Reliability of rock-fall protection galleries

A case study with a special focus on the uncertainty modeling

Matthias Schubert,
Daniel Straub,
Michael H. Faber

Institute of Structural Engineering IBK
Chair of Risk and Safety
Swiss Federal Institute of Technology Zürich

Overview

- Introduction
- Probabilistic modeling of rock detachment frequencies
- Modeling the rock-fall process
- Resistance of rock-fall protection galleries
- Conclusion

Introduction

- The increase of the traffic in mountainous regions necessitate protection structures against natural hazards.

- Difficult or impossible to describe loads due to such hazards in codified format.

- These events are rare, site specific and object related.

- Due to the lack of a codified format, inconsistent decisions are made in regard to the reliability of protection structures.

- Only a risk-based approach can ensure optimal the choice and design of a protection structure.

Introduction

- A case study has been carried out on a existing rock-fall gallery built in 1975 in the Swiss alps.

- A geological expertise for the special case was analyzed.

- The steepness slope was modified for this study to obtain higher energies.

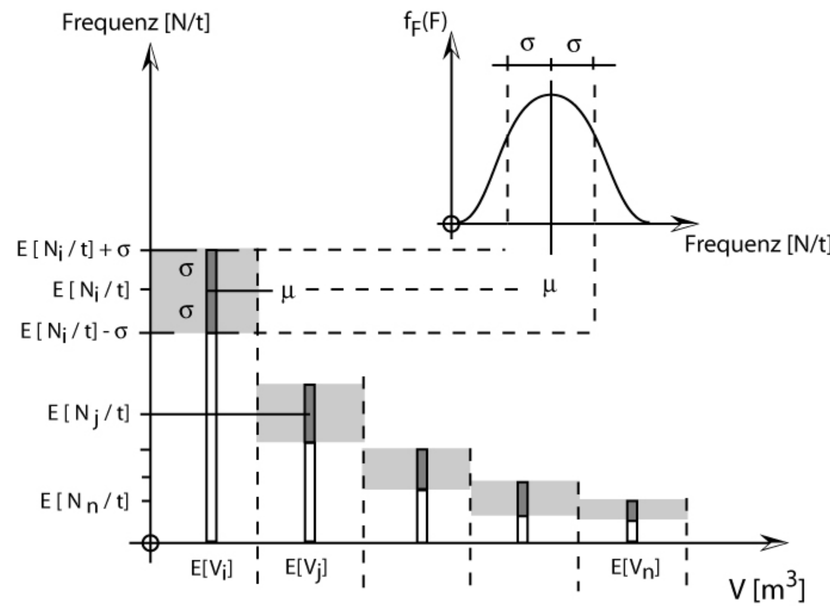
- All diagrams and graphs which are shown in this presentation are results of this case study.

Probabilistic modeling of the rock-fall frequency

- Due to the highly specific nature of rock-fall, no or only few quantitative data is available.

- Geological expertises are traditionally of a qualitative or semi-quantitative character.

- For a probabilistic approach it is necessary to model these information and the inherent uncertainties.



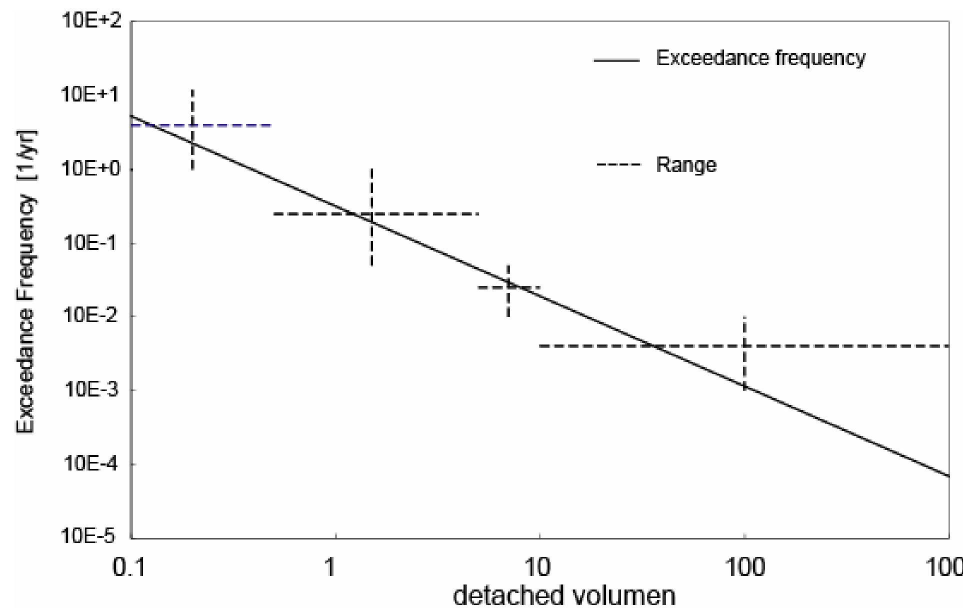
Probabilistic modeling of the rock-fall frequency

- Most exceptional loads are described by their exceedance frequency

- In the present study case a power-law is applied – without any physical or mathematical foundation.

- The exceedance frequency of a detached rock is defined as

$$H_V(v \mid a,b) = a \cdot v^{-b}$$



Probabilistic modeling of the rock-fall frequency

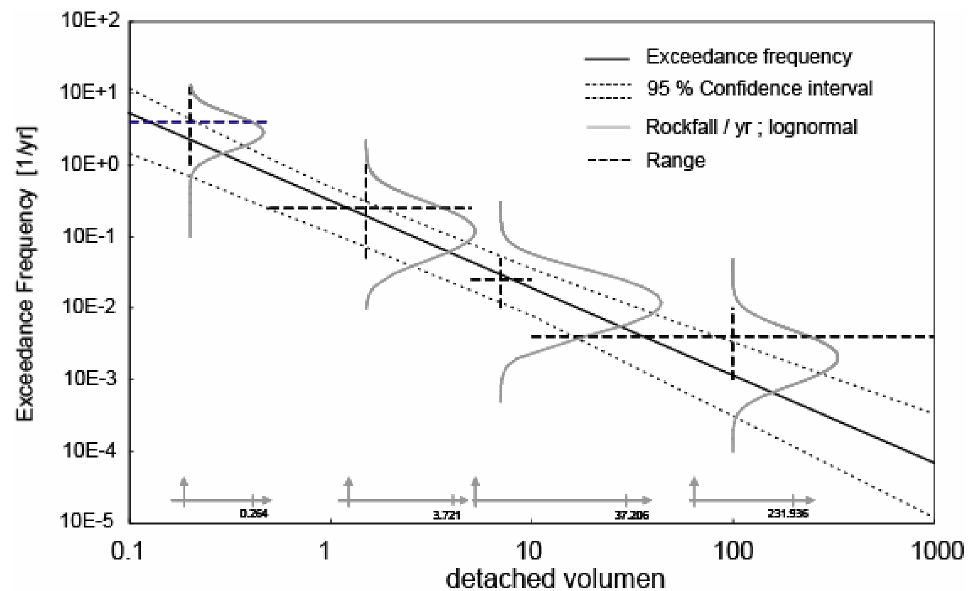
- The uncertainty in this estimation can be quantified by fitting a probability density function to the estimated frequency.

- From the geological expertise, distributions are then fitted for each given volume range.

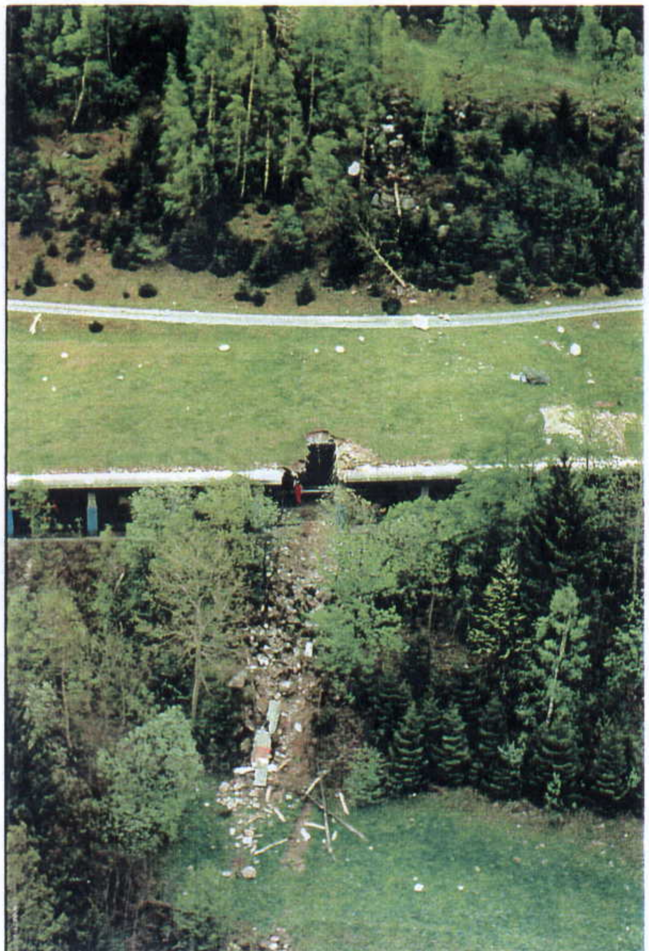
- The parameters *a* and *b* are then estimated together with the uncertainty on the estimation.

- The predictive frequency distribution of a detachment is calculated by:

$$h_V(v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h_V(v \mid a,b) \cdot f_{a,b}(a,b)\, da\, db$$



Modeling the rock-fall Process



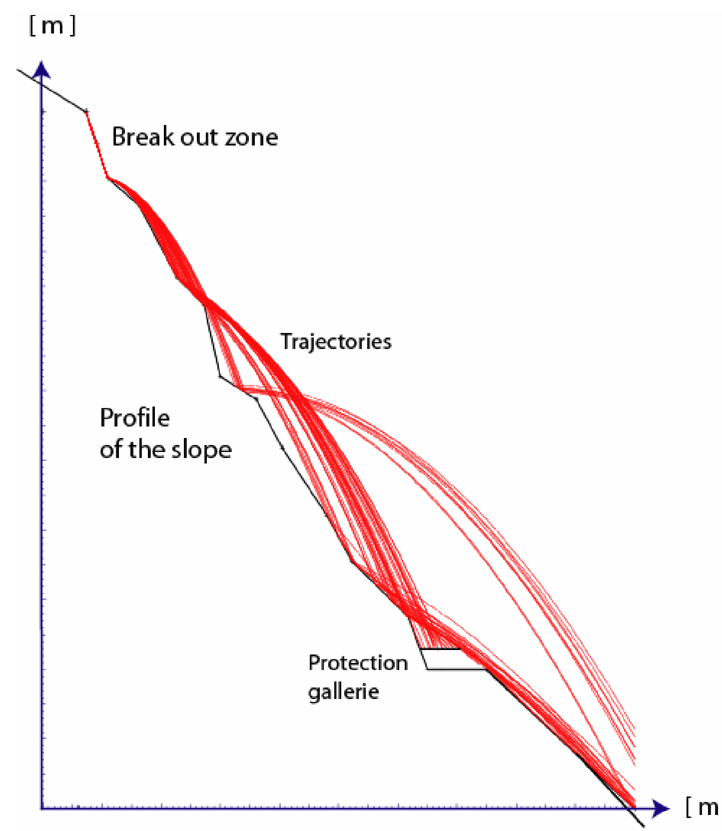
- Once a stone is detached the falling process determines the kinetic energy of the stone.

- The main parameters describing the falling process are

    - Profile of the slope
    - Coefficient of restitution
        - geology
        - morphology
        - vegetation
        - structure of the contact surface

Modeling the rock-fall Process

- The falling process is simulated by standard rock-fall programs.
- They are based on a Monte Carlo simulation.
- Using this programs, parameter studies can be performed.
– Simulations over the possible range of rock-volumes.



Modeling the rock-fall Process

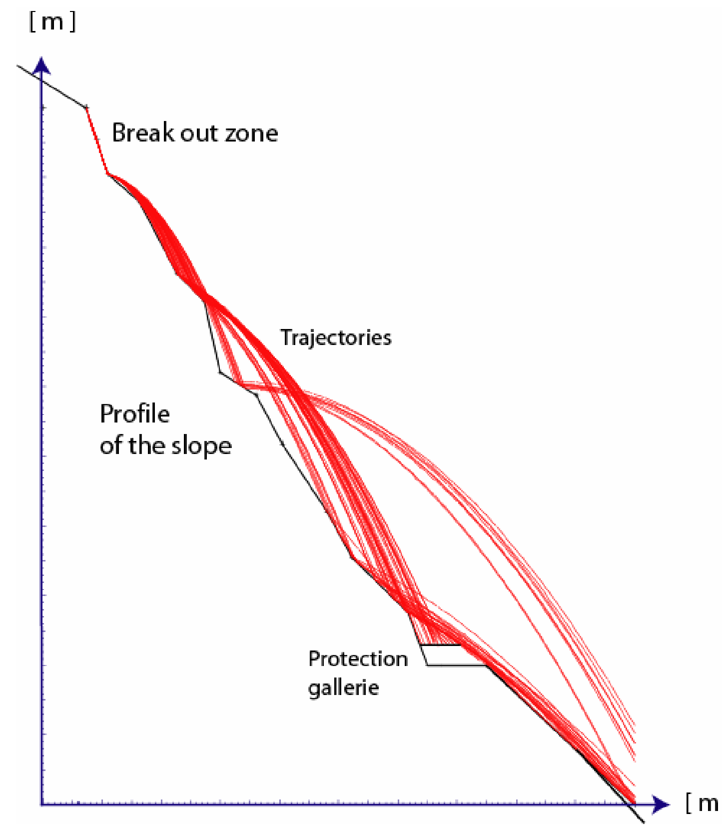
- With these simulations a PDF of the energy at the gallery conditional on the detached volume is obtained.

$$\mathrm{f}_E^G(e|v)$$

- The joint frequency distribution of volumes and energies of the rocks hitting the gallery can then be calculated :

$$\mathrm{h}_{EV}^G(e,v) = \mathrm{f}_E^G(e|v) \cdot \mathrm{h}_V(v)$$

$$\mathrm{H}_{EV}^G(e,v) = \int_e^{\infty}\int_v^{\infty} \mathrm{f}_E^G(e|v)\,\mathrm{h}_V(v)\,\mathrm{d}v\,\mathrm{d}e$$



Modeling the rock-fall Process

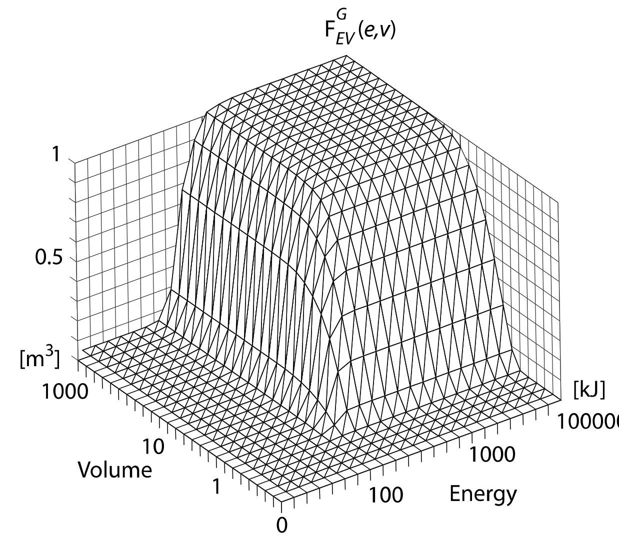
- For the calculation of the reliability of rock-fall protection structures the extreme value is of interest.

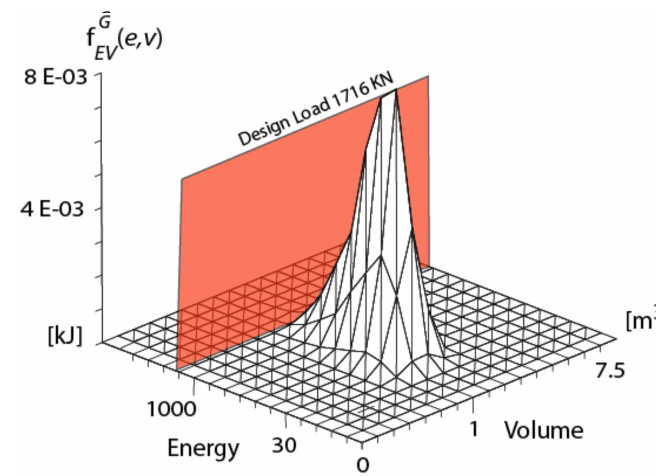
- Assuming rock-fall follows a Poisson process, the CDF is:

$$F_{EV}^{G}(e,v) = 1 - e^{-H_{EV}^{G}(e,v)}$$

- The original design load was 1716 KN ~ 300 yr.

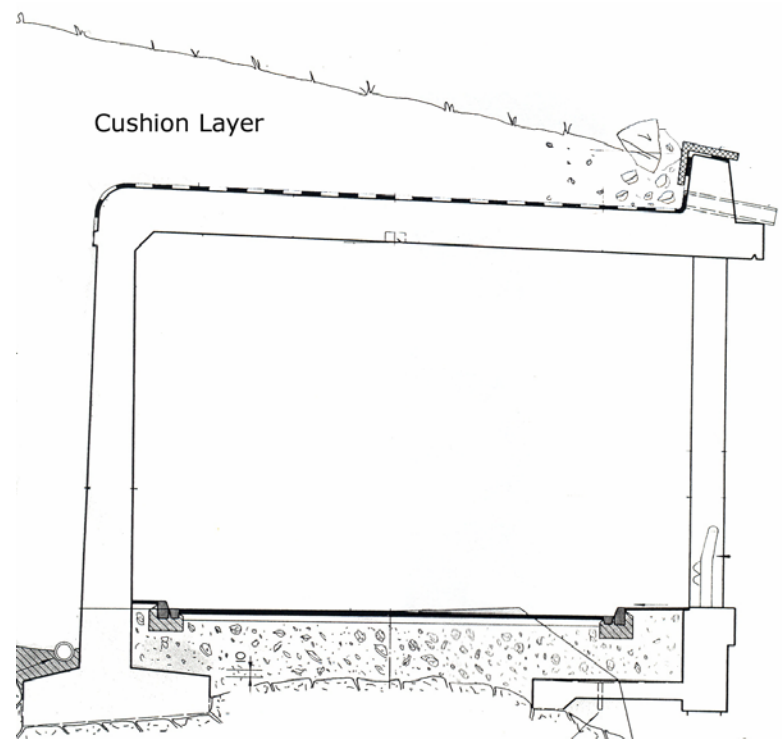
- This estimation is conservative for this gallery.





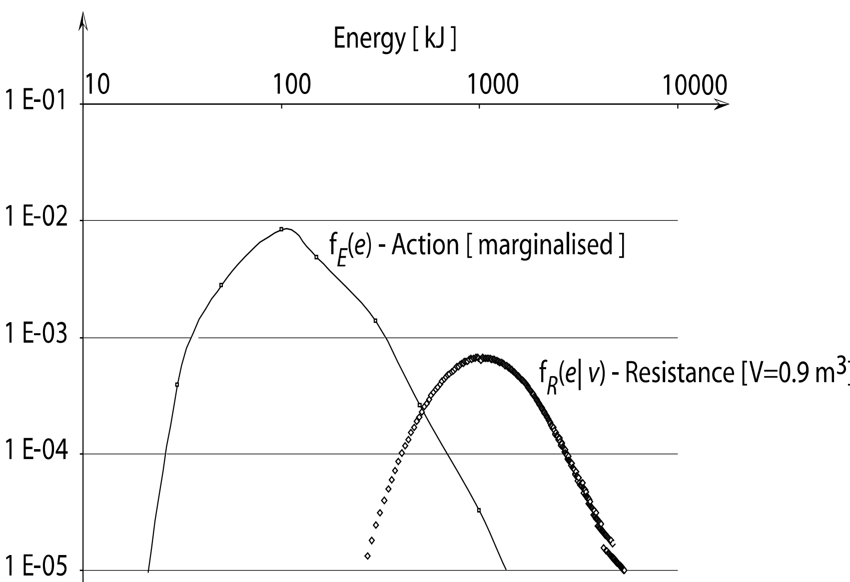
Resistance

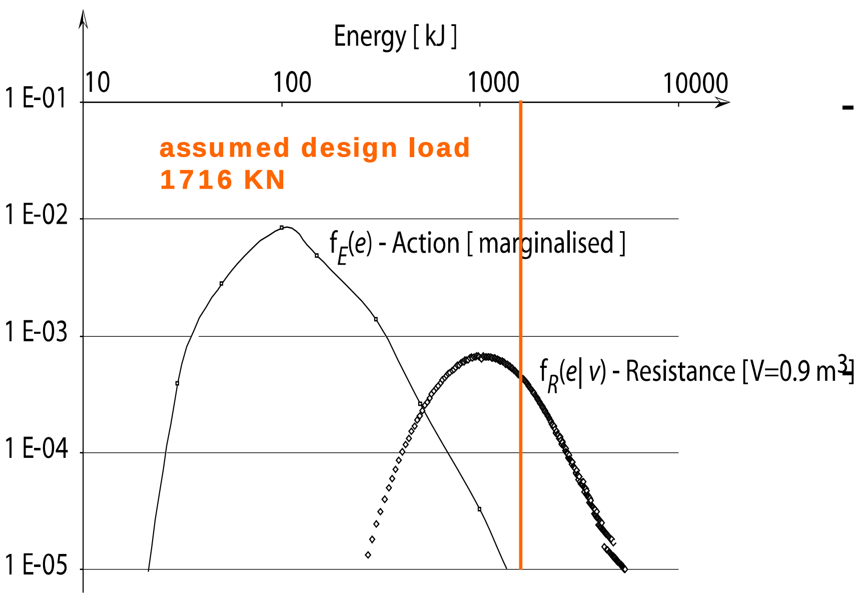
- On most of the protection galleries a cushion layer is present.
- This layer mitigates the so called “hard impact”.
- It dissipates the energy of the rocks and share it to a larger area
- In our studies a static equivalent load for the dynamic impact is assumed.



Resistance

- The main failure mechanism is punching.
- With a model for the resistance against punching shear it is possible to perform a reliability analysis.





Probability of failure

- With the assumed steepness of the slope the probability of failure for the gallery was calculated:

$$P_f = \int_{-\infty}^{\infty} F_R(EV) \cdot f_S(EV)\, dV\ dE$$

$$P_f = 6.34\ \mathrm{E}-03\ [\ \mathrm{yr}^{-1}] = 1/158\ \mathrm{yr}$$

- There was no failure at this location until now
    - The slope is not steep enough to reach such energy

- The resistance of the gallery is undervalued in regard to the design load
    - In the early 70th punching was not considered

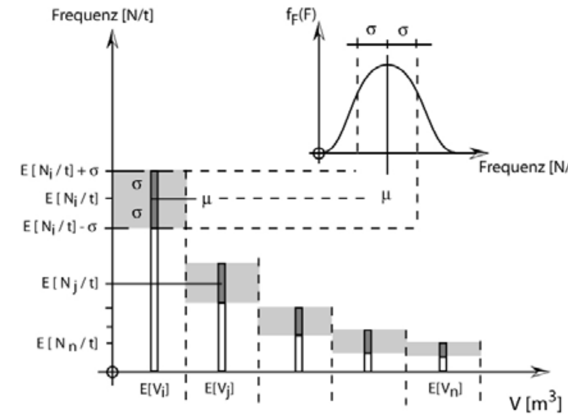
Conclusions

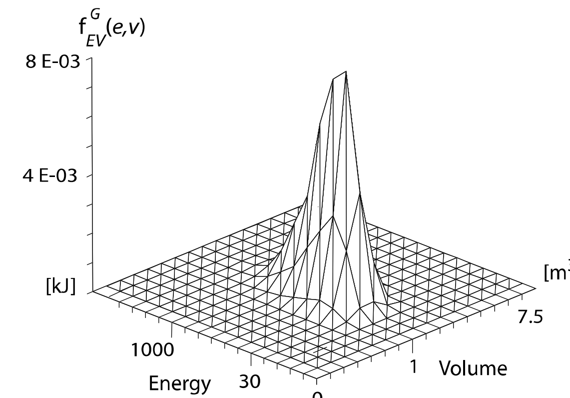
- This approach enables to deal with semi-quantitative statements and assess a predictive frequency distribution of rock fall events.

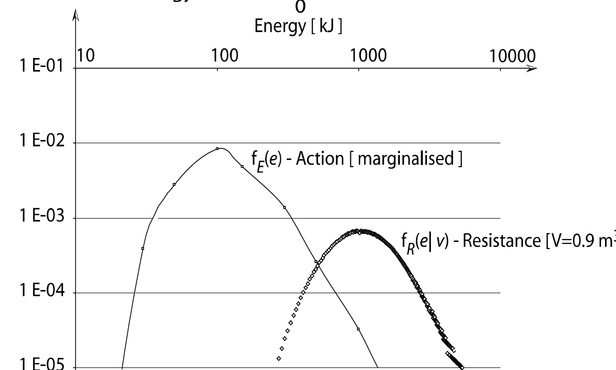
- A model for reliability analysis of rock-fall protection galleries has been developed.

- It is possible to derive and verify design loads for new and existing structures

- This facilitates the optimal planning of risk mitigation actions







Reliability of rock-fall protection galleries

Thank you for your attention