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CHARACTERIZATION OF DESIGN IMPACT LOADS FOR ROCK-FALL PROTECTION

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Overview

- Introduction
- Modeling of the exposure
- Uncertainties in the rock-fall model
- Determination of impact design loads
- Conclusions

Introduction

- Infrastructures and buildings in mountainous regions are exposed to gravitative natural hazards.

- These risks are addressed through a variety of protection measures.

- Significant costs associated with such measures – decisions should be made on a consistent scientific basis.

- A proper modeling of the processes, the performance of protection structure and the associated uncertainties is crucial.

Detachment of a stone

System Exposures

- The relevant parameter is the volume of a detached rock volume V or rock mass.
- Rock-fall is an uncertain process – impossible to predict the time and extend of the next event.
- The relevant rock-fall parameter can be described as a random variable V.
- Typically described by its annual exceedance frequency $H_V(v) = E\,[\,N\,(v)\,]$.

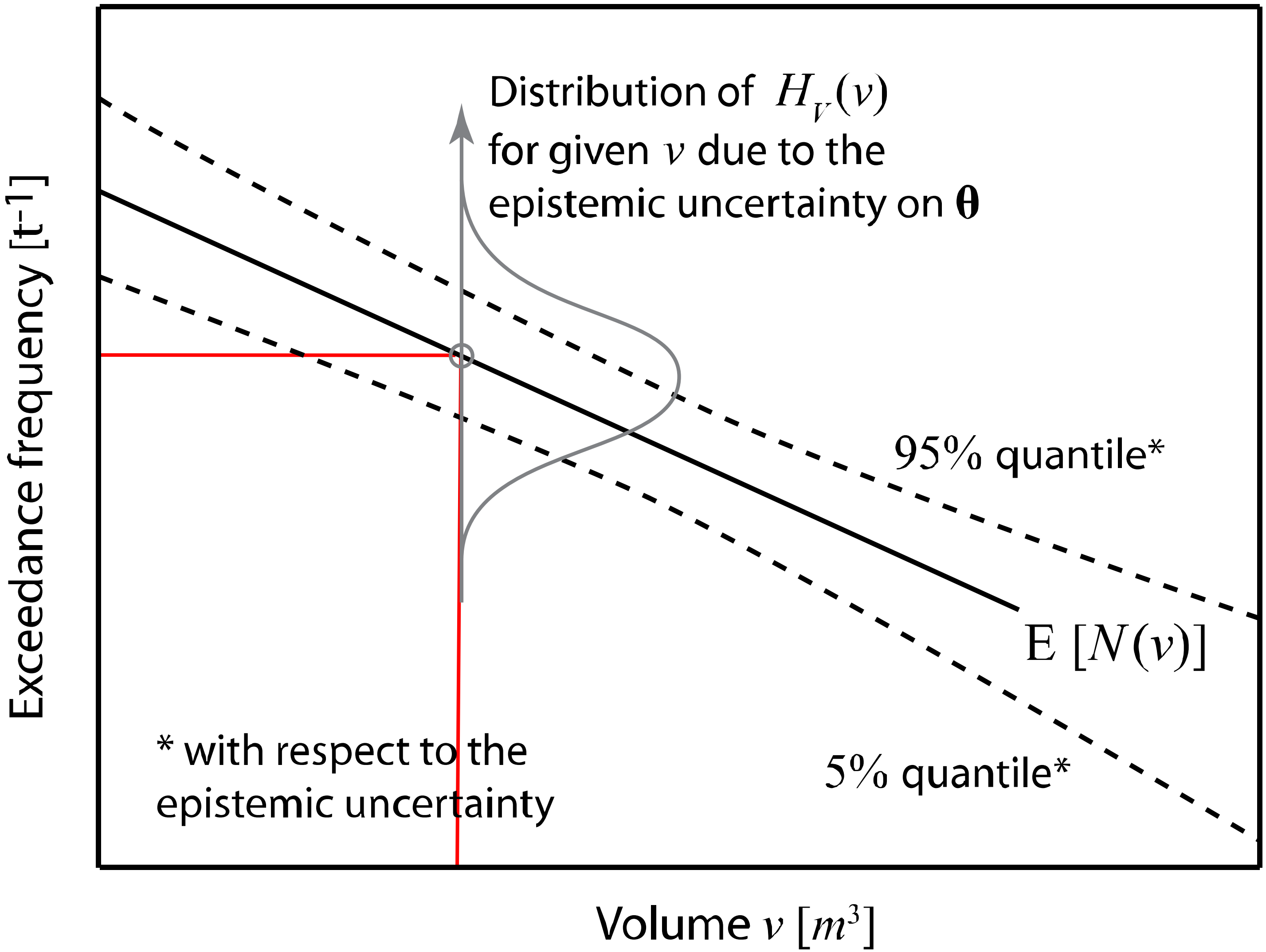
Uncertainties in rock-fall exposure

Useful to distinguish between:

- Aleatoric uncertainties (randomness)

- Epistemic uncertainties (knowledge)

Uncertainties in rock-fall exposure



Uncertainties in rock-fall exposure

- The exceedance frequency can be described by , e.g.:

$$H_V(v|\theta) = a\, v^{-b}$$

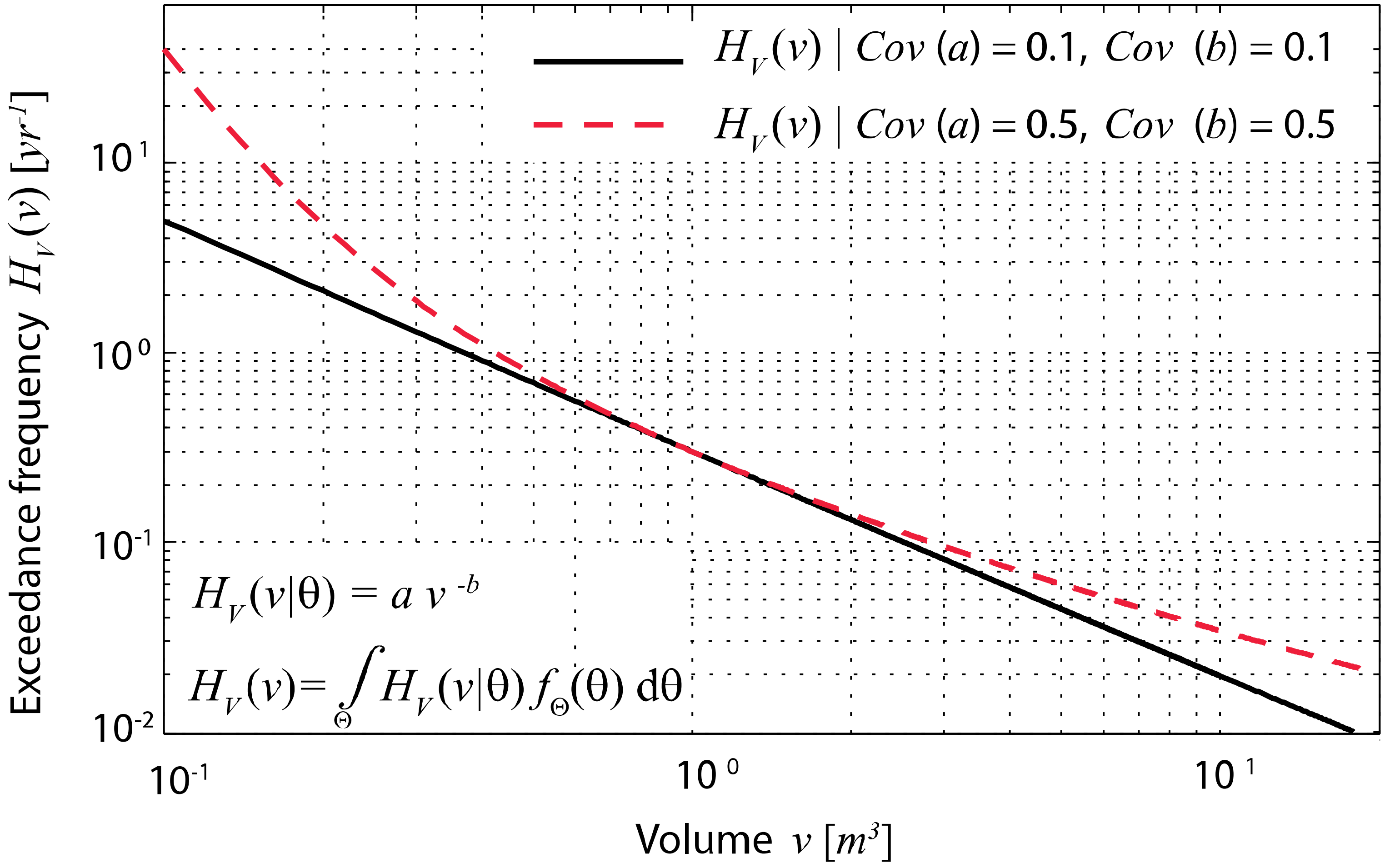
- Include the epistemic uncertainties by modeling the parameters (A,B) as a random vector $\theta=[a,b]^T$

$$f_\Theta(\theta) \qquad \Theta \sim LN(\mu_a, \mu_b, \sigma_a, \sigma_b, \rho_{a,b})$$

- The unconditional exceedance frequency can be calculated:

$$H_V(v) = \int_\Theta H_V(v|\theta)\, f_\Theta(\theta)\, \mathrm{d}\theta$$

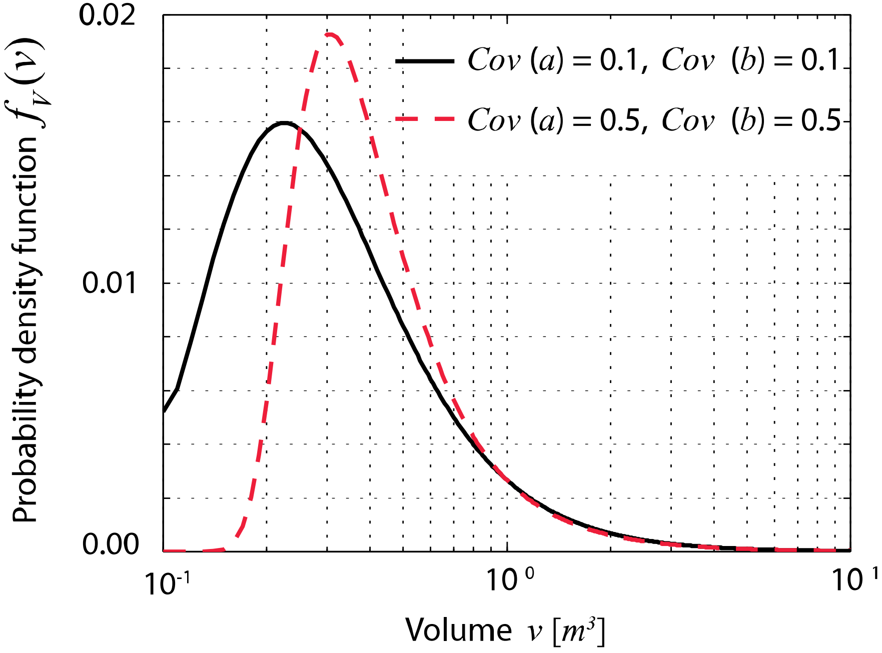
Uncertainties in rock-fall exposure



Modeling of the rock-fall exposure

- For protection structures the maximum annual rock-fall event is of interest.
- Derivation of the distribution $f_V(v)$ of the maximum annual rock-fall event from the exceedance frequency $H_V(v)$:

$$f_V(v) = \frac{d}{dv}\left(\exp\left(-\overbrace{H_V(v)}^{\text{exceedance frequency}}\right)\right)$$



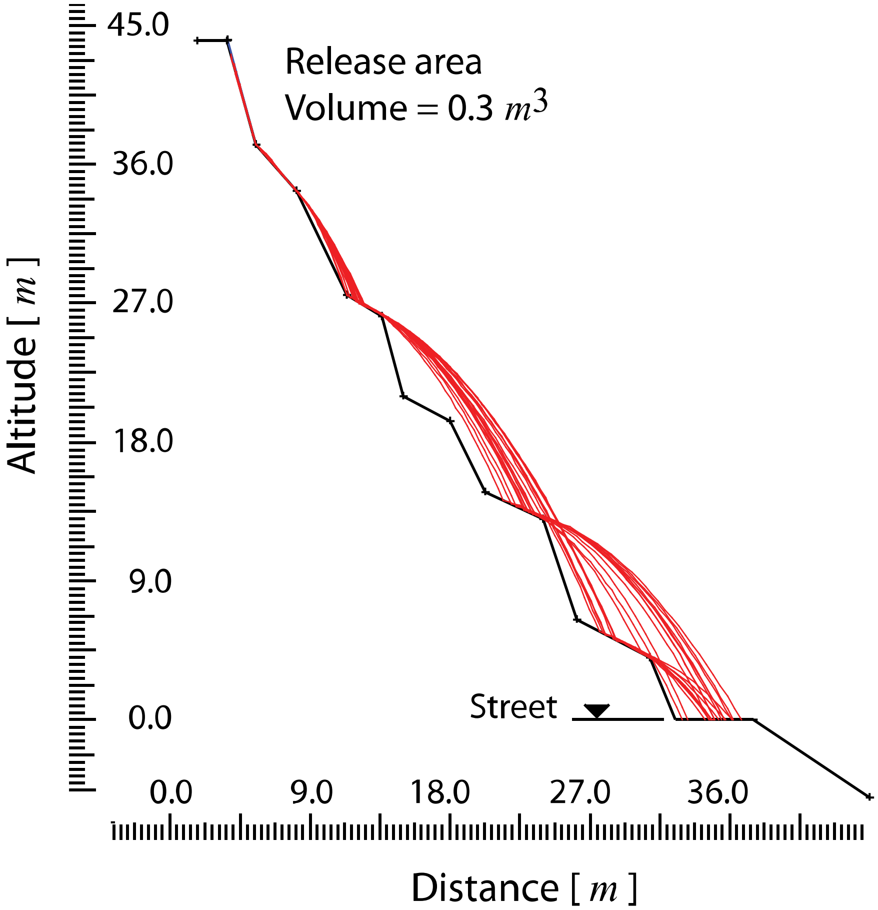
Falling process of a stone

Uncertainties in rock-fall trajectory

- Once a rock is released its trajectory is mainly determined by the topography, its mode of motion and its material characteristics.

- Aleatoric uncertainties in falling process.

- Trajectory models use Monte-Carlo-Simulations.



Uncertainties in rock-fall trajectory

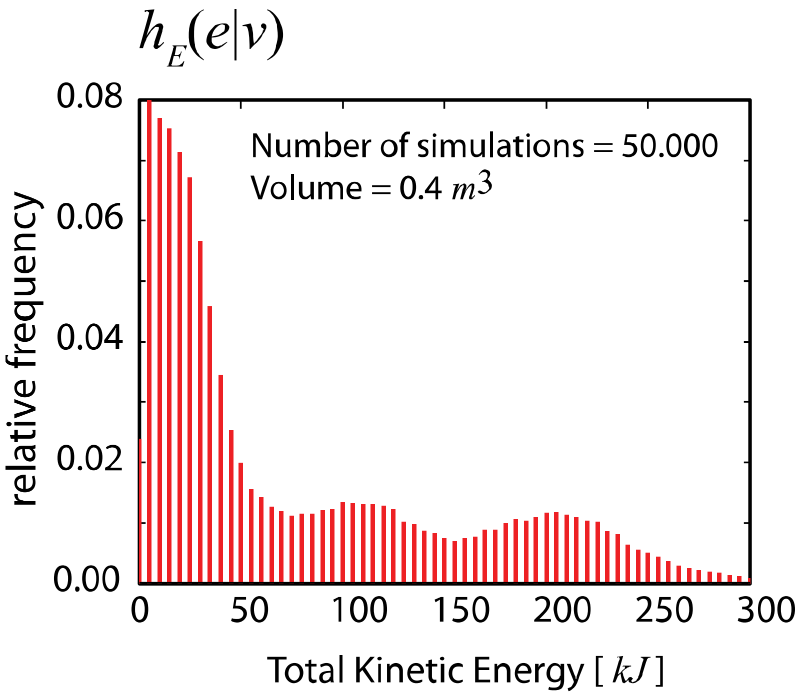
- Epistemic uncertainties in the trajectory analysis due to model assumptions (2D,3D, lumped mass assumption, impact model, simplification of the slope, etc.).

model uncertainty ~ LN(μ,σ)

$$\underbrace{f_E(e|v)} \approx \underbrace{h_E(e|v)}\ \overbrace{f_{X1}(x1)}$$

relativ frequency distribution of the energy for a given rock-fall volume at a specific location

distribution of the energy for a given rock-fall volume at a specific location

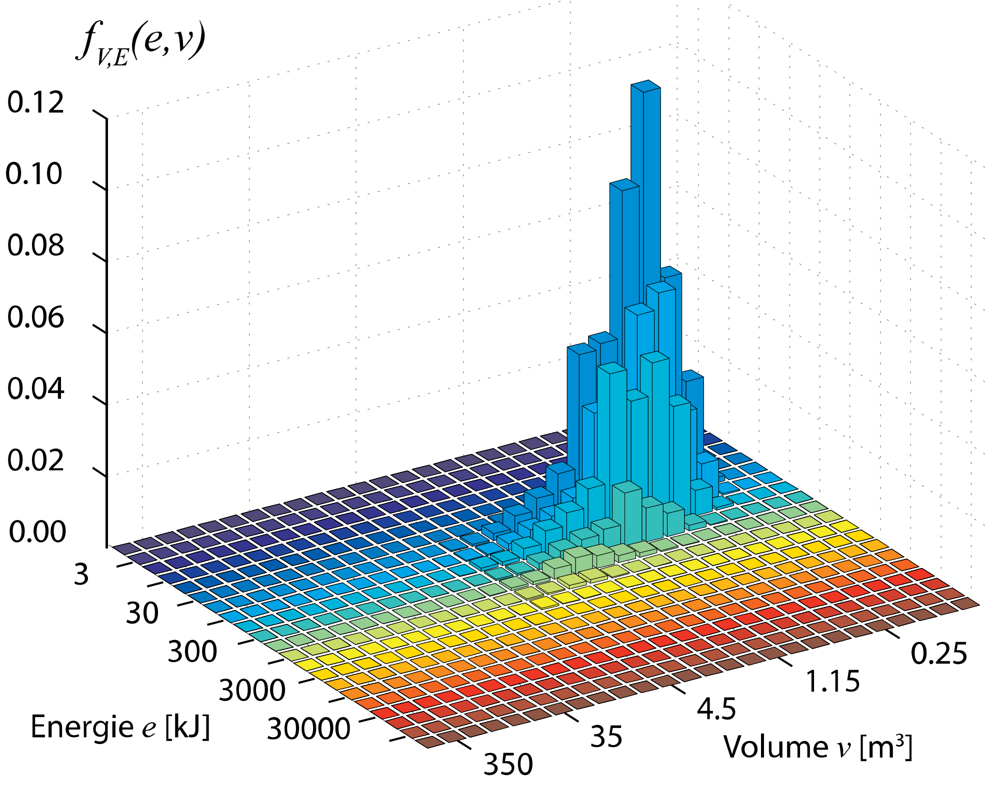


Determination of the impact load

Characterization of the load

- The joint distribution of the maximum annual energy (or velocity) and volume is then calculated by:

$$f_{V,E}(e,v) = \underbrace{f_E(e|v)}_{\text{result of the trajectory model}} \; \underbrace{f_V(v)}_{\text{result of the detachment model}}$$



Resistance of the protection structure

System resistance: Failure probability of protection structures

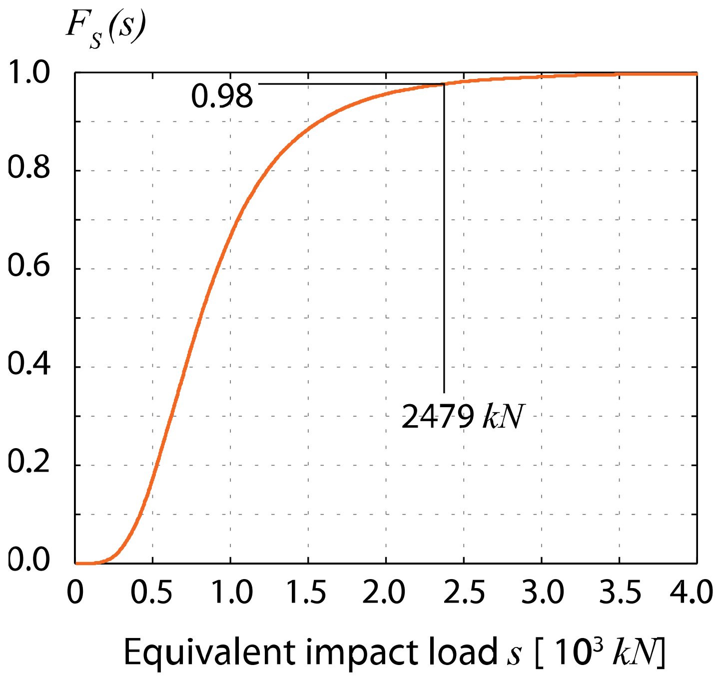
- How can a design load be determined?
  - Code based design
  - Reliability based approach, target reliability
  - Risk based approach

System resistance: Code design of protection structures

e.g. code based design for a protection gallery:

$$S = X_2\, C_k\, 2.8\, c^{-0.5} \left(3V/(4\pi)\right)^{7/30} M_E^{0.4} \tan(\varphi)\, E^{0.6}$$

X_2	~ LN(1.0.2)	Model uncertainty
C_k	~ N(1.2,0.2)	Constr. coefficient
c	~ N(0.75,0.15)	layer thickness
M_E	~ N(30000,7000)	Y-modulus soil
$\tan(\varphi)$	~ N(0.5773,0.05)	friction angle
V,E	~ $f_{V,E}(v,e)$	joint distribution of the energy and stone volume



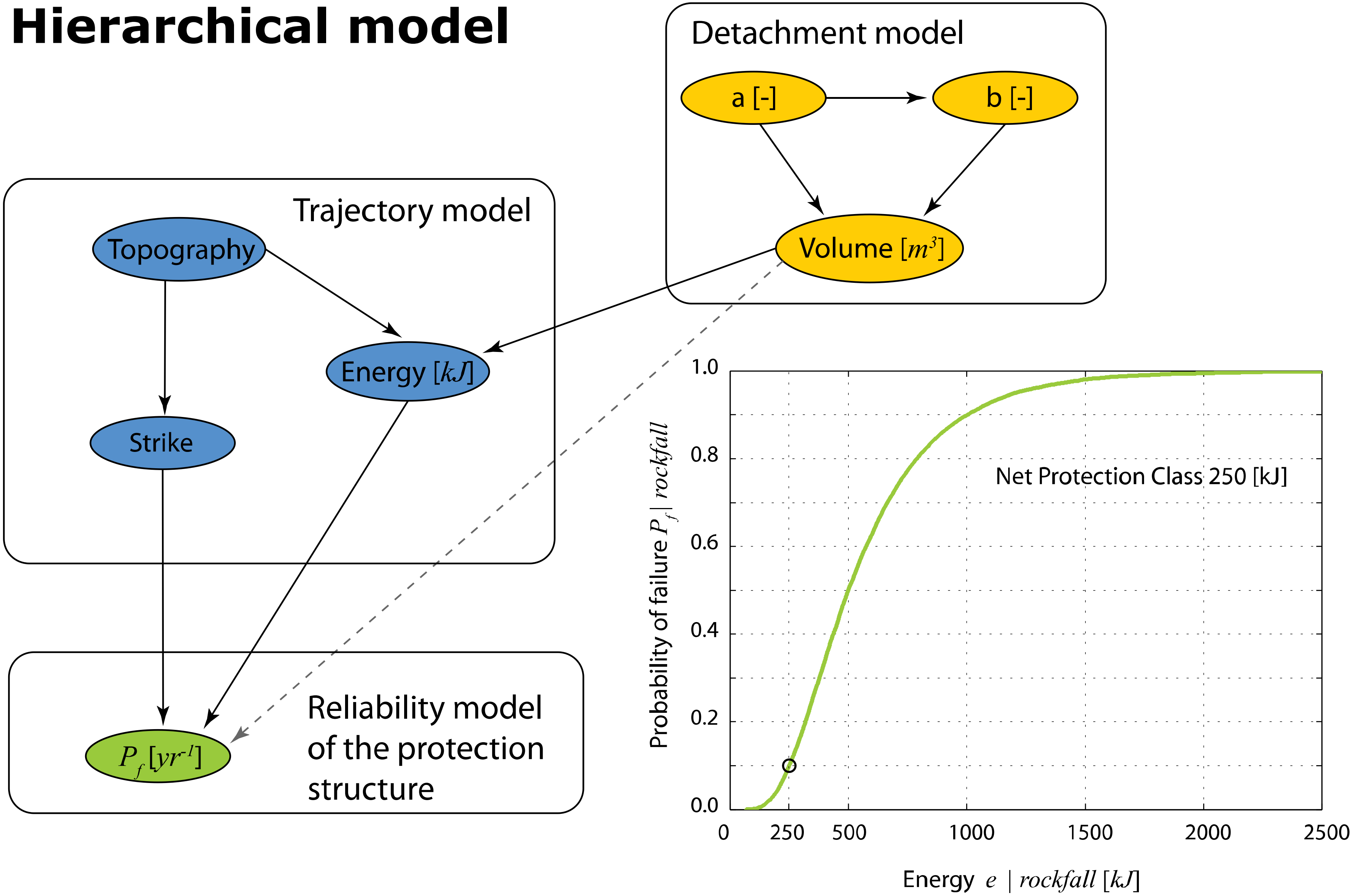
System resistance: Failure probability of protection structures

Probability of failure of a protection structure can be calculated:

$$Pr(F) = \int_0^\infty \int_0^\infty Pr(F|e,v)\ f_E(e|v)\, f_V(v)\ de\ dv$$

- FORM, SORM, simulation techniques
- Stochastic FEM (response surface, sensitivity based approach)
- Development of vulnerability curves for pre-fabricated protection structures.

Hierarchical model



Detachment model

a [-]

b [-]

Volume $[m^3]$

Trajectory model

Topography

Energy $[kJ]$

Strike

Reliability model of the protection structure

$P_f\,[yr^{-1}]$

Conclusions

- Methodology for the assessment of design loads is presented
- Generic methodology: different models applicable; part wise exchangeability.
- Facilitates the design according to codes.
- Facilitates the risk assessment and a risk based design.

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Thank you for your attention!

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