Numerical Climbing Fall Simulator

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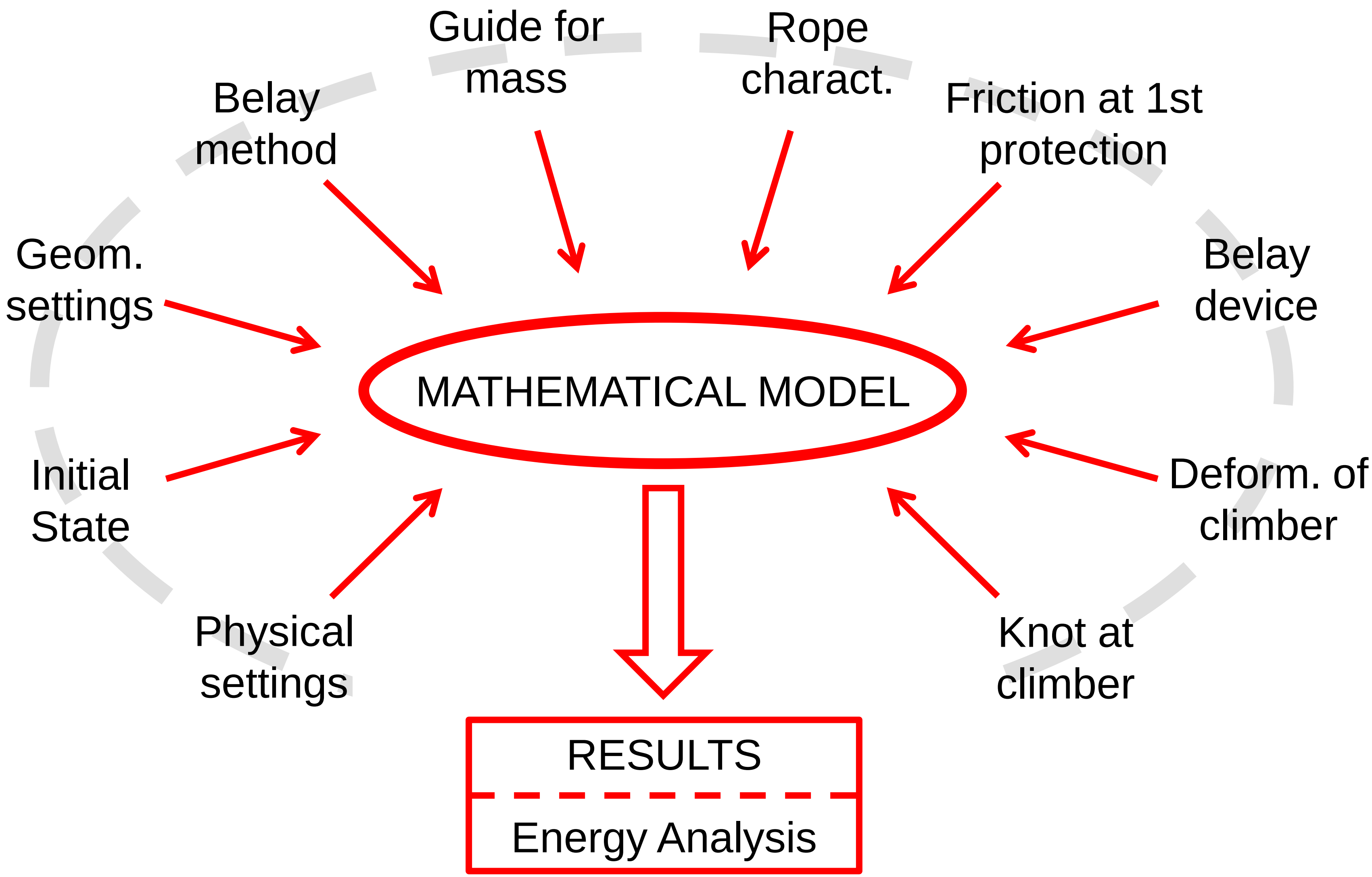
Complete Simulation Model



Mathematical Model

- Mainly two different ways of theoretically investigating a climber's fall are known:

→ The method of energy exchange

→ **Integration of the differential equation of motion**

- This program uses the method of numerically integrating the differential equation of motion, both for the climber and belayer:

$$M_C \cdot \mathbf{a}_\mathrm{C} = \left(\mathbf{F}_\mathrm{GravC} + \mathbf{F}_\mathrm{RopeC} + \mathbf{F}_\mathrm{AdC} + \mathbf{F}_\mathrm{Guide}\right) \qquad \text{Climber}$$

$$M_B \cdot \mathbf{a}_\mathrm{B} = \left(\mathbf{F}_\mathrm{GravB} + \mathbf{F}_\mathrm{RopeB} + \mathbf{F}_\mathrm{Sb} + \mathbf{F}_\mathrm{AdB}\right) \qquad \text{Belayer}$$

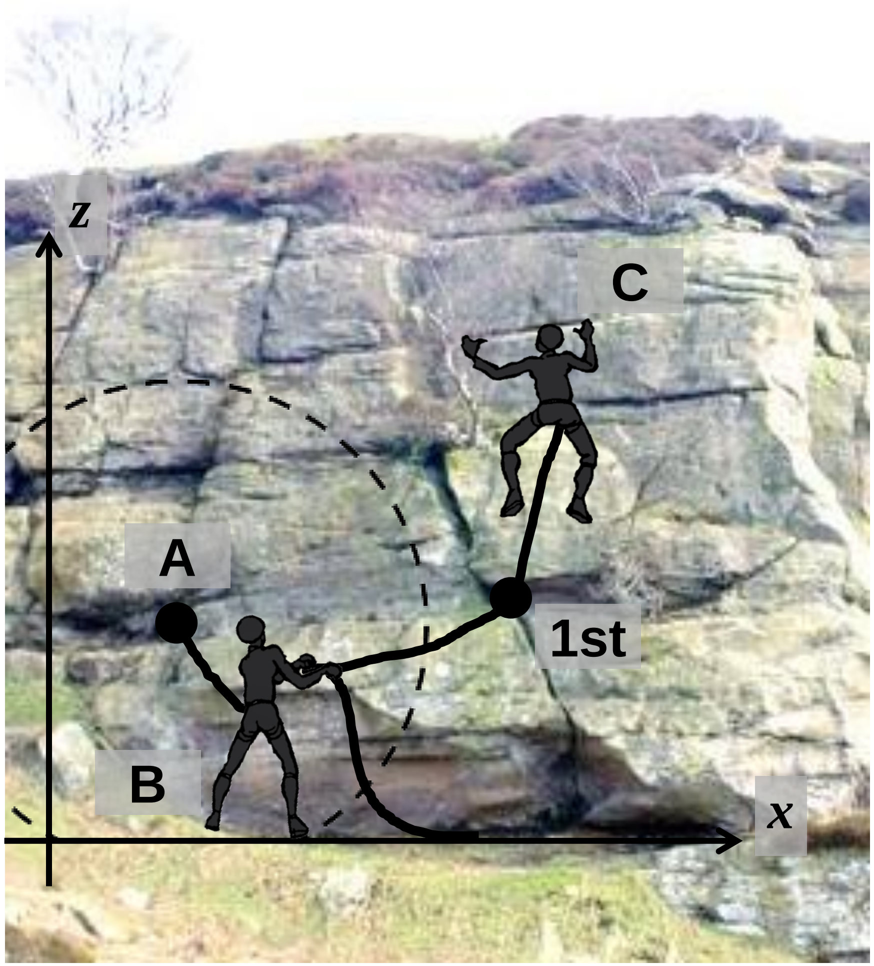
Physical Settings

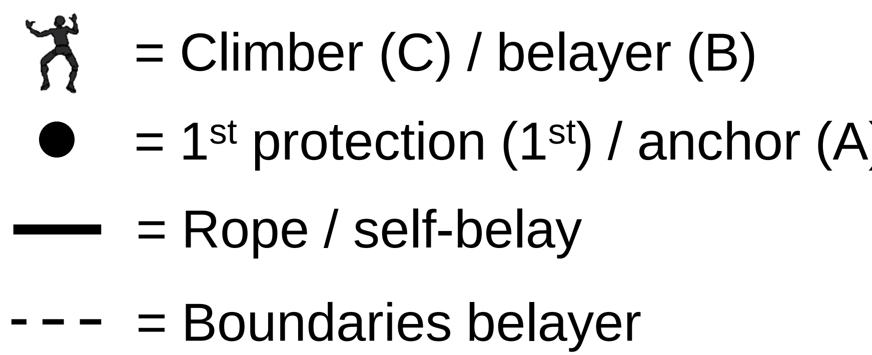
- **Constants**
  Masses, air drag constants, cross sectional areas, friction constants, ...

- **Physical constants**
  Gravity, air density, …

- **Air velocity**
  Meteorological effects

Geometrical Settings and Initial State





Belay Method

- The **belay method** is defined by the geometrical setup and the initial state

- **Mobile belayer**:
The belayer (with or w/o belay device) can be moved by the rope force within it's boundaries, given by the self-belay

→ Influence of the belayer on the results

- **Fix belayer**:
The belayer is attached directly to the anchor and can't move

→ NO influence of the belayer on the results

Guide for Falling Mass

- A **guide for the falling mass** can be added to simulate laboratory fall situations with rigid masses

- No movement of the mass in x-direction

- Constant clamping force and friction of the sliding mass in the guide

- EN 892:2004 Dynamic mountaineering ropes:
  The guide model is mainly used to simulate standard falls according to the European Standard EN 892:2004

Rope Characteristics, Rope Model

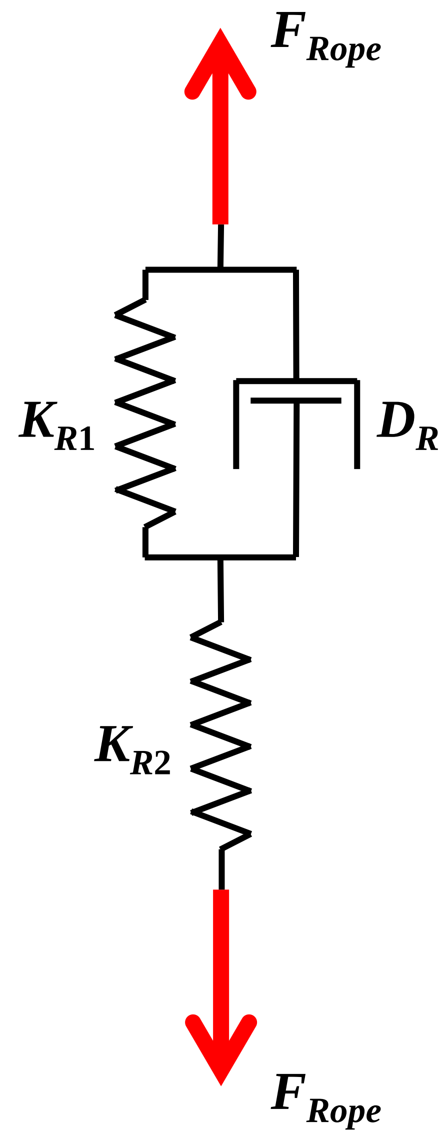
- **3 – Parameter viscoelastic rope model**: Spring (K_{R2}) in series with an in-parallel combination of a spring (K_{R1}) and dashpot (D_R) [Pavier, 1998]

- Calibration of the rope parameter: Comparison of simulation results with real rope values commonly available from product data sheets (EN 892:2004):

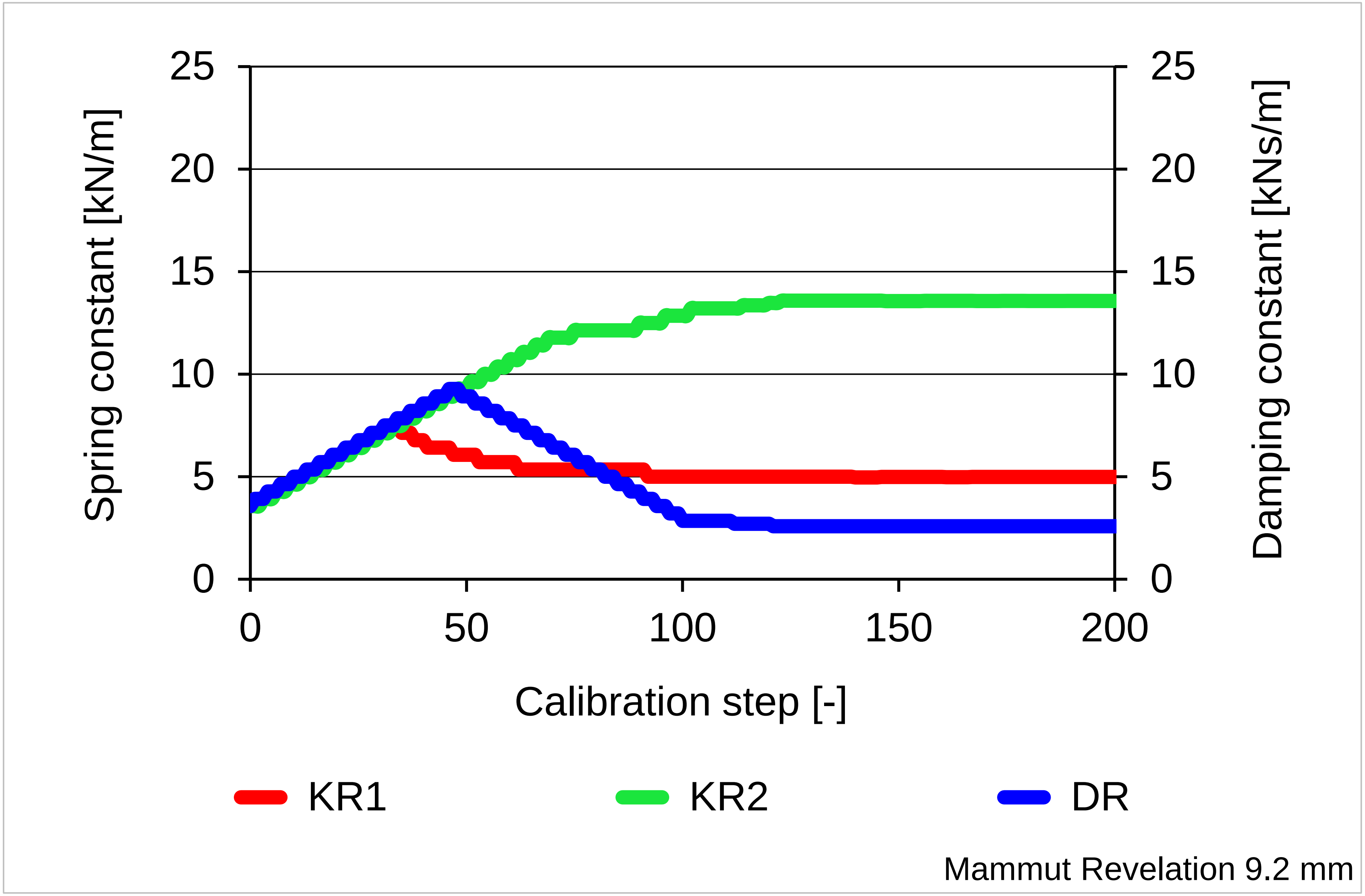
→ Static elongation (free hanging test)

→ Dynamic elongation (fall test)

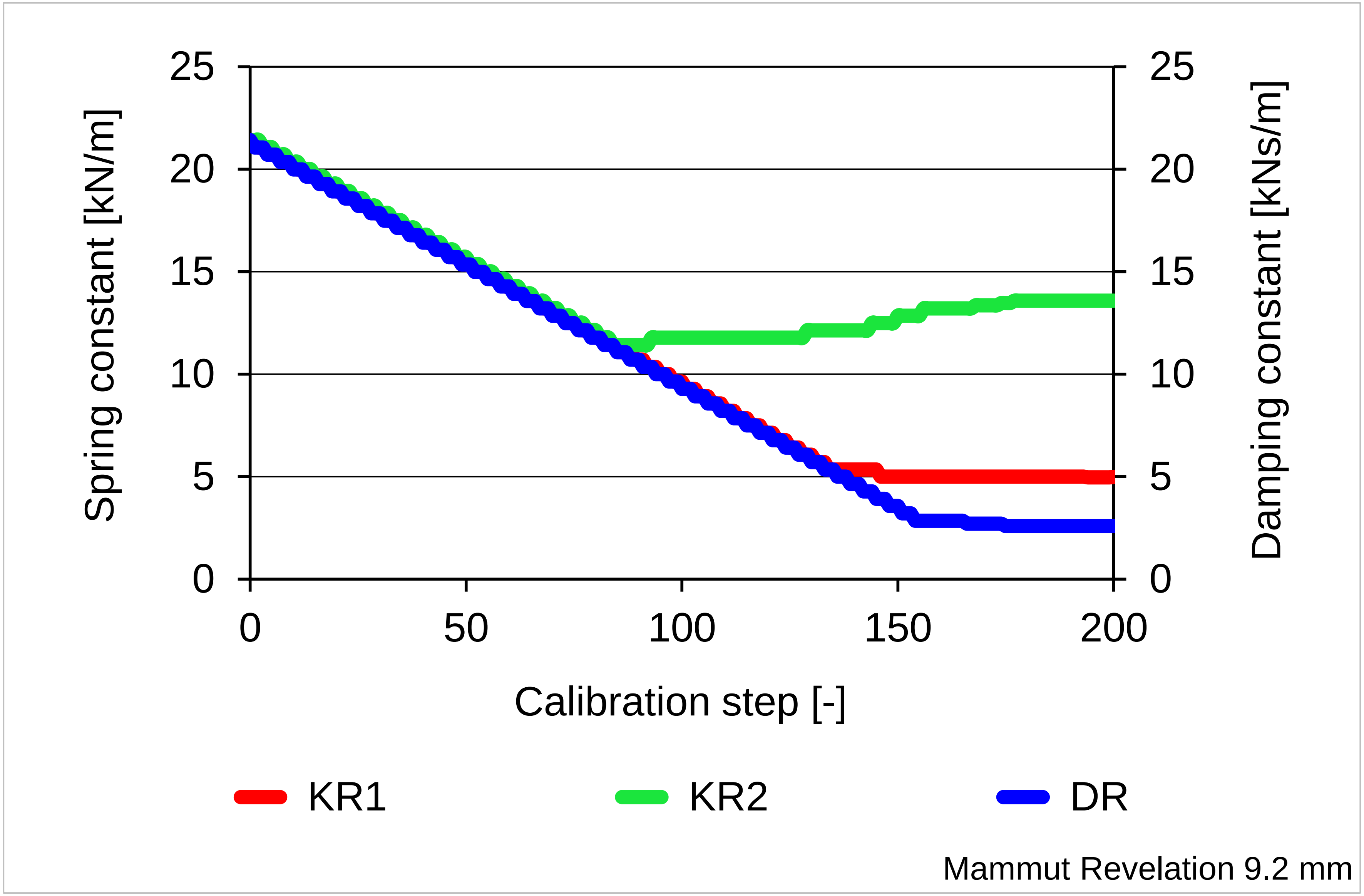
→ Impact force (fall test)



Rope Parameter Calibration (1)



Rope Parameter Calibration (2)



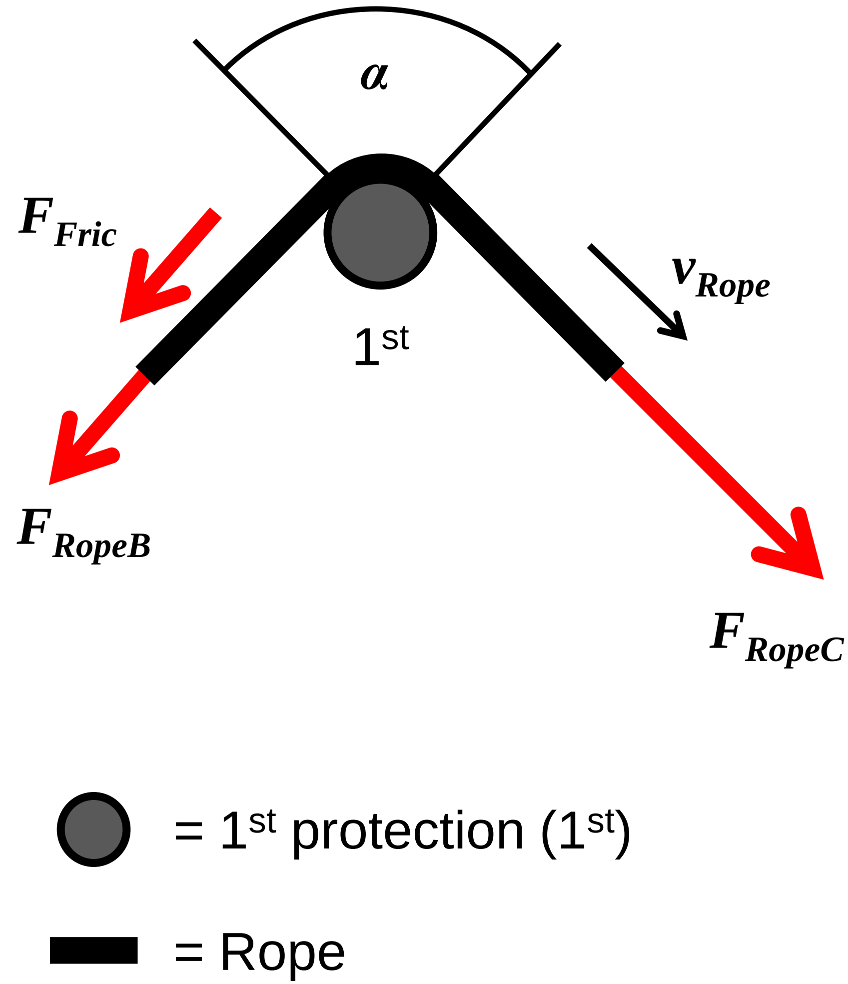
Friction at 1st Protection

- **Friction force F_{Fric}**
  (Euler-Eytelwein)

$$F_{RopeC} = F_{RopeB} \cdot e^{\mu \cdot \alpha}$$

$$F_{Fric} = F_{RopeC} - F_{RopeB}$$

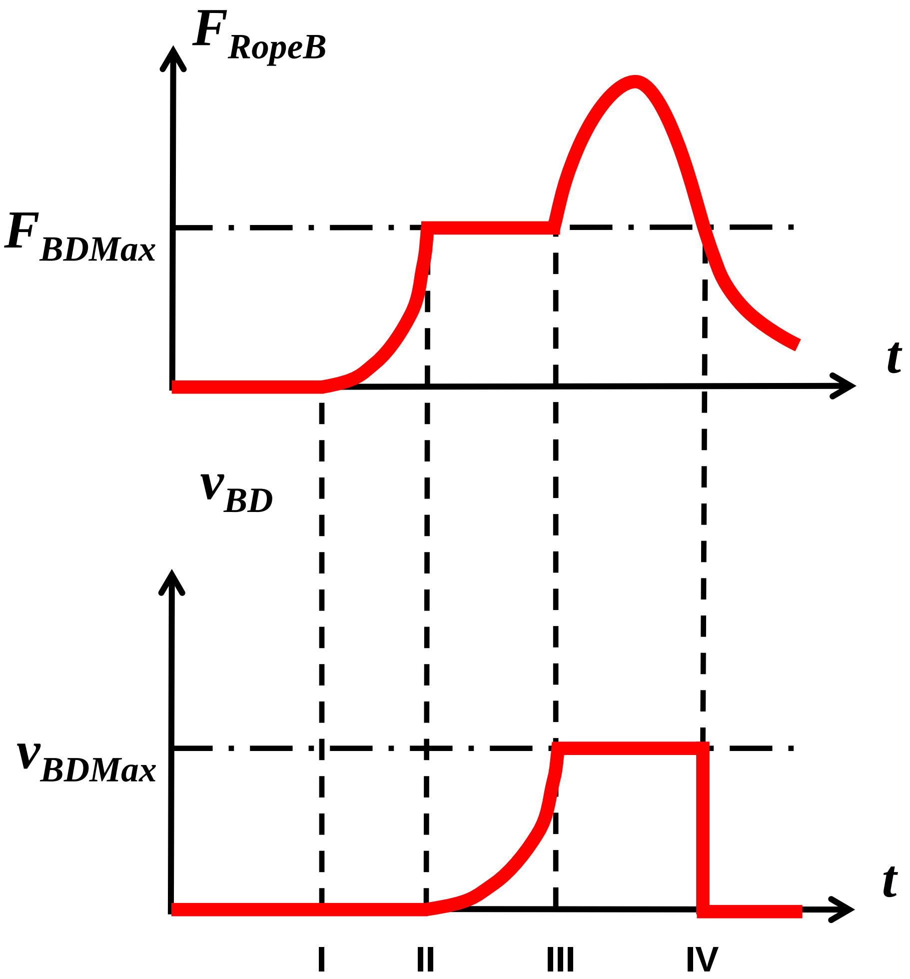
- **Dynamic rope length**:
  Dynamic change of the active rope length with the value of the friction force [Spoerri, 2014]



Belay Device

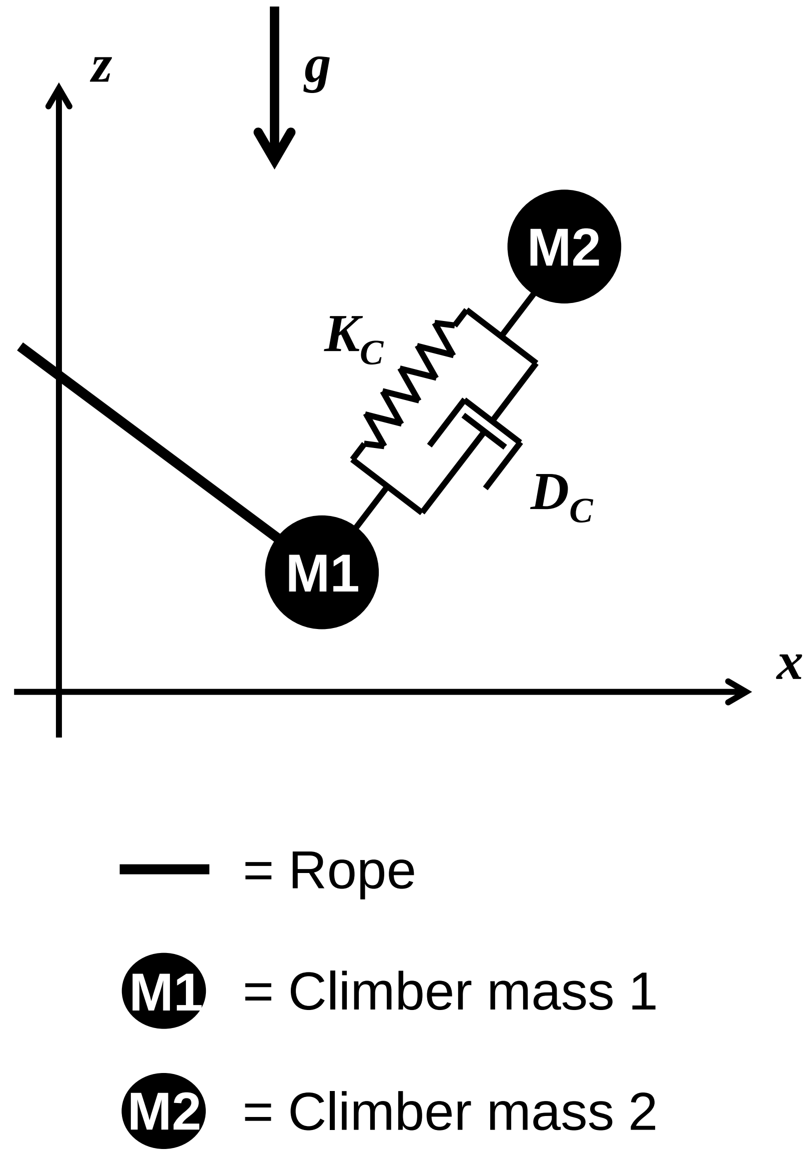
- **Dynamic belay (with belay device)**:
  The rope force at the belayer is limited using a two parameter model [Bedogni, 2002]

- F_{BDMax} = Maximum force belay device
- v_{BDMax} = Maximum rope slip velocity



Deformation of the climber

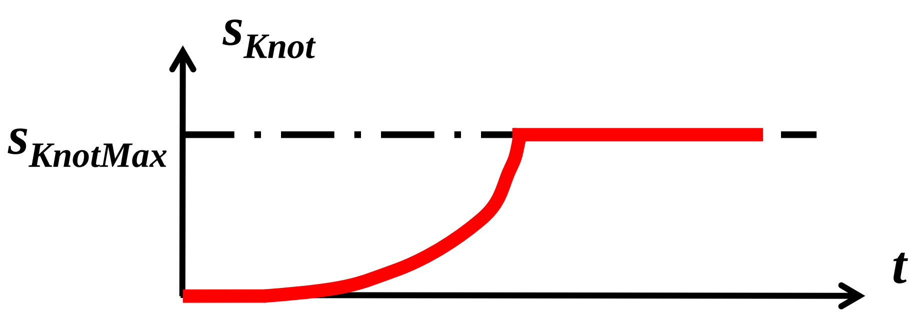
- Human body as energy absorbing element by deformation
- **2-Masses model**:
  Two masses connected with an in-parallel combination of a spring (K_C) and dashpot (D_C)
- No torsion, only tensile and pressure forces
- The total mass is shared about 50% for M1 and 50% for M2 [Mägdefrau,1998]

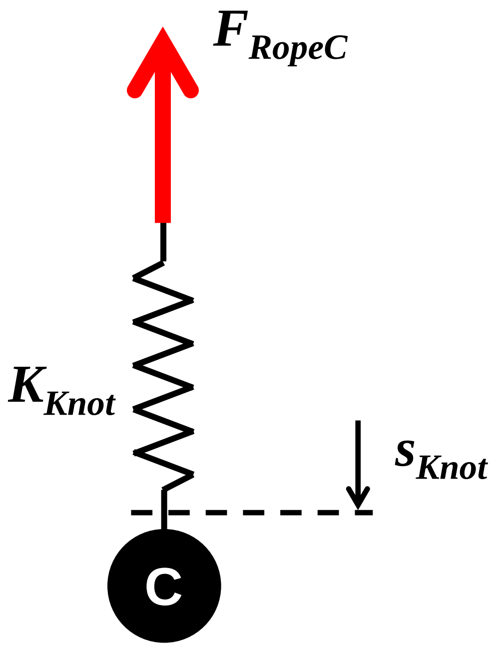


Knot at Climber

- Knot as energy absorbing element [Attaway, 2002]

- **Linear spring knot model**: A linear spring (K_{Knot}) is used to model the knot properties [Schad, 2000]

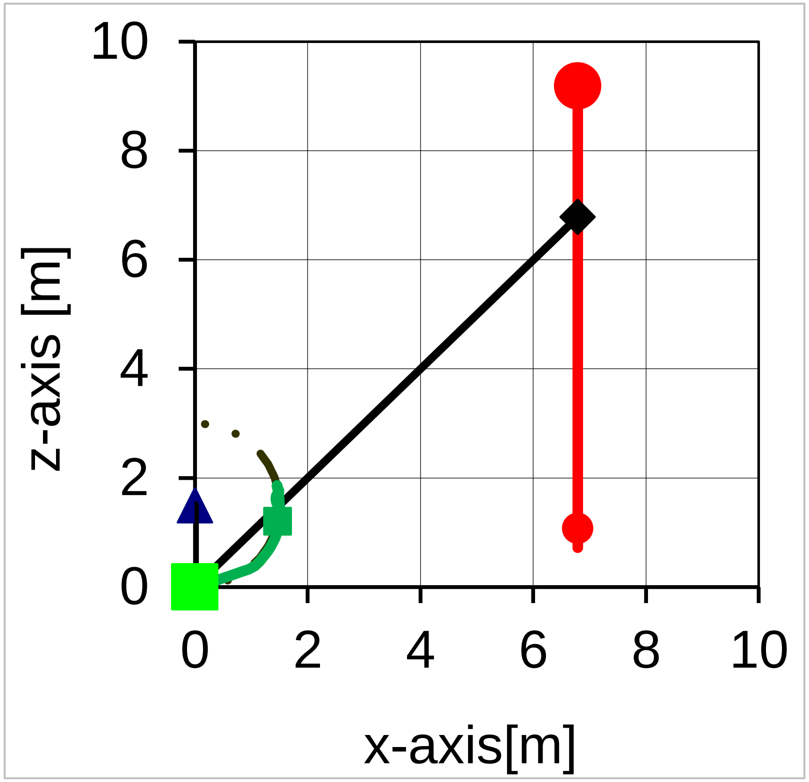


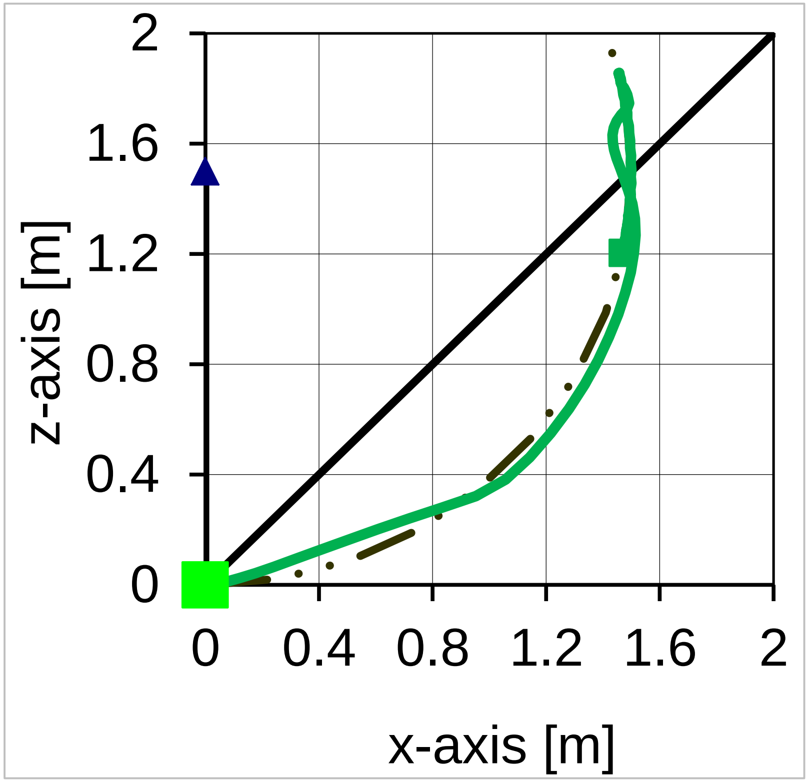


C = Climber

Results

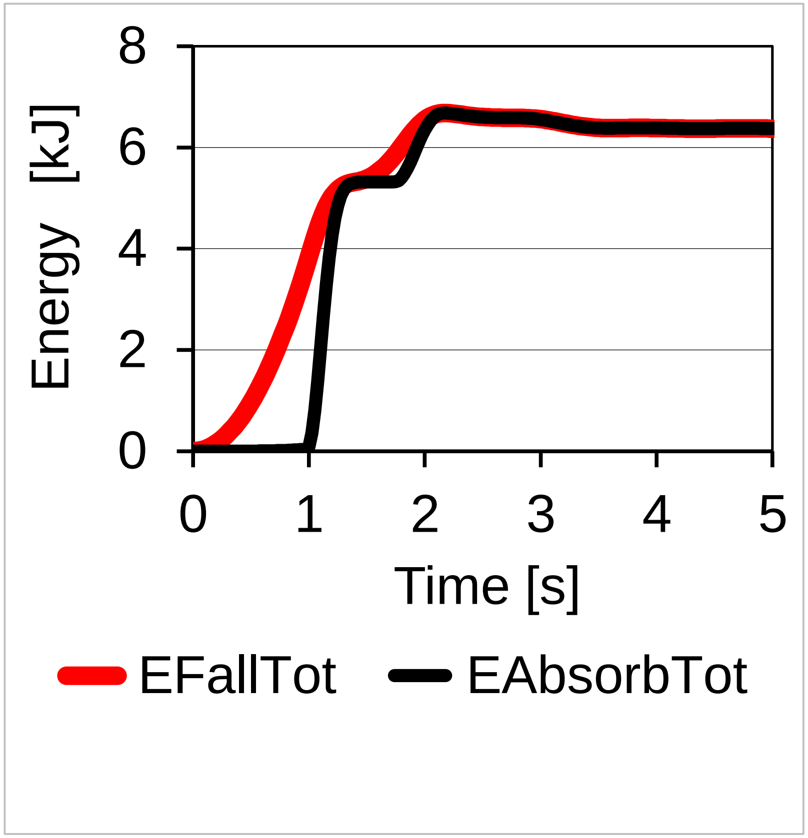
- Semmel C (2002) Ein Praxisvergleich von Sicherungsmethoden beim Klettern. DAV Panorama 5:59–61



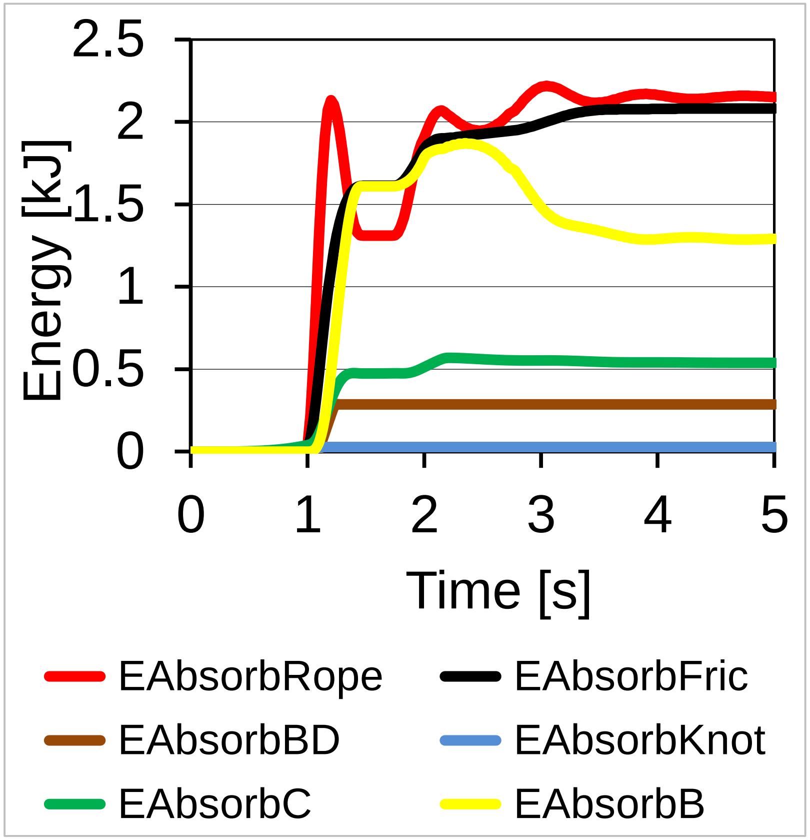


Energy Analysis

$$E_{FallTot} = E_{AbsorbTot}$$



$$E_{AbsorbTot} = E_{AbsorbRope} + E_{AbsorbFric} + E_{AbsorbB} + E_{AbsorC} + E_{AbsorbBD} + E_{AbsorbKnot} + E_{AbsorbGuide}$$



Thank you and safe climbing!