GEOBRUGG Conference, Metsovo, Greece

June 28th to 29th, 2002

Design of Rock Fall Mitigation Measures

- A State of the Art Report -

By Dr. Raymund M. Spang

Contents

Definition of rockfall

- Rockfall is a mass movement in steep slopes, including one or a few rolling, bouncing, sliding or falling rock blocks, without a continuous contact with the slope surface. Its volume is restricted to a few cubic meters.

Modern rockfall mitigation measures

- Active measures, definition, examples: scaling, anchoring, netting, shotcrete sealing or covering (not regarded within this lecture).
- Passive measures, definition, examples: stops or diverts rockfall; berms, galleries, ditches, barriers.

Basic conditions for the need of rockfall mitigation measures

- There are instable rock blocks on a slope or rock can become instable;
- Rockfall can be triggered;
- Slope inclination allows for an acceleration;
- There is a sensitive object within the range of rockfall;
- Rockfall represents an unacceptable risk for this object.

Basic technical questions for design

- Kinetic energy (See)
- Bounce height (hit on trees)
- Distribution of energy and bounce height.
- Return period vs. energy and bounce height. (Rocks aside a road – Arnsberg, Kehlstein)

Basic approach

- Kinetic energy: from in situ tests by measuring velocity or from back calculation of velocity from foot prints (Arnsberg); by using potential kinetic energy or by rockfall simulation.
- Bounce height: from in situ tests or by measuring the height of hits on trees, or from back calculation of velocity from footprints (Arnsberg); or by rockfall simulation.

- Distribution of energy and bounce height: by back calculation from mapping debris cones (energy) and systematic mapping of hits on trees; or by rockfall simulation.
- Return period: by existing records or by assessment of the decisive geological factors.

Pre–selection of the appropriate measure

- Energy range of different passive measures.(diagram)
- Feasible heights of structures;
- Cost and maintenance.

Design of selected mitigation measures

- Galleries: Swiss recommendations on forces on galleries against rockfall (not considered in this lecture)
- Ditches: RITCHIE
- Dams: no generally accepted rules for dimensioning dams against impacts; see for example PLONER, SÖNSER, TROPPER
- Barriers: According to the following example

Koumi Line, Nagano Prefecture, Japan (SPANG & KRAUTER, 2001)

Project

General geotechnical information

- Slope geometry
- Surface near geological conditions
- Size of instable rock blocks (rock face, debris cone)
- Triggering (freezing, earthquakes, high precipitation)
- Acceleration
- Risk (2 existing mitigation structures, partly destroyed)
- Bounce height indications (trees, structure)
- Frequency/return period

Rockfall simulation

- Programme
- Pre-selection of input data
- Calibration
- Results (bounce height and energy distributions, location etc.)

Safety factors

- Conventional safety factors for energy and height of structure
- Probabilistic approach

Selection of barrier (EOTA, Swiss guideline for the approval of rockfall protection kits, SPANG, 2002)

- “Minimal height”
- “Minimal energy”
- “Maximal deformation”
- „Service energy“
- „Zero maintenance“
- Other technical considerations (Corrosion protection, foundation)

Kinetic energy

$$E_{kin} = f \cdot E_{pot;}\ 0 \leq f \leq 1 \qquad \textbf{(1)}$$

$$E_{tot} = E_{trans} + E_{rot} \qquad \textbf{(2)}$$

$$E_{trans} = \frac{m}{2} v^2 \qquad \textbf{(3)}$$

$$E_{rot} = \frac{1}{2} I\omega^2 \qquad \textbf{(4)}$$

$$E_{tot} = \frac{1}{2}\left(m \cdot v^2 + I\omega^2\right) \qquad \textbf{(5)}$$

Conventional safety factors

$$h_D = h_{\max} \cdot f \qquad f_h \geq 1{,}5 \text{ ......} 2 \text{ ......}$$

$$E_D = E_{\max} \cdot f \qquad f_E \geq 1{,}5 \text{ ......} 2 \text{ ......}$$

Probabilistic approach

- **Probability P_v of certain rockfall volumes** (from geotechnical mapping)

Vol. **m³**	**Return period** **a**	**Probability $P_{v/a}$** **/**
0,5	1	1
5	50	2×10^{-2}
30	500	2×10^{-3}

- **Design energy E_D for a selected return period n**
    - V = const, n = 500 years
    - Rockfall simulation for 10.000 rocks for statistical reliability

Summation diagram

For "$E_D = E_{95}$" Probability of values > E_{95} $P_{E>E_D}$

$$P_{E>E_D}\{x_i \geq x\} = 1 - 0{,}95 = 0{,}05 = 5 \cdot 10^{-2}$$

- **Probability of occurrence P_a für $E \geq E_D$ / t**

(t = 1 year or t = life time of the structure)

$P = P_v \cdot P_{E>E_D}$, für n = 500 years

$P_{500} = 2 \cdot 10^{-3} \cdot 5 \cdot 10^{-2}$

$= 10^{-4}$

Return period

$n = \frac{1}{P_{500}}$

$= \frac{1}{10^{-4}}$

= 10.000 years