REINFORCED RIB SHOTCRETE (RRS) FOR UNDERGROUND TUNNELS IN INDIA

by

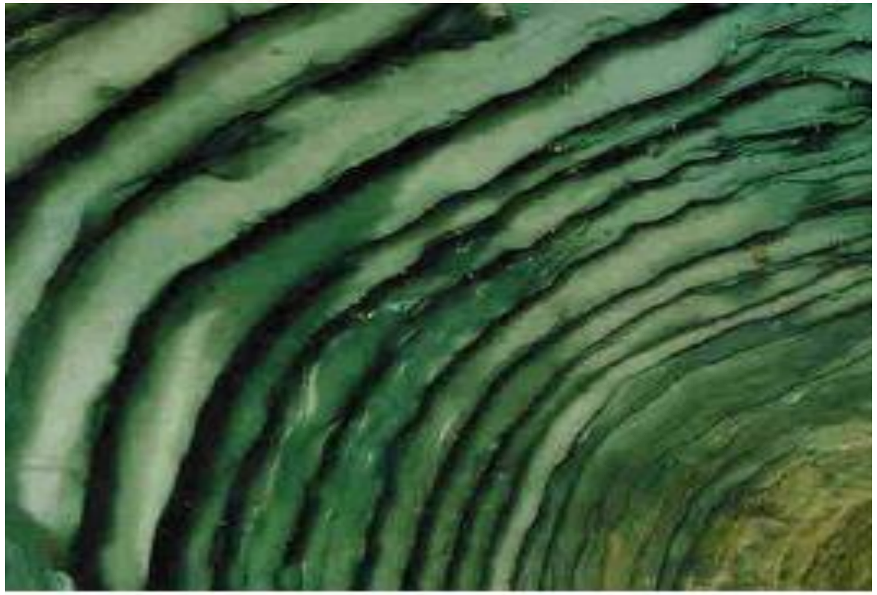
AKX MALIK

Engineering Manager (Tunnels)

Akx@Lntecc.com

INTRODUCTION

- Tunnel Design methods and Support systems
- Let’s think of alternative supports for sustainability.
- How RRS got introduced as a support system?
- Designing RRS for tunnels
- Tunnels in weak rocks, hard rocks
- RRS as a flexible, cheaper, leaner support
- Shotcrete here – Permanent **sprayed concrete** lining
- **Unexplored in Indian sub-continent**



Application of RRS in National theatre Stadium, Oslo

Various Tunnel Design Methods

Empirical Design – *Based on Q, RMR classification etc*

Analytical Design – *IS 13365 (2), IS 15026, B. Singh (1995)*

Numerical Design – *Phase2/RS2, FLAC, 3DEC, UnWedge etc.*

?

What happens when a rock mass is excavated?

How do various support systems work?

Tunnel support system

Depends on

- Rock mass conditions
- Rock behavior
- Geological profile
- In-situ stress conditions
- Structural discontinuities
- Groundwater conditions

Function of Support System

- **Reinforcement** – Strengthening of Rock Mass
- **Suspension** – of loose rock block
- **Confinement** – of exposed surface

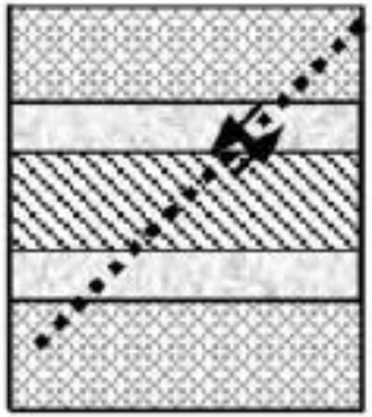
RRS is specifically recommended for very poor to extremely poor rock mass

Tunnel support system

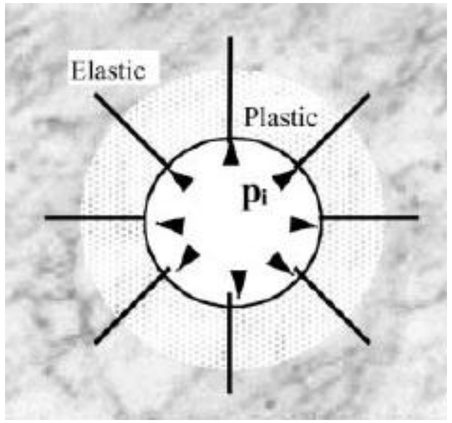
For e.g. Rockbolts

- Increases Properties – higher effect of confinement in low strength (Residual vs peak)
- Provides a confining stress (negligible but effective)
- Increases shear strength
- Tensile and shear resistance to joints and prevent sliding
- Helps in Arch formation – artificial arches

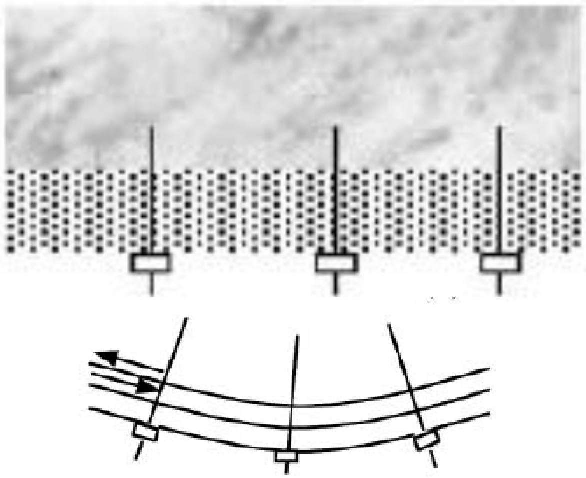
However, all supports work in conjunction to each other, not independently



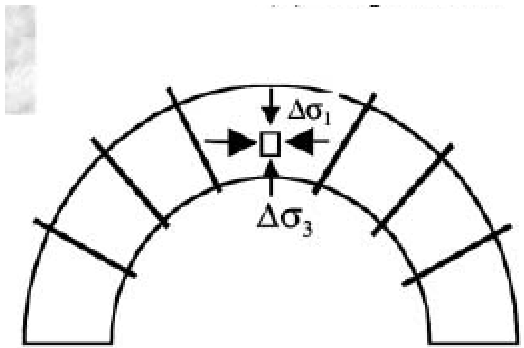
Increases property



Provides Internal pressure



Holding/ suspension of failure zone



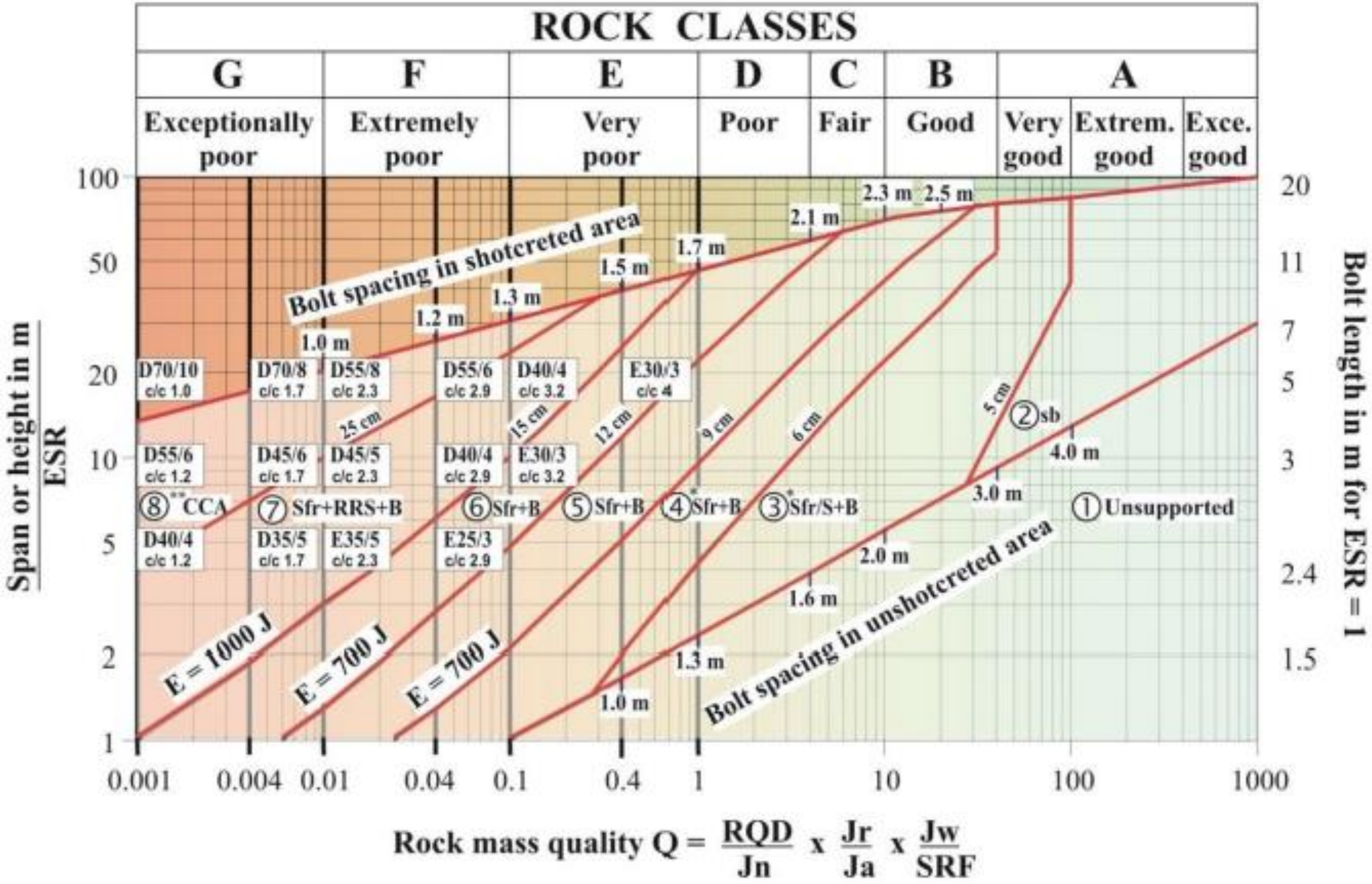
Arch formation (in-situ stresses are favourable)

Development of RRS

RRS was first presented by Dr. Nick Barton and Dr. Grismtad in 1993 at World Tunneling congress, and later taking data from **3 tunnels** where it was applied (with Q less than 0.4), it was incorporated in **Q Chart (2002) .** The three tunnels are:

- Froya Subsea tunnel
- Laerdal tunnel (~9m span - Longest tunnel in the world)
- National theatre stadium in Oslo (22m span).

A **numerical analyses** for three different sizes were performed (**5m, 10m and 20m**) to check **shear forces** and **bending moments** in such spans for different reinforcements (4 bars, 6 bars), and compared with data from the three tunnels.



Q Rock support chart, Barton & Grimstad (2014)

Design of RRS system

Design methodology

- Deformation
- Bending Moment
- High deformations-Load bearing member

Behavior

- **Deformation < critical strain**

  Reinforcement support

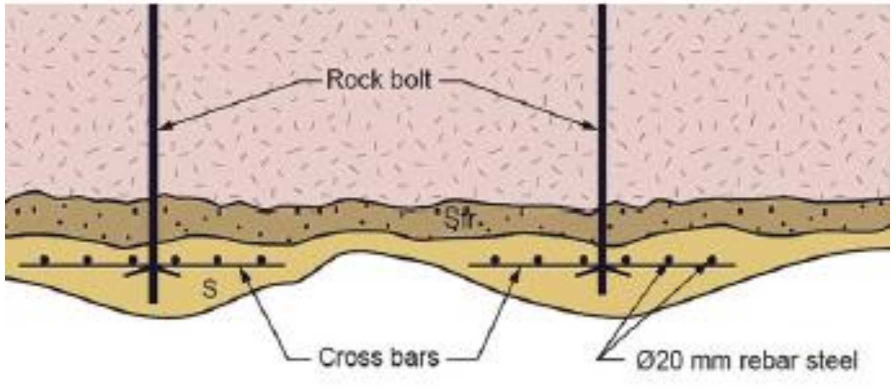
  Non-arched profile-sufficient

  Aesthetics – separate layer

- **Deformations > critical strain**

  Load bearing member

  Arched profile

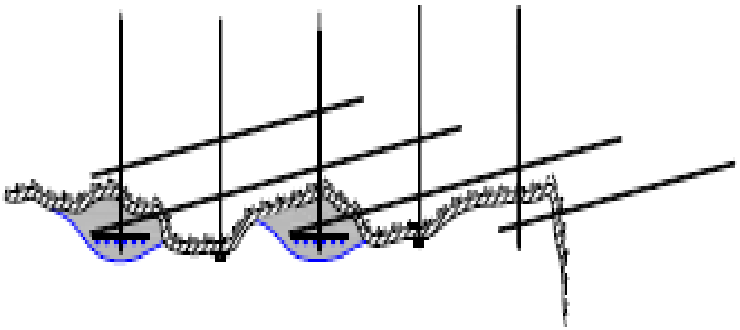


Figures: Execution of RRS in a tunnel in Oslo (Grimstad et al, 2003 and NPRA, 2010)

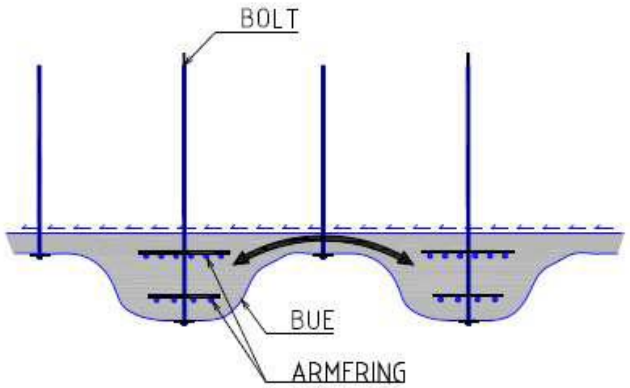
Elements used in RRS design (NGI handbook)

The main parameters to be chosen in RRS are:

- Single or double reinforcement (6, 6+2, 6+4)
- Shotcrete thickness (150-550mm)
- Reinforcement dia (16-20mm)
- Spacing between the ribs (1.5m-3m c/c)
- The bolt support into the rockmass



Single Reinforcement
For uniform loads



Double Reinforcement
For non- uniform loads

Application of RRS

When **Sprayed concrete** is **insufficient** to bear rockload or blasts with large overbreaks.

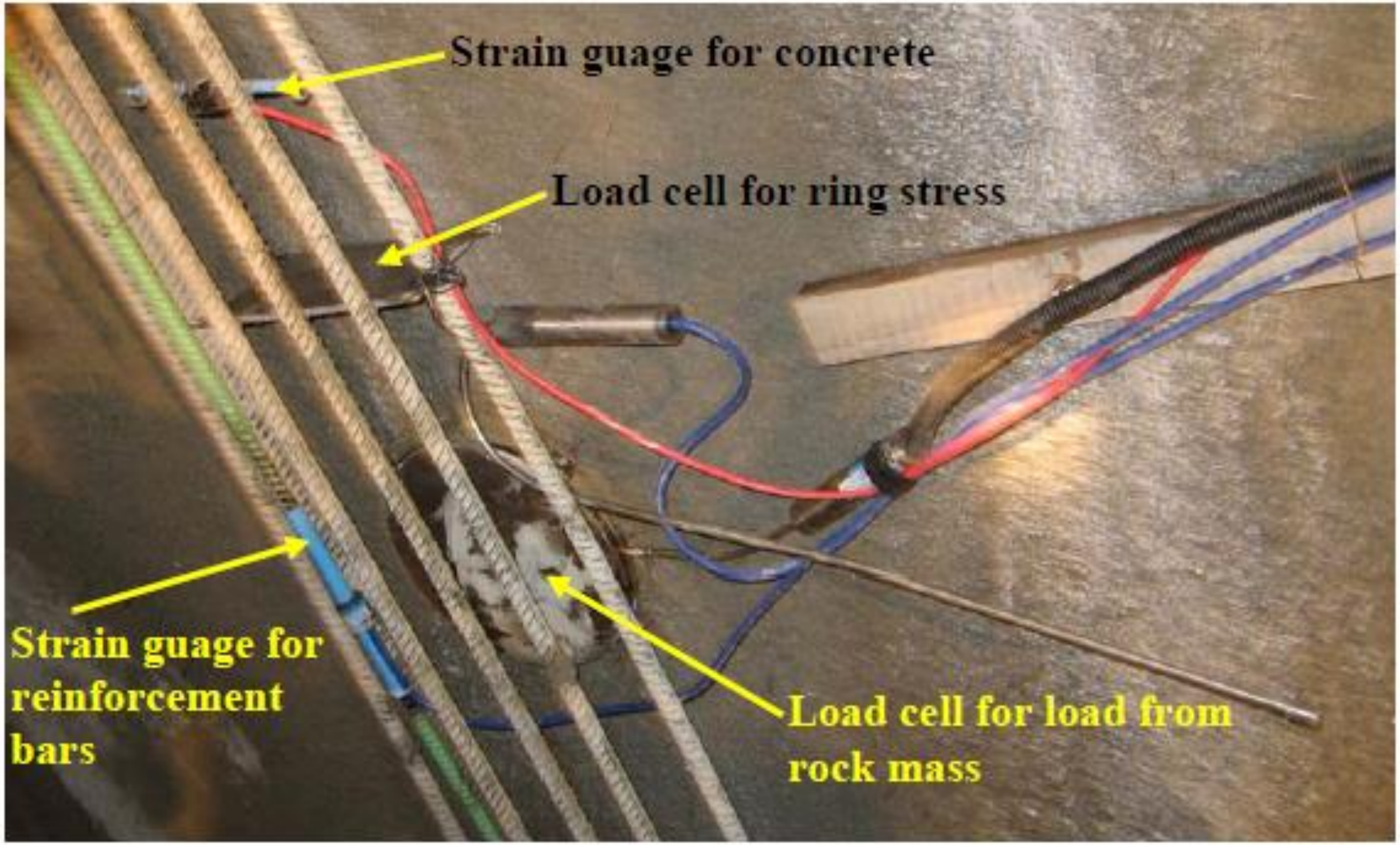
Characteristics

“RRS typically consists of **six rebars** c/c **10 cm** mounted to rock bolts **c/c 1.5m to 3m** along the tunnel periphery and covered with **sprayed concrete**.

12-15 cm thick layer of **SFRS** is applied **before** installing ribs, to act as **temporary support** and **smooth out** rock surface. In design this layer can be **included** in the total thickness.

RRS is installed in Norwegian tunnels instead of the in situ cast **concrete lining** (CCA). CCA was common in extremely and exceptionally poor rock (Q= 0.1 – 0.001) earlier. RRS is in shape and support capacity similar to sprayed lattice girders, but offer more **flexibility less time** in application because **RRS is not prefabricated**.

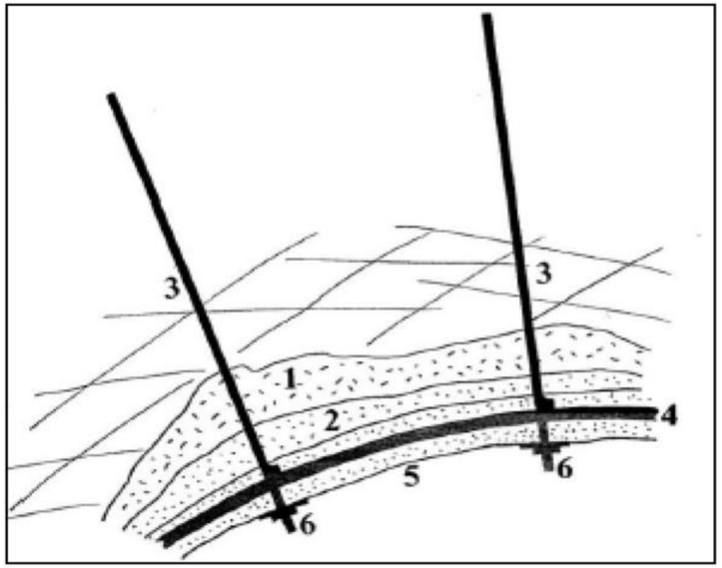
Instruments for RRS



Use of RRS in different tunnels (outside India)

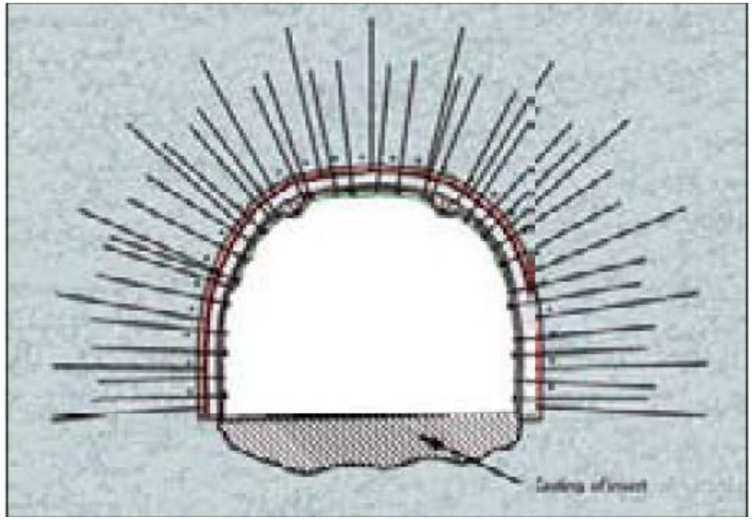
Few Case studies of rock falls, RRS application:

1. Froya Subsea Tunnel
2. Laerdal Tunnel
3. National Theatre Oslo
4. Loren Road Tunnel
5. Finnfast Subsea Tunnel
6. Baerum Railway Tunnel
7. Soras Road Tunnel
8. Ra Road Tunnel



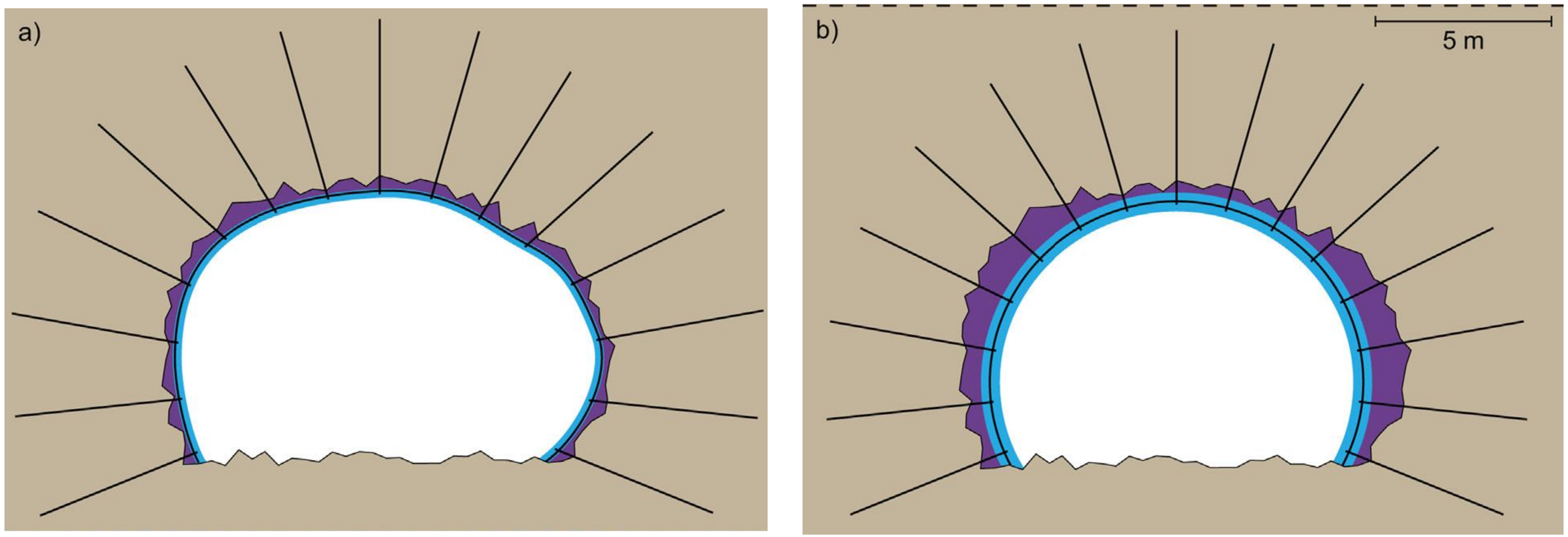
Following support measures were taken in the Laedral tunnel after a rock fall incident :

Support	Specifications
Blast round	2.5 m
Spiling Bolts	6m long
Fiber reinforced shotcrete)	250 mm
Rock Bolts	5 m long, 1.5 m c/c
RRS : Single Layer	2.5 m c/c



(a) Rock Fall in Laedral Tunnel; (b) Support protection using rock bolts, SFRS and RRS

Unarched and arched RRS



Transition from unarched to arched RRS in recent years (leading to abrupt increase in support system) – need to understand rock behavior, support requirements, geological conditions, functional requirements before making such decisions.

Discussion on Application of RRS

RRS works as a **load bearing** support when deformations expected in the tunnels are high (~strain >1%). However, if the deformation expected are less (Strain <1%), then RRS acts as a **reinforcement support**.

We need RRS to act as a **load bearing support** when **high deformations** are expected, then **arched profile** is necessary (prevalent in the crown of the tunnel). But, if it acts more as **a reinforcement** where **low deformations** are expected, and not contributing to arch action, then RRS can be **applied locally** if necessary.

“Be careful of the unwanted **abrupt increase** of the support thickness (waste of resource), from simple reinforcement with rock bolts and sprayed concrete to load-bearing constructions, such as **arched RRS**. A more gradual transition from rock bolts and sprayed concrete to load-bearing support would be logical”

Ribs carry not only **the rock mass** above, but **also the distributed load** from the rock mass between the ribs.

If **no cast concrete** ring is installed in the **invert,** then it is very important **to install extra rock bolts through the lower part of the ribs**, near the invert in order to avoid unwanted deformations or collapses.

It should be stressed that the **support pressure** might **vary** significantly related to corresponding Q values. Therefore, in the **lower rock mass qualities** it is better to **observe** the **deformations** some time after temporary support, before making the design for the RRS. In the better rock mass qualities **stress reduction** will often occur during deformation. Hence, the rock mass will take a large part of the load after deformation, and the need for **extra support** will be **reduced**.

Finite element analysis

Parametric Study- Variation in SFRS and RRS thickness

Material Parameters – Typical Very poor rock

- Deformations
- Bending Moment

Type of support	Analyses and Support Method
Support Type 1	Roof –200 mm SFRS, 450 mm RRS (II) Wall – 200 mm SFRS, 450 mm RRS (II)
Support Type 2	Roof –200 mm SFRS, 450 mm RRS (II) Wall – 100 mm SFRS, 350 mm RRS (I)
Support Type 3	Roof –200 mm SFRS, 450 mm RRS (II) Wall – 100 mm SFRS
Support Type 4	Staged relaxation Type 1 support
Support Type 5	Staged relaxation Type 2 support
Support Type 6	Staged relaxation Type 3 support

Results & Discussion

A) Deformations

No Major change at different locations

B) Bending moment

Bending moment in 4,5,6 is considerably lower than 1,2, 3. Few cases increasing and should be further substantiated with instrumented data from site.

Bending Moment (MNm)	Support Type 1	Support Type 2	Support Type 3	Support Type 4	Support Type 5	Support Type 5
Maximum	2.42	1.77	1.51	1.06	0.95	0.93
@ Crown	0.88	0.66	0.64	0.78	0.84	0.51
@ Spring Line	1.95	1.42	0.57	0.47	0.78	0.78
@ Wall	1.89	1.45	-	0.62	0.46	-

Benefits of RRS over Lattice Girders and wire

- Challenging **3D shuttering** during final concreting works of LG
- Complex LG design for curves in tunnels.
- **Unbolted** Lattice girders invite deformations and yielding
- Easy **handling** of RRS, especially in cases of large caverns.
- In deep overbreaks, difficult to make good **contact** between tunnel perimeter and LG.
- For LG rock mass deformation is needed to make ‘solid’ but only **local** contact. Rock mass strength may be reduced in the wrong places as a result.
- When load starts to be applied by less stable parts of the excavation perimeter, the **footings** of the lattice girder will inevitably **deform** by a finite amount.
- **Strain** must build up in the steel bars of LG for it to apply **resistance** to further deformation.
- Final lining is installed late (years, improper investigations for GRC, LDPs), which in reality is a **dangerous phase**, notable collapses occur due to unexpected anisotropic loading by jointed rock, which is suddenly not loading as expected in the isotropic modelling.

Conclusion

- RRS for very poor to extremely poor rock mass conditions
- Think ahead of conventional methods - **Lattice girders, wiremesh, cast lining**
- Reduce **complexities** in tunneling. Study rock behavior and design support.
- RRS a good alternative- **Thinner liner support, flexible application**
- Higher BM – lead to thicker support**, proper analyses**
- Arched & Un-arched Roof – careful selection
- Reduces Unwanted extra support measures
- **Reduce cost & prevent delays**

THANK YOU

Let's Build Sustainable and Resilient Tunnels