Formal snow avalanche risk assessment to buildings and optimal design of defense structures

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CONTEXT

To protect elements at risk (humans, roads, houses, etc.) against snow avalanche hazard, civil engineering structures such as dams or mounds can be used. Generally, the design of such defense structures is based on the definition of a reference hazard used to define the potential loading applied.

Avalanche risk :
- people rather than infrastructures: 30 deaths/year in France
- skiers, back-country skiers and ski resorts
- roads and communication networks
-buildings and inhabitants (lack of space)

The principle of this study is to combine the model describing avalanche hazard with a quantitative assessment of its consequences for one or several elements at risk. To do so, a **reliability approach** is conducted to establish **vulnerability relations**. On the other hand, outputs from a statistical-numerical physical avalanche model are used to quantify the hazard intensity (Eckert et al., 2012).

The cost benefit risk framework allows finding **optimal design of defense structures** by minimizing risk functions.

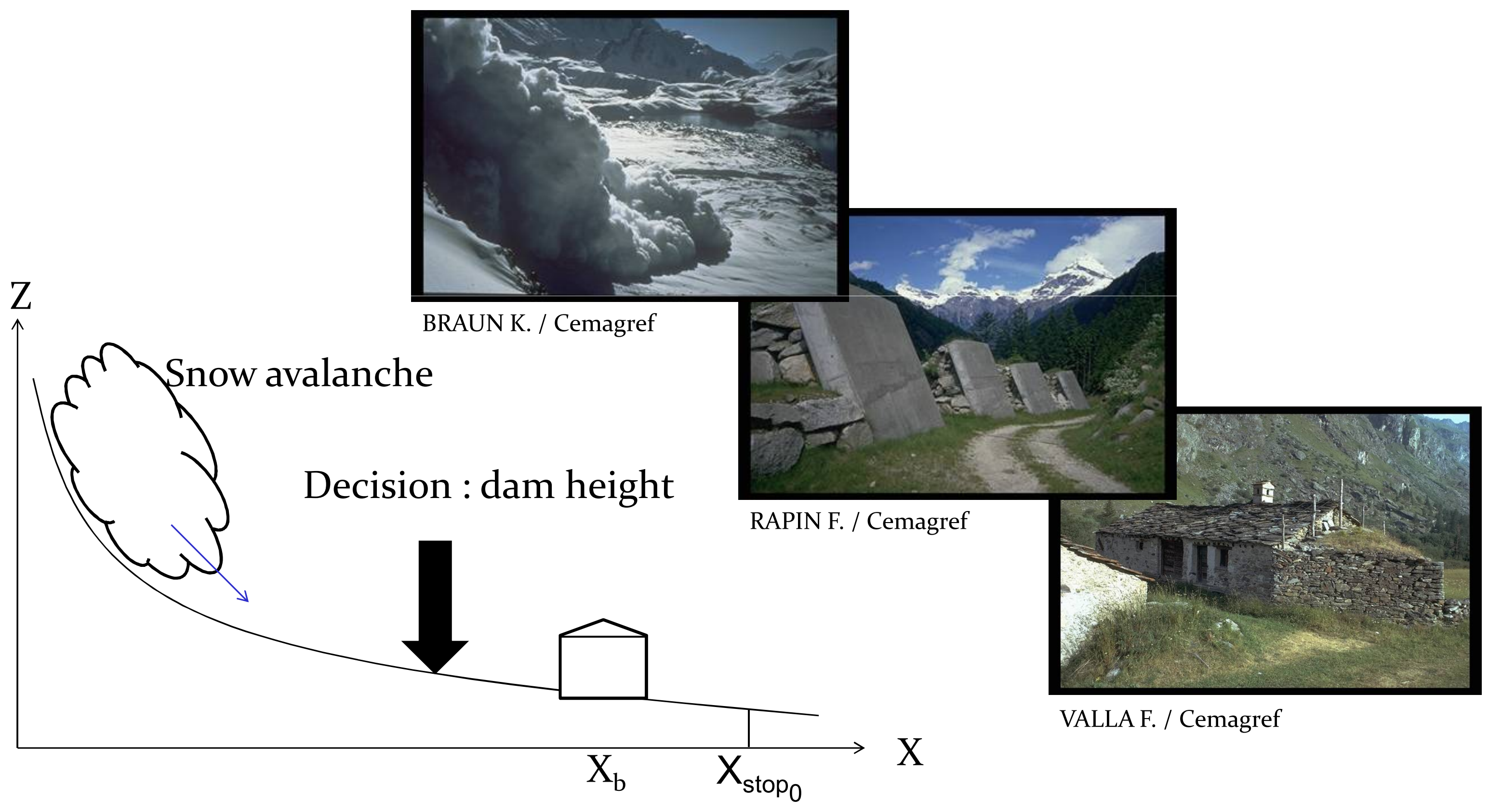


Fig. Considered framework : X_b: building position corresponding to 10-year return period, X_{stop_o}: runout distance abscissa without dam, X_d: projected dam abscissa

RISK FRAMEWORK

Risk defined in the context of natural hazards as the **mean expected loss** and can be modifier by a decision d such as a dam height.

$$R_w = E_y\left[\sum_{z\in w} q(z_w) z_w V(z,y)\right] = \sum_{z\in w} q(z_w) z_w \int p(y) V(z,y) dy$$

w: **system at risk**: any element or combination of elements z_w witch is/are likely to be affected: physical ones such as persons, buildings, traffic roads, a full mountain village…, etc., and immaterial ones such as the image of a mountain village which is important for attracting tourists…, etc.

q(z_w): **weighting factor** representing the exposition rate of z_w, generally fraction of time

p(y): **(stochastic) avalanche model**: describes the variability of snow avalanches on the studied site

V(z,y): **vulnerability relation**: deterministic function for each type of element at risk that links hazard magnitude to the damage level: "damage susceptibility"

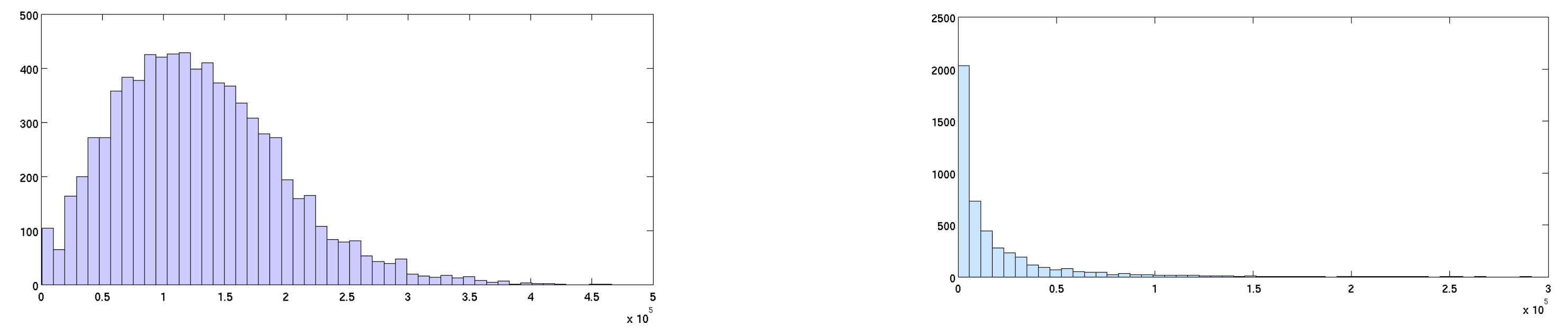
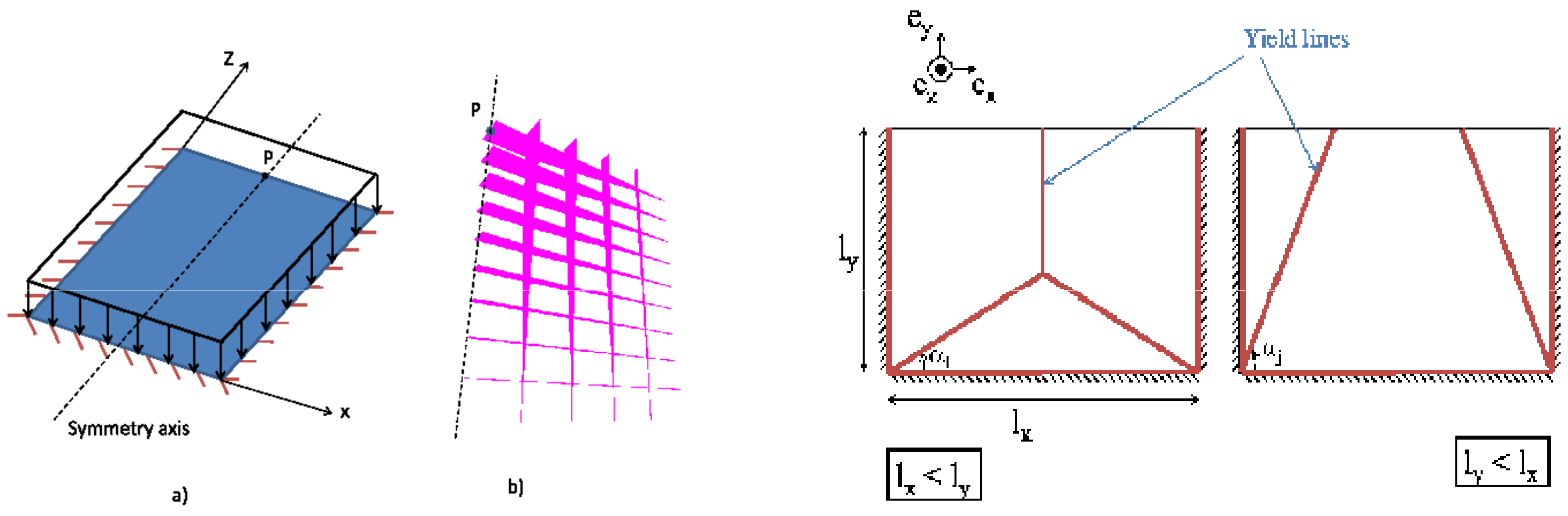


Fig. Pressure histogramms at two different abscissa along the avalanche path (495 m and 1995 m) from Eckert et al., 2010

VULNERABILITY: EVALUATING FRAGILITY CURVES

1. **Build a model to summarize the building behaviour:**
 Finite Element Methods resolution solved with CAST3M



2. **Consider an intensity index**
-the maximum pressure of the avalanche signal (Bertrand et al., 2010)

3. **Choose a failure criterion:**
- Yield line theory (Favre *et al., 1990) provides an ultimate load for the structure*
- The failure criterion is established as 15% of the maximum displacement

4. **Probabilistic description of concrete:**
-Young's modulus: $E_c = 10.5 f_c^{1/3}\left(\frac{1}{1+\beta_d\varphi(t,\tau)}\right)$ where $(1+\beta_d\varphi(t,\tau))$ is equal to *1*.

- Ultimate compressive stress: $f_c = \alpha(t,\tau) f_{c_0}^{\lambda}$ where $\alpha(t,\tau)$ deterministic, characteristic compressive stress and *λ* follow a log-normal distribution

- Density, length: normal distribution

FIRST RESULTS

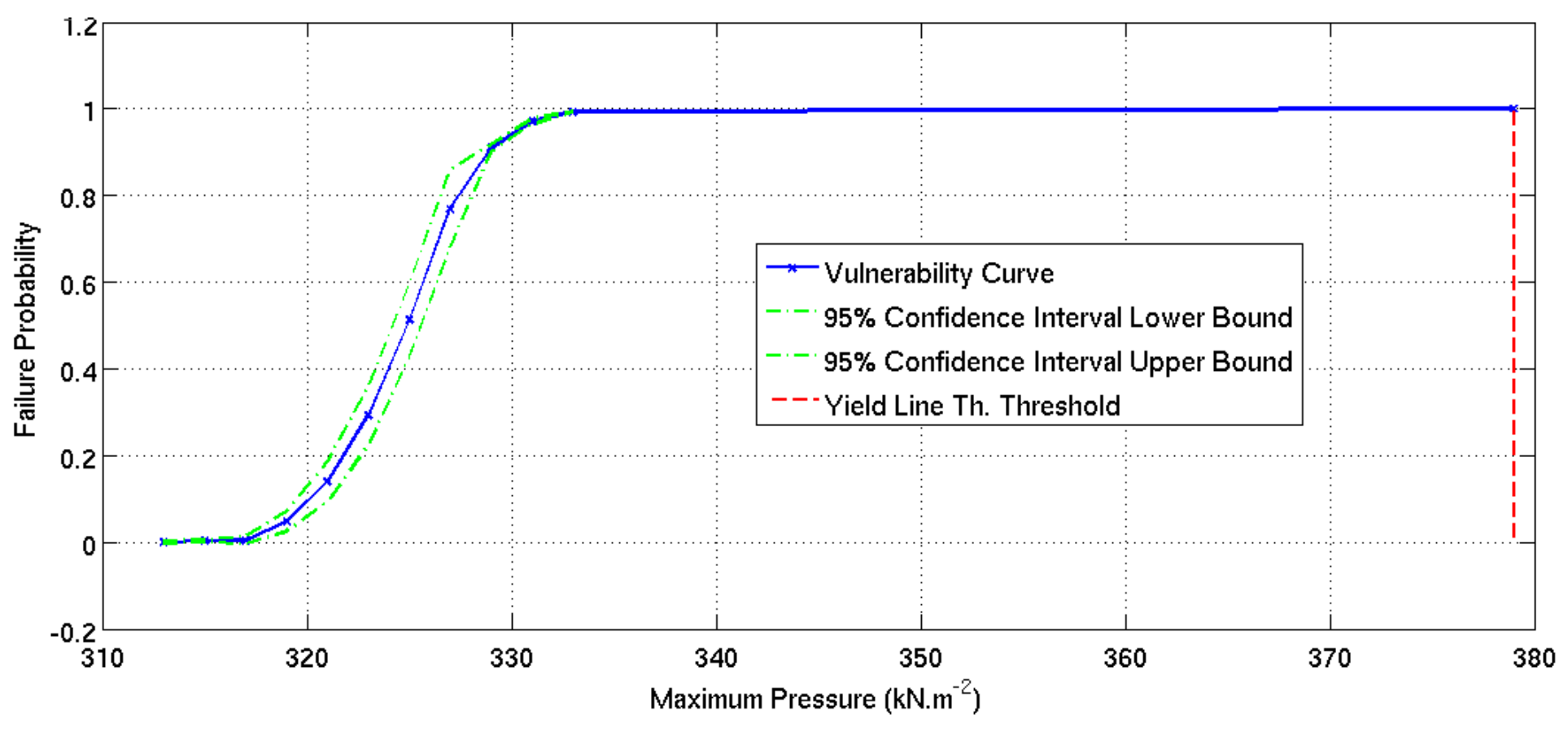


Fig. Fragility curve obtained with Monte Carlo simulation

By combining reliability approaches with the finite element method applied on the structure studied, **fragility curves** are obtained.

They provide the probability of the considered element to be destroyed as a function of the loading. We considered a building in the avalanche slope, whit main wall faceingthe avalanche .

Thus for each level of sollicitation, the fragility curve gives a univoque **vulnerability quantification**.

Vulnerability curves from the litterature are obtained by empirical or numerical approaches. They take into account various types of vulnerability relations: economical, physical, etc. **Vulnerability relations** have to be well determined as their influence on risk is strong:

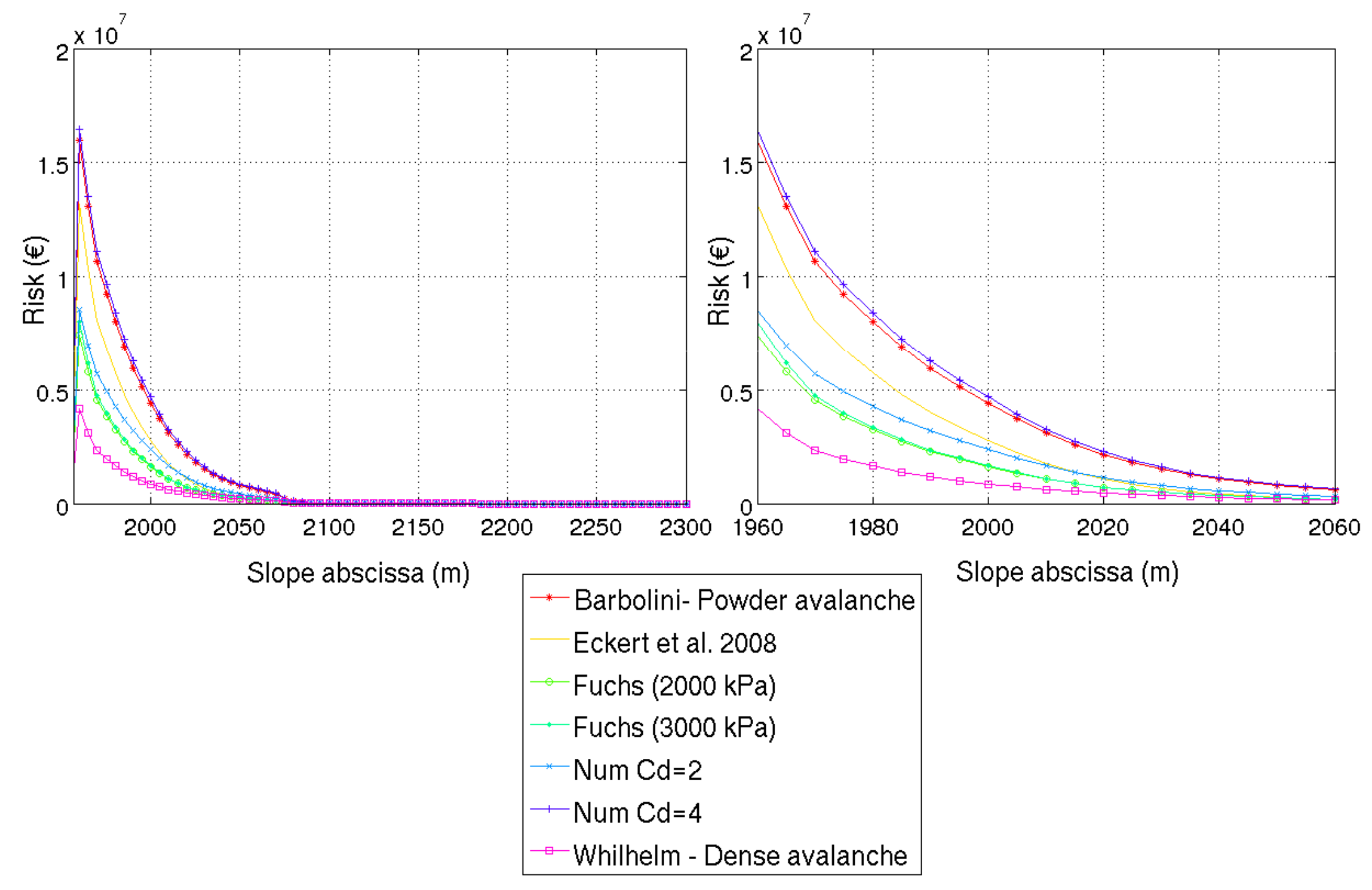


Fig. Risk functions for the considered case study: a single building valued 300,000€ in the runout zone

Influence on the **optimal desing** calculation is lower since considering several fragility curves shapes yields similar optimal dam heights.

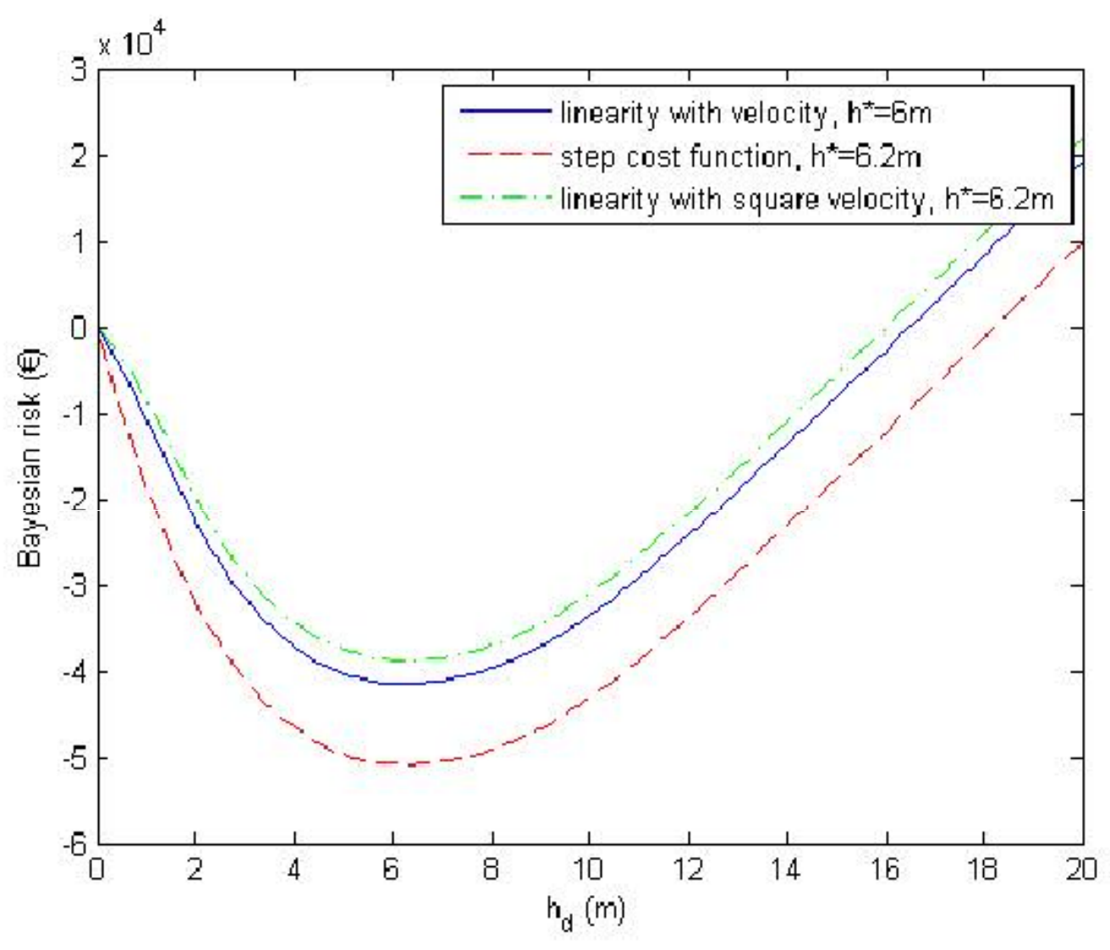


Fig. Same case study but considering the reference . The curve gives R(h)-r(0), the benefit of the dam construction as a function of the dam height for a fixed building position and various vulnerability relations.

Conclusions:
- reliability approach allows to produce more robust vulnerability relations usable in the risk calculation
- risk quantification is influenced by fragility curves
- optimal design is less sensitive to vulnerability relations

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http://www.avalanches.fr/mopera/mopera.htm