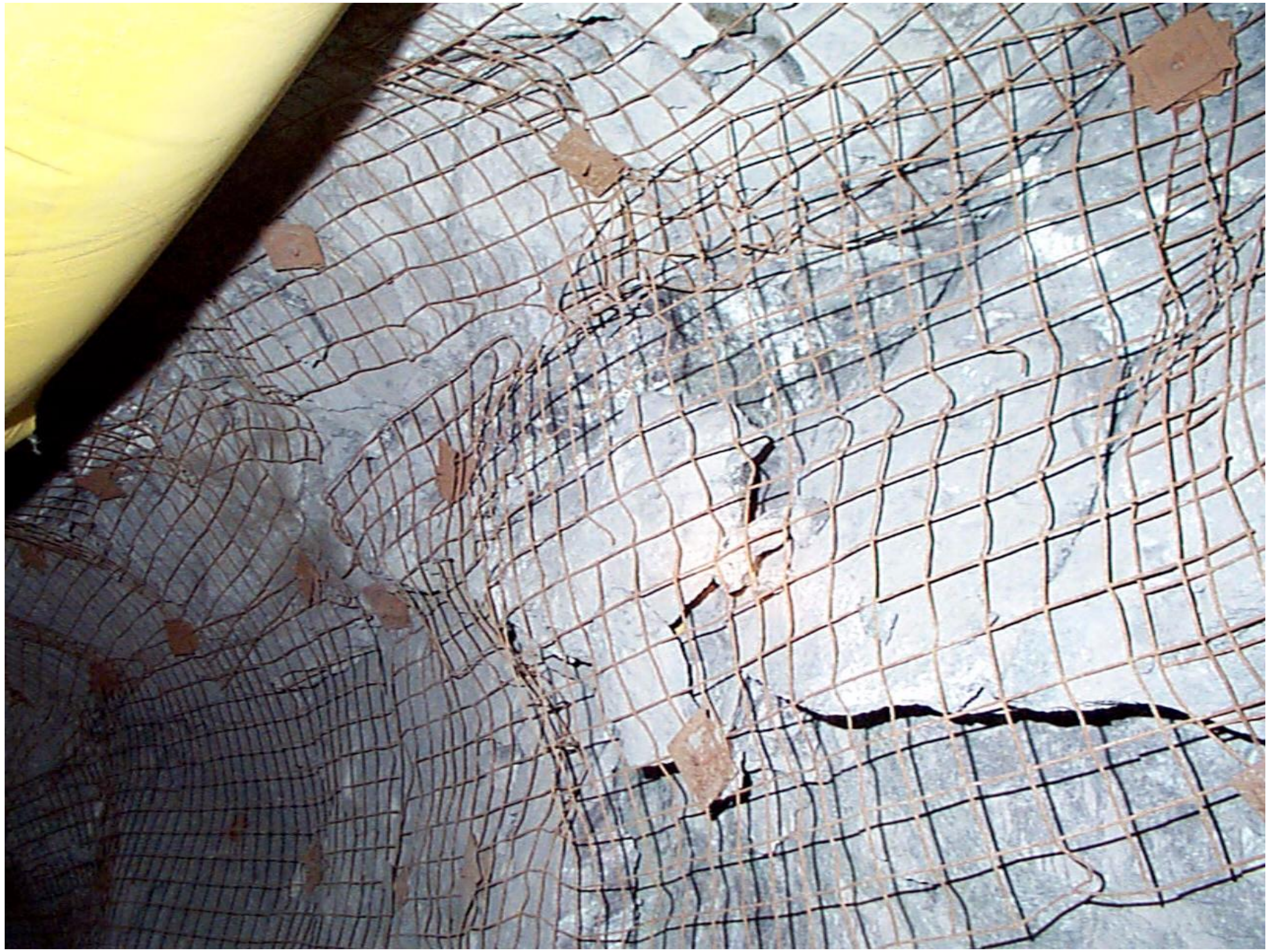
Some common mistakes in bolting

- Two bolts shouldn't be installed this close together
- Note 2nd plate on mechanical bolt

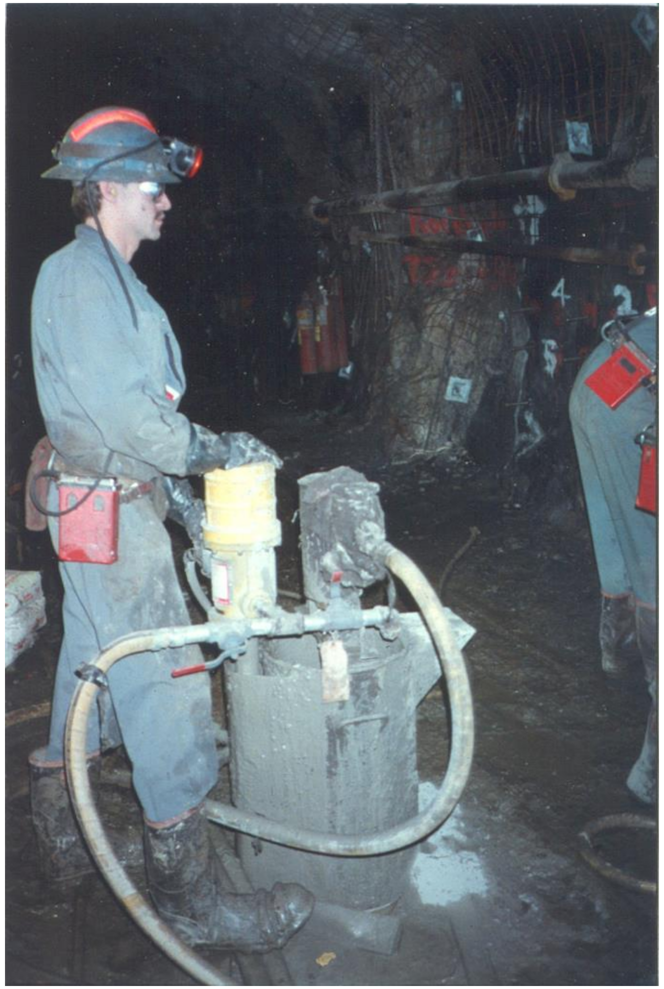
- When using with wire meshes, bolt plates should pin over the mesh

Poor scaling

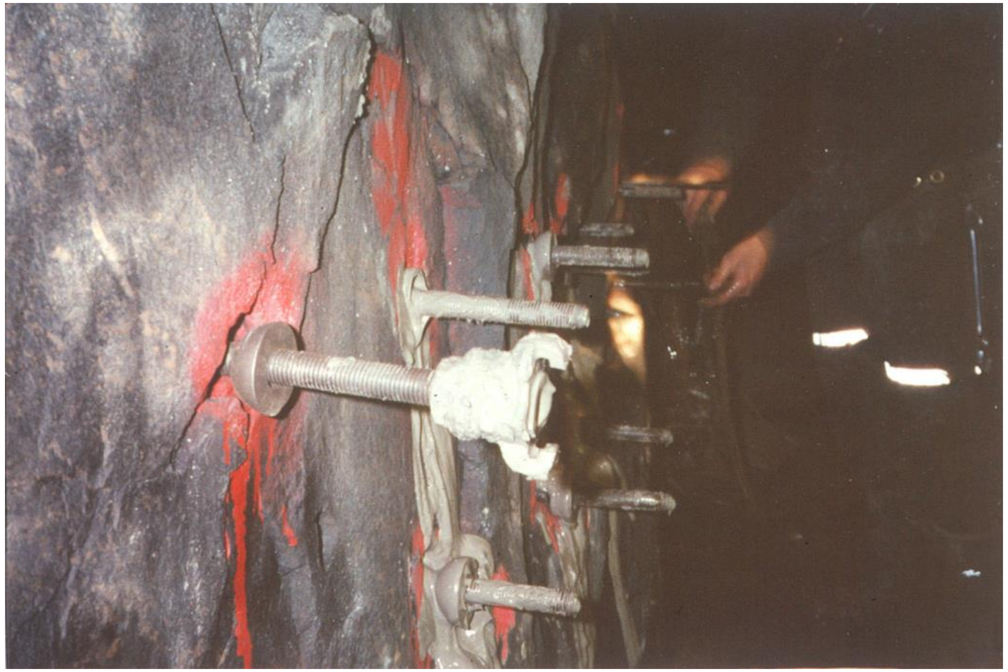




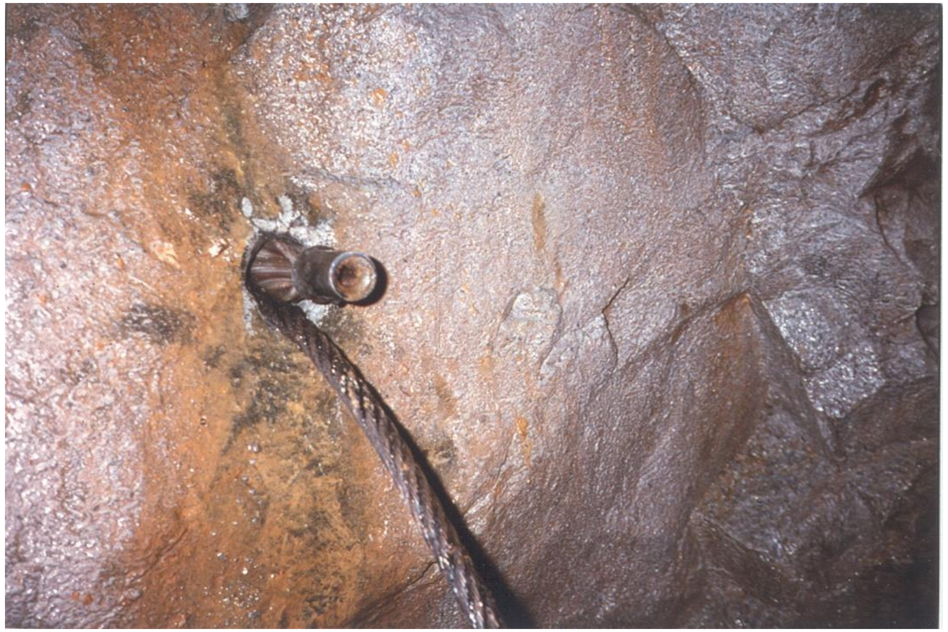
Field photos



Mixing cement grout in a Speidel pump/mixer



Grouted pipe bolts (0.4 w/c grout)



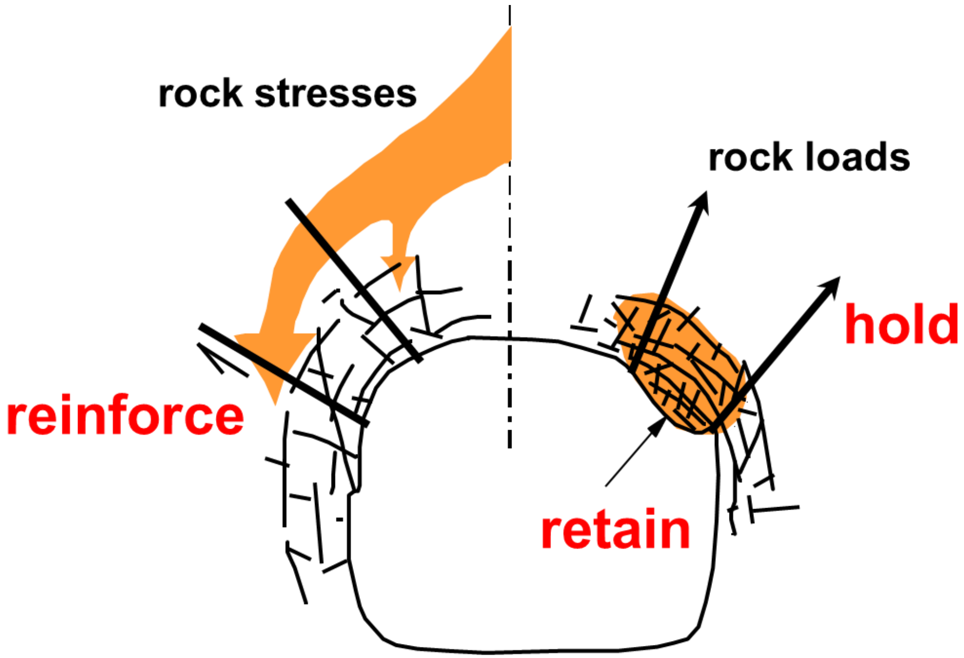
Swellex bolt

Shotcrete

- Mostly wet-mix concrete, applied by a pressurized nozzle to spray concrete directly to the rock surface
- Widely used in tunneling, mining, hydropower and slope stabilization
- Can be reinforced by steel fiber or polymer fibers

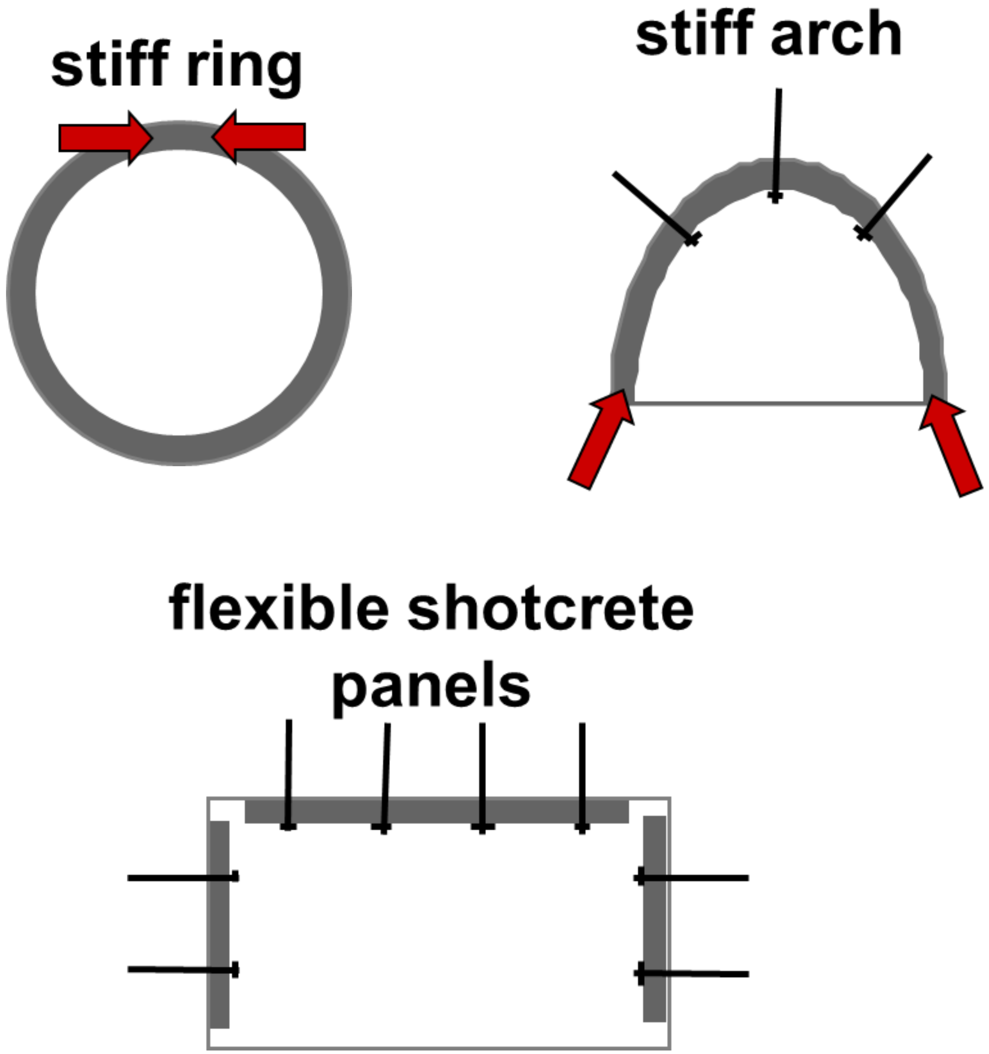
Role of shotcrete

- Shotcrete as a “super-mesh”
  - strengthen mesh overlaps
  - protect mesh
  - distribute loads to bolts and mesh wires
- Confine rock mass with support pressure
- Provide a frictional interlock at the excavation surface
- Prevent ravelling of loose rock
- Dissipate energy during fracturing

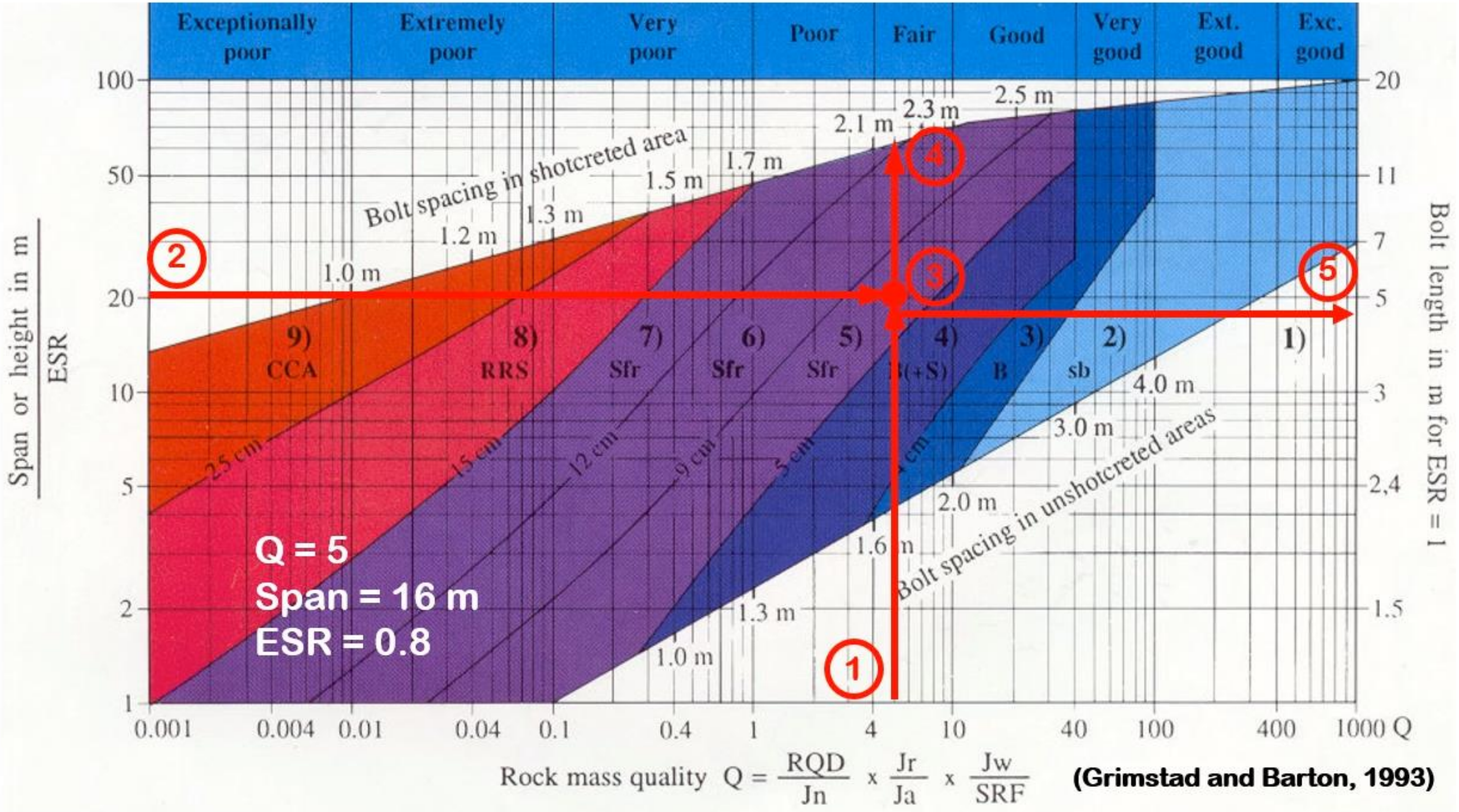


Design goal

- Fundamental goal of shotcrete design is to create a self-supporting arch of shotcrete bolts and rock - a reinforced structure that can survive imposed loads and deformations
- Support must be designed as an integrated system that includes more than just shotcrete (rockbolts or grouted rebar and mesh)



Empirical design

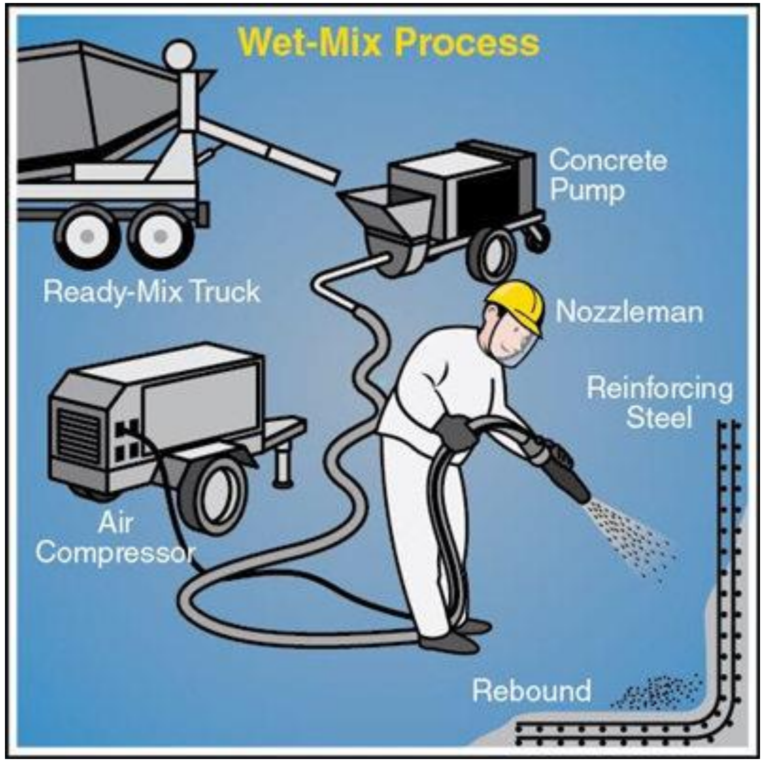


(Grimstad and Barton, 1993)

1) Unsupported
2) Spot bolting, sb
3) Systematic bolting, B
4) Systematic bolting, (and unreinforced shotcrete, 4-10 cm), B(+S)
3 5) Fibre reinforced shotcrete and bolting, 5-9 cm, Sfr+B
6) Fibre reinforced shotcrete and bolting, 9-12 cm, Sfr+B
7) Fibre reinforced shotcrete and bolting, 12-15 cm, Sfr+B
8) Fibre reinforced shotcrete, >15 cm, reinforced ribs of shotcrete and bolting, Sfr, RRS+B
9) Cast concrete lining, CCA

Shotcrete application methods

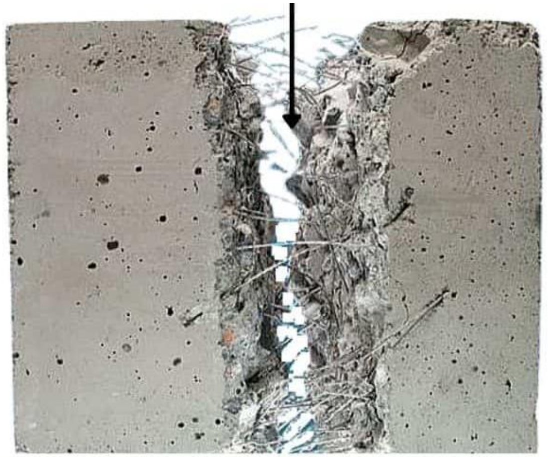
- **Dry-mix** method used as initial application method with 1000kg bags of shotcrete delivered to working area, later on can be mixed on site.
- **Wet-mix** application has increased mechanization, and shotcrete delivery by slick lines and/or underground ready mix trucks



Typical dry shotcrete mix design

Components	kg/m^3	Percent
Cement	420	18.6
Micro-silica additive	42	1.9
Blended aggregrate	1735	76.9
Steel fibres	59	2.6

*Fast setting admixtures (accelerators)



Shotcrete application methods

Dry mix vs. wet mix

Factor	Dry Mix	Wet Mix
Machinery	Lower total expenditure. Conveyance by compressed air (low efficiency). Maintenance relatively simple and infrequent.	Less machinery at work site. Diesel or electric power more efficient than compressed air. Less wear rate in pump, hoses and nozzles. 60% less air consumed.
Mixing	At work site. Pre-mixed, dry ingredients can be used but cannot be left open in humid or wet environments. Performance impaired by wet sand.	Accurate mixing remote from work site. Multiple handling avoided. Can use bulk ready mix. Wet sand acceptable.
Output	Rarely exceeds 5 m^3/hr in place. Can by conveyed over longer distances than wet mixes, maximum 400m horizontally and 100m in elevation. 50-100m normal.	Higher than similar dry mix machines; 2-10 m^3/hr when boom mounted.
Rebound	Can be 15-40% from vertical walls, 20-50% from overhead. Forms rebound pockets. Loss of aggregate makes compliance with mix specification difficult, and excess cement is usually added.	Low rebound with correct mix, can be less than 10%. Little loss of aggregate. Rebound pockets do not occur.
Impact Velocity	Higher-better adhesion; easier to use overhead.	Generally adequate for tunnel/mine work.
Addition of reagents	Powders in mixer or gun. Liquids at nozzle.	Generally as liquid.
Dust	Suppression additives, pre-wetting with 5-15% moisture or ‘semi-wet’ methods can reduce dust formed.	Very little dust formed: can be one sixth that from dry-mix spraying. Better visibility. No danger of lamination by dust.
Versatility	Can be used for sand blasting, guniting, refractory materials, repairs, resurfacing.	Can be used as concrete pump for pouring in place.

Wet-mix advantages vs dry mix

- Far less rebound: 5-10% is normal with use of correct equipment and trained personnel
- Better working environment; dust problem reduced
- Thicker layers because of effective use of the admixing materials
- Controlled water dosage (constant defined w/c ratio)
- Improved bonding
- Higher compressive strength and very little variation in results
- Much larger production and consequently improved total economy
- Use of steel fibres and new advanced mixtures

Wet-mix disadvantages vs dry mix

- Limited conveying distance (max. 150 m)
- Increased demands on aggregate quality
- Can withstand only limited interruptions
- Cost of cleaning equipment

Poor installation procedures

- Poor thickness control
- Walls and backs not clean
- Shoot at angle, high rebound
- Plain shotcrete has little flexural strength
- Weak fibre used
- Imposed deformation exceed fibre reinforcement capacity

Steel fiber-reinforced shotcrete

- Fibers are in 30-35 mm length
- Improve crack resistance and tensile strength of shotcrete

Typical wet-mix shotcrete mix for remote spraying (Concrete Institute of Australia, 2010)

Constituent Materials	Mix design per m^3	
	Civil	Mining
Strength grade (MPa)	40	40
Cement (kg)	420	440
Cement type	SL	GP
Fly ash (kg)	60	Optional
Silica fume (kg)	40	20
10 mm aggregate (kg)	450	500
Coarse sand (kg)	780	680
Fine sand (kg)	380	500
Total water (litre)	208	200
Steel fibre (kg) OR Macro-synthetic fibre (kg)	40-60 9-10	30-40 5-8
Water reducer admix. (litre)	1	1
Superplasticiser admix. (litre)	3	3
Hydration control admix. (litre)	1	2
Nominal slump (mm)	120-150	120-150
Water/cementitious material ratio	0.38-0.45	0.40-0.48