TUNNEL SUPPORTS CIRCULAR TUNNEL

(IN CONTINUATION OF TUNNEL IN WEAK ROCK)

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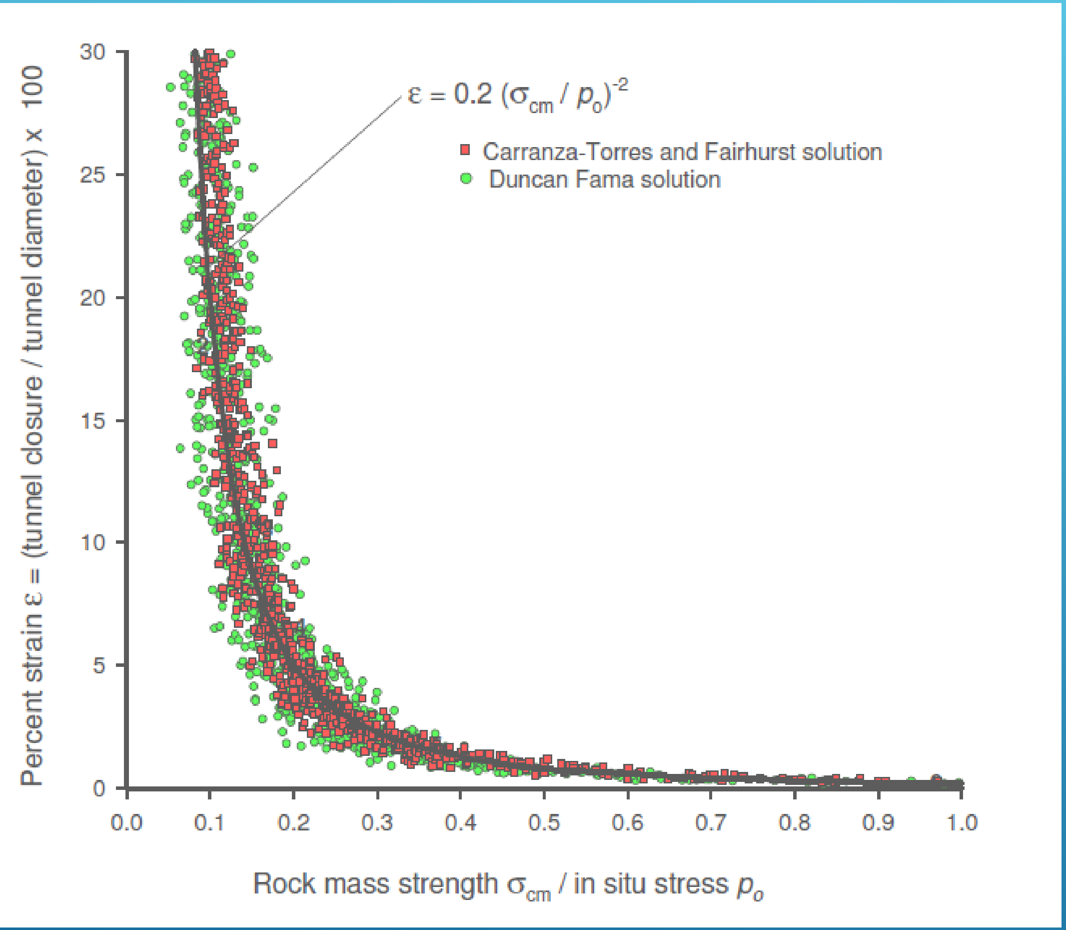
BASIC CONCEPT

This presentation is based on paper by Hoek : Tunnels in weak rocks

Based on basic concepts:

- The process of designing of support system.
- How rock mass surrounding tunnel deforms
- How support system acts to control this deformation.

Dimensionless Plots of Tunnel Deformation



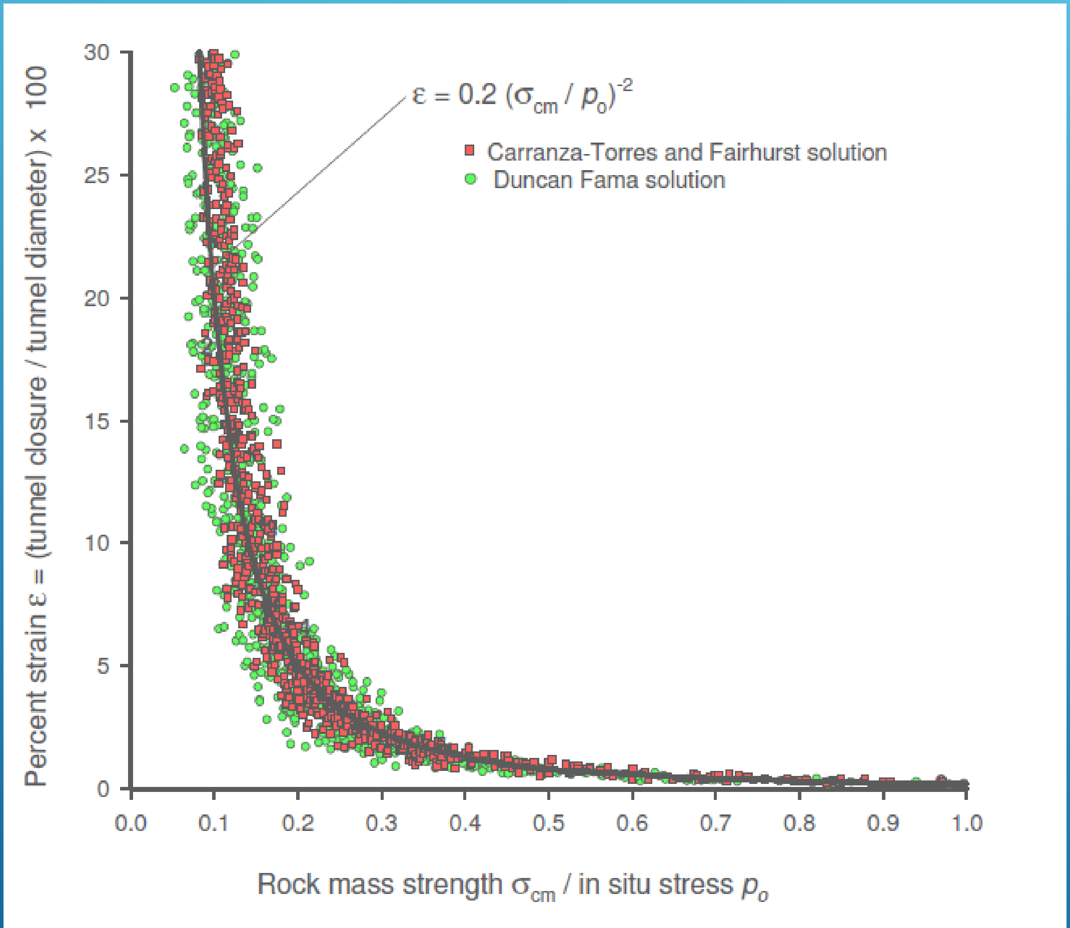
This Figure is a plot between

- Percentage strain i.e. ratio of tunnel wall displacement to tunnel radius and
- the ratio of rock mass strength to in situ stress.

Dimensionless Plots of Tunnel Deformation

This plot shows that:

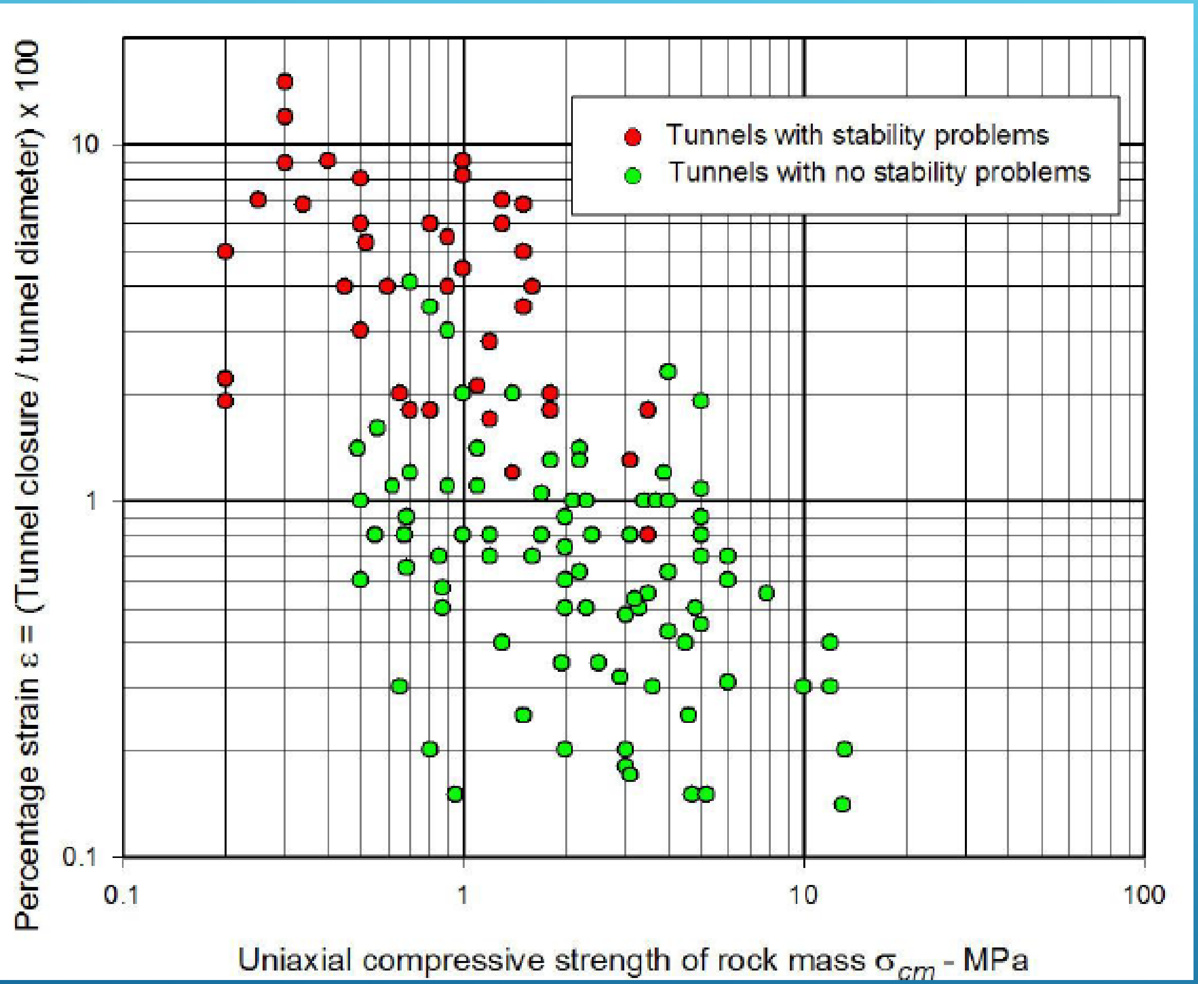
Rock mass Strength Vs In situ Stress



If Rock mass strength (σ_{cm}) reduced below < 20% of in situ stresses (p_o).

Deformation increases substantially, if it is not controlled by any support system, the opening will collapse.

Tunnel closure Vs Tunnel Diameter



Based on observations and measurements it is being suggested:

If Tunnel Closure > 1% of Tunnel Diameter

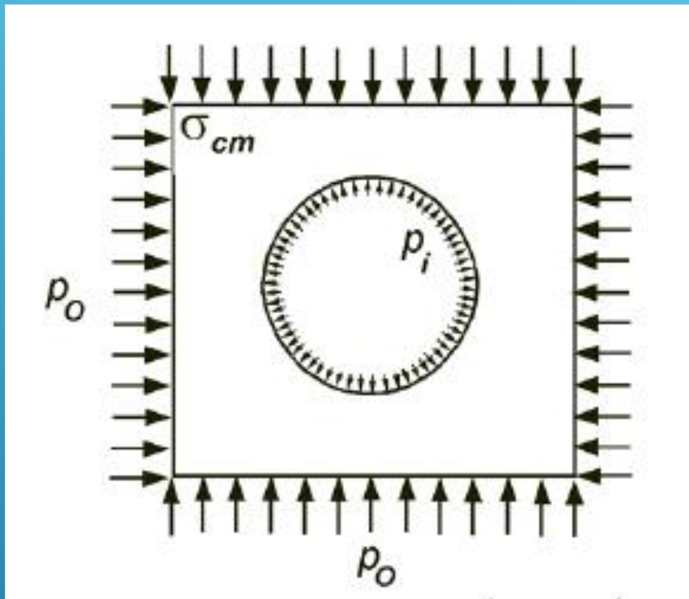
There is onset of instabilities in the tunnels

Therefore from the **above two conditions** the conclusion is the following

- If Rock mass strength (σ_{cm}) reduced below < 20% of in situ stresses (p_o).
- Tunnel Closure > 1% of Tunnel Diameter

Deformation increases substantially, if it is not controlled by any support system, the opening will collapse

Tunnel Displacement for Different Support Pressures



rp = Plastic zone radius
u_i = Tunnel sidewall deformation
r_o = Original tunnel radius in metres
pi = Internal support pressure
p_o = In situ stress = depth below surface × unit weight of rock mass
σ_{cm} = Rock mass strength = $2c'\cos\phi'/(1-\sin\phi')$

Internal Support Pressure pi

pi which called here internal pressure means support pressure like rock bolts, shotcrete, steel ribs etc.

pi = 0 means unsupported tunnel

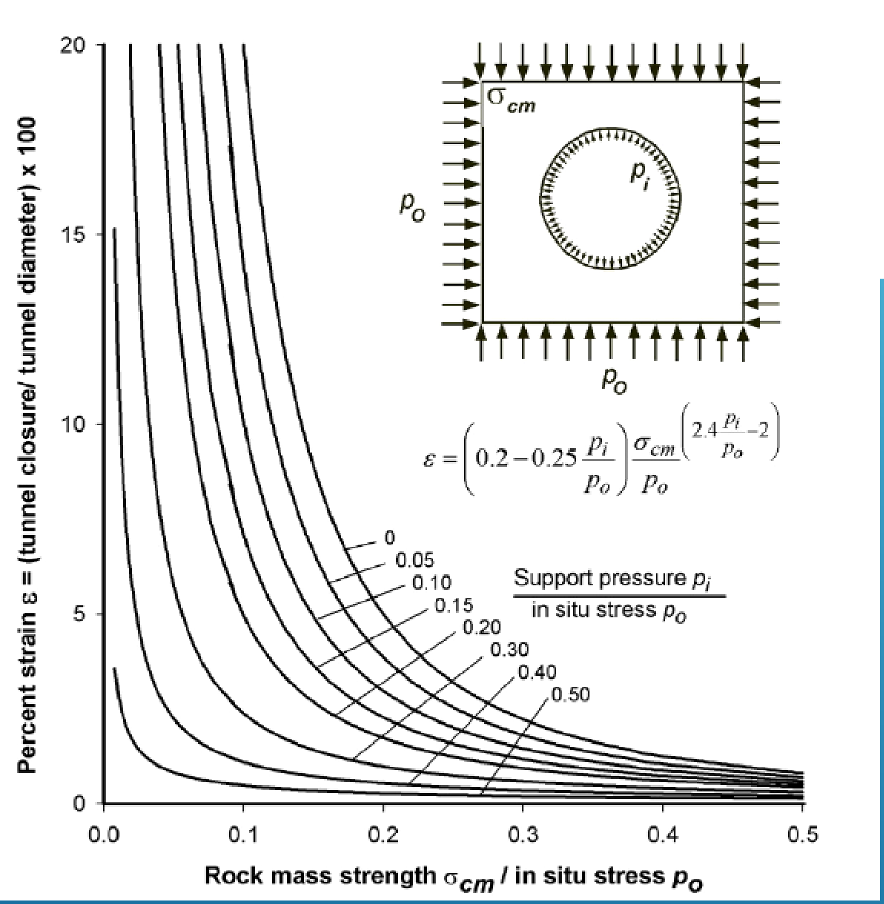
Here we talk internal pressures with respect to in situ Stress i.e. pi/p0

Rockmass Strength σcm

Strength of the rock mass surrounding the tunnel plays an important roll in determining the support pressures. This strength we usually determined from

Roclab software. The parameters required for determining its value are USC, GSI, Ei, depth from surface, D blasting factor.

Tunnel Displacement for Different Support Pressures



rp = Plastic zone radius

u_i = Tunnel sidewall deformation

r_o = Original tunnel radius in metres

pi = Internal support pressure

p_o = In situ stress = depth below surface × unit weight of rock mass

σ_{cm} = Rock mass strength = $2c' \cos\phi' / (1 - \sin\phi')$

Y – axis : Percentage strain ε (tunnel closure/tunnel diameter)

As per slide number 5, the convergence shall be less than 1%.

X-axis: Rockmass strength/in situ stress

Statistical Curve : for different support pressures/in situ stress

The series of curves shown in figure are defined by equation below:

$$\varepsilon\% = \frac{ui}{ro} \times 100 = \left(0.2 - 0.25\frac{p_i}{p_o}\right)\frac{\sigma_{cm}}{p_o}^{\left(2.4\frac{p_i}{p_o}-2\right)}$$

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Practical Example

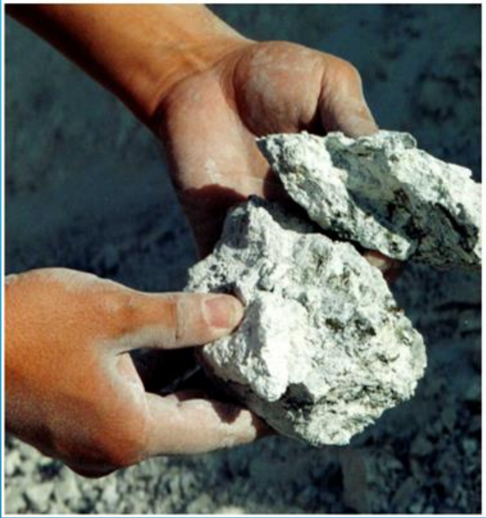
A drainage tunnel of 4m is to excavate in rock mass behind the slope of open pit mine. So following are inputs of this example:

Inputs

Tunnel Span = 4m

Tunnel depth = 150m

Unit weight of rock = 0.027MN/m3



Fault Zone Rock mass

Granodiorite

UCS of intact rock = 100Mpa (from lab)

GSI = 55

Fault Zone

UCS of rock in fault zone = 10MPa (from lab)

GSI = 15

All above parameters will be used to determine the rock mass properties

Rock mass properties of Granodiorite and Fault zone

RocLab (Rocscience software)

Practical Example

Rock mass properties of Granodiorite and Fault zone

RocLab (Rocscience software)

Material	σ_{ci} - MPa	GSI	m_i	σ_{cm}	σ_{cm}/po
Granodiotite	100	55	30	33	8.25
Fault	10	15	8	0.6	0.15

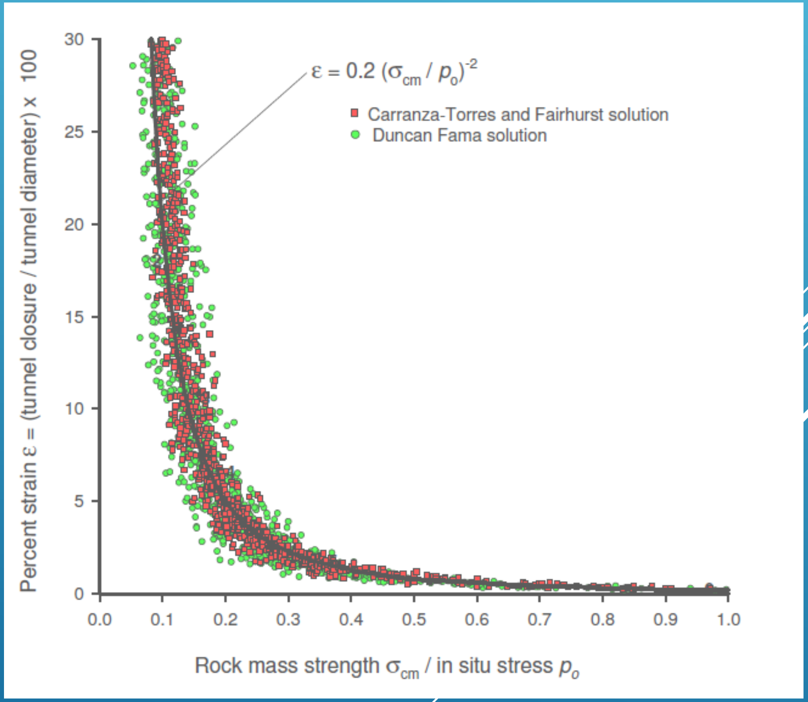
Granodiotite

Po = 150 x 0.027 = 4.05MPa

σcm/po = 33/4.05 = 8.15 ≅8.25

As per graph

- The size of the plastic zone and the induced deformations will be negligible
- No support system is reauired.
- Spot bolting and shotcrete provided.



Practical Example

Rock mass properties of Granodiorite and Fault zone

RocLab (Rocscience software)

Material	σ_{ci} - MPa	GSI	m_i	σ_{cm}	σ_{cm}/po
Granodiotite	100	55	30	33	8.25
Fault	10	15	8	0.6	0.15

Fault

σcm/po = 0.6/4.05 = 0.15

For unsupported tunnel with 2m radius

Pi = 0 (internal support pressure inside tunnel)

$$\frac{rp}{ro} = \left(1.25 - 0.625\frac{p_i}{p_o}\right)\frac{\sigma_{cm}}{p_o}^{\left(\frac{p_i}{p_o} - 0.57\right)}$$

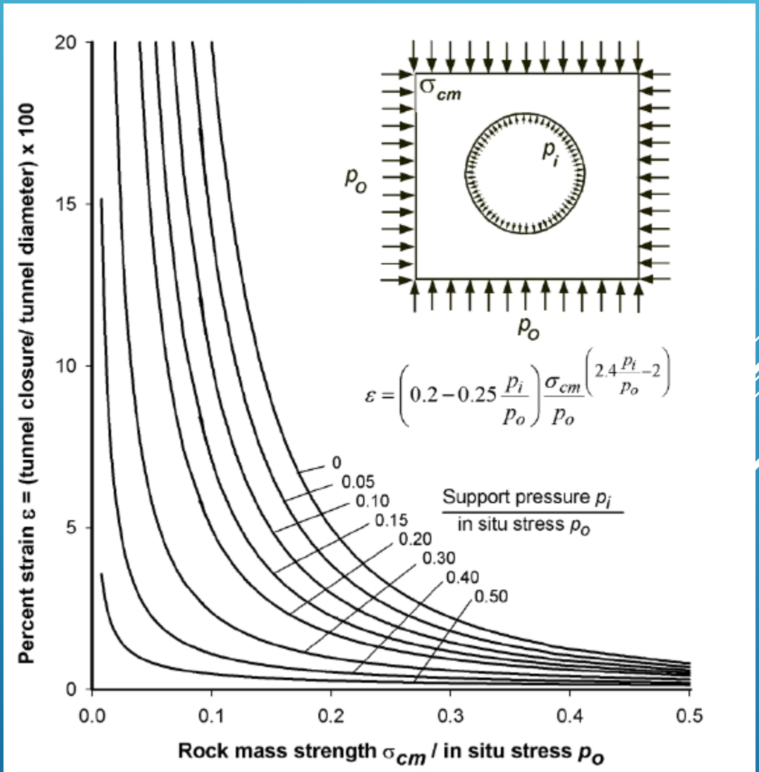
rp = 7.5m (Radius of plastic zone)

In Graph for

p0/pi = 0 & σcm/po = 0.15

Stain in tunnel = 9%, therefore

Deformation = 0.18m



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Practical Example
Determination of Support Measures

Support System for Tunnel in Fault Zone

Deformation in tunnel = 180mm (Deformation is very High needs Support system)

Strain Tunnel = 9%

Therefore substantial support is required in order

convergence to an acceptable level.

Assume the acceptable limit is 2%

and σ_{cm}/p_o = 0.15

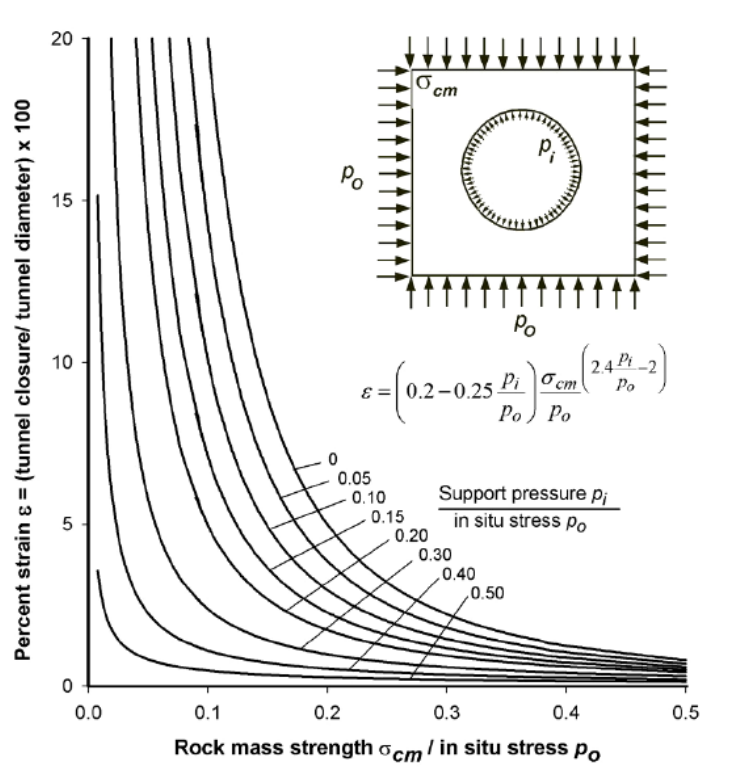
From graph the determined internal support pressure is approximately

p_i/p_o = 0.25

p_o = 4 MPa (provided in slide 10)

∴ **pi = 0.25x 4 = 1MPa** (required internal press

to support tunnel at 2% convergence.



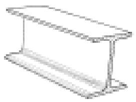
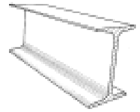
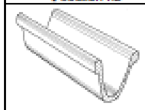
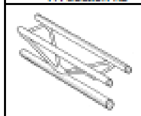
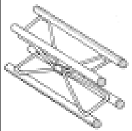
Support System for Circular Tunnel

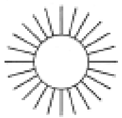
This is the figure from where we will select supports to generate support pressures inside tunnel greater that 1MP (determined in last slide.

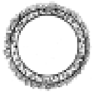
Support Capacity > 1MPa

Supports that can be provided in the tunnel are:

1. Steel Sets
2. Lattice Girder
3. Shotcrete
4. Concrete lining
5. Rock bolts or cables
6. Combination of above supports

Support type	Flange width - mm	Section depth - mm	Weight – kg/m	Curve number	Maximum support pressure p_{imax} (MPa) for a tunnel of diameter D (metres) and a set spacing of s (metres)
 Wide flange rib	305	305	97	1	$p_{i\,max} = 19.9D^{-1.23}/s$
	203	203	67	2	$p_{i\,max} = 13.2D^{-1.3}/s$
	150	150	32	3	$p_{i\,max} = 7.0D^{-1.4}/s$
 I section rib	203	254	82	4	$p_{i\,max} = 17.6D^{-1.29}/s$
	152	203	52	5	$p_{i\,max} = 11.1D^{-1.33}/s$
 TH section rib	171	138	38	6	$p_{i\,max} = 15.5D^{-1.24}/s$
	124	108	21	7	$p_{i\,max} = 8.8D^{-1.27}/s$
 3 bar lattice girder	220	190	19	8	$p_{i\,max} = 8.6D^{-1.03}/s$
	140	130	18		
 4 bar lattice girder	220	280	29	9	$p_{i\,max} = 18.3D^{-1.02}/s$
	140	200	26		

Support type		Curve number	Maximum support pressure
 Rockbolts or cables spaced on a grid of s x s metres	34 mm rockbolt	10	$p_{i\,max} = 0.354/s^2$
	25 mm rockbolt	11	$p_{i\,max} = 0.267/s^2$
	19 mm rockbolt	12	$p_{i\,max} = 0.184/s^2$
	17 mm rockbolt	13	$p_{i\,max} = 0.10/s^2$
	SS39 Split set	14	$p_{i\,max} = 0.05/s^2$
	EXX Swellex	15	$p_{i\,max} = 0.11/s^2$
	20mm rebar	16	$p_{i\,max} = 0.17/s^2$
	22mm fibreglass	17	$p_{i\,max} = 0.26/s^2$
	Plain cable	18	$p_{i\,max} = 0.15/s^2$
	Birdcage cable	19	$p_{i\,max} = 0.30/s^2$

Support type	Thickness - mm	Age - days	UCS - MPa	Curve number	Maximum support pressure p_{imax} (MPa) for a tunnel of diameter D (metres)
 Concrete or shotcrete lining	1m	28	35	20	$p_{i\,max} = 57.8D^{-0.92}$
	300	28	35	21	$p_{i\,max} = 19.1D^{-0.92}$
	150	28	35	22	$p_{i\,max} = 10.6D^{-0.97}$
	100	28	35	23	$p_{i\,max} = 7.3D^{-0.98}$
	50	28	35	24	$p_{i\,max} = 3.8D^{-0.99}$
	50	3	11	25	$p_{i\,max} = 1.1D^{-0.97}$
	50	0.5	6	26	$p_{i\,max} = 0.6D^{-1.0}$

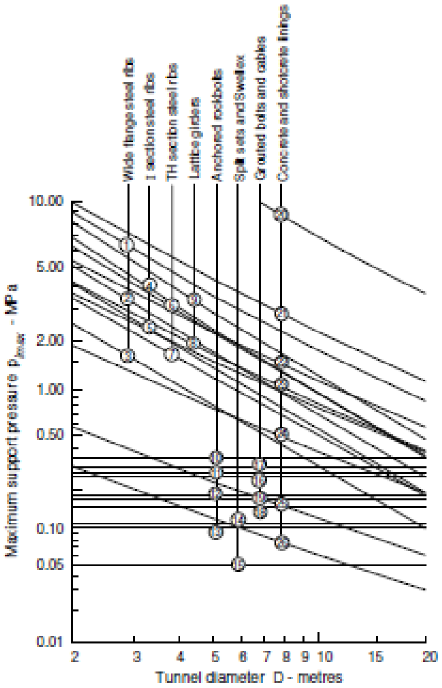


Figure 8: Approximate maximum capacities for different support systems installed in circular tunnels. Note that

Support System for Circular Tunnel

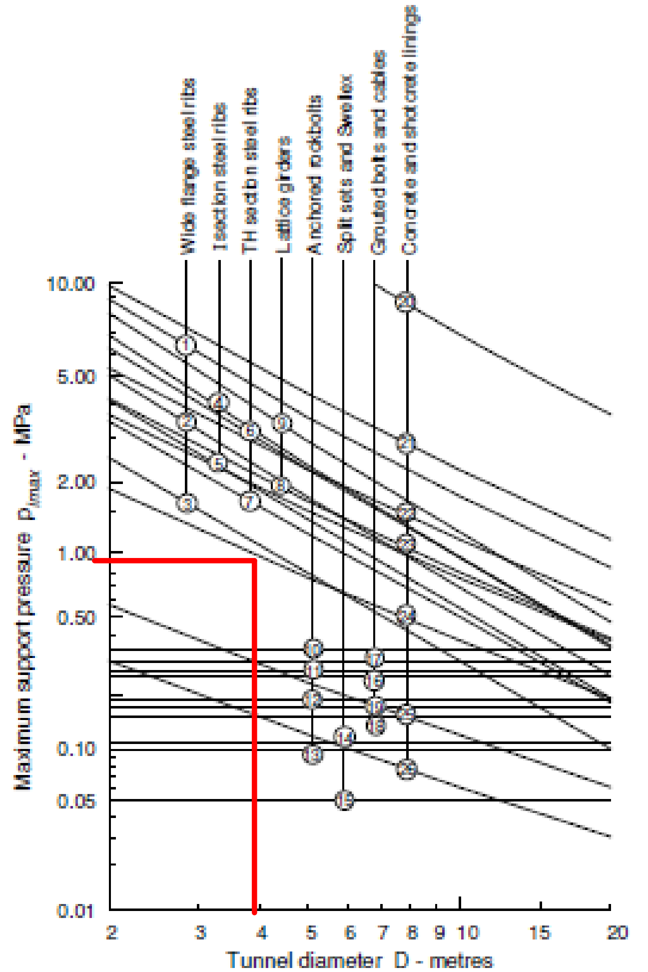


Figure 8: Approximate maximum capacities for different support systems installed in circular tunnels. Note that steel sets and rockbolts are all spaced at 1 m.

From Figure 8, select:
X – Axis – 4m tunnel diameter
Y – Axis – 1Mpa Support Pressure

In this **figure number** are given, which are corresponding to support measures provided in figure in last slide.

Therefore, now numbers can be select for support pressure greater than > 1MPa can be selected.
And support can be selected to support tunnel.

There are many constraints of this method which are not covered in this presentation. To know more, read Tunnels in Weak Rock paper by Hoek.

Support System for Circular Tunnel

The required **internal support pressure is 1MPa**. Therefore the provided shall be more than 1Mpa.
In graph in **slide 14, there are curve numbers 1 to 26** which represents type of support like steel ribs, lattice girder, shotcrete, concrete lining, rock bolts which are presented in figure provide **slide no 13**.

From figure 8 in slide 13, you can decide the type of support you need to provide to support the tunnel.

Support system depends upon the rock class tunnel is going through like in
Good Rock – Spot Bolting & Shotcrete
Fair Rock – Pattern Bolting & Shotcrete
Poor Rock – Pattern Bolting & Shotcrete
Very Poor to Extremely Poor – Steel Ribs and Shotcrete

Here Tunnel is passing through fault zone so the it is very poor to extremely poor rock. Therefore the support system should be steel ribs .

Support System for Circular Tunnel

From **Slide 14**, we will **select no. 3** curve number as it is providing internal support pressure more than required support pressure of 1Mpa .

Curve No. 3

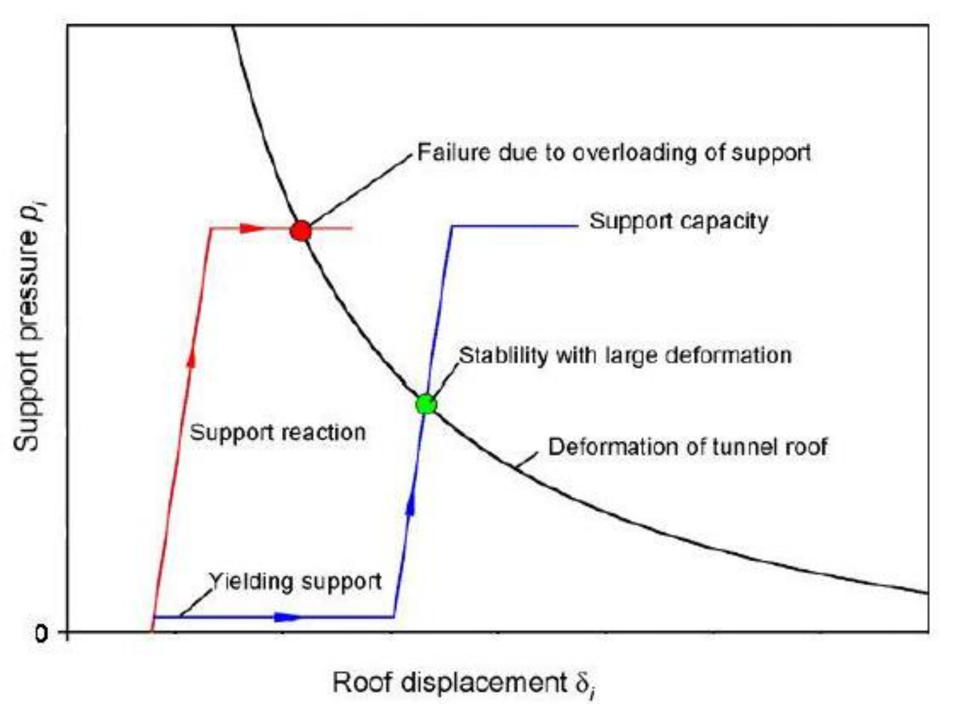
Maximum Support pimax = $7.0\ D^{-1.4}/s = 7.0 \times 4^{-1.4}/1$

= 4.9 MPa is the provided **pressure by Steel Ribs** spaced at 1m distance.

Ground Reaction Curve Vs Support Reaction

Ground Reaction Curve is shown as curve and Support Reaction Curve is shown
as linear .

- **Red line** shows failure of support if support being applied as the deformation of tunnel just initiated. In this case as tunnel deforms all the pressure come on support and it fails.
- Blue line shows the right time of installing supports, allowing a certain amount of convergence in tunnel (like 2% in example we adopted).



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