GEOHAZARD SOLUTIONS

The Use of Flexible Systems for Natural Hazard Mitigation

ROCKFALL
- Low Energy Barriers
- High Energy Barriers
- Drapes

ROCK and SLOPE
- Anchored Mesh
- Slope Stabilization
- Protection Meshes

SNOW
- Avalanche Barriers
- Snowslide Protection
- Ice Drapes

HYDRO
- Debris Flow
- Shallow Landslide
- Erosion Control
NATURAL HAZARD PROTECTION SYSTEMS

Geobrugg Protection Systems

SNOW Avalanche Protection Structures
Geobrugg Protection Systems

ROCKFALL - Barriers and Catchfences
Geobrugg Protection Systems

ROCKFALL – Barriers and Catchfences
NATURAL HAZARD PROTECTION SYSTEMS

Geobrugg Protection Systems

ROCK & SLOPE – Drapes and Attenuators
SLOPE STABILIZATION

Geobrugg Protection Systems

ROCK and SLOPE – Anchored Mesh Solutions for Unstable Slopes
ROCK and SLOPE – Anchored Mesh Solutions for Unstable Slopes
NATURAL HAZARD PROTECTION SYSTEMS

Geobrugg Protection Systems

HYDRO - Debris Flow Barriers
Presented by Bob Lyne
ROCK | high tensile ringnet canopies and the behavior to self-cleaning effects together to alternative systems
AGENDA

1. HISTORY AND EXECUTED PROJECTS IN THE PAST
2. NEW GENERATION OF CANOPIES
3. FULL-SCALE TESTS
4. PARAMETER STUDY WITH FARO
5. COMPARISON TO CONCRETE GALLERY
When and why is self cleaning necessary?

- No endangered objects below the road
- Or with addition of rockfall barrier (low energy) below the road
01

HISTORY AND EXECUTED PROJECTS IN THE PAST
One early attempt to divert rocks with wood and springs
MONTSERRAT (SPAIN), 1992

- Energy rating: 500kJ
- Width: 4 – 8m
VARNERFLUH (SWITZERLAND), 2000

Real Scale Testing with high velocity up to 43m/s and 700kg
VARNERFLUH (SWITZERLAND), 2000

Real Scale Testing with high velocity up to 43m/s and 700kg
VARNERFLUH (SWITZERLAND), 2000

Full-scale Testing movie

1. Length of barrier : l=22m
2. Height of barrier : h=4m
3. Post spacing : s=5/10/7m
4. Post inclination : $\alpha=10-15^\circ$
5. Post profile : HEB-140
6. Net angle : $\beta=45^\circ$
PONTIS SUD (SWITZERLAND), 2008

Validation with simulation up to an energy of 2000kJ

<table>
<thead>
<tr>
<th>Load case</th>
<th>LC1</th>
<th>LC2</th>
<th>LC3</th>
<th>LC1+S</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROCK z-disp</td>
<td>-5.7 [m]</td>
<td>-6.7 [m]</td>
<td>-5.8</td>
<td>-4.8</td>
</tr>
<tr>
<td>Vertical displ rel. to bottom post level</td>
<td>-1.9 [m]</td>
<td>+1.4 [m]</td>
<td>-1.9 [m]</td>
<td>+1.8 [m]</td>
</tr>
</tbody>
</table>
Studied options:

- **Option 0:** Rockfalls of up to 2’000 kJ every 10 years
- **Option 1:** Extension of existing tunnel: 8.0 Mio. CHF
- **Option 2:** Concrete rockfall canopy: 3.5 Mio. CHF
- **Option 3:** Flexible gallery: 1.1 Mio. CHF
NEW GENERATION OF CANOPY
2. SCC-500

Self cleaning canopy up to 500kJ

- Developed with experience of rockfall system
- Self-cleaning effect till 500kJ
- Maximum energy level 1000kJ
- Low maintainance
- Easy installation
NEW GENERATION OF CANOPY

Staking out – flexible in all directions

<table>
<thead>
<tr>
<th>H – Post Length</th>
<th>a</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.00</td>
<td>5.50</td>
<td>1.30</td>
<td>6.00</td>
</tr>
<tr>
<td>7.00</td>
<td>6.50</td>
<td>1.50</td>
<td>7.00</td>
</tr>
<tr>
<td>8.00</td>
<td>7.50</td>
<td>1.50</td>
<td>8.00</td>
</tr>
</tbody>
</table>

γ: appr. 45°, depends on ground geometry
f: depends on installation height. In minimum 10m
NEW GENERATION OF CANOPY

Installation Assembly – very easy and clear

- Vertical rope
- Upslope rope
- Bottom support rope
- Lateral rope
- 1``Shackle
- Downslope rope
- 4x double wire clips
- 1``Shackle
FULL-SCALE TESTS
## TESTS EXECUTED WITH FLEXIBLE CANOPIES

Flexible canopy system with different load cases

<table>
<thead>
<tr>
<th></th>
<th>TEST 1</th>
<th>TEST 2</th>
<th>TEST 3</th>
<th>TEST 4</th>
<th>TEST 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kJ)</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>Position</td>
<td>Middle</td>
<td>Middle</td>
<td>Border</td>
<td>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td>Serie</td>
<td>1st</td>
<td>2nd</td>
<td>3rd</td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td>Post length</td>
<td>8m</td>
<td>8m</td>
<td>8m</td>
<td>8m</td>
<td>8m</td>
</tr>
<tr>
<td>ROCK</td>
<td>rotation</td>
<td>rotation</td>
<td>rotation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Self-cleaning</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Deformation</td>
<td>6.10m</td>
<td>5.40m</td>
<td>5.80m</td>
<td>6.70m</td>
<td>5.30m</td>
</tr>
</tbody>
</table>
TEST 3 BORDER FIELD – 500KJ

Full-scale test according to ETAG 027 guideline

- Mass $m=1600\text{kg}$
- Velocity $v=25\ \text{m/s}$
- Energy $E=500\text{kJ}$
TEST 3 BORDER FIELD – 500KJ

Comparison of FARO simulation with test

<table>
<thead>
<tr>
<th>Faro 500kJ</th>
<th>Test 500kJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top support rope</td>
<td>150 kN</td>
</tr>
<tr>
<td>Bottom support rope</td>
<td>155 kN</td>
</tr>
<tr>
<td>Vertical rope</td>
<td>375 kN</td>
</tr>
<tr>
<td>Upslope rope</td>
<td>30 kN</td>
</tr>
<tr>
<td>Downslope rope</td>
<td>185 kN</td>
</tr>
<tr>
<td>Lateral rope</td>
<td>305 kN</td>
</tr>
<tr>
<td>Posthead rope</td>
<td>150 kN</td>
</tr>
</tbody>
</table>
PARAMETER STUDY WITH FARO
PARAMETER STUDY WITH FARO

Self-cleaning effect and the energy distribution

α = net angle

1) $E_{\text{kin}} = \text{max.}$, kinetic energy is maximum by first contact rock and net

2) $E_{\text{ten}} = \text{max.}$, deformation energy is maximum, velocity of rock is zero, $v=0$ m/s

3) $E_{\text{pot}} = \text{max.}$ deformation, rebound point of the rock, velocity is negative (rebounding rock)

<table>
<thead>
<tr>
<th>First net contact</th>
<th>Stopped block</th>
<th>Block moved out</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{pot}} = 0$</td>
<td>$E_{\text{pot}} = 0$</td>
<td>$E_{\text{pot}} = \text{max.}$</td>
</tr>
<tr>
<td>$E_{\text{kin}} = \text{max.}$</td>
<td>$E_{\text{kin}} = 0$</td>
<td>$E_{\text{kin}} = 0$</td>
</tr>
<tr>
<td>$E_{\text{ten}} = 0$</td>
<td>$E_{\text{ten}} = \text{max.}$</td>
<td>$E_{\text{ten}} = 0$</td>
</tr>
</tbody>
</table>
PARAMETER STUDY WITH FARO

Parameter and influence for the canopy system to self-cleaning effect

A1 - Post length
L = 6.0m – 10.0m

B1 - Net angle
α = 30° – 50°

C1 – post spacing
S = 6.0 – 12.0m
PARAMETER STUDY WITH FARO

Ring Net

- Elastic properties
- Plastic properties
- Damage
- Ring-to-ring contact (friction)
- Diameter
- # Winding number
PARAMETER STUDY WITH FARO

Winding number

- Increasing load capacity with increasing winding number

- 7/3/300: 50 kN / Ring
- 12/3/300: 100 kN / Ring
- 16/3/300: 140 kN / Ring
- 19/3/300: 180 kN / Ring
## Ring Properties

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic &amp; plastic behavior</td>
<td>Permanent plastic deformation</td>
<td>Elastic behavior</td>
</tr>
<tr>
<td>Elastic behavior</td>
<td>Elastic Rebound</td>
<td></td>
</tr>
</tbody>
</table>
System Brakes – Energy Dissipating Devices

- High activation force
- Barrier reacts mostly elastic
- Controlled anchor forces
PARAMETER STUDY WITH FARO

Explanation of the FARO results

- Brake elongation = Energy absorption
- Anchor Forces Constant
- Max. elongation
- Self-cleaning
- Brake aligns with support ropes

Graphs showing:
1. Elongation of dissipating devices in comparison with different ring numbers over the length.
2. Total displacement of the ring net in comparison with different ring numbers over the length.
PARAMETER STUDY WITH FARO

Self-cleaning behavior depending on post length

![Graph showing elongation of dissipating devices in comparison with different winding numbers of the ring net, post length](image1)

![Graph showing total displacement of the ring net in comparison with different winding numbers of the ring net, post length](image2)
Self-cleaning behavior depending on net angle

- Elongation of dissipating devices in comparison with different winding numbers of the ring net, net angle
- Total displacement of the ring net in comparison with different winding numbers of the ring net, net angle
PARAMETER STUDY WITH FARO

Self-cleaning behavior depending on post spacing
Concrete width : 9.95m
Gallery length : 110m and 155m
Roof thickness of concrete : 0.70m + appr. 1.00m damping material (gravel, soil)
Energy level : 300 – 500 kJ
MODIFICATION
ROCKFALL-X®

Mattstock, Churfirsten, Switzerland

Energy level : 200 – 1900 kJ
Rockfall-X® bags : 1300 pcs à 1.30m and 575 pcs à 2.00m
Flexible systems reduce the impact force. This fact allows a very economic use of material. Additionally, the forces in the foundation and wire rope anchors are reduced.
THANK YOU