Response to the editor

Thank you for the answers to the referee comments. In particular referee #2 rises critical issues, which have to be addressed carefully in the revised manuscript. If issues cannot be addressed there has to be a sound justification for this. Your manuscript will be reviewed again.
We thank the two reviewers for their detailed comments. We have taken into account all the proposed changes made by the referee #1. We also agree with most of the critical comments raised by referee #2 and have made substantial modifications to the manuscript:

- Many technical details concerning the Finite Element (FE) model have been moved to a new document which presents the "Supplementary Materials". Several figures and Tables have also been moved in the SM to alleviate the main text of the manuscript.
- Clarifications have been made concerning the main steps of the proposed approach
  - we estimate a snow-and-rain load at Section 2.4,
  - we then model this load using a quasi-dynamic approach where the snow-and-rain load is applied on the structure in Section 3, with three different load distributions (uniform, accumulation on the sides, accumulation on the center),
  - The different failure criteria and the buckling analysis are now explained in plain terms (new section 3.3),
  - A new Figure (Fig. 7) illustrates the FE simulations and how they are exploited to obtain the loads associated to different failure criteria.
  - Figure 8 now compares the estimated snow and rain and failure loads in Sections 2 and 3.
- We now motivate more clearly the estimation of the rain-on-snow surcharge, and cite different studies which have been dedicated to this question.

Anonymous Referee #1

#RC1.1. Since this building collapse has little to do with climate change, I recommend deleting all these sections. The influence of climate change on snow load in the Mediterranean region would have to be shown with a more detailed study.
These sections have been removed from the revised manuscript.

#RC1.2. l.44-46. Add the time of collapse (The collapse took place on March 1 at around 6 pm): makes the understanding of the weather evolution described in chapter 2 easier.
Ok, this has been done.

#RC1.3. l.94-95: Add: the collapse took place at around 18:00.
Ok, this has been done.

#RC1.4 l.101: What does exceptional mean in the context of building design? Normal variable action = return period of 50 years (load coefficient 1.5), accidental action (load coefficient = 1.0) = return period of 100 - 300 years. Situation on 1 March corresponds rather to an accidental situation?
The characterisation of the snow load in terms of building design is discussed in Section S4 in the SM and the design value of exceptional ground snow load is given in Table S7. Here, we wanted to indicate that this event is qualitatively atypical (snow depth above 30 cm happened only four times in the last 70 years, as indicated in the conclusions). However, we agree that the term "exceptional" should not be used here. It has been replaced by "atypical".

Figure S8 in the SM now shows that the snow-and-rain load estimated in Section 2 is of the same order of magnitude as the design value of the exceptional ground snow load to be considered in an accident situation.

#RC1.5. Caption Figure 4: The red marker shows the position of the collapsed building.
Thank you for this comment, this has been added.

#RC1.6. l.136-137: Difficult to figure out what that means? Eyewitnesses? Info on Facebook?
We agree that this sentence was ambiguous, it has been deleted.

#RC1.7. l.138: filled? better infiltrated?
Thank you for this comment, we have replaced "filled" by "infiltrated".

#RC1.8 l.142-143: Time 18:00 or 6 pm - better everywhere the same time format.
We agree. 6 pm has been replaced by 18:00.

#RC1.9 l.144: Depends on drainage or runoff conditions. Dry snow can only absorb about 10-15% of water, which simply flows down through the snowpack. If the water cannot drain away at the base, it will remain there.
This mention of 'boundary conditions' was misleading in this sentence, it has been removed.

#RC1.10 l.159: unit? beaufort? better m/s.
The mention of 'Force 1' has been removed.

#RC1.11 Caption Figure 6: give the numbers for width, length and height to have an idea on the size of the building.
Thank you for this comment, this has been added.

#RC1.12 l.175: add as reference: Table A1. Geometrical properties of the structure
This has been added.

#RC1.13 l.210: new? better give a reference for the applied EC edition
The exact reference ‘prEN 1993-1-1:2022 (2022) Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings.’ has been added following the suggestion of a previous referee to justify the values of yield stress (fy) and ultimate stress (fu) for the steel (see RC1.14 just below).

#RC1.14 l.210-211: what are these factors? 1.25 and 1.2?
According to the reference mentioned just above in RC1.13, and more precisely according to its Table E1 which contains the statistical parameters for the most relevant mechanical properties, the average values of yield stress fy and ultimate stress fu for steel, of type S235, were calculated as fy = 1.25 * 235 MPa = 294 MPa and fu = 1.2 * 360 MPa = 432 MPa. Again, we have followed here the suggestion from a previous referee who had asked us to use those mean values, as provided by the Eurocode prEN 1993-1-1:2022 (Eurocode 3: Design of steel structures) instead of the very low (very unlikely) characteristic values which we had used in our initial simulations.

#RC1.15 l.219: snow and rain load
Thank you, this has been corrected.

#RC1.16 l.228: pressure distribution -> load distribution
Thank you, this has been corrected.

#RC1.17 l.230: how was this maximum pressure calculated? snow part? water part?
This maximum pressure was arbitrary because in practice the code diverges before reaching such a high level of maximum pressure. It is deliberately high to ensure that it is higher than the values of the loads leading to the various failure criteria. These technical details are now provided in section S2 and table S3 in the SM.

#RC1.18 l.232: not very realistic for Montpellier
We agree, this sentence has been removed (these numerical values were just given as virtual examples but they do not help and can lead to confusion).

#RC1.19 Caption Table 2: influence width for the calculation of the line loads?
Based on the range of snow-and-rain loads applied to the structure in the case of uniform distribution, the line loads are calculated considering the length of each T-profile (3 m) combined with the number of surface elements 3 m x 3 m at stake (which is directly connected to the location of the T-profile in the roof). For T-profiles located at the edges of the roof, there is one surface element to consider. For T-profiles inside the roof, there are two elements to consider. These details are now provided in the SM (table S3) and the corresponding text has been revised in order to recall the length of each T-profile (3 m) and to mention the surface considered depending on their location in the roof.

#RC1.20 l.249-250: The 2018 event showed that rain on snow is very important. Has it rained after these snowfalls? how much?

Figure 1 below shows the weather data from the SAFRAN reanalysis at the grid point covering Irstea building for three past snow events. It has not rained after the snowfall on the 14-01-1987 according to SAFRAN data. Some rain has been recorded for the other two events but they are limited to a few mm. For the 7th of March 2010, produce mostly rain instead of snow, which does not correspond to the 10 cm observed on this date. Consequently, we have decided to add only a sentence indicating the amount of rain after the snow for the event of the 22/01/1992.

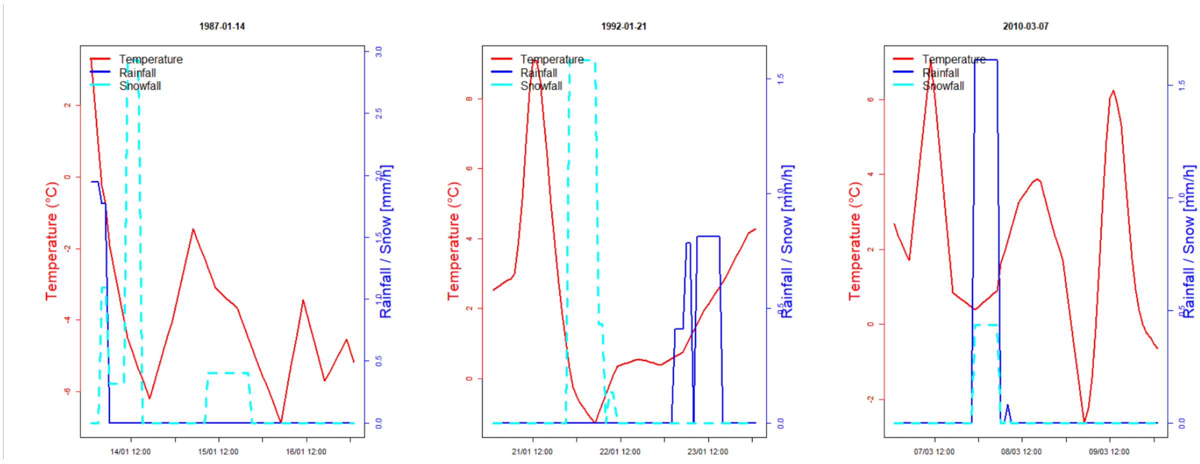

Figure 1: Weather data from the SAFRAN reanalysis at the grid point covering Irstea building for three past snow events.

#RC1.21 l.259: within the manufacturing tolerance?

Yes, it has been added.

#RC1.22 l.263: Not clear: concrete base has crack and chips, so you can see the reinforcement?

We have revised this item to make this point clearer. We now say: "presence of cracks (on several blocks) and spalls so that the reinforcement can be seen (on one block) on the basal concrete blocks for anchoring the V-columns."

#RC1.23 l.299-300: are the numbers correct? 735 kN/m2???

Thank you for denoting these typos. Indeed, these numbers were in N/m2. This has been corrected.

#RC1.24 l.360-364: A simpler approach would be to assume that in addition to the 30 cm of snow with density of 250 kg/m3 (= 75 kg/m2), about 50 to 60 mm of rain (50-60 kg/m2) was added (assumption: rain stays on roof, no runoff). This results in a load of the snow-water mixture of about 125 to 135 kg/m2.

We agree, this paragraph and section 2.4 have been modified in order to avoid providing estimates of the snow density of this snow-water mixture.

#RC1.25 Figure 17: Diagram is difficult to understand, Snow depth is not constant over time: new snow settles fast. If rain starts the snow depth should decrease = no horizontal blue line.
We agree and this figure has been replaced by Figure 10, which simply compares the values of snow-and-rain loads and failure loads estimated in Sections 2 and 3. Only the snow depth before rain is now estimated at 30 cm with a density of 250 kg.m-1 and 50-60 mm respectively, to obtain the ultimate snow-and-rain load.

#RC1.26 l.418: better: long-span
Thank you for this comment, this has been changed.

#RC1.27 l.419: Climate change has no influence on the possible size of the span of a large hall....much more important is that water drainage is guaranteed at all times on a hall with a large span. Seems to have been the main problem with this hall. There have been hall collapses during very heavy rainfall combined with strong winds that pushed all the water on the roof to one side, causing the overloading of the drainage system.
We agree, the reference to climate change has been deleted.

#RC1.28: Section 3: The collapse of this hall has no relation to climate change. This section contains too little relevant data to add value to the paper. Therefore, this section should be deleted.
This section has been removed in the revised manuscript.

#RC1.29 l.485: steel structures
Thank you, this has been corrected.

#RC1.30 l.491-494: this section should be deleted.
This section has been deleted.

#RC1.31 l.587-592: are the units correct? kN/m2?? this are very huge loads!
These units were incorrect indeed, the correct unit is N/m2.

Reviewer #4 (Report #2)

RC4.1. The paper is very difficult to read due to a lack of simple and clear structuring and due to too lengthy explanations of not really relevant issues.

We agree that the structure of the paper could be improved and that many details were not required in the main text of the manuscript. While the revised version maintains the overall structure of the paper (section 2 details the meteorological event, section 3 is dedicated to the analysis of the snow load impact on the structure, section 4 aims at synthesizing the main results and key messages), we have decided to move many subsections (section 3.2 description of the finite element model, Figure 8, Appendices) in a new document "Supplementary materials"**.** We made an effort to improve the general flow of the paper and to clean the parts of the paper that were focused on too many details that are indeed not essential to the key messages of the paper. For example, we reorganized some parts as follows:

- the description of the building after the collapse is now provided in the introduction, as it provides the main motivation for the finite element model.

- Section 3 about the FE simulations has been entirely rearranged, with a new subsection 3.2 about the different distributions of the snow-and-rain load on the roof. Subsection 3.3 has been simplified, the technical details being provided in the SM. Figure 7 and the subsection 3.3 try to describe in plain terms the purpose of the FE simulations (failure criteria, buckling analysis).

We hope that the new version of the paper can alleviate the criticisms of the referee on this point.

RC4.2. Incorrect terminology in the structural engineering parts of the paper, e.g. characteristic values and design values are mixed up. Limit states are not clearly defined, etc.
True, we have now clearly distinguished the transient (characteristic value) and accidental (design value) situations in section S3 of the SM and specified which failure criteria are SLS and ULS in the main text.

RC4.3. If buckling of truss bars is the relevant collapse mechanism then it would be necessary to explain why the nodes of the truss were not properly modelled in the finite element analysis, i.e. a simple modelling without gusset plates is insufficient. The correct restraints of the truss bars at their ends has to be included in the analysis.
We are not sure to understand this comment about the gusset plates. We believe that a rigid linkage is a reasonable representation of the initial state of the structure, where round tubes are welded to T-beams. It is now explained in more detail at the end of section S2 of the SM.

RC4.4. Why no shape factor according to EN 1991-1-3 was used to determine the snow load on the roof should be explicitly justified. This assumption is not acceptable without profound justification.
A shape factor of 0.8 was used to calculate the design roof snow loads recommended by Eurocode 1. In contrast, the roof snow load at the end of the snowfall event was estimated to be equal to the ground load, as the roof was completely sheltered from the wind and the

observed temperatures suggested that there was no snowmelt during the snowfall event (see Schriever, W. R. « Estimating snow loads on roofs ». National Research Council of Canada. Division of Building Research, février 1978. https://doi.org/10.4224/40000746).

RC4.5. The roof draining system is assumed to have been blocked from the beginning without proper justification.

We agree that this assumption was not properly discussed and motivated, and a paragraph has been added in Section 2.4. We recall here the dynamic of the rain-on-snow event. The snow firstly filled the space delineated by the roof and the surrounding sidewalls (see Figure S5 in the SM). Given the snow depth (30 cm), the snowpack was covering most of the roof draining system, which has certainly slowed down the evacuation of most of rainwater coming after, as previously discussed in the literature (Colbeck, 1977; O'Rourke and Downey, 2001; Otsuki et al., 2017). In addition, it must be noted that the openings for draining away rainwater were not numerous and were pretty small, that the slope of the roof was small (1%) and that the roof has a large span, which corresponds to the most critical cases of rain-of-snow surcharges (O'Rourke and Downey, 2001). Those characteristics of the roof draining system with snow initially settled on the roof offered limited chance of draining efficiently the water which came after the solid snow precipitation. And we recall that there was evidence of significant storm-water accumulated on the roof of the neighboring building (of similar construction as the one investigated) after the event, which may corroborate the fact that the system was not so efficient at draining the water. We agree that this remains a pessimistic scenario and that some water could have been evacuated but this remains a challenge to estimate the water discharge and how it affected the snow-and-rain load. As we do not want to add other parameters (and related uncertainty) to our analysis, we chose to stick to this assumption.