Standards and best Practice for Design of Rockfall Protection Measures in Austria

Standards and best Practice for Design of Rockfall Protection Measures in Austria
Overview:

- Motivation for standardization
- Content of ONR 24810
- Design according to ONR 24810
- Catchment fences
- Embankments
- Maintenance and inspection
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Why standards for design of rockfall protection

1. Definition of minimum requirements for design approach
2. Legal reasons (liability in case of disasters)
3. Quality management
4. Priorization of investments
5. Ensure „return on investment“ for mitigation measures
What was the management approach in the past?

1. No formal requirements existent before 2013, state of the art not defined formally
2. Individual internal standards for different organizations (such as railroads, highways, Torrent and Avalanche Control (WLV))
3. Some regulation regarding approval of catchment fences (ETAG 027, since 2008)
4. No standard procedures regarding:
   Design block size, characteristic actions, application of modeling tools, design of embankments …
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Content of Austrian Standard Rule ONR 24810

- Terms and definitions
- Site investigation
- Modeling of rockfall processes
- Mitigation structures (rockwall stabilization, catchment fences, embankments, galleries) and their verification and constructive rules
- Inspection and maintenance of realized measures
Concept of partial factors of safety on:
- Effect and
- Resistance of protection measure
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Consequence classes

Qualitative rating in the case of failure of the system or component being classified with regards to the degree of loss of human life, and economic, social or environmental impacts.

<table>
<thead>
<tr>
<th>Consequence Class</th>
<th>Description</th>
<th>Examples of buildings and civil engineering works</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC3</td>
<td><strong>High</strong> consequence for loss of human life, or economic, social or environmental consequences <strong>very great</strong></td>
<td>Grandstands, public buildings where consequences of failure are high (e.g., a concert hall)</td>
</tr>
<tr>
<td>CC2</td>
<td><strong>Medium</strong> consequence for loss of human life, economic, social or environmental consequences <strong>considerable</strong></td>
<td>Residential and office buildings, public buildings where consequences of failure are medium (e.g., an office building)</td>
</tr>
<tr>
<td>CC1</td>
<td><strong>Low</strong> consequence for loss of human life, and economic, social or environmental consequences <strong>small or negligible</strong></td>
<td>Agricultural buildings where people do not normally enter (e.g., storage buildings), greenhouses</td>
</tr>
</tbody>
</table>

EN 1990: “Eurocode: Basis for structural design”
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Site Investigation

- No design of mitigation measures without conducting a thorough site investigation

- **Initiation zone:**
  - Rock mass characterization
  - Joint and discontinuity patterns and analysis
  - Failure mechanisms, etc.

- **Transition zone:**
  - Morphology
  - Dampening buffers
  - Evidence of frequency
  - Bounce height indicators, etc.

- **Deposition zone:**
  - Site morphology
  - Relief (relative to initiation zone)
  - Identification of debris from previous events
  - Evidence of frequency, bounce height indicators
  - Accessibility (in particular for construction and maintenance)
  - Location of elements at risk, etc.
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Example: block size distribution of source area

Distribution of joint bordered rock bodies

© Palmström 2000

Torrent and Avalanche Control Austria (WLV)
Geological Service
Michael Moelk & Gernot Stelzer
Standards and best Practice for Design of Rockfall Protection Measures in Austria

block-size distribution on slope

Perzentile [%]

0 10 20 30 40 50 60 70 80 90 100

block volume [m³]

0,0 0,5 1,0 1,5 2,0 2,5 3,0 3,5 4,0 4,5 5,0 5,5 6,0

96%
## Determination of volume of design block

<table>
<thead>
<tr>
<th>Event Frequency Class</th>
<th>Event Frequency n</th>
<th>Fractile of Design Block (volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF 4 (very high)</td>
<td>n ≥ 10 ( &gt; 10 events per year)</td>
<td>$V_{98}$</td>
</tr>
<tr>
<td>EF 3 (high)</td>
<td>1 ≤ n &lt; 10 (1 to 10 events per year)</td>
<td>$V_{97}$</td>
</tr>
<tr>
<td>EF 2 (low)</td>
<td>0.03 ≤ n &lt; 1 (1 event per year to 1 event per 30 years)</td>
<td>$V_{96}$</td>
</tr>
<tr>
<td>EF 1 (rare)</td>
<td>n &lt; 0.03 (&lt; 1 event per 30 years)</td>
<td>$V_{95}$</td>
</tr>
</tbody>
</table>
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Catchment Fences

Torrent and Avalanche Control Austria (WLV)
Geological Service

Michael Moelk & Gernot Stelzer
## Standards and best Practice for Design of Rockfall Protection Measures in Austria

| EOTA | European Organisation for Technical Approvals  
| Europäische Organisation für Technische Zulassungen  
| Organisation Européenne pour l'Agrément Technique |

(Construction Products Directive)

### ETAG 27

**GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL**

of

**FALLING ROCK PROTECTION KITS**

Edition 2008 - 02 - 01

Standards and best Practice for Design of Rockfall Protection Measures in Austria

Design: Energy

Verification condition: \( T_{E,d} \leq T_{R,d} \), whereby

\( T_{E,d} \) … Design value of effect energy
\( T_{R,d} \) … Design value of resistance energy
Design: Bounce height

Verification condition: \( h_{E,d} \leq h_{R,d} \), whereby

- \( h_{E,d} \) ... Design value of bounce height
- \( h_{R,d} \) ... Design value of resistance height of the barrier
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Design: Foundation using Micropiles (1)

Verification condition \( E_d \leq R_d \), whereby

- \( E_d \): Design effect value (load)
- \( R_d \): Design resistance value

Determination of design resistance value \( R_d \) by

- Verification of steel cross section of micropile
- Verification of surface between anchor grout body and underground
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Design: Foundation using Micropiles (2)

Verification of surface between anchor grout body and underground

- Design resistance value $R_{t;d}$ with pretests

\[
R_{t;d} = R_{t;k} / \gamma_{s,t}, \quad \text{whereby}
\]

- $R_{t;k}$ characteristic value of pull-out resistance
- $\gamma_{s,t}$ partial safety factor (=1.15)

\[
R_{t;k} = \min \left[ \left( R_{t;m} \right)_{\text{mitt}} / \xi_1, \left( R_{t;m} \right)_{\text{min}} / \xi_2 \right], \quad \text{whereby}
\]

- $(R_{t;m})_{\text{mitt}}$ average pull out force of pretest
- $(R_{t;m})_{\text{min}}$ minimum pull out force of pretest
- $\xi_1, \xi_2$ distribution factor acc. to table 8

| Table 8 - Distribution Coefficient Depending on Number of Pretests |
|---|---|---|---|---|---|
| $n = \geq 5$ | $n = 1$ | $n = 2$ | $n = 3$ | $n = 4$ |
| $\xi_1$ | 1.40 | 1.30 | 1.20 | 1.10 | 1.00 |
| $\xi_2$ | 1.40 | 1.20 | 1.05 | 1.00 | 1.00 |
Resistance of foundation:
Pull-out tests on micropiles (suitability-tests/approval test)

Pull-out equipment (only perpendicular to slope)

Pull-out equipment (also oblique angles possible)
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Tripod pull-out device type WLV Imst

Torrent and Avalanche Control Austria (WLV) Geological Service

Michael Moelk & Gernot Stelzer
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Online-measurement of force and displacement

Beam structure
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Design of Rockfall Embankments

Torrent and Avalanche Control Austria (WLV)
Geological Service
Michael Moelk & Gernot Stelzer
Parameters describing the rockfall impact on embankments

+ Impact energy
+ Impact angle
+ Impact position
+ Rotation
+ Penetration
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Approach taken in Austrian Standard ONR 24810:2013

1. Scaled test
2. Assessment of deformation geometry
3. Development of a design approach
4. Definition of design criteria for embankments
5. Continuous evaluation of concept
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Model tests

- Soil embankment
- Reinforced embankment
- Soil embankment with rip-rap
- Soil embankment with damping layer

Torrent and Avalanche Control Austria (WLV)
Geological Service
Michael Moelk & Gernot Stelzer
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Model setup
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Boundary conditions:
- linear ascending and then linear descending development of force and
- linear descending velocity

Reference: upper diagrams from Blovsky
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Standards and best Practice for Design of Rockfall Protection Measures in Austria
Standards and best Practice for Design of Rockfall Protection Measures in Austria

\[ B = 5 - 6 \text{ D} \]
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Determination of penetration $\delta$ for various types of embankments

Data derived from model testing

$$E^* = \frac{T_{E,d}}{\gamma A E \cdot D \cdot h_a}$$

- **Soil embankments**
  - $E_{\text{ROT}} \geq 1/\theta$

- **Soil embankments with rip-rap**
  - $E_{\text{ROT}} \leq 15\%$

- **Reinforced soil embankments**
  - $E_{\text{ROT}} \leq 15\%$

$E^*$ vs. $\delta/b$
Verification of total stability

Failure mechanisms for total stability (load case 1: ULS, no rockfall)

Ultimate limit state (ULS)
- Equ: loss of equilibrium
- STR: failure of the structure
- GEO: failure of the ground
- UPL: Failure by uplift
- HYD: hydraulic heave
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Inspection and Maintenance

Torrent and Avalanche Control Austria (WLV) Geological Service

Michael Moelk & Gernot Stelzer
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Inspection and Maintenance – Extension of Lifetime

- Critical state
- Irreversible damages or failure of structure possible
- Lifetime without periodical inspection and maintenance
- Lifetime with periodical inspection and maintenance
- Periodical inspection and maintenance
- No inspection and no maintenance

Torrent and Avalanche Control Austria (WLV)
Geological Service
Michael Moelk & Gernot Stelzer
Operative instruments of inspection according to ONR 24810 (1)

First registration of construction in database

- First registration of construction in database
  - Independent document apart from inspection, technical description of protection measure

Inspection

- Visual – also from distance.
- In case of event: on sight check for damages or deficiency
- Once per year
- Trained personnel
Operative instruments of inspection according to ONR 24810 (2)

Control
Inspecting construction on sight
Intervals: CC 1 ≤ 10 y
   CC 2 ≤ 7 y
   CC 3 ≤ 5 y
Trained personnel or expert

Special control
In case of an event
After exceptional events (falling trees, extreme winters …)
Interval: if required
Trained personnel or expert

Testing
If evaluation by control not possible
In case amount of damage cannot be evaluated
=> Special test procedures
Expert
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Operative instruments of inspection according to ONR 24810 (3)

<table>
<thead>
<tr>
<th>State Class</th>
<th>Structural Safety</th>
<th>Fitness for Use</th>
<th>Time to Start Measure</th>
<th>Examples at Rockfall Catchment Fences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>given</td>
<td>given</td>
<td>long-term</td>
<td>no damage visible</td>
</tr>
<tr>
<td>2</td>
<td>given</td>
<td>given</td>
<td>long-term</td>
<td>minimal corrosion, minimal wear and tear</td>
</tr>
<tr>
<td>3</td>
<td>given</td>
<td>given</td>
<td>middle-term</td>
<td>plastic deformation of net, visible deformation brake element</td>
</tr>
<tr>
<td>4</td>
<td>limited</td>
<td>very limited</td>
<td>short-term</td>
<td>eroded or buckled micropiles, deformed posts, strongly deformed brake elements, decreased nominal height, rope ruptures, deformed shackles and wire rope clips, pulled micropiles, filled nets, broken welds</td>
</tr>
<tr>
<td>5</td>
<td>not given</td>
<td>not given</td>
<td></td>
<td>completely destroyed</td>
</tr>
</tbody>
</table>
Standards and best Practice for Design of Rockfall Protection Measures in Austria

Thank you for your attention!
Standards and best Practice for Design of Rockfall Protection Measures in Austria

KONTAKT

Michael Mölk, Mag.
Wildbach- und Lawinenverbauung
Geologische Stelle
W. Greil Str. 9
6020 Innsbruck
Austria
T: +43 512 584200-38
F: +43 512 584200-44
E: michael.moelk@die-wildbach.at

Gernot Stelzer, Dipl.-Ing. Dr. mont.
Trumer Schutzbauten GmbH
Weißenbach 106
5431 Kuchl
Austria
T: +43 664 8341386
E: g.stelzer@trumer.cc