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Analyse fiabiliste d'un mur en béton armé soumis à une avalanche de neige et modélisé par éléments finis et modèle masse-ressort

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Summary

Snow avalanche hazard

- threatens mountain community (people, buildings, communication networks, skiers...)
- need for long term mitigation measures

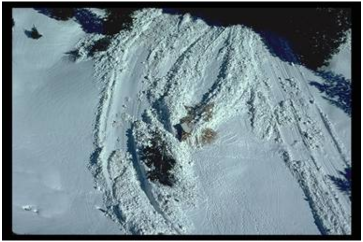


Figure: Dense snow avalanche consequence: one building was destroyed (Le Sappey en Chartreuse - VALLA F. - Isère)

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

$\Longrightarrow$ Risk improvement: precise quantification of avalanche hazard and **vulnerability of exposed elements**

Literature curves:

- Wilhelm, 1998: vulnerability of concrete buildings with reinforcement, piecewise according to damage thresholds
- Fuchs, 2007: economical approaches
- Bertrand *et al.*, 2010: numerical simulation
- Barbolini *et al.*, 2004: empirical estimates

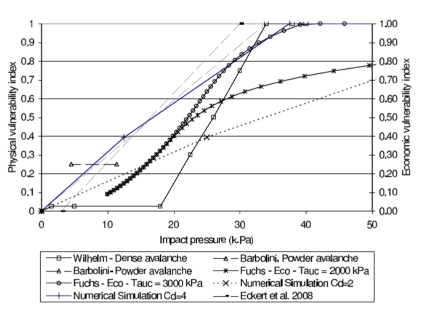


Figure: Vulnerability curves from different literature sources (Naaim *et al.*, 2008)

Reliability based curves:

- Definition of several limit states based on moments calculation
- Easy to compute but rough model using abacus
- Collapse pressure using yield line theory

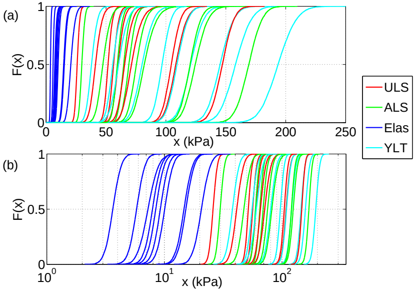
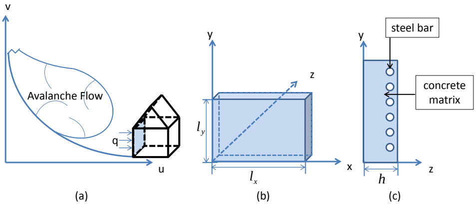


Figure: Vulnerability curves using simple engineering models (Favier *et al.*, 2014)

RC wall features

- Wall with two supported edges composed of concrete and steel bars orthogonally disposed.
- Concrete and steel parameters: f_{c28}, f_t, ε_{uc}, f_y, ε_{uk}
- Uniformly loaded

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



RC behaviour

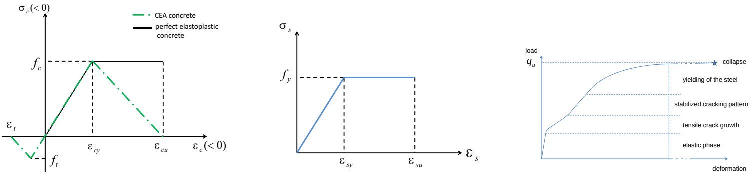


Figure: Concrete, steel and RC behaviour.

RC wall models

- FEM model: accurate but time consuming.
- Mass-spring model: general description behaviour of the wall but computation time saving.
- Yield line theory: only models the collapse of the wall, no intermediate step.

Models implementation

FEM

The finite element model (FEM) is built with Cast3m software. Reinforcing steel is modelled using linear segments. Concrete is modelled with quadrilateral elements with a quadratic approximation function.

Mass-spring

The moment-curvature curve of the system is built by discretizing along the length of the section. Stress distribution is defined, then the corresponding strain diagram is established.

Yield line theory

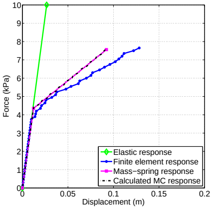
Under an external loading, cracks will develop to form a pattern of "yield lines" until a mechanism is formed Johansen (1962). The ultimate load is calculated from the equality between the external energy (W_{ext}) and the internal energy (W_{int}).

Validation of the model

Table: Ultimate displacement and ultimate pressure provided by the three models.

Models	Ultimate pressure	Ultimate displacement
Mass-spring	7.58 kPa	0.0923 m
Finite element	7.65 kPa	0.1283 m
Yield line theory	7.56 kPa	—

Figure: Load-displacement curve obtained with finite element model and mass-spring model. Pushover test is done on the structure until collapse.



Reliability methods

Statistical distribution: normal distributions with a 5% CoV

- First set: l_x, l_y, h, f_c, f_y, f_t, ρ_s
- Second set: f_c, f_y, f_t, ρ_s
- Third set: f_c, f_y, f_t

Failure probability calculation

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

$(r : resistance, s : sollicitation)$

Reliability methods to approximate fragility curves

- N Monte Carlo simulations
- Kernel smoothing fitting
- Taylor expansion to approximate 1^{st} and 2^{nd} moments of the outputs' distribution

Reliability methods

Kernel smoothing

Kernel smoothing enables to approximate $\hat{p}(y)$ considering a normal kernel K, with Silverman rule (Wand *et al.*, 1995) to evaluate the optimal bandwidth h:

$$\hat{p}(y) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{y - Y_i}{h}). \tag{2}$$

Taylor expansion to approximate 1^{st} and 2^{nd} moments of the outputs distribution

No covariances are considered between input variables:

$$\hat{\mu}_Y = M(\mu_X) + \frac{1}{2}\sum_{i=1}^{n} \frac{\partial^2 M}{\partial^2 X_i}(\mu_X).\sigma_{X_i}, \tag{3}$$

$$\hat{\sigma}_Y^2 = \sum_{i=1}^{n} (\frac{\partial M}{\partial X_j}(\mu_X))^2.\sigma_{X_i}. \tag{4}$$

Vulnerability curves (fragility curves)

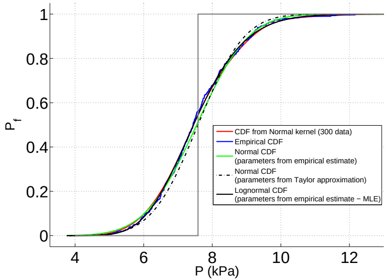


Figure: Vulnerability depending on the reliability methods used.

Vulnerability curves

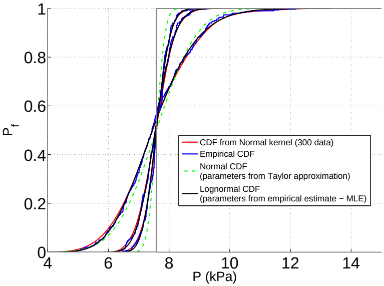


Figure: Vulnerability depending on the number of input parameters.

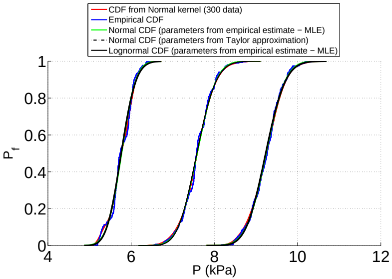


Figure: Effect of the steel density on fragility curves.

Take home message

- Systematic methodology approach to assess fragility curves based on: reliability methods and not time-consuming mechanical modeling
- Fragility curves set available for risk analysis
- Increase of knowledge concerning the vulnerability behavior of RC structures
- Possibility to link fragility curves of buildings to human vulnerability used in risk (not shown today)

Perspectives

- Use more complex mechanical modeling including a strain rate effect
- Use real avalanche signal
- Quantify risk sensibility to fragility curves

Thank you for your attention. Any questions ?

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Spring-mass model

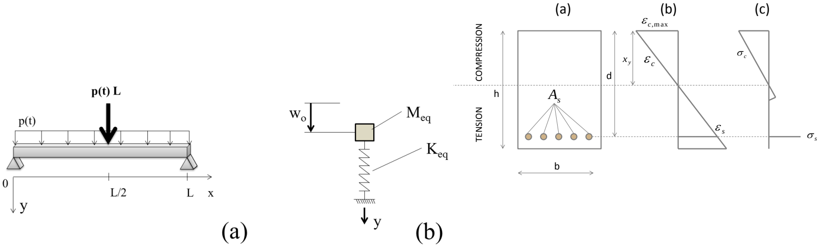

Figure: Mass-spring system and cross-section of the RC beam (a), stress diagram (b), strain diagram (c).

Translational equilibrium equation

$$b \int_0^{x_y} \sigma_c dy = \sigma_s A_s + b \int_{x_y}^{h} \sigma_c dy$$

Spring-mass model

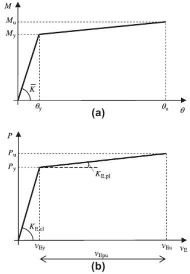

Figure: (a) Bilinear moment curvature bending relation of the beam ; (b) corresponding bilinear load-displacement relation of then equivalent SDOF model Carta et Stochino (2013).

Newmark solving scheme to solve:

$$M_{E,el}\frac{d^2v_E(t)}{dt^2} + K_{E,el}(t)v_E(t) = P_E(t)\ for\ 0 \leq v_E \leq v_{Ey}\ ,$$

$$M_{E,pl}\frac{d^2v_E(t)}{dt^2} + K_{E,pl}(t)v_E(t) + (K_{E,el}(t) - K_{E,pl}(t))v_{Ey} = P_E(t)\ for\ v_{Ey} \leq v_E \leq v_{Eu}\ ,$$