

# Courbes de fragilité par analyse fiabiliste, application en analyse de risque

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# Summary

## Snow avalanche natural hazard

- threatened mountain community (people, buildings, communication networks, skiers...)
- need for long term land use planning



Figure: Dense snow avalanche consequence: one building was destroyed (Le Sappey en Chartreuse - VALLA F. - Isère)



Figure: February 1999 avalanche of Montroc: 17 destroyed buildings and 12 deaths (Mont-Blanc, French Alps)

⇒ Risk improvement: precise avalanche hazard and **vulnerability of exposed element**

## Avalanche models

- Fully statistical model (inference on available real data)
- Deterministic propagation models depending on a constitutive law with random input:
  - Coulombian friction law (1 coeff.)
  - Voellmy friction law (2 coeff.)
  - More complex friction law ( $> 2$  coeff.)

## Output of avalanche models

- Velocity, runout distance are direct output of models
- Pressure computations is under interests,  $C_x$  is the drag coefficient to be determined to assess pressure on the obstacle:
  - $C_x = 2$ , constant drag coefficient.
  - $C_x$  defined according to fluid properties and obstacles shape.

## Time and spatial variations for structure study

- Pressure is considered to uniformly impact the structure
- Time variation of the avalanche signal is not considered as structure response is supposed to be quasi-static

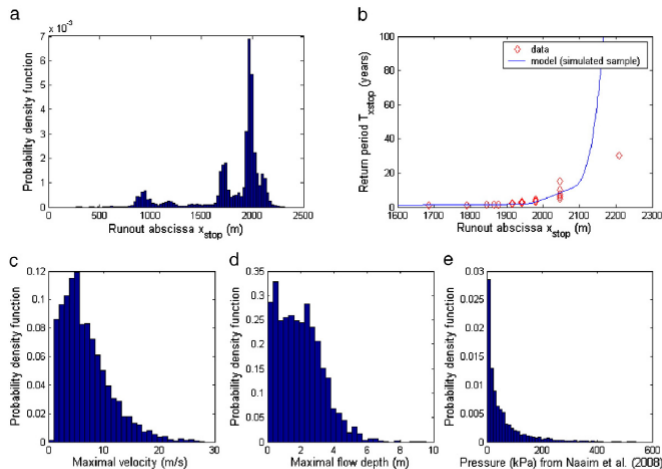


Fig. 1. Multivariate statistical-dynamical avalanche model. Avalanche model and case study from Eckert et al. (2010a): a) local runout distance distribution, b) one-to-one relation between runout distance and return period. For a runout distance corresponding to a 10 year return period, the conditional distribution of c) maximal velocity, d) maximal flow depth, and e) impact pressure computed following Naaim et al. (2008), taking the rheology of snow into account.

## Literature curves:

- Wilhelm, 1998: vulnerability of concrete buildings with reinforcement, piecewise according to damage thresholds
- Fuchs, 2008: economical approaches
- Bertrand et al, 2010: numerical simulation
- Barbolini et al., 2004: empirical estimates

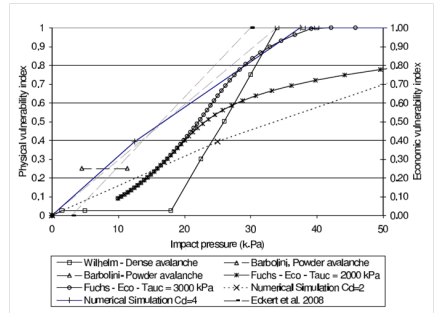


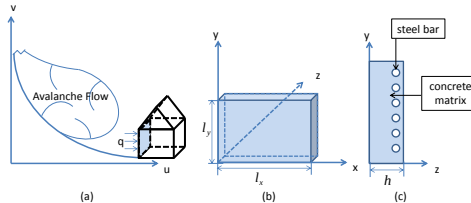
Figure: Vulnerability curves from different literature sources (Naa'im et al., 2008)

# Overview

## RC wall features

- Boundary conditions taken into consideration: clamped, supported and free edges.
- Uniformly loaded

Figure: Dwelling house impacted by a snow avalanche (a) - RC wall geometry (b-c)

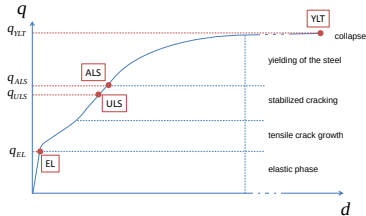


# RC behavior

## RC wall features

- Composed of concrete and steel bars orthogonally disposed.
- Concrete and steel parameters:  $f_{c28}$ ,  $f_t$ ,  $\varepsilon_{uc}$ ,  $f_y$ ,  $\varepsilon_{uk}$

Figure: Transitions between each damage levels of RC



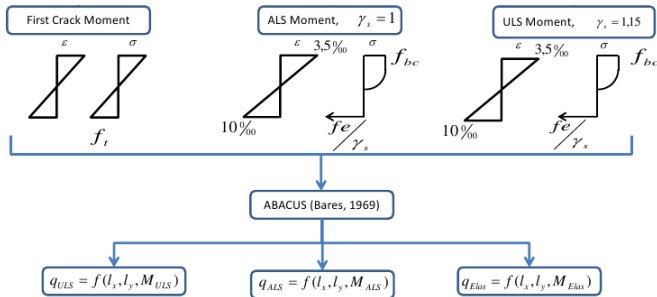


# Under bending

## RC wall features

- Under bending, moments in the section can be calculated at 3 stages.

Figure: Stress/Strain diagram according to 3 bending stages



# Collapse

## Collapse defined with the yield line theory (Johansen, 1962)

- define a yield line patterns set depending on boundary conditions
- internal and external forces are calculated
- determine the failure pattern minimizing the collapse load

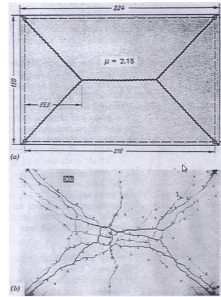


Figure: Uniformly loaded slab simply supported at all edges: theoretical yield line pattern and experimental crack pattern on bottom surface (Sawczuk et Jaeger, 1963)

# Statistical input variables and failure probability calculation

## Statistical distribution

- Normal distribution with a 5% CoV:  $l_x, l_y, h, f_{c28}, f_y, f_t$
- JCSS distribution:
  - $f_{c28} = \exp(m + t_\nu s(1 + \frac{1}{n})^{0.5})$ ,
  - $f_{bc} = \alpha f_{c28}^\lambda Y_1$ ,
  - $f_t = 0.3 f_{bc}^{2/3} Y_2$ ,
  - $l_x, l_y, h, f_y$ .
- Normal correlated distribution with a 5% CoV and JCSS correlation matrix.

## Failure probability definition

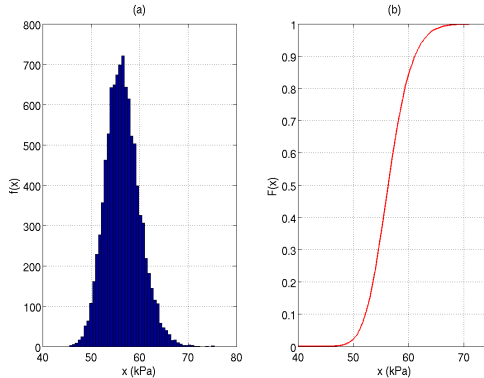
$$P_f = P[r \leq s] = \int_{-\infty}^s f_R(r) dr. \quad (1)$$

( $r$  : resistance,  $s$  : sollicitation)

## Monte Carlo simulations and Sobol index

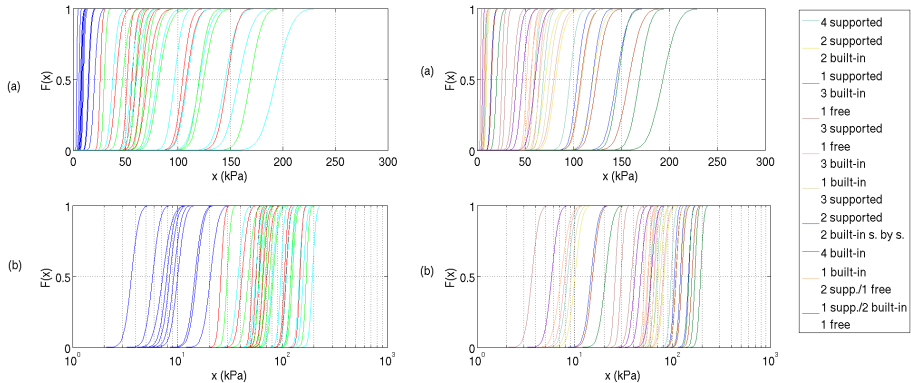
- $N$  Monte Carlo simulations:  $f_R(r)$  is described with confidence intervals
- $S_{Ti} = 1 - \frac{V_{X_{\sim i}}(E_{X_i}(Y|X_{\sim i}))}{V(Y)}$  are calculated as  $\hat{S}_{Ti} = \frac{1}{2N} \sum_{j=1}^N (f(A)_j - f(A_B^{(i)})_j)^2$

# Fragility curves derivation: example



**Figure:** Output histogram of the ULS case for a rectangular wall with one free edge and three clamped edges with normal independent inputs (a), cumulative distribution function associated (b)

# All configurations overview



**Figure:** Fragility curves according to boundary conditions sorted by failure criterion: (a) linear frame, (b) semi log frame.

**Figure:** Fragility curves according to boundary conditions sorted by boundary conditions: (a) linear frame, (b) semi log frame.

# Inputs influence

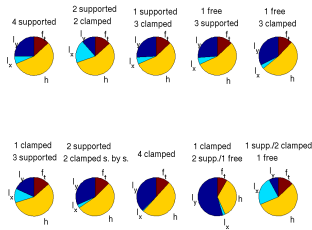


Figure: Sensitivity pies for the elastic failure criteria

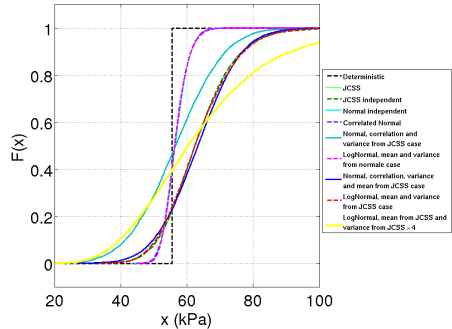


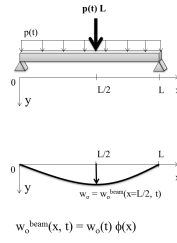
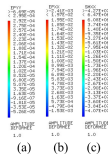
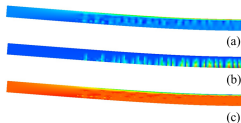
Figure: Comparison between fragility curves from different inputs distribution and deterministic approach of a slab with one free edge and three clamped edges under ULS considerations.

## Take home message

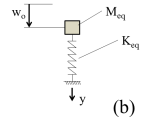
- Systematic methodology approach to assess fragility curves based on: reliability framework and not time-consuming mechanical modeling
- Fragility curves set available for risk analysis
- Increase of knowledge concerning the vulnerability behavior of RC structures
- Description of sensitivity analysis

## To follow

- Use more complex mechanical modeling such as FEM
- Quantify risk sensibility to fragility curves



(a)



(b)



(c)



## Risk calculation

$$r_z = \int p(y) V(z, y) dy \quad (2)$$

- $r_z$ : specific risk
- $p(y)$ : avalanche intensity distribution
- $V(z, y)$ : damage vulnerability/susceptibility/fragility for the element  $z$  towards the avalanche intensity  $y$
- $z$ : element at risk
- $y$ : avalanche intensity

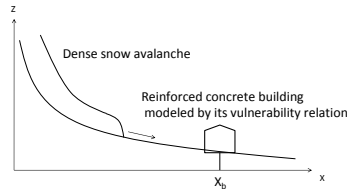


Figure: Considered framework :  $x_b$ : building abscissa at various positions in the runout zones.



## Use of statistical–dynamical outputs

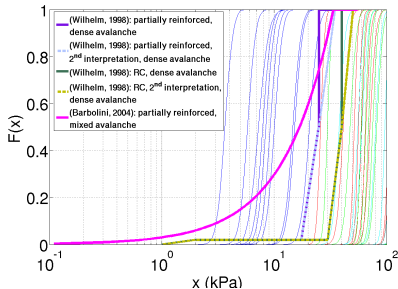
- the avalanche intensity: the pressure, the runout and the avalanche occurrence
- the pressure is deduced from the velocity of the flow, the drag coefficient  $C_x$  is considered from [?] or [?]:  $Pr = C_x \frac{1}{2} \rho v^2$  .

## Computations

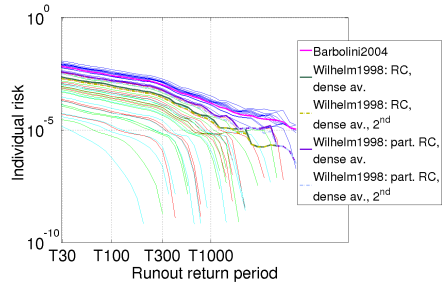
$$r_z(x_b) = \lambda \int p(Pr|x_b \leq x_{stop}) P(x_b \leq x_{stop}) \times V(z, Pr) dPr . \quad (3)$$

$$R_b(x_b) \approx \lambda \times P(x_b \leq x_{stop}) \times \frac{1}{N} \sum_{k=1}^N V(b, Pr_k) . \quad (4)$$

# Overview

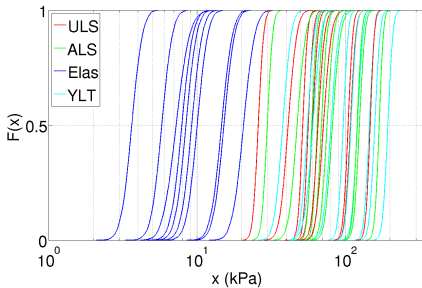


(a) Vulnerability relations for reinforced concrete structure.

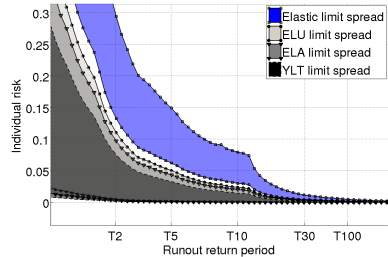


(b) Risk calculation and confidence intervals for structural vulnerability and literature relations.

## Bounds for risk (Fig.)



(c) Vulnerability relations for reinforced concrete structure.



(d) Risk calculation for structural vulnerability: min and max bounds.

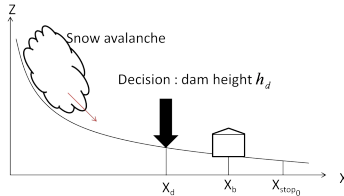


Figure: Schéma récapitulatif de la décision

## Decisional calculation

The decision is the height of a protective dam  $h_d$ . The decisional risk is calculated as:

$$R_b(h_d) = C_0 h_d + C_1 A \lambda \int p(Pr | x_b \leq x_{stop, h_d}) p(x_b \leq x_{stop, h_d}) \times V(b, Pr) dPr . \quad (5)$$

## Obstacle - Flow interaction

The velocity at the dam abscissa

$$\frac{v_{hd}^2}{v_{d0}^2} = 1 - \frac{\alpha h_d}{2h} . \quad (6)$$

## Velocity propagation

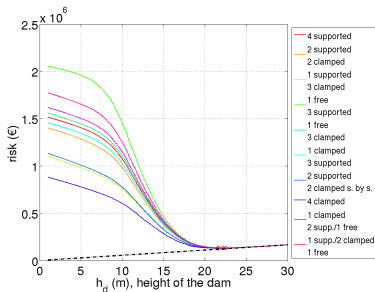
The velocity after the dam abscissa:

- Sliding block propagation
- Shallow water equation propagation
- Delta propagation:

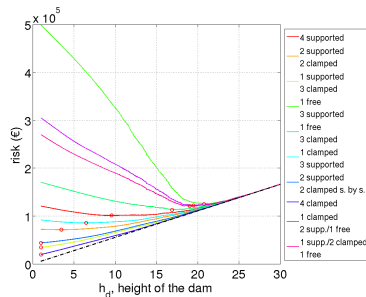
$$\delta_{velocity} = v_0(x_d) - v_{hd}(x_d) \quad (7)$$

$$v_{hd}(x) = \begin{cases} v_0(x) - \delta_{velocity} & \text{if } x \geq x_d \\ v_0(x) & \text{else .} \end{cases} \quad (8)$$

## Decisional risk calculation



(a) Optimal design for decisional risk to reach the elastic limit state of the structure.



(b) Optimal design for decisional risk to reach the collapse state of the structure.

## Vulnerability sensitivity of decisional risk calculation

The optimal decision is the height of a protective dam  $h_d$ . It looks like it is less influenced by the vulnerability inputs than the risk calculation.

# Conclusion

## Take home message

- Fragility curves with a semi-analytical and numerical approaches
- Possibility to link them to human considerations
- Providing bounds to risk calculation
- Vulnerability relations important for risk calculation, less for optimal design calculation

## Things to do

- Analytical sensibility of the risk (not presented today)

