RESPONSE TO THE REVIEW #2 OF MANUSCRIPT NUMBER: NHESS-2022-93

RC2#1 The topic of the manuscript is appropriate for the Journal, but due to a number of deficiencies the manuscript cannot be recommended for publication. The reviewer recommends REJECTING based mainly on the following arguments:
A) The analysis is at some steps too simplified and many important aspects are not analysed.
B) In general, the manuscript raises more questions than it provides answers. Based on the arguments below, the conclusions of the study seem to be poorly grounded. The authors fail to adequately support their conclusion "*The collapse of the Irstea Cévennes building can certainly be explained by the intensity of the rain-on-snow event, and by the fact that the water could not flow, as the drainage system was blocked by frozen snow settled at the bottom under cold conditions*." What was wrong then? Structural design? Low design loads in the standard? It is insufficient to claim that a wrong drainage system was the only cause. Can we substantiate that there was free water able to flow on the nearly flat roof at the time of collapse?
C) The manuscript is structured in a way that is difficult to follow – the main text often refers to the annexes where little information is provided then.

We thank the reviewer for these comments. We actually agree with most of them and we strongly believe that they can be addressed in a revised version of the manuscript. Please see below a detailed response to each of these comments and the proposed modifications.

RC2#2 "*In our study, it is supposed that the initial state was perfect and corresponded to all the features provided in the previous subsection*." From a perspective of forensic engineering, this assumption is very doubtful. We have evidence that the structure collapsed and a similar neighbouring structure survived, and by experience we know that a vast majority of collapses was caused by gross errors. And yet we still consider the state of the structure before the collapse was perfect? Assuming the perfect initial state, the analysis of the second structure may reveal similar load bearing capacity as for the collapsed one.

This study is carried out without taking into account any previous deterioration of the structure due to temporary loads that may have been applied to this structure during past events, since we have very little information on them. To our knowledge, the most heavy snow loads that the building had to support in the past since construction were:

- around 27 cm on 14-16 January 1987;
- around 28 cm on the 22 january 1992;
- less than 10 cm on 7 March 2010.

For those loads, the simulations show that the behaviour of the structure remains elastic.

However, we agree that this hypothesis may be considered as optimistic. Note that this optimistic choice may however be partly balanced by the fact that we took pessimistic values for material properties (see comment RC2#5 and our response to that comment). We will further discuss this point in the revised manuscript when pointing out some shortcomings of our approach in the conclusion.

Concerning the neighbouring building, it has a main metal frame similar to that of the structure studied but it has a number of load-bearing walls inside (because of the presence of many house offices), thus preventing large bending of the metal frame. This may be one reason –among others– why this neighbouring structure is stronger and survived the rain-on-snow event of 2018 (see lines 281-285 of the original manuscript).

To finish, it is important to clarify that the purpose of this study is only scientific and not forensic.

RC2#3 Did past surveys of the structure report any defects? Corrosion? Deflections and imperfections? How about the second building – is there any evidence of imperfections, deflections? This could be relevant, assuming the structures were built in a similar way.

To our knowledge, there has not been any survey about the structure of the Cévennes and Minéa buildings between the construction date and the 2018 event. Only a technical opinion on the strength of the neighbouring Minéa building was requested just after the 2018 event. This report concluded that the overall strength of the structure was satisfactory but a number of points of vigilance were identified:

- a significant storm water stagnation on the roof;

- at the level of the roof metal frame, slight buckling phenomena as well as traces of corrosion at some profiles (angles and tubular profiles);

- a phenomenon of buckling on one of the profiles of a Saint-Andre's cross;

- a satisfactory condition of the V-columns, with a slight corrosion at the head and at the anchor plate;

- the presence of cracks and scatters with visible reinforcements in concrete blocks used for anchoring V-columns.

No indications about deflection or imperfection are provided in this report.
A brief discussion on this information about the overall state of the neighbouring building after the 2018 event will be added to the revised manuscript (current section 4.2 of the initial manuscript).

RC2#4 Is there any evidence that the drainage system was blocked and water pooled on the roof? Was the snowpack frozen / icy due to previous freeze-thaw cycles or was it already melting? Analysis of air temperatures a few days before the collapse could help.

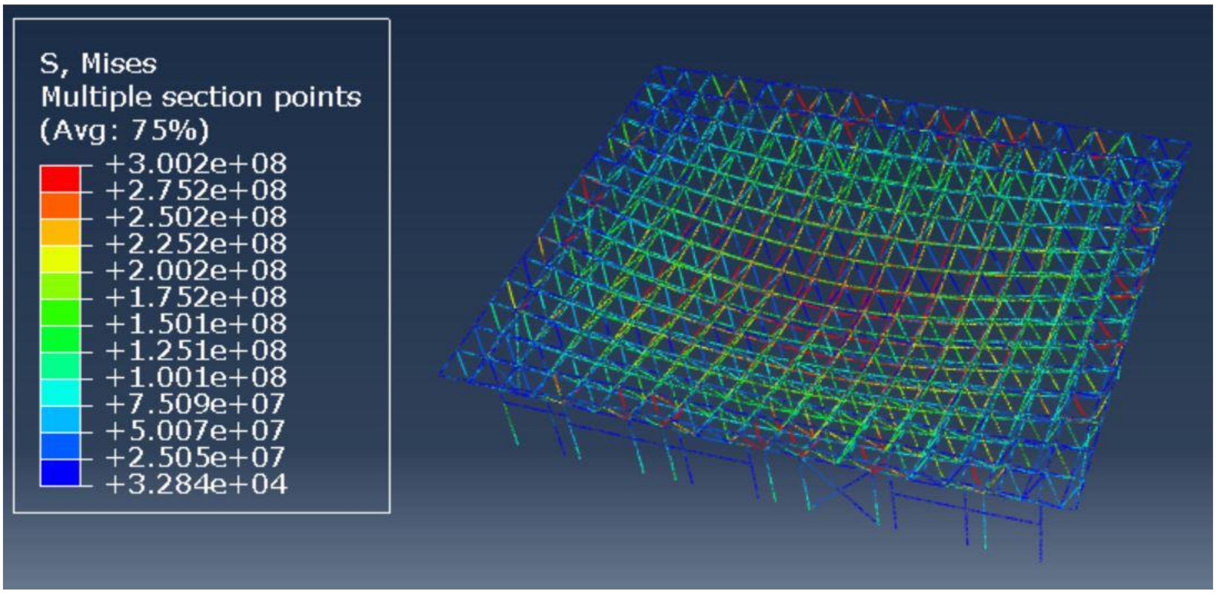
Photographs taken a few days after the rain-on-snow event of 2018 show a stagnation of water on the roof of the neighbouring building and therefore a problem of storm water drainage, as mentioned among the points of vigilance identified in this building (see our response to the previous comment). This strongly suggests a similar problem for the Cevennes building before its full collapse.
The drainage openings, which were only 20 cm high, were certainly not blocked by ice (the temperature being between 0 and 4°C on the day of the collapse) but simply by the dense snowpack already in place when the precipitation turned into rain. As indicated in Section 2.1, this meteorological event followed a cold spell and air temperatures were largely below 0°C when snow started to fall (see Fig. 5): the snowfall event only occurred on the 28th of Feb. 2018 and there was no snowpack before this date. Moreover, all testimonies indicate a wet snowpack at the end of the snowfall.
We will improve our discussion on the above-mentioned points in the revised manuscript.

RC2#5 Many details of the structural analysis are missing; some assumptions need thorough revision:

The authors try to make a retrospective analysis of "what likely happened before the collapse". While correctly considering best estimates of the roof snow load, they fail to consider best estimates for material properties – according to the new Eurocode for design of steel structures, prEN 1993-1-1:2022, S235 has mean of fy = 1,25 x 235 = 294 MPa, mean of fu = 1,2 x 360 = 432 MPa, $\varepsilon_u \geq 15\%$. In prEN 1993, 235 MPa is said to correspond to a 1‰ fractile of the distribution of fy, thus a very low – very conservative – very unlikely value. Consideration of more realistic values for material properties would likely amplify the importance of failure modes related to loss of stability.

We took pessimistic values for material properties to somewhat offset the fact that we supposed a perfect initial state of the building (see our response to comment RC2#2). We thank the reviewer for those information about material properties and ran new simulations with fy = 294 MPa, fu = 432 MPa and εu=20%. The results of the new simulations based on the assumptions proposed by the reviewer will be presented in the revised manuscript.
Moreover, it should be noted that following a remark by reviewer 1 on buckling, calculations have since been made showing clearly a problem at the level of the eastern façade for which we had little information on the distribution of the posts and their profile, as indicated on the paper. We conducted a new archival research, which has allowed us to clarify this point and the new simulations also took into account this aspect considering new (more realistic) features for the eastern facade.
Preliminary modelling results of loads leading to the different damage criteria, incorporating the two changes presented above, are presented below (table and figure).

Failure criterion	Loads (N.m-2)	
	Before	After
ymax=0.225	1275	1360
ymax=0.27	1500	1660
Elastic limit	1000	1320
Ultimate limit	2375	Not met



Further analysis of the new simulations is under progress and will be presented in the revised version of the manuscript.

RC2#6 Loss of stability will contribute to collapse mechanisms of common steel structural members. Expected values of eccentricities and imperfections should be considered in the analysis. How was this done?

There are already a number of sources of uncertainty regarding the initial state of the structure (e.g. material properties, as for instance discussed in the previous comment) and the intensity of the climatic event (snow height and density, amount of rain, etc.). For simplicity, no eccentricities or imperfections were taken into account in our analysis and we will follow this assumption in the revised manuscript, because we think that other sources of uncertainty are of primary importance for the analysis proposed here. We will explicitly mention this point in the revised version of the manuscript. However, we agree that global and local structural imperfections should be taken into account in the analysis. We think that the simplest way to consider such imperfections would be to introduce horizontal equivalent forces or to incline all the columns of the facades (for geometric imperfections). We propose to carry out numerical simulations in this direction to somewhat quantify the effect of imperfections on the strength of the structure. Preliminary numerical simulations integrating horizontal equivalent forces on the top of columns seem to show in the present case a negligible impact of geometric imperfections.

RC2#7 *ultimate limit criterion (full failure and collapse of the structure)*. When considering εu ≥ 15%, exceeded fu in one cross-section is unlikely to lead to collapse, right?

Yield and ultimate criteria mentioned in the article are effectively satisfied when the steel yield or ultimate strengths are reached in at least one cross-section. So, they both indicate a beginning of deterioration which can then produce a (potential) significant impact on the structure. As the reviewer is pointing out, the ultimate limit criterion therefore does not correspond to the full failure and collapse of the structure. This point will be clarified in the revised article and the term 'collapse criteria' will be systematically replaced by the more appropriate term 'failure criteria'.

RC2#8 *We also conclude that the building, at the moment of its collapse in 2018, was respecting the new regulations*. How is this substantiated? Assuming it was in the perfect initial state before the collapse?

The simulations carried out show that the structural limits (ultimate limit criterion and deflection) are reached for loads exceeding the snow loads recommended by the regulations in force at the time of construction and by the Eurocode into effect, under the assumption of a perfect initial state. We thus confirm that theoretically (assuming a perfect initial state) the building was complying with past regulations and new regulations regarding snow loads. We will remind in Appendix of the revised manuscript that those calculations were made under the assumption of perfect initial state.

RC2#9 *Under current regulations, yield occurs for a load less than the exceptional load recommended by Eurocode but the building fails serviceability (excessive deflection) for snow load largely above the permanent project situation and slightly above the accidental project situation recommended by Eurocode*. Numbers are missing here.

The values of loads leading to yield and excessive deflection (1 000 and 1 275 N.m-2, respectively) are provided in Table 3 of the original manuscript, whereas the loads corresponding to the permanent/transient and accidental project situations (550 * 0.8 + 200 = 640 and 1 350 * 0.8 + 200 = 1 280 N.m-2, respectively) are provided in lines 389-390. We agree that those values should be reminded in the paragraph mentioned above for a better readability. We propose to detail (as mentioned above) the values of loads corresponding to the permanent/transient and the accidental project situations in lines 389-390 and to modify this paragraph as follows:

"Under current regulations, yield occurs for a load of 1 000 N.m-2, which is less than the exceptional load recommended by Eurocode, equal to 1 280 N.m-2. However, the building fails serviceability (excessive deflection) for a snow load of 1 275 N.m-2, which is largely above the permanent project situation (that corresponds to a snow load equal to 640 N.m-2) and is of the same order of magnitude as the accidental project situation (which corresponds to a snow load equal to 1 280 N.m-2 recommended by Eurocode)."

However, all the above-mentioned numerical values will have to be reviewed carefully in the light of the new simulations which will integrate new (more realistic) inputs for both the new values of the steel behaviour law and the new modeling of the eastern facade (see, in particular, our response to comment RC2#5).

RC2#10 Details of the roof snow load modelling are also missing:
This rain-on-snow event is exceptional – this should be quantified – what is an occurrence rate of such an event? Snow load maxima (including the effect of rain on snow) should be analysed for the location and the return period for the ground snow load experienced at the event should be estimated. This would help to classify if the ground snow load reached serviceability, design (return period of ~hundred years) or accidental load levels. Missing are details for the roof snow load – what is the characteristic roof load? What is the design value? How do they compare to the estimated roof load?

Such a snow event is rare in the region of Montpellier. Ground measurements indicate that snow depth of more than 25 cm have occurred only five times since the 1950s: 35 cm in February 1954, 35 cm during the winter 1962-1963, 27 cm on the 14-16/01/1987, 28 cm on the 22/01/1992 and the event of 2018 described in the present manuscript. The return period of the snow event alone exceeds 10 years (5 events in 70 years). What makes the rain-on-snow event exceptional is the large amount of rainfall which has followed the snow event. We do not know if the other large snow events were followed by an intense rainy period. Moreover, it is difficult to apply a standard statistical approach (using the fitting of a probability distribution) to snow load maxima at this location (i) because of the absence of systematic measurements and (ii) because of the vast majority of zero values in the series of annual maxima, snow events being very rare in this Mediterranean region (Section 4.3). As a consequence, it is not possible to provide a precise return period for the "rain-on-snow" event.

Concerning the second part of the comment, the roof snow load has been considered as equal to the ground snow load. For the 2018 rain-on-snow event, this load is estimated between 1520 and 1640 N/m2 for a snow density equal to 250 kg.m-3 and a snow height of 30 cm and 35 cm, respectively. The load leading to the failure of the structure obtained by the FE simulations (red lines) is compared to those values (blue lines) in Figure 13.

RC2#11 … *we can roughly estimate that the very wet snowpack on the roof easily reached a high density around 600 kg.m−3 at the time of the collapse*. In the scientific paper such estimates should be based on sound arguments.

The assumed value of 600 kg/m3 for ultimate snow density was deemed to correspond to an "equivalent" snow and rain density uniformly distributed over the roof. In fact, the wet snowpack was probably heterogeneous with zones of soared snow at higher density (300-400 kg/m3) than the initial (already wet) snow (250 kg/m3) and other zones at the bottom with accumulated water (1000 kg/m3) due to preferential water flows. The value of 600 kg/m3 used in this study corresponds to an equivalent value to define the (equivalent) pressure exerted by the combination of snow and rain accumulations. Following remarks by the first reviewer, we now account for the heterogeneity of the mixture of wet snow and water, by considering different scenarios of (simplified) non-uniform pressure distributions that will be presented in a revised version of our manuscript (more details about those scenarios for pressure distributions are given in our reply to reviewer #1).

RC2#12 How was the effect of exposure considered? What was the wind speed during the snowfall? For many flat roofs, it holds roof snow load = 0,8 x ground snow load. Discuss this.

On the day of the collapse, the wind was force 1, with a velocity between 0 and 3 m/s. It is therefore unlikely that the wind could have had an effect on the snow distribution on the roof level before and at the time of the collapse. In our study, the snow load on the roof has been estimated to be equal to the snow load on the ground. We think this is a reasonable assumption because of the following reasons: the roof slope was low, a small wall was present all around the edges of the roof, the snow was wet and relatively heavy and the wind was not strong enough to modify (reduce) the snow height on the roof. The shape factor of 0.8 was only used to back-calculate the snow load recommended by the regulation (see our response to the comment RC2#9).

RC2#13 How important are wind effects for the design of structural members? Is wind negligible in comparison to snow?

Extreme wind conditions have to be taken into account when designing structural members, as indicated in Eurocode 1. But wind effects were negligible on the day of the collapse. As such, we didn't assess this aspect for the 2018 event. This aspect is out of the scope of the 2018 event.

RC2#13 The first paragraph of the introduction is very general – it seems to have no link with the other text. Delete it or make clear how it is related to the following analysis.

We agree that this first paragraph is not closely related to this study and we propose to remove the first paragraph and start the introduction by focusing on static snow loads.

Editorial comments:
- Terminology: this type of roof is commonly referred to as "flat roof", not a plate roof.
- The use of English could be improved. In particular damage should not be (in the context of this study) used in plural.
- The check by a native speaker experienced with technical texts would help to re-phrase some clumsy statements.
- Some typos appear in the text. Lineic is line load?

We thank the reviewer for those language corrections and we will correct them in a revised version of the article.