

ROCKFALL MITIGATION MEASURES FOR HILL ROADS



Presented by:

Prof. T. N. Singh

Geo-sciences Chair Professor, IIT Bombay

CONTENTS

INTRODUCTION

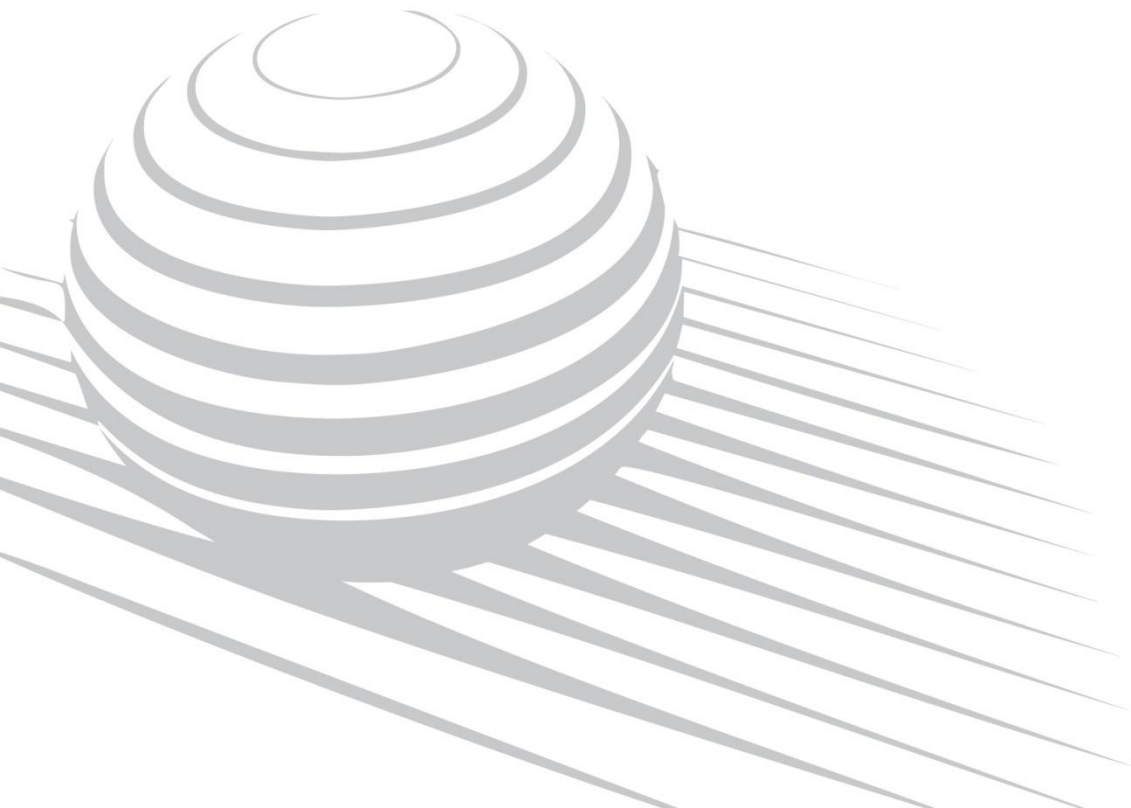
ROCKFALL MITIGATION MEASURES

CASE STUDIES

SUMMARY

REFERENCES

INTRODUCTION



INTRODUCTION

IMPORTANCE OF ROCKFALL PROTECTION



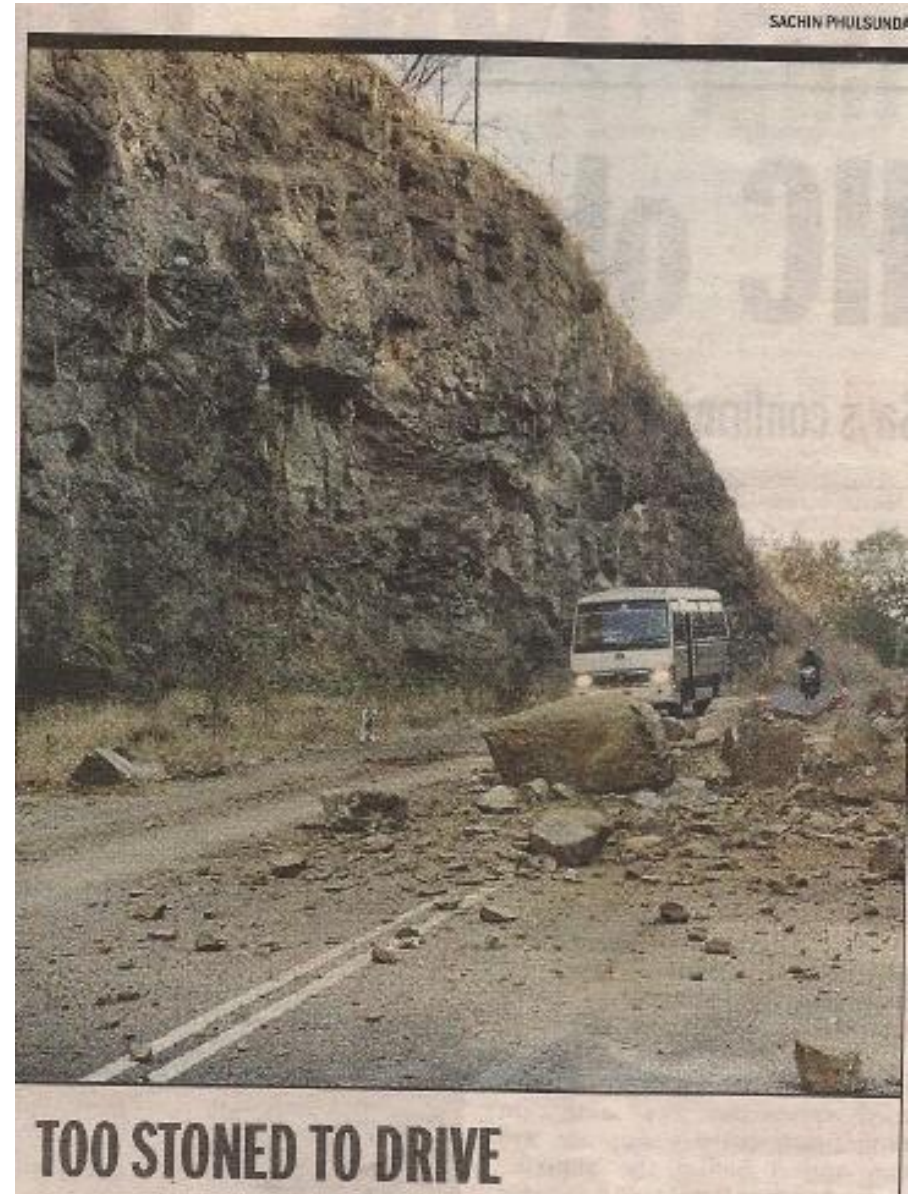
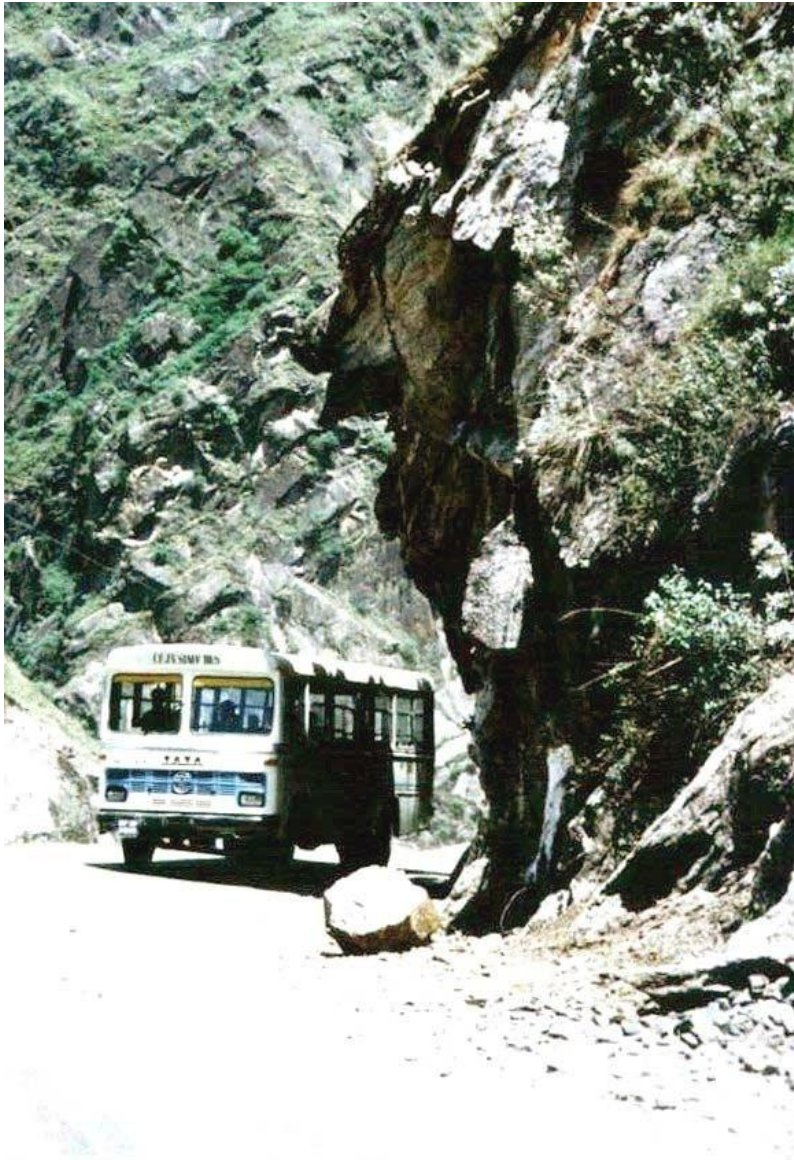
Roads, railways, infrastructure and residential areas frequently face the risk of rock slope instability.

..and something must be done if we want to safely use roads and protect lives!



INTRODUCTION

IMPORTANCE OF ROCKFALL PROTECTION



INTRODUCTION

IMPORTANCE OF ROCKFALL PROTECTION

Panthal Bridge



INTRODUCTION TYPICAL PROBLEMS- HILL ROADS

The typical problems encountered during any kind of hill road development works are mainly:

- 1) Slope stability problems on upslope and valley sides
- 2) Subsidence of Pavement
- 3) Erosion

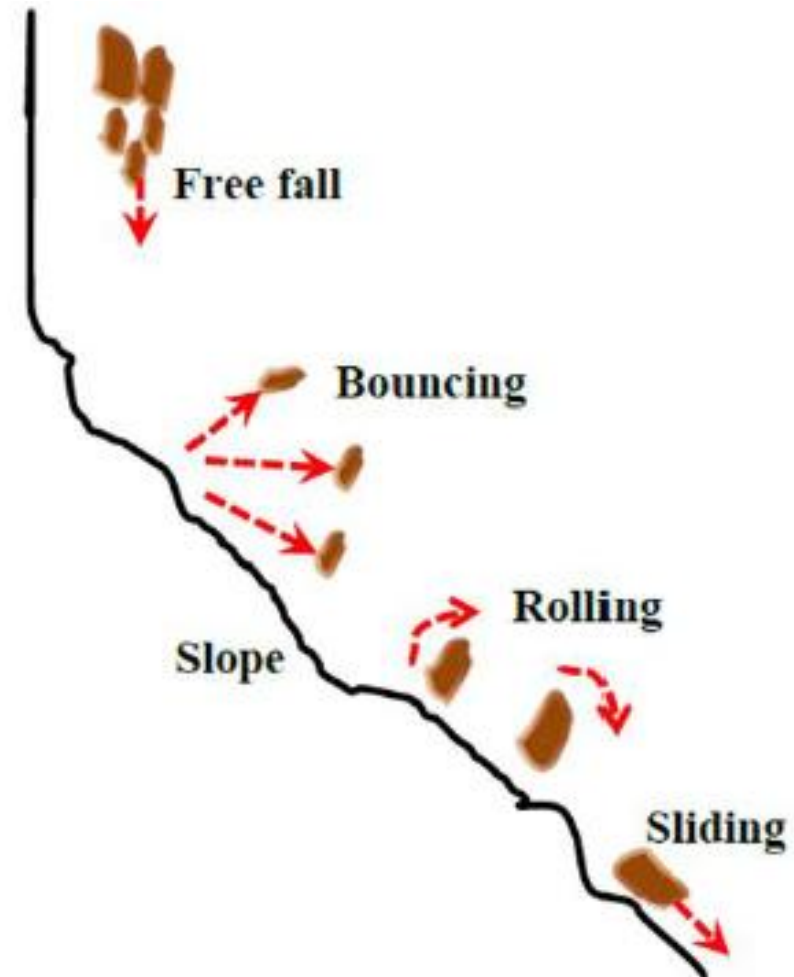
Drainage



INTRODUCTION

ROCKFALL -DEFINITION AND TYPES

- natural downward motion of a detached block or debris of blocks which may involve the process of
 - free falling
 - Bouncing
 - rolling and
 - sliding



INTRODUCTION

ROCKFALL -CAUSES

- causes of rockfalls are dependent on :
 - weather conditions in the area
 - geology and structural conditions at site
 - including steep rock slopes
 - zones of weak rocks
 - adversely oriented joints, fractures and faults.

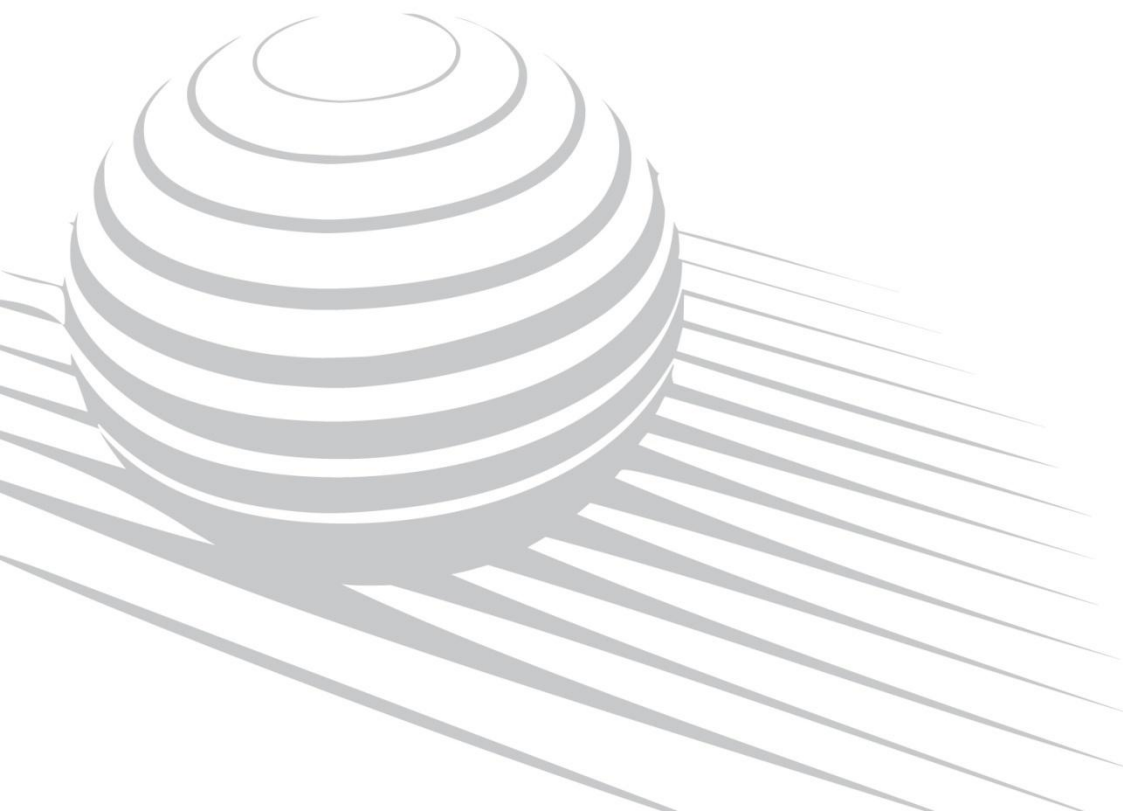


INTRODUCTION

ROCKFALL -CAUSES

- Climatic variation
- Steep slopes
- Loss of shearing strength
- Presence of highly fractured rock mass
- Water / ice
- Removal of support
- Earthquakes
- Other vibrations





ROCKFALL MITIGATION MEASURES

**TRADITIONAL AND
MODERN SOLUTIONS**

ROCKFALL MITIGATION MEASURES

- **Warning Measures**

- Help in the detection of an impending rockfall or slope movement
Eg. Raksha Dhaga along Konkan Railway route.



Applicable on Hill Roads

- **Protection Measures**

- Protect the area by controlling the direction and distance of fall.
Eg. Drapery system, Berms, Ditches, Barriers, Rock sheds.

- **Retention Measures**

- Retains the debris from falling down the slope.
Eg. Mesh with anchors

- **Prevention Measures**

- Act to control the detachment of rock/ stabilize the rock slope
Eg. Rock anchors, blasting, and trimming techniques commonly adopted in Border Roads.

(Source: IRC-HRB-Special Report-23)

Rockfall Mitigation Measures

Applicable or Hill Roads

Rockfall Warning Measures

Fences and warning signals

Rockfall Protection Measures

Berms/Benching

Drapery system

Rockfall Barriers & Embankments

Rockfall Ditches and Trenches

Rockfall Attenuators or Hybrid Barriers or Hanger Nets

Debris flow Barriers

Rock Sheds and tunnels

Erosion Control Mats/blankets and other Bio-engineering Methods

Rockfall Retention Measures

Mesh with nails or anchors surficial strengthening

Shotcreting

Chemical stabilisation of slope face

Rockfall Prevention Measures

Reinforcing the slope face

Rock Removal

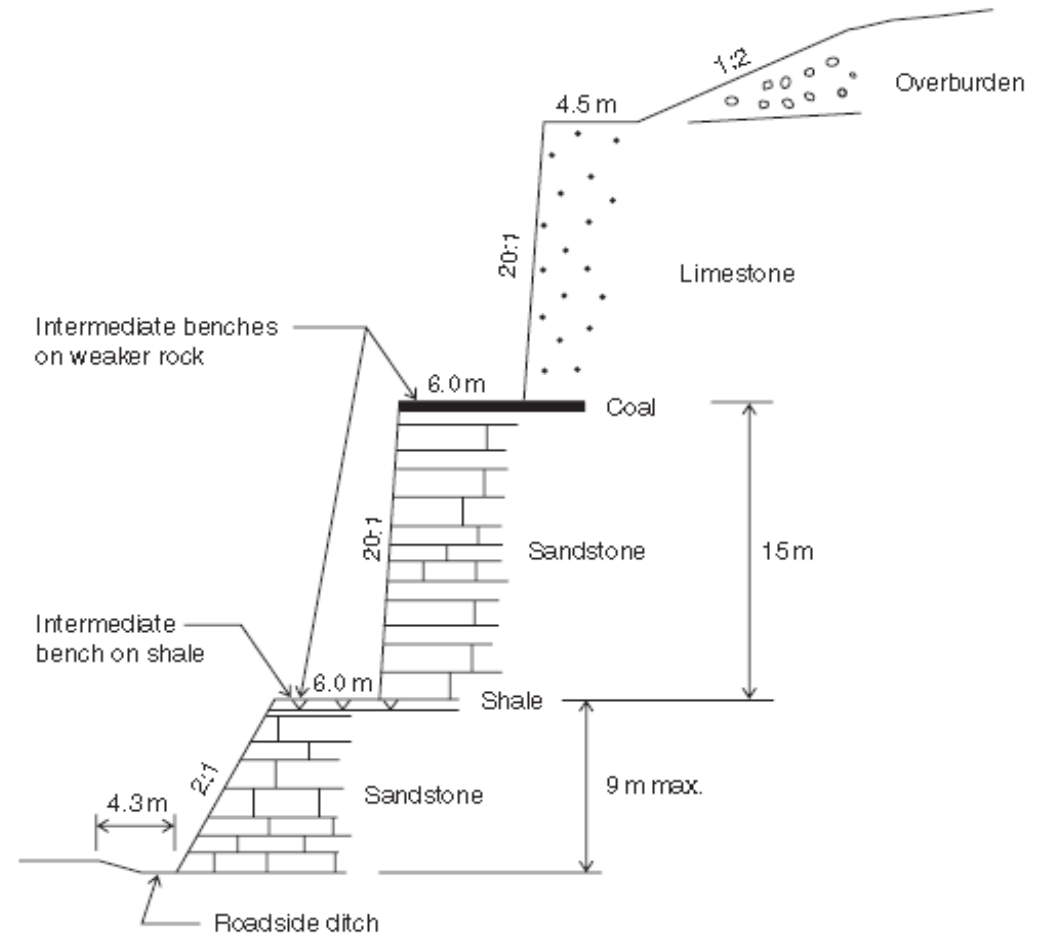
Drainage Systems

ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

BERMS/BENCHING

- a popular technique
- used where a break in slope is required to restrict rockfalls, especially in cut roads.
- very effective means of reducing the energy of rockfalls
- frequently used on permanent slopes.



Configuration of benched cut in horizontally bedded shale and sandstone, with weaker coal and shale formations located at toe of cut faces.

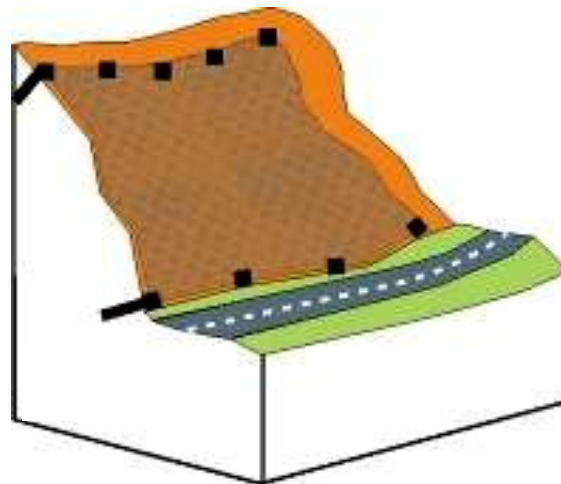
(Source: IRC-HRB-Special Report-23)

ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

DRAPERY SYSTEM

- Aimed at controlling rockfall along the slope.
- function is to let the small debris collected at the toe of the slope.



ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

DRAPERY SYSTEM

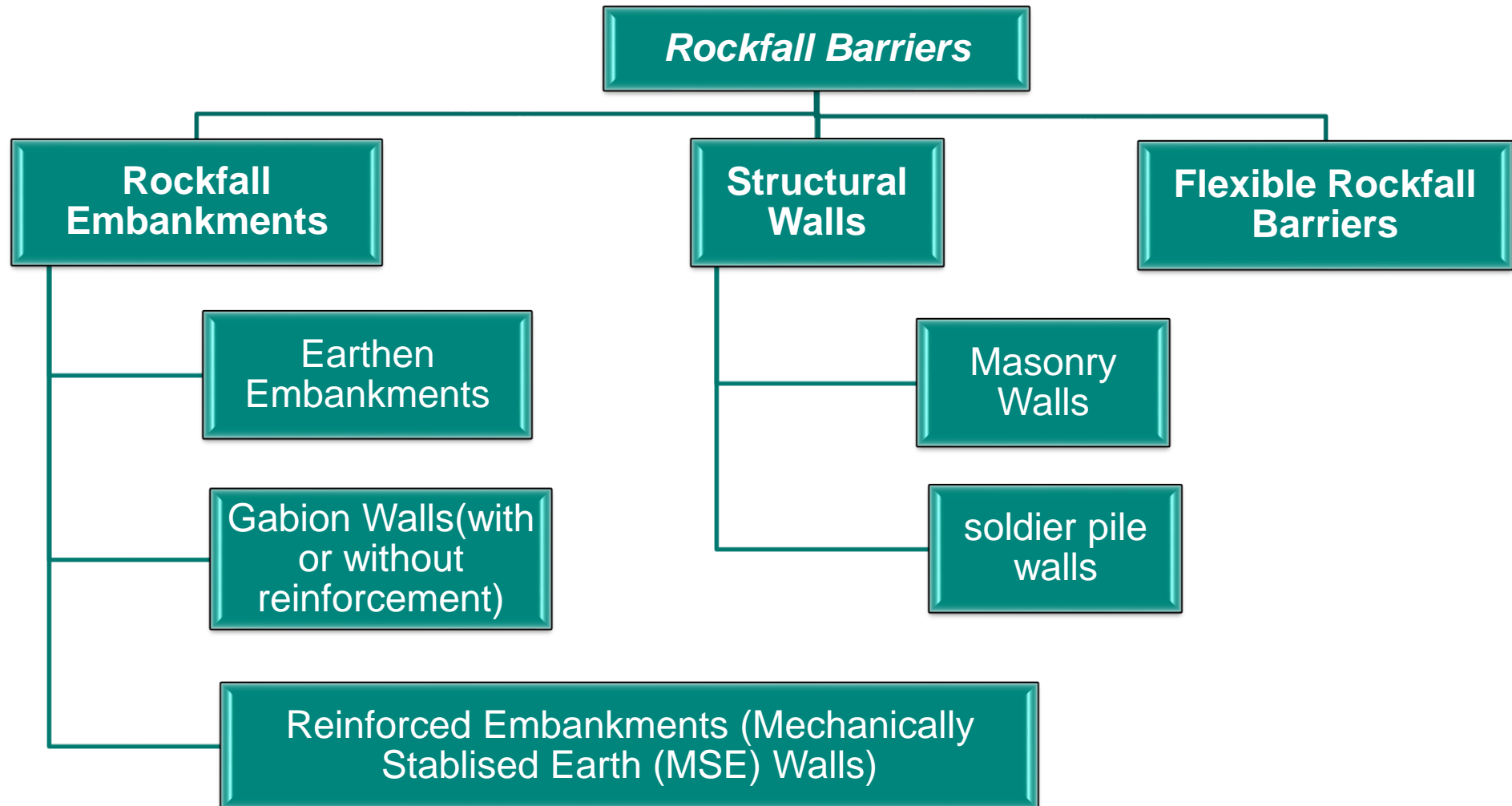


ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL BARRIERS

- Structures aimed at catching and stopping the falling rock.



ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL BARRIERS

- Barriers of variable geometry are often the best solution when it is impossible to control the rock fall.
- chosen in relation to the energy of the rock falling phenomena.

ROCKFALL MITIGATION MEASURES

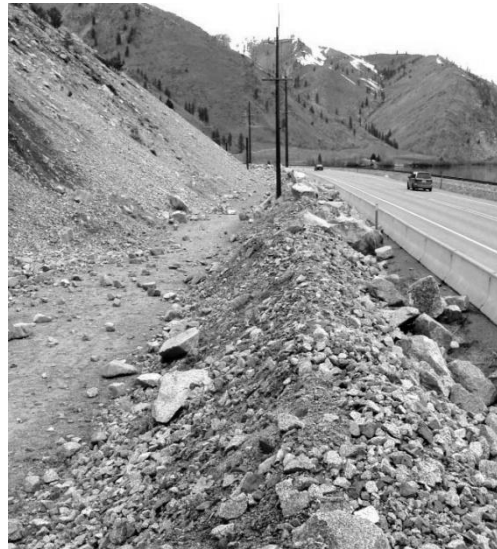
ROCKFALL PROTECTION MEASURES

ROCKFALL BARRIERS

ROCKFALL EMBANKMENTS



Conventional earthen berms



Gabion wall with reinforcement



Reinforced Embankments

(Source: IRC–HRB-Special Report-23)

ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL BARRIERS

STRUCTURAL WALLS



Concrete barriers



Masonry walls, either mortared or dry stack



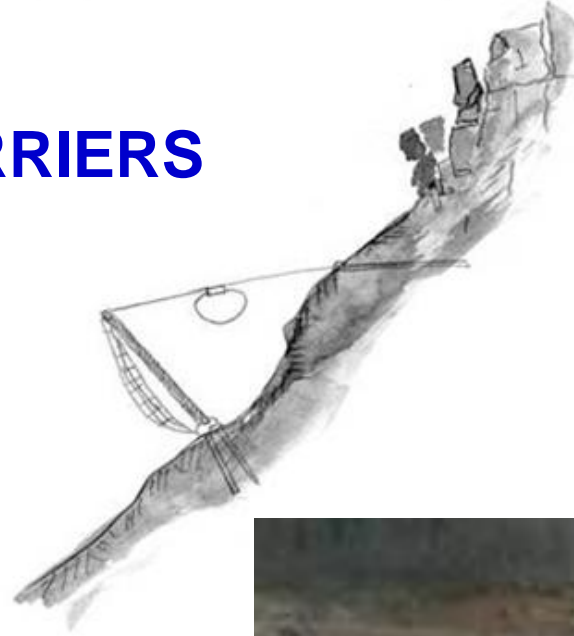
Timber Soldier-pile walls

ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL BARRIERS

FLEXIBLE ROCKFALL BARRIERS



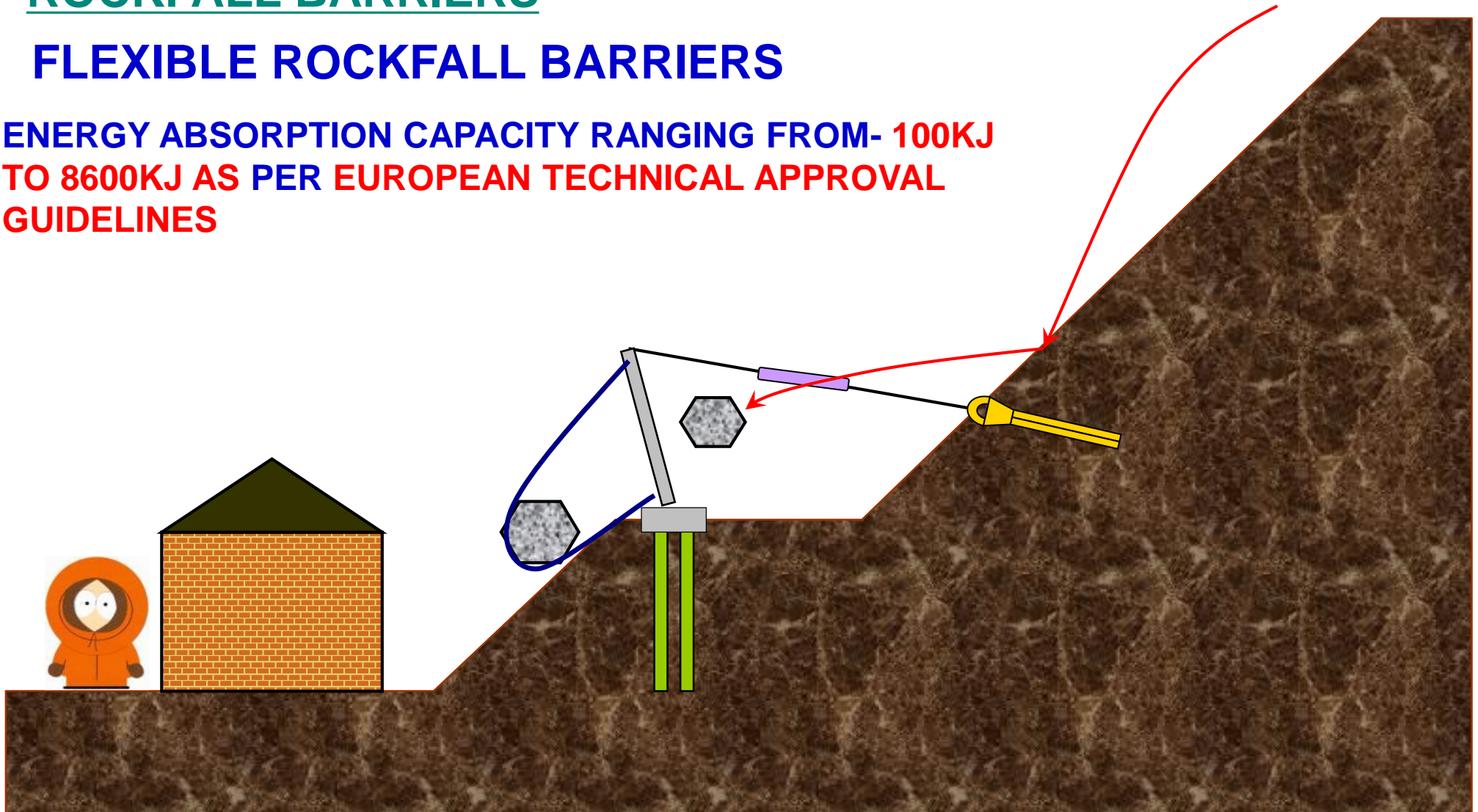
ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL BARRIERS

FLEXIBLE ROCKFALL BARRIERS

- ENERGY ABSORPTION CAPACITY RANGING FROM- 100KJ TO 8600KJ AS PER EUROPEAN TECHNICAL APPROVAL GUIDELINES

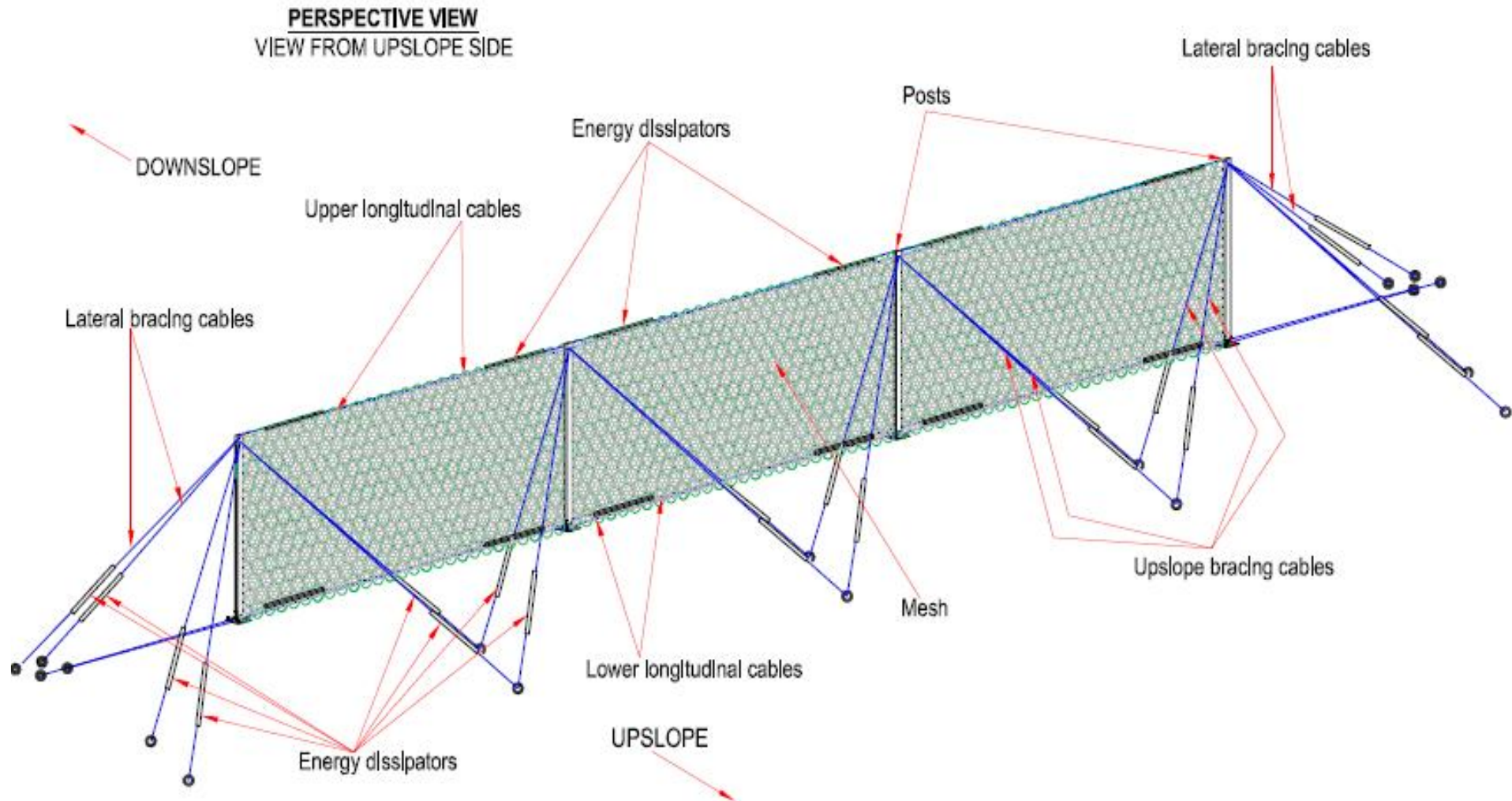


ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL BARRIERS

FLEXIBLE ROCKFALL BARRIERS

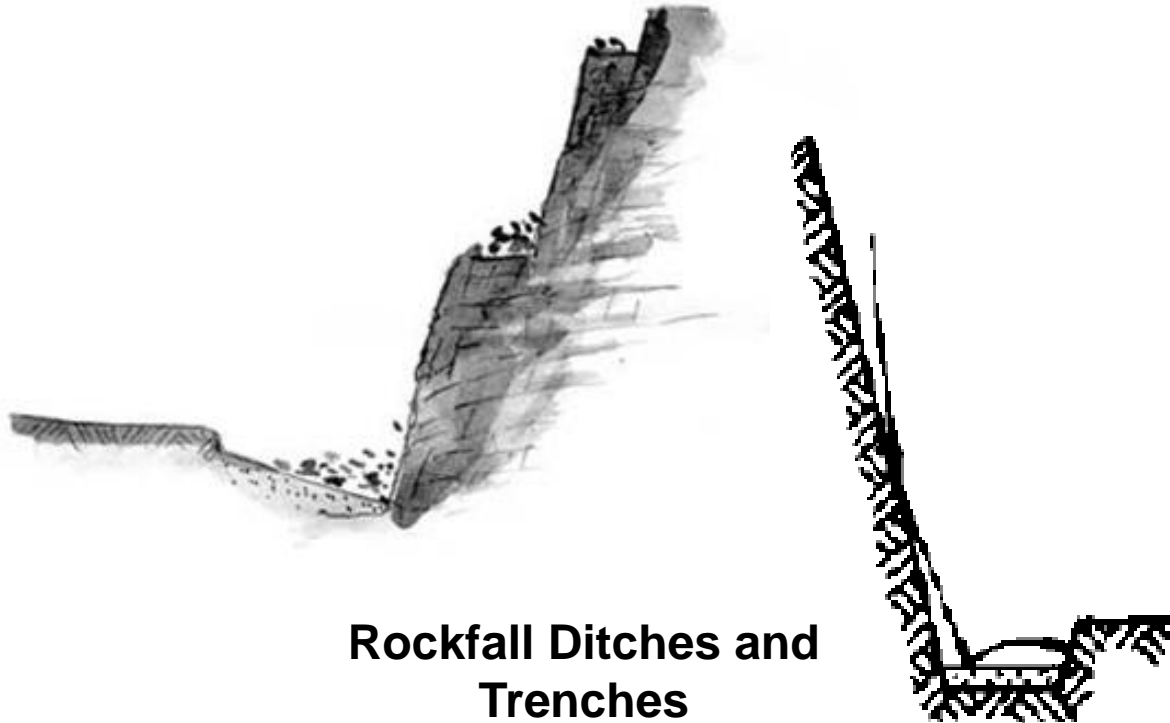


ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL DITCHES AND TRENCHES

- made at the toe of the slope to contain the falling rocks from the slope.
- one of the most effective permanent Rockfall mitigation systems for most highways when properly planned.



**Rockfall Ditches and
Trenches**

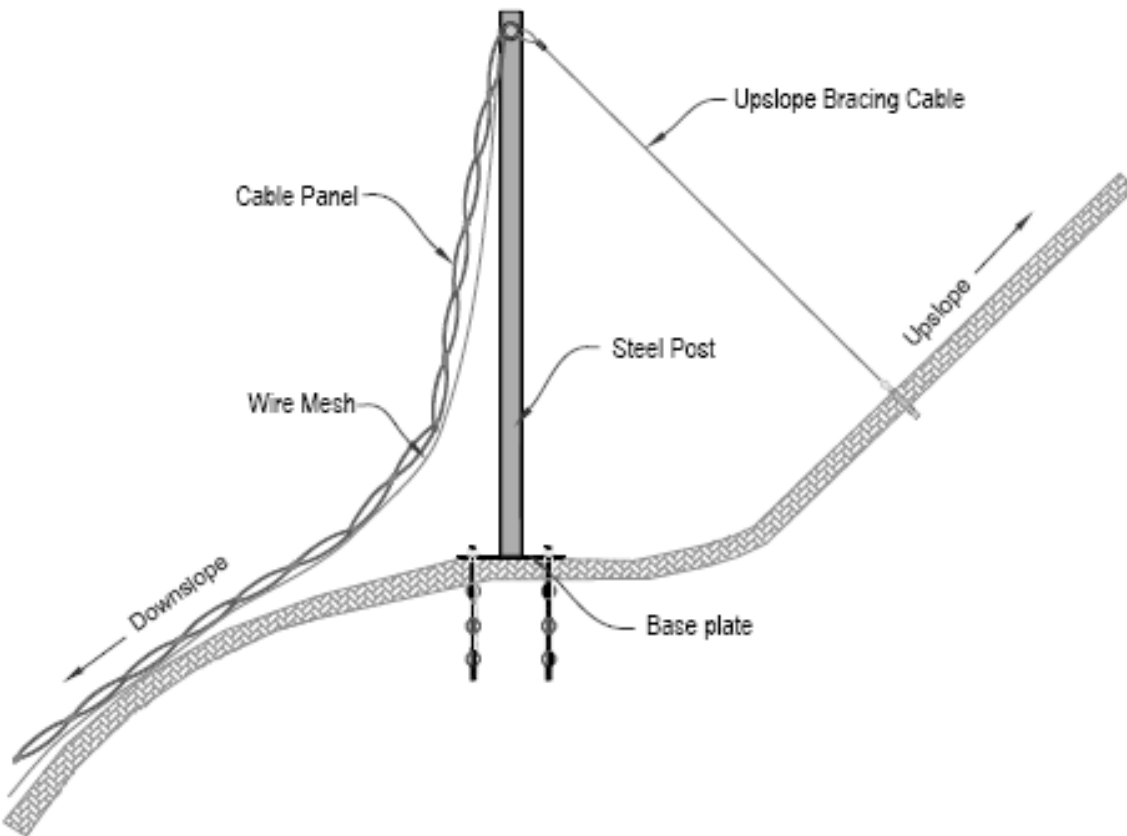
(Source: IRC-HRB-Special Report-23)

ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL ATTENUATORS OR HYBRID BARRIERS OR HANGER NETS

- a combination of rockfall protection drapes/rockfall nettings and flexible rockfall protection barriers without bottom supporting ropes.



Example of a rockfall attenuator system

ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL ATTENUATORS OR HYBRID BARRIERS OR HANGER NETS



ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCKFALL ATTENUATORS OR HYBRID BARRIERS OR HANGER NETS



Rock Momentum greatly reduced as panel and rock vertically rise

ROCKFALL MITIGATION MEASURES

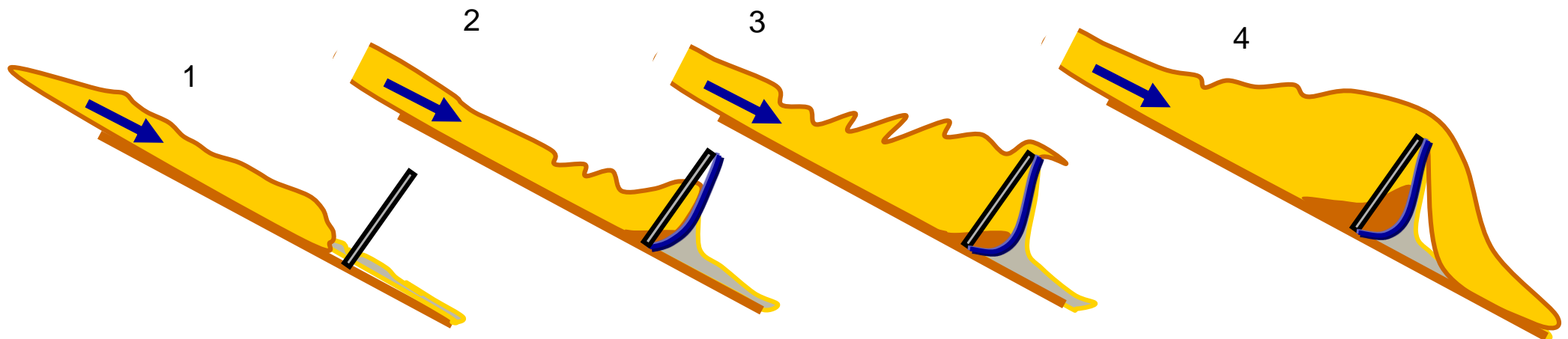
ROCKFALL PROTECTION MEASURES

DEBRIS FLOW BARRIERS

- made of flexible ring nets withstands high static & dynamic loads.
- separates the water from debris thus reducing the destructive force.



Debris Flow Barriers

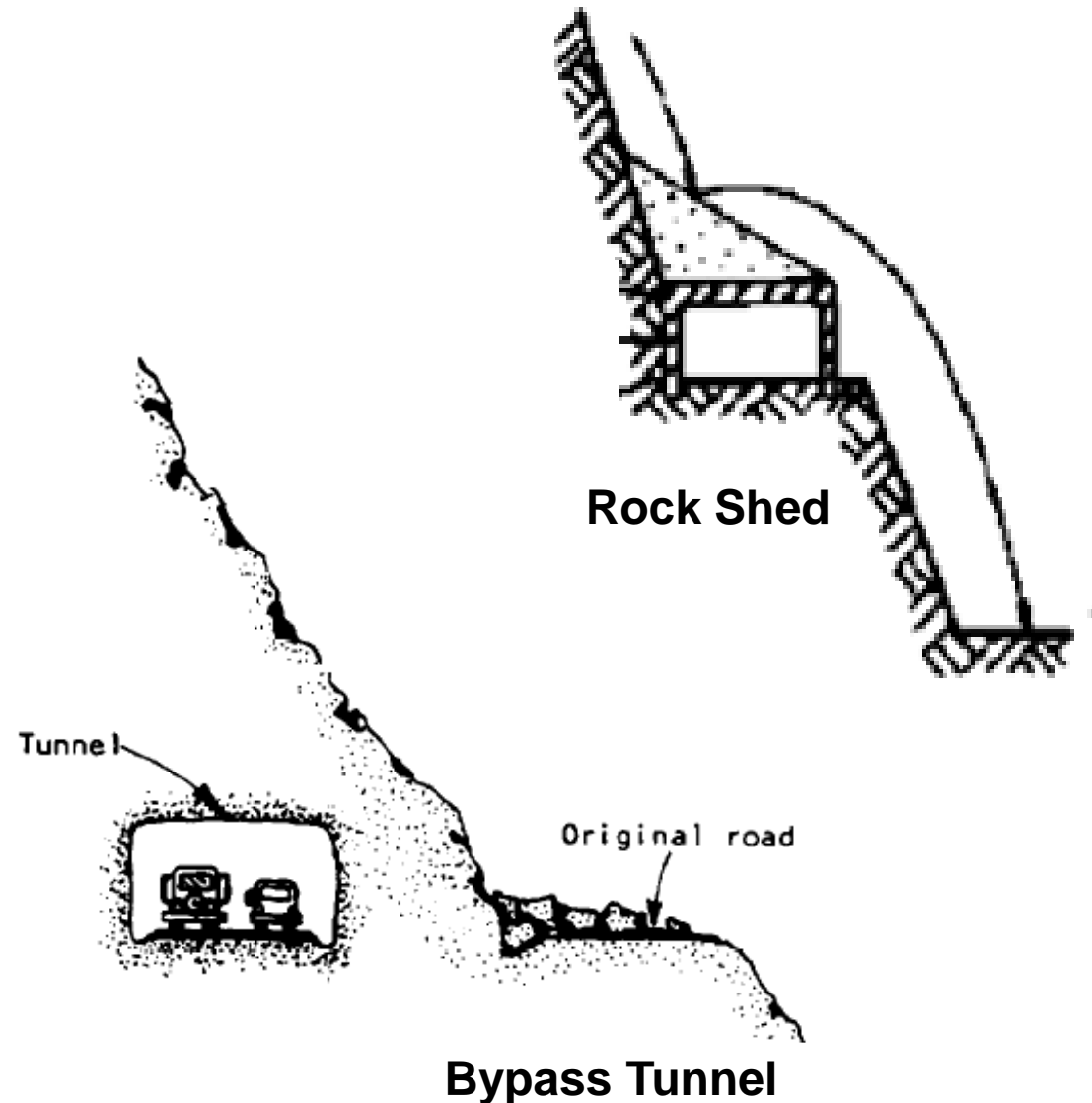


ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCK SHEDS AND TUNNELS

- are widely used on steep slopes above narrow railways or roadways.
- requires a steeply sloping roof covering a relatively narrow span.



ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

ROCK SHEDS AND TUNNELS



Typical rock shed construction: (a) Reinforced concrete structures with horizontal roof covered with layer of gravel (b) Sheds constructed with timber and reinforced concrete with sloping roofs that deflect rockfalls over the railway

(Source: IRC-HRB-Special Report-23)

ROCKFALL MITIGATION MEASURES

ROCKFALL PROTECTION MEASURES

EROSION CONTROL MATS AND OTHER BIO-ENGINEERING METHODS

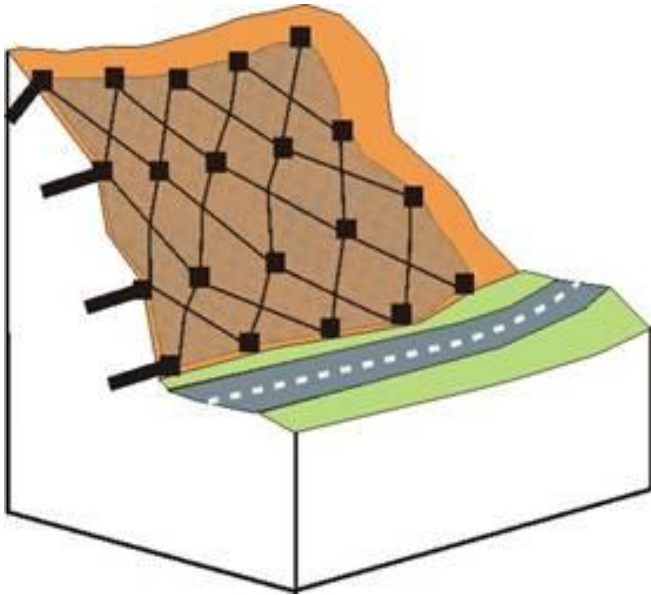
- coir jute/ three dimensional erosion control mats
- Used when the slope to be protected contains soil mixed with boulders
- designed to allow passage of water while retaining in situ soil without clogging.



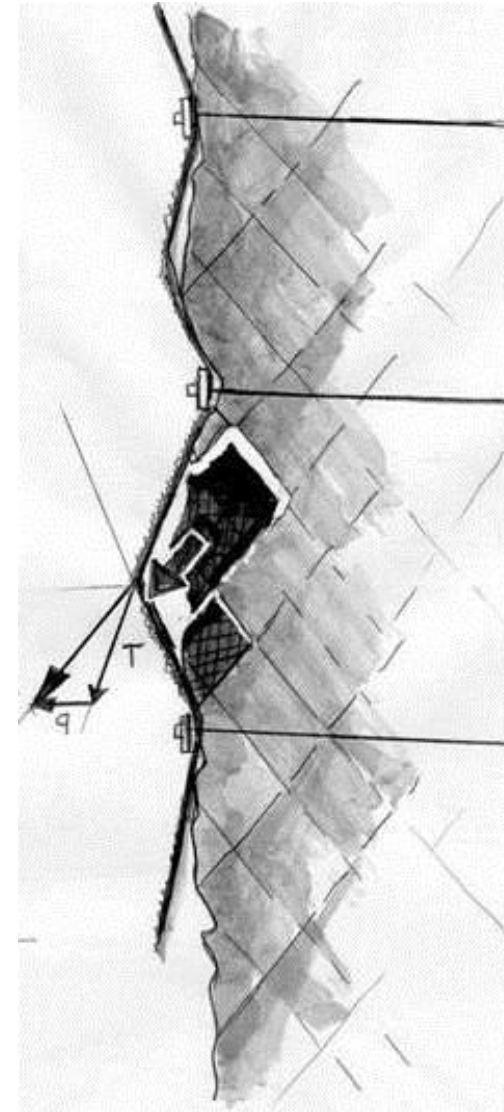
ROCKFALL MITIGATION MEASURES

ROCKFALL RETENTION MEASURES

MESH WITH NAILS OR ANCHORS SURFICIAL STRENGTHENING



- to strengthen the top loose surface along the rock slope.



ROCKFALL MITIGATION MEASURES

ROCKFALL RETENTION MEASURES

MESH WITH NAILS OR ANCHORS SURFICIAL STRENGTHENING

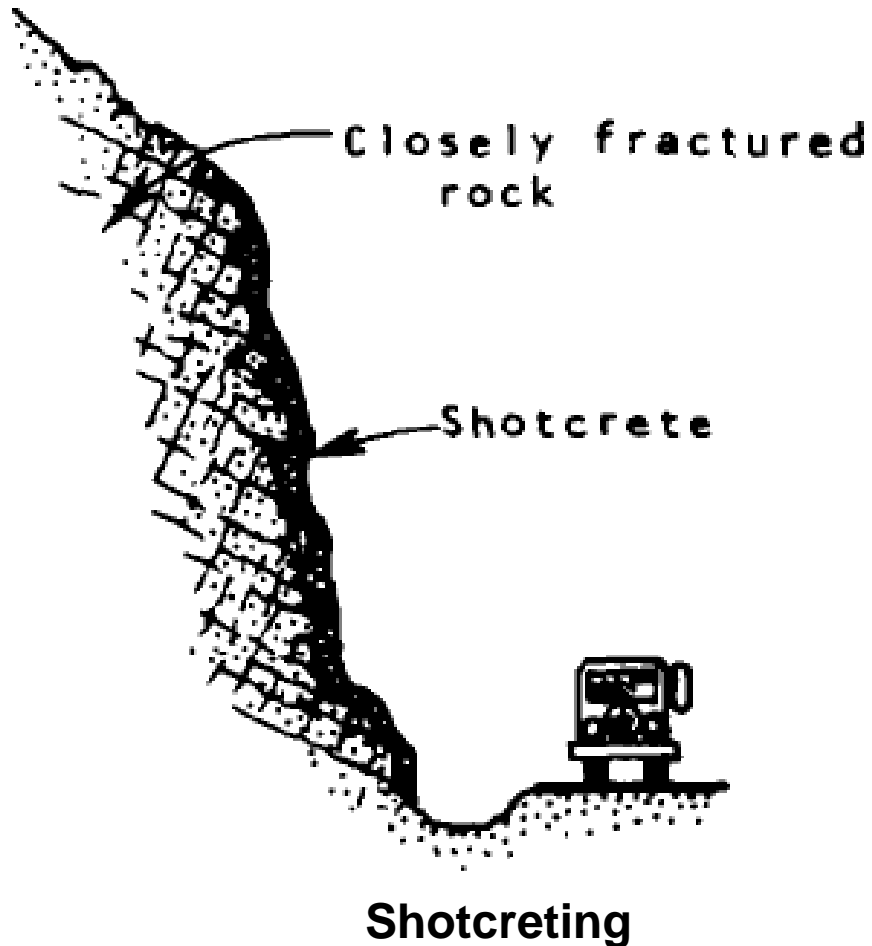


ROCKFALL MITIGATION MEASURES

ROCKFALL RETENTION MEASURES

SHOTCRETING

- in cases of
 - severely jointed rock forming small blocks
 - weathered rock surfaces zones and beds of closely fractured or degradable rock

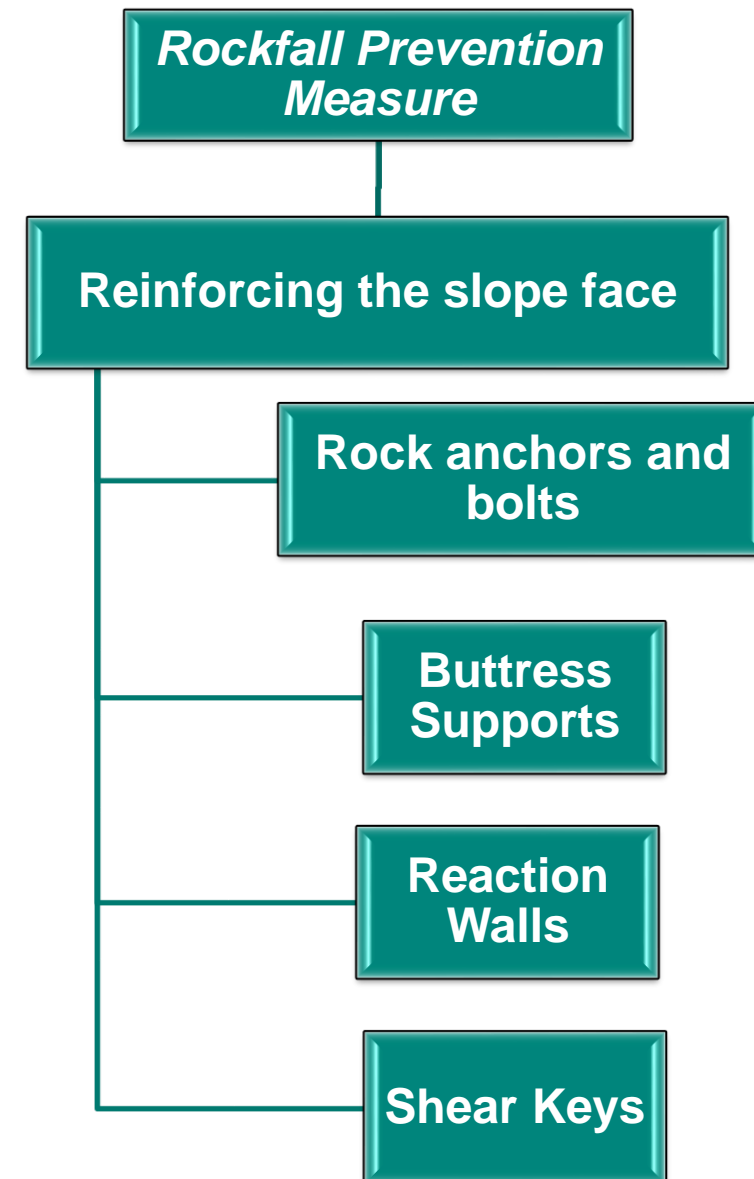


ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

REINFORCING THE SLOPE FACE

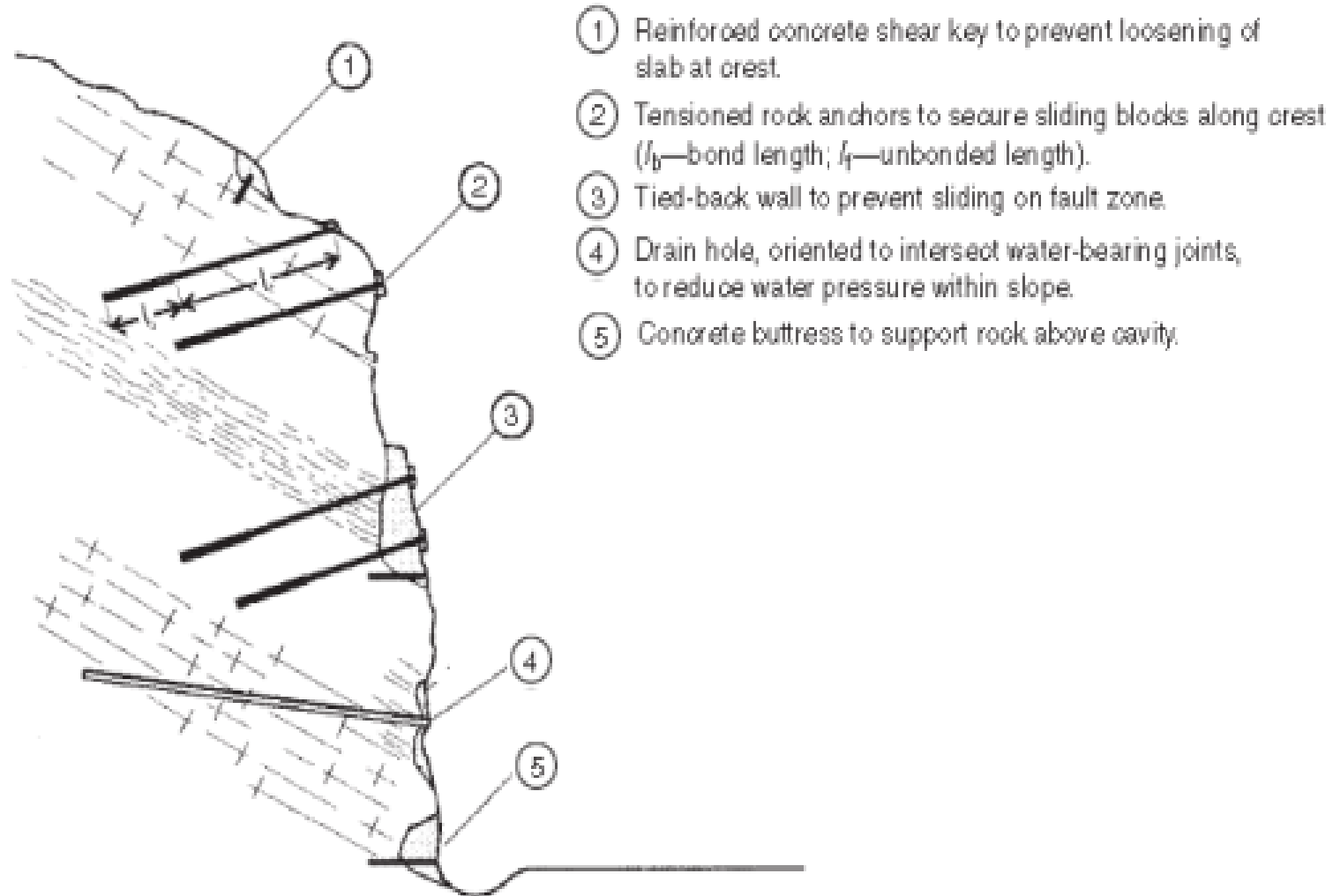
- To minimize relaxation and loosening of the rock mass that may take place as a result of excavation.
- most effective if it is installed prior to excavation-a process known as pre-reinforcement.



ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

REINFORCING THE SLOPE FACE



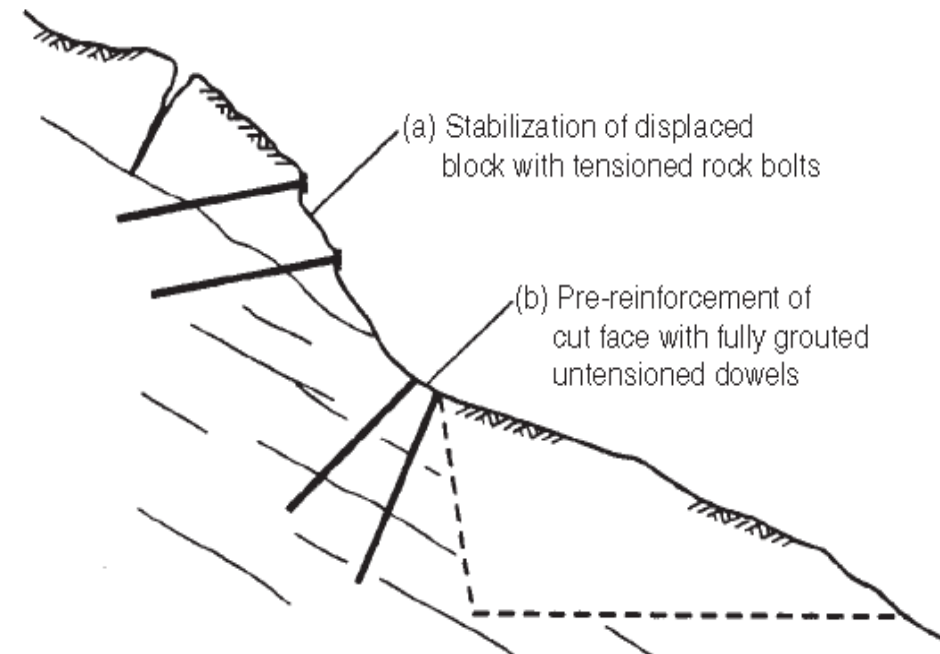
ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

REINFORCING THE SLOPE FACE

ROCK ANCHORS

- to prevent sliding of blocks or wedges of rock on discontinuities dipping out of the face.
- may be fully grouted and untensioned, or anchored at the distal end and tensioned.

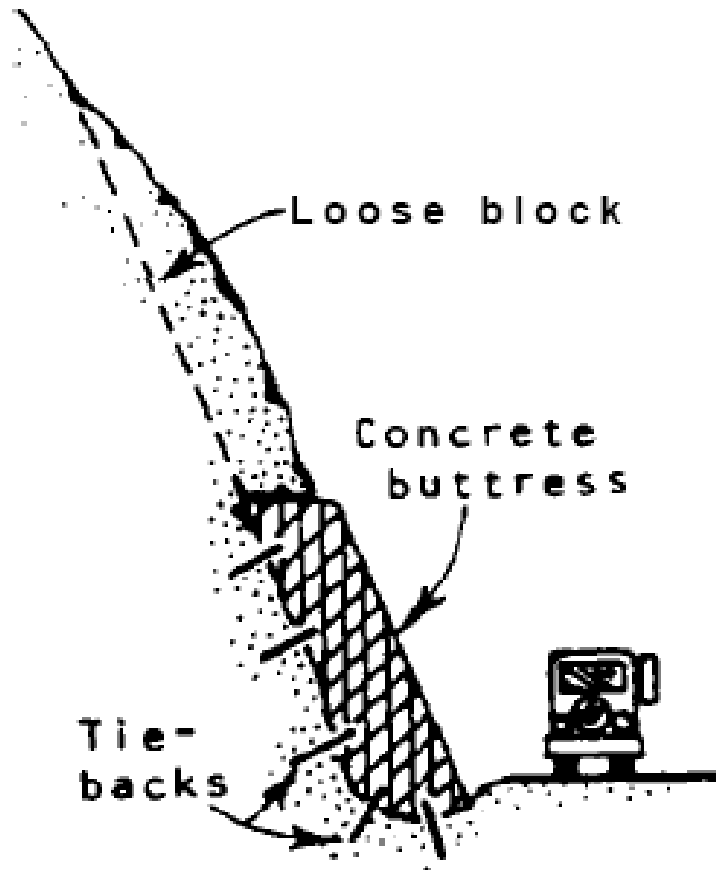


ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

REINFORCING THE SLOPE FACE

BUTTRESS SUPPORT



- Where a rockfall or weathering has formed a cavity in the slope face, it may be necessary to construct a concrete buttress in the cavity to prevent further .
- fulfils two functions:
 - to retain and protect areas of weak rock
 - to support the overhang.

ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

REINFORCING THE SLOPE FACE

REACTION WALL

- reinforced concrete/ concrete wall
- protection against ravelling of the rock, and a large reaction plate for the rock anchors.
- Drain holes are provided throughout to prevent water pressure build-up behind the wall.



Reaction wall to prevent rockfall

REINFORCING THE SLOPE FACE

SHEAR KEY

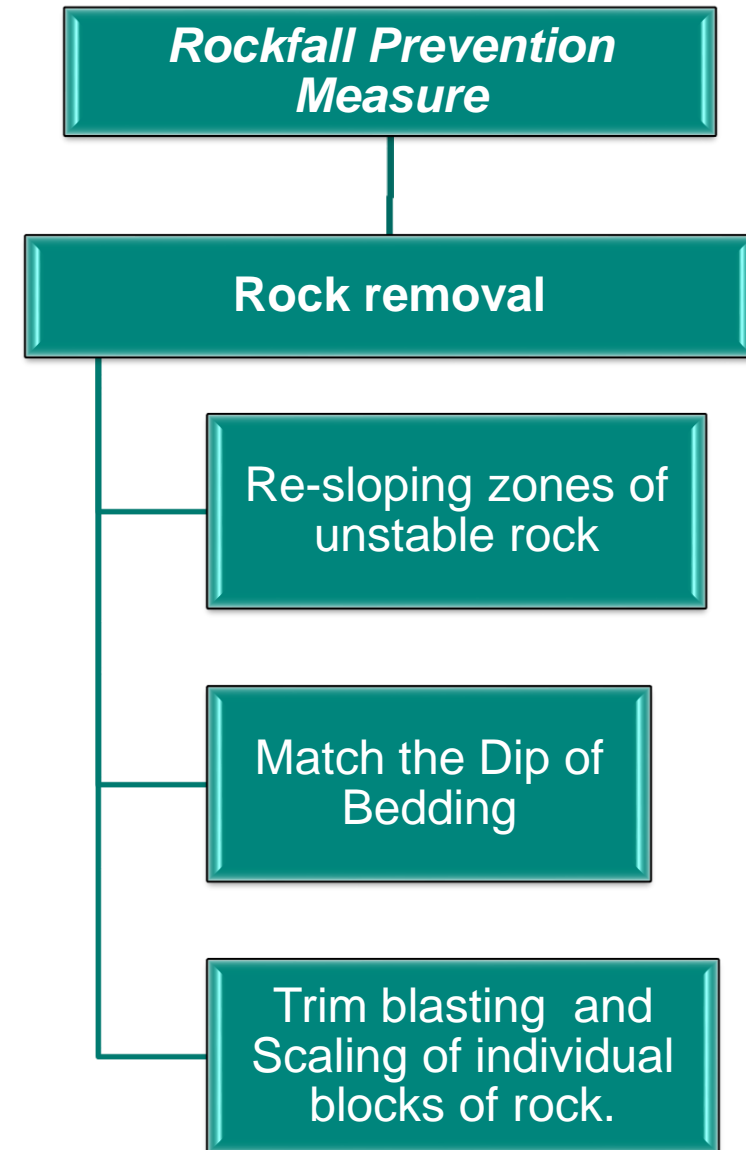
- provide support for blocks of rock upto about a meter thick, as well as zones of loose and weathered rock at the crest of the slope.
- are used where the support required is limited by the size of the blocks, and to prevent ravelling and loosening of closely fractured, weak rock.

ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

ROCK REMOVAL

- Stabilization of rock slopes can be accomplished

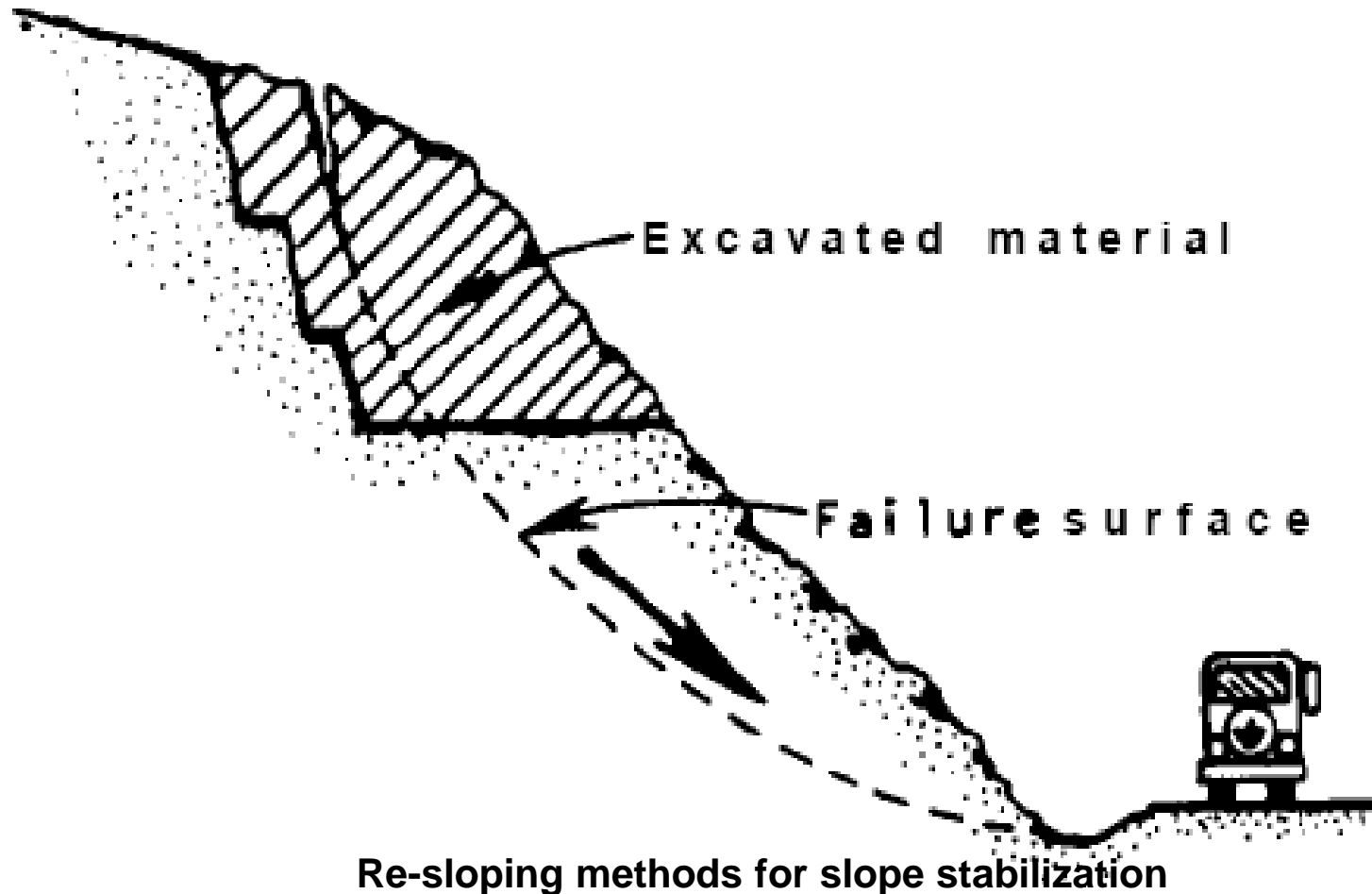


ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

ROCK REMOVAL

RE-SLOPING ZONES OF UNSTABLE ROCK



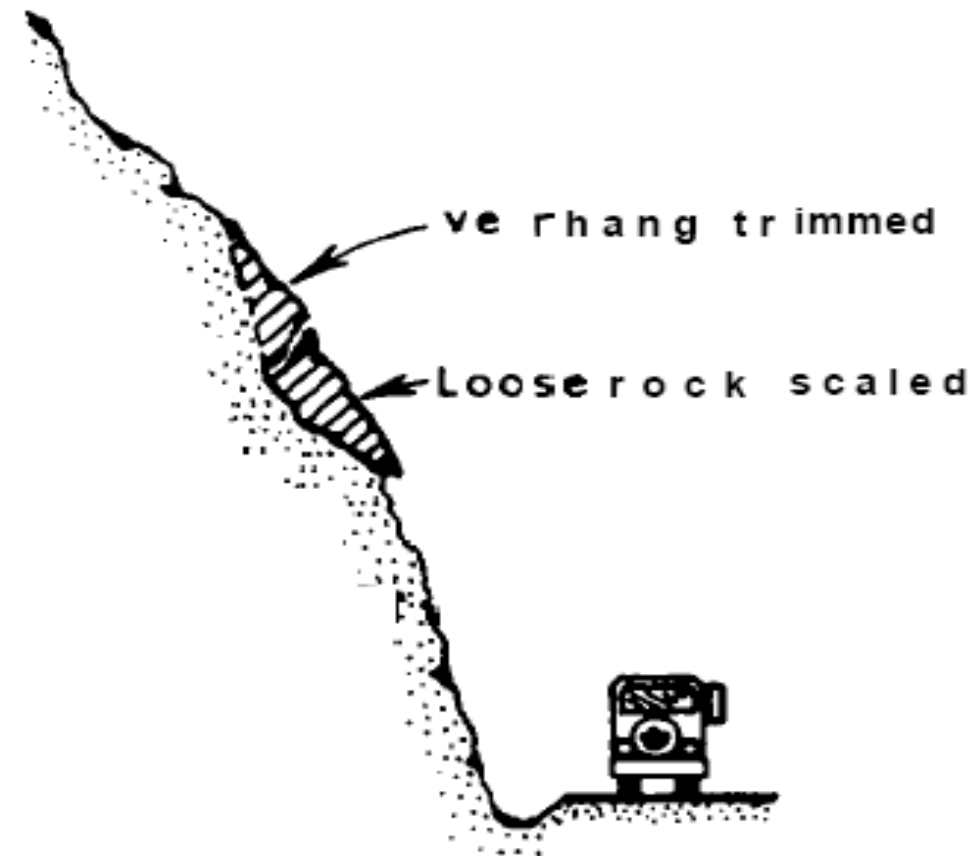
ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

ROCK REMOVAL

SCALING AND TRIM BLASTING

- **Scaling** → process of removing loose or potentially unstable material that might dislodge or affect the trajectory of falling rock by creating a launching point for materials falling from above.
- accomplished by any of these methods:
 - hand scaling
 - mechanical scaling
 - trim blasting (small blasting operations)



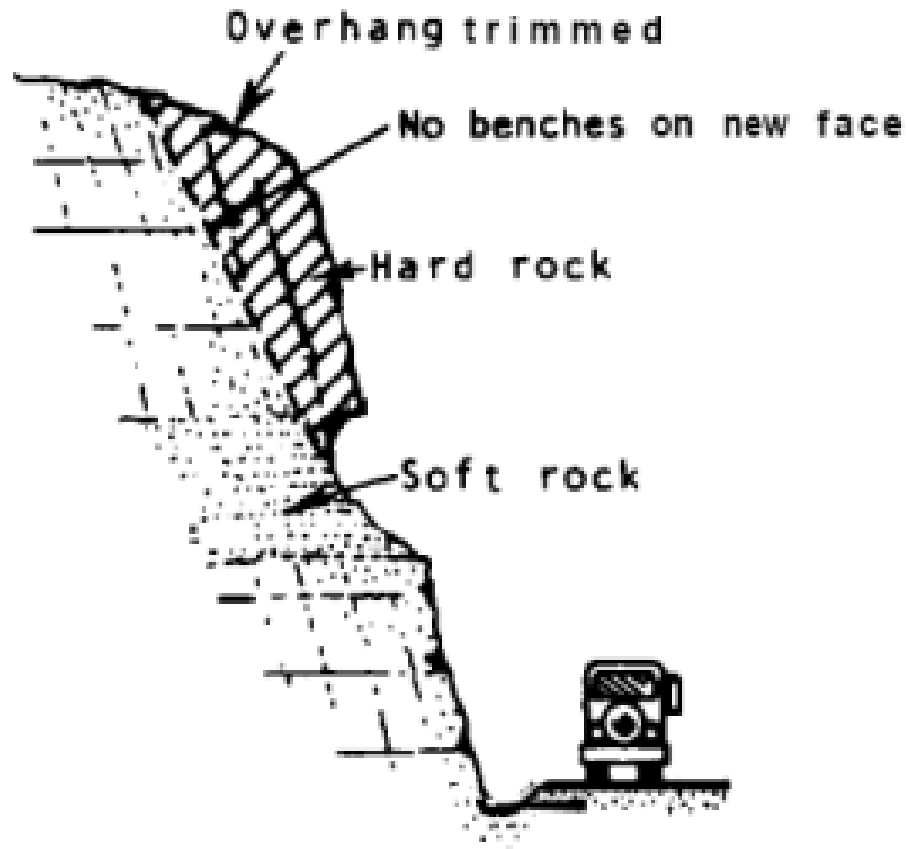
ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

ROCK REMOVAL

TRIM BLASTING

- is done for the removal of the overhang (formed by failure or weathering of a rock slope)



ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

DRAINAGE SYSTEM

- Slope stability can be improved through the installation of drainage systems, which most often consist of horizontal weep drains.
- In general, the drains are installed as uncased holes in massive rock units, drilled with a track rig or portable drill.
- In weak or highly fractured rock, the drain may be cased with a perforated polyvinylchloride (PVC) pipe to maintain the drain opening.
- Nonwoven geotextile may be wrapped around the perforated pipe to prevent the clogging of the drainage system.

ROCKFALL MITIGATION MEASURES

ROCKFALL PREVENTION MEASURES

DRAINAGE SYSTEM

- **Drain holes/ Drain pipes** – Drain holes/ Perforated pipes wrapped in geotextile are placed in upward drilled holes at the toe of rock slopes. This helps in dipping the phreatic surface and also reducing the pore water pressure in rock / soil slopes.



July 2016



Rockfall Mitigation Measures

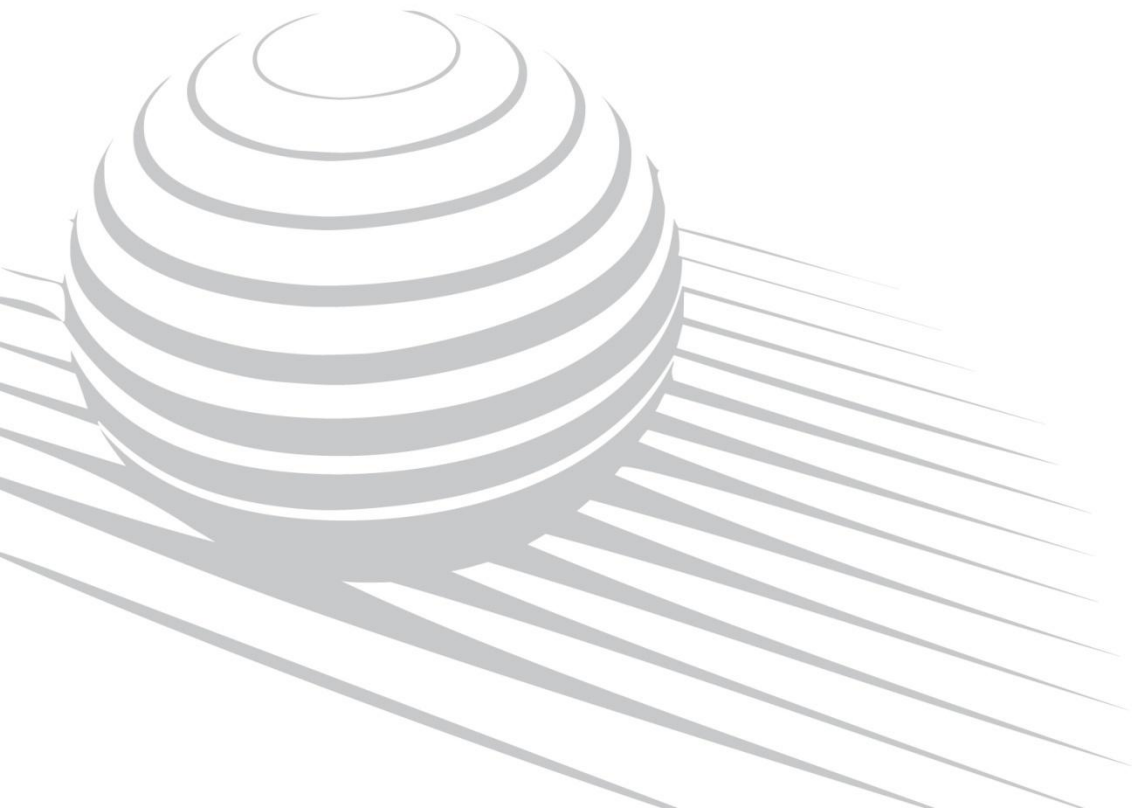
ROCKFALL MITIGATION MEASURES

SELECTION OF SUITABLE MITIGATION MEASURE

- Mitigation selection should be based on :
 - degree of security or reliability necessary for a site
 - constructability of the potential options
 - service life required
 - suitability of potential mitigation options with respect to the characteristics of the specific rock mass
 - cost effectiveness
 - aesthetics

)

CASE STUDIES





Rockfall Mitigation Works at Saptshrungi Gad, Nashik

**CLIENT:PUBLIC WORKS DEPARTMENT, NASHIK,
MAHARASHTRA (INDIA)**

Rockfall Mitigation Works at Saptshrungi Gad, Nashik

Photos of Rockfall event happened in 2008



Rockfall Mitigation Works at Saptshrungi Gad, Nashik

Products/Systems adopted (in general)

- **Products:**
 - Mono oriented Reinforced Steel Wire Mesh : IRC HRB- Special Report 23-clause:5.3
 - Rhomboidal Cable Wire Rope Panels: IRC HRB- Special Report 23-clause:5.1.1
 - Dynamic Rockfall Barrier: ETAG-027, IRC HRB- Special Report 23-clause:5.5
 - Anchors: Self Drilling Anchors-25mm/ 32mm
- **Systems:**
 - **Secured Drapery System:**
 - Mono oriented Reinforced Steel Wire Mesh + Rhomboidal Cable Wire Rope Panels+ Anchors -2-3m long
 - **Dynamic Rockfall Barrier:**
 - 5000kJ/7m high

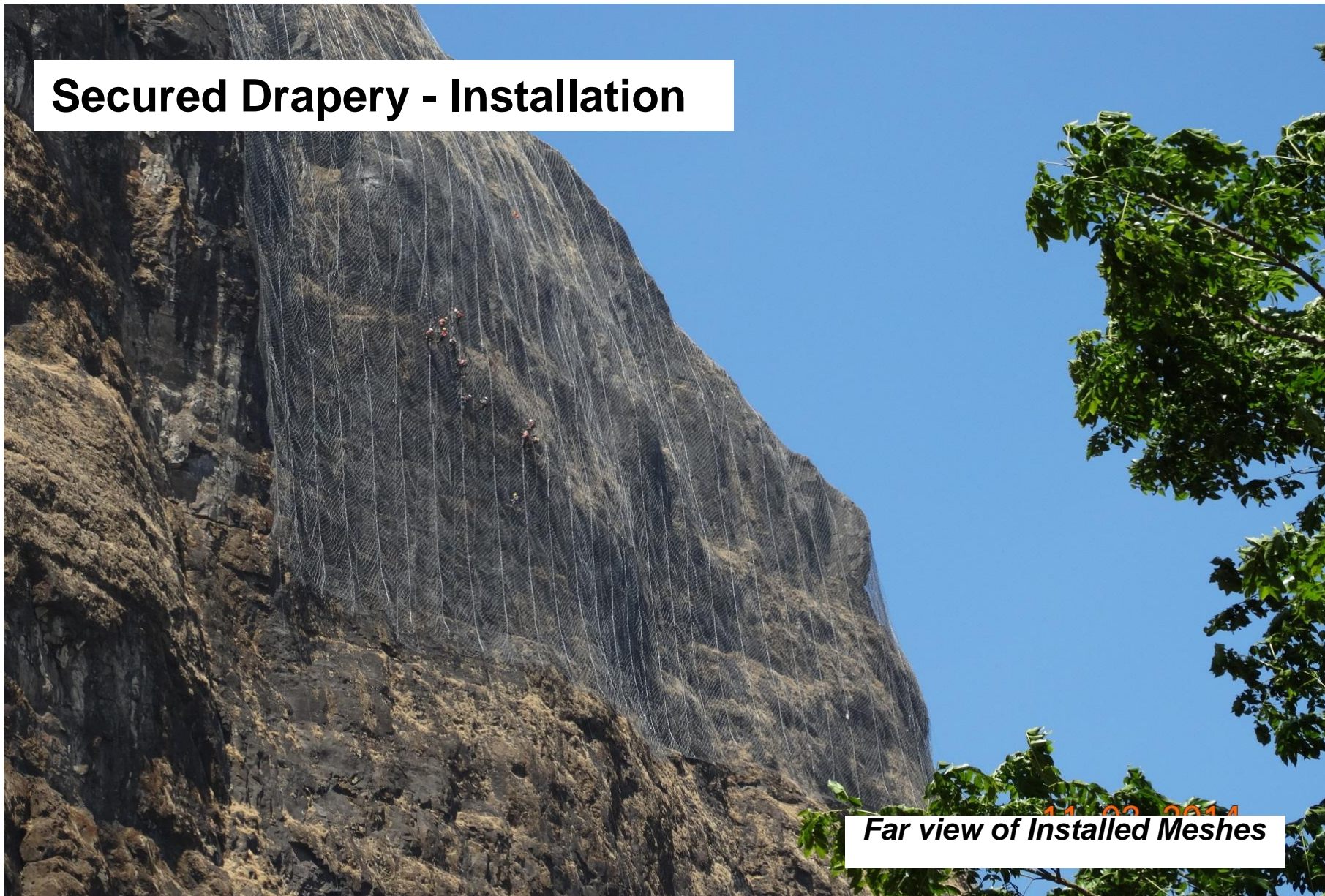
Rockfall Mitigation Works at Saptshrungi Gad, Nashik

Secured Drapery - Installation



Rockfall Mitigation Works at Saptshrungi Gad, Nashik

Secured Drapery - Installation



Far view of Installed Meshes

Rockfall Mitigation Works at Saptshrungi Gad, Nashik

Dynamic Rockfall Barrier Installation



Helicopter waiting in Helipad to take off with barrier components



Helicopter transferring the barrier components to the temporary storage location near to the slope

Rockfall Mitigation Works at Saptshrungi Gad, Nashik

***Completed Dynamic
Rockfall barrier***



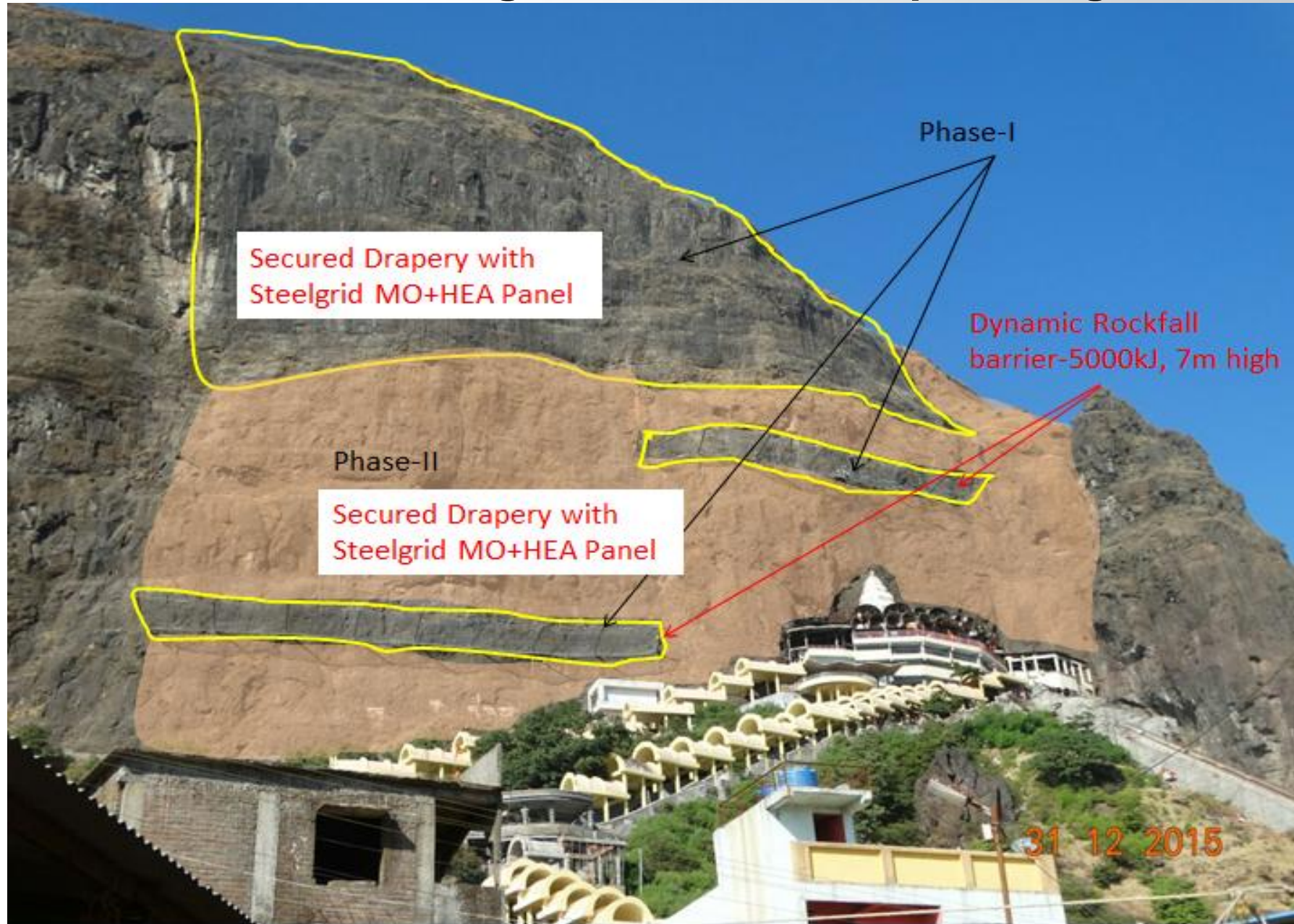
CASE STUDY

Rockfall Mitigation Works at Saptshrungi Gad, Nashik



*Dynamic Rockfall Barrier-
5000kJ,
7m high*

Rockfall Mitigation Works at Saptshrungi Gad, Nashik





Mumbai –Pune Expressway

CLIENT: MSRDC(MAHARASHTRA STATE ROAD DEVELOPMENT CORPORATION LTD.) (INDIA)



Rockfall Mitigation works along Mumbai –Pune Expressway



Photograph showing the rock slide near Khandala tunnel (Mumbai corridor) (source: NDTV news)



Photograph showing aftermath of the rockfall happened near Adoshi tunnel (source: Indian Express Newspaper)

Rockfall Mitigation works along Mumbai –Pune Expressway

Products/Systems adopted (in general)

- **Products:**

- Mono oriented Reinforced Steel Wire Mesh : IRC HRB- Special Report 23-clause:5.3
- Rhomboidal Cable Wire Rope Panels: IRC HRB- Special Report 23-clause:5.1.1
- Dynamic Rockfall Barrier: ETAG-027, IRC HRB- Special Report 23-clause:5.5
- Anchors: Continuously Threaded Anchors- 25mm/ 32mm

- **Systems:**

- **Secured Drapery System:**

- Mono oriented Reinforced Steel Wire Mesh +Diagonal Cable wire ropes+ Anchors-2-6m long
- Mono oriented Reinforced Steel Wire Mesh + Rhomboidal Cable Wire Rope Panels+ Anchors- 2-15m long

- **Dynamic Rockfall Barrier:**

- 1500kJ/5m high, 250kJ/3.5m high

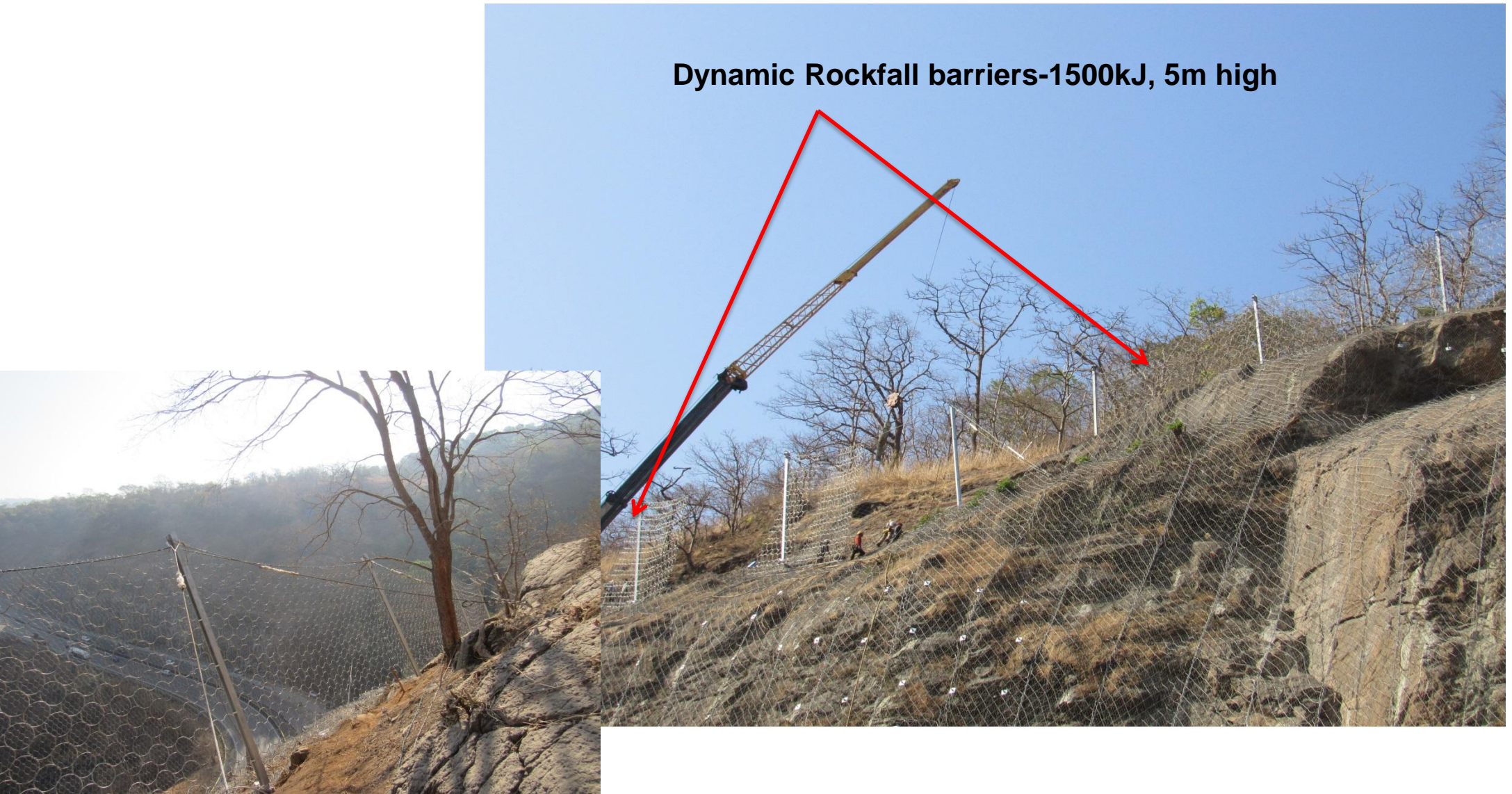
Rockfall Mitigation works along Mumbai –Pune Expressway

Adoshi Stretch



Rockfall Mitigation works along Mumbai –Pune Expressway

Adoshi Stretch



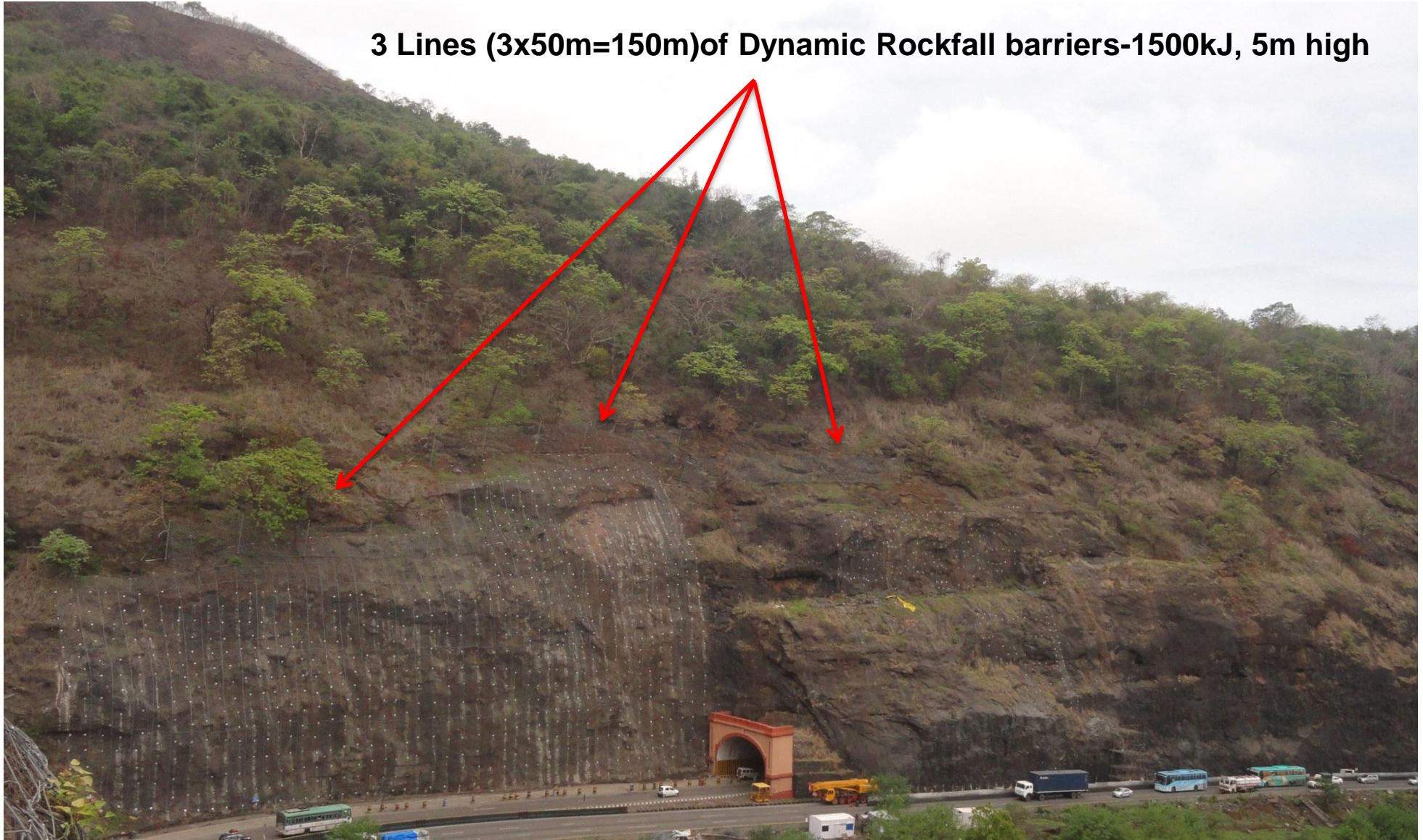
July 2016

Rockfall Mitigation Measures

Rockfall Mitigation works along Mumbai –Pune Expressway

Adoshi Stretch

3 Lines (3x50m=150m)of Dynamic Rockfall barriers-1500kJ, 5m high



Rockfall Mitigation works along Mumbai –Pune Expressway

Adoshi Stretch



Rockfall Mitigation works along Mumbai –Pune Expressway

Khandala Stretch (Mumbai corridor)



Rockfall Mitigation works along Mumbai –Pune Expressway

Khandala Stretch (Mumbai corridor)



Rockfall Mitigation works along Mumbai –Pune Expressway

Khandala Stretch (Mumbai corridor)



Rockfall Mitigation works along Mumbai –Pune Expressway

Amrutanjan Stretch



Rockfall Mitigation works along Mumbai –Pune Expressway

Amrutanjan Stretch



Rockfall Mitigation works along Mumbai –Pune Expressway

Amrutanjan Stretch

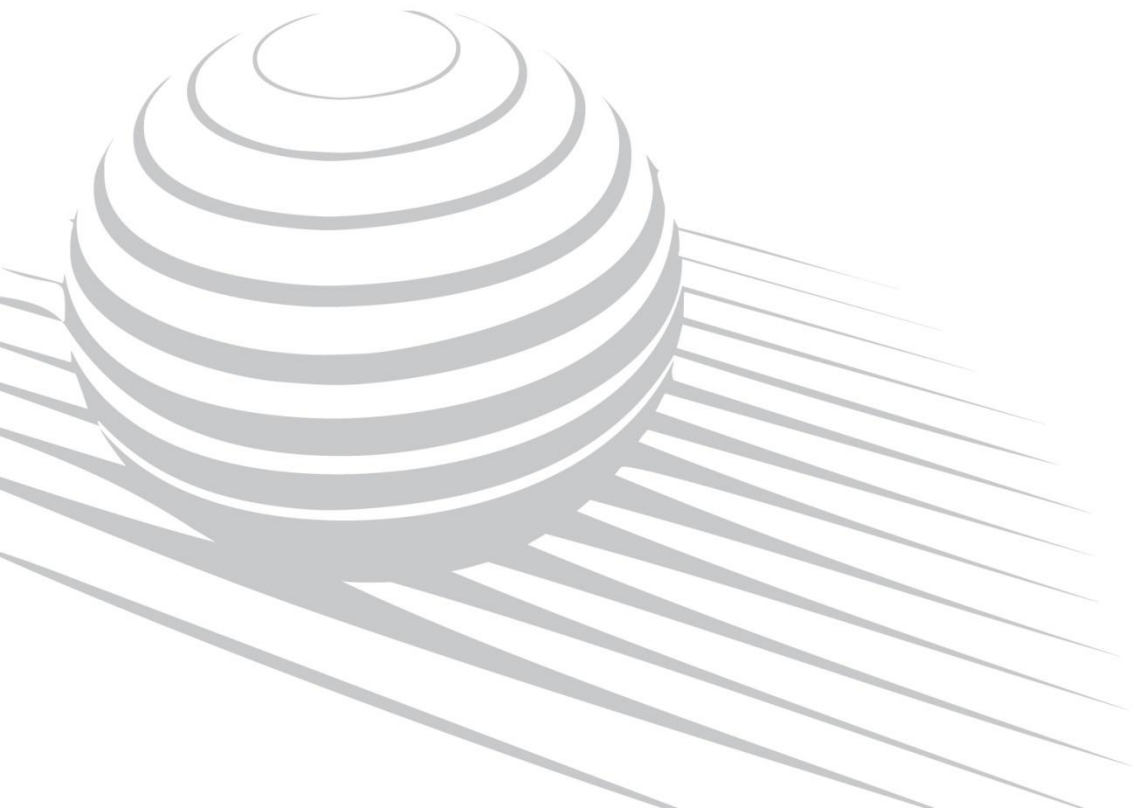
Shotcreting over red-bole locations with proper drainage provisions



July 2016

Rockfall Mitigation Measures

SUMMARY



- Modern methods of Rockfall Mitigation has expanded the solution range in a versatile way.
- tools and simulation softwares →analysing forces and impact energy computations→optimise Rockfall Mitigation measures.
- Rockfall Mitigation Measures →shall be considered in the **planning stage of the project** →shall result in reduction or elimination of hazardous conditions and related cost of mitigation measures

- include **geotechnical investigation and maintenance for cut-side slope of hill roads (where frequent Rockfalls are observed), as a regularized item** for hill road projects- soil strata and rocky strata.
- On existing problematic stretches, Rockfall events should be **documented properly and continuously on regular basis** to establish areas and impacts of increased Rockfall activity and help with future mitigation selection and design.
- The **monitoring of installed mitigation measures**, during and post construction shall be made part of the major projects.
- **Maintenance of the proposed rockfall mitigation measure** also plays a major role in its performance.

- 1) IRC-HRB-Special Report-23. State of the Art: Design and Construction of Rockfall Mitigation Systems. New Delhi, 2014.
- 2) Washington State Department of Transportation. (2007). "Design Manual" M 22-01.05.



THANK YOU