Review: Assessing fragility of a reinforced concrete element to snow avalanches using a non-linear mass-spring model
(by P. Favier, D. Bertrand, N. Eckert, I. Ousset, and M. Naaim)

First, the authors would like to thank the referees to give their time to read and react on our paper proposal. It is always a pleasure to exchange scientific ideas and other points of views. Below is a detailed response to all the comments and question raised.

REFEREE #3

The paper 'Assessing fragility of a reinforced concrete element to snow avalanches using a non-linear mass-spring model' aimed to establish a bridge between civil engineering and the snow avalanche community. The authors proposed an efficient Single-Degree-of-Freedom (SDOF) model to account for the behavior of an Reinforced Concrete (RC) wall under snow avalanche pressures. The validity of the proposed approach was validated by using finite element and yield line theory analyses. Afterwards several reliability models were incorporated to obtain the so-called fragility curves for the different RC elements suffering from avalanche pressures. The authors also pointed out that their methods would be potentially applicable for the other natural hazards assessment such as rockfall or landslide engineering. It is found that the paper was very well written, the mathematical analyses were sound, and most importantly, the perspective to develop a practical model for analyzing fragility of snow avalanche defense structures was particularly interesting.

The authors thank the referee for this positive comment. Below is a detailed answer to all the point and question raised

However, it is worth pointing out that in the paper the practical prospective of the proposed SDOF model in snow avalanches is yet less convincing. The critical point is that the model is based on the assumption that the load is only quasi-static and the inertial effects are not involved.

The authors invite the referee to have a look at the answers given to the referee #1 who underlined this aspect. The authors hope that the new version of the manuscript will be clearer on the fact that the proposed SDOF model accounts for potential inertial effects, *i.e.* the SDOF model describes the dynamic response of the structure which indicates that it is reliable even under non quasi-static loading. As an illustration we now provide examples of fragility curves obtained with different loading rates.

It is thus suggested that the authors consider the following points: (1) In the introduction part the authors mentioned that 'Until now, very few fragility curves have been established for snow avalanches. : : : Using such numerical approaches, snow avalanche fragility curves have recently been proposed (Favier et al., 2014; Ousset et al., 2016)'. How are these researches exactly handling non-uniform load in their models?

In sake of simplicity, within both papers, the pressure field applied to the structure has been assumed uniformly distributed and the mechanical response of the structure has been supposed *quasi*-static.
Specifically, in the case of Favier *et al.* (2014), the calculations are based on classical beam or slab theories under elastic or elasto-plastic assumptions (yield line analysis). The pressure loading due to the avalanche can be chosen as the user wants (punctual, triangular, parabolic, *etc.*). If the elastic theory is used, it will change the distribution of the internal forces (bending moment, axial and shear forces) within the structural member but at the cross section scale, its strength will be computed in the same way (mechanical balance of the forces and stresses develop within the more loaded cross section). If the structure strength calculation is performed with the help of the yield line theory, the modification of the pressure field will change the failure pattern of the structural member (*i.e.* location of the yield lines) and thus the calculation of the internal and external work. Thus the equations should be adapted to the studied case but the process remains the same.
Within the paper of Ousset *et al.* (2016), the computation of the structure is carried out by 2D finite element simulations. These kinds of approaches are time consuming but in the same time are quite

flexible and adaptable. The application of a pressure field is performed by imposing nodal forces onto the nodes of the mesh. The magnitude of the forces can be adjusted as a function the node's location and thus non uniform pressure fields can easily considered.
To sum up, for both methodologies, non-uniform pressures field can be used. And what we propose in this article is somewhat an intermediate approach combining computation efficiency and precision in the description of the mechanical response of the structure.

(2) Is the proposed model more suitable for structural fragility assessment in a snow pack condition? Here the inertial effects are less important compared to snow avalanches.
But even in this situation the load would not be uniform.

The proposed SDOF model has been developed in order to simulate potential dynamic effects in RC members subjected to pressure fields. The formulation of the SDOF model involves determining first the *quasi*-static response of the structure. Then the resolution through time of the ordinary differential equations governing the structure dynamics is performed using suitable time integration schemes (Newmark algorithm). Thus, the SDOF model can also be used to assess fragility of the defense structure loaded in snow pack conditions. That said, it should be noticed that once the single degree of freedom equivalence is done, the spatial distribution of the pressure field is fixed (in term of shape and no in term of intensity which can varies through time). In the case of structures loaded in snow pack conditions, the shape of the spatial distribution of the pressure field will evolve through time (slowly => no inertial effect). Then, the SDOF equivalence should be updated as a function of the snow cover features (snow cover depth, vertical pressure gradient, humidity, *etc.*). Knowing the evolution of the spatial distribution of the pressure field, SDOF approaches can be used to assess the capacity of the structural member (its strength).

(3) At the last paragraph of conclusions, the authors have stated that a further development of model considering typical time evolutions of the pressure signal is important. It would be great if the authors can already address a bit how one can extend their models to those non-uniform load cases.

If the authors have well understood the referee's comment, the question focuses on non-uniformly spatially distributed pressure fields. In the paper, the pressure magnitude evolves through time (triangular time evolution), but the user can define the time pressure signal he wants (sinusoidal, trapezoidal, given *in situ* pressure measurement, *etc.*). Similarly, the spatial distribution of the pressure field is supposed uniform and remains the same during all the avalanche/structure interaction but other choices can be made.
Specifically, the way to account for non-uniform pressure field is detailed in the book of Biggs (1964). The SDOF equivalence is based on an assumed shape of the actual structure (phi(x)). The latter is taken to be the same than the one resulting from the static loading application. Next, equivalent factors (so called *transformation factors*: $K_M=M_e/M_t$ and $K_L=k_e/k=F_e/F$ where M_t is the total mass of the structure, k its stiffness and F the time evolution of the force/pressure) can be calculated to determine the equivalent mass M_e (mobilized mass during the structure movement), the equivalent structure stiffness (k_e) and the equivalent force (F_e) to apply onto it. The following equations arise:

$$K_M = \frac{\int^L m\phi^2(x)\,dx}{mL} \qquad\qquad K_L = \frac{\int^L p\phi(x)\,dx}{pL}$$

Where m is the mass of the beam per unit length and L the length of the beam, p is the spatial distribution of the pressure field **which can be uniform or not**. The equations of motion are then written as

$$M_e\ddot{y} + k_e y = F_e(t)$$

$$\Leftrightarrow$$

$$K_M M_t\ddot{y} + K_L k y = K_L F(t)$$

$$\Leftrightarrow$$

$$K_{LM} M_t\ddot{y} + ky = F(t)$$

where y is the displacement at the point where the deflection is equal to that of the equivalent system.

The authors have added within the new version of the paper a complement to the paragraph 3.2.3. to underline that non-uniform pressure fields can be easily considered within the same framework.

Small corrections: (1) In the caption of Figure 11, it should be ‘mixed deterministic-statistical with sets (1,a,a) and (3,a,a)’. (2) In Figure 13c, the position of the label ‘Pressure (kPa)’ is not correct.

Thank you, all the suggested corrections have been made.