Assessing and Modelling Buildings Failures caused by External Events at Ringhals NPP

Erik Sparre*[a], Carl Sunde[b], and Cilla Andersson[c]
[a] Risk Pilot, Malmo, Sweden
[b] Risk Pilot, Gothenburg, Sweden
[c] Ringhals, Varobacka, Sweden

*erik.sparre@riskpilot.se

Abstract:

External events usually challenge the different buildings and an important part of the analysis of these events is to determine at which loads the buildings can be damaged. Relatively new regulations in Sweden require that buildings containing safety relevant equipment should be re-analyzed, using state-of-the-art deterministic structural mechanic methods to verify that the buildings can withstand certain loads from external events. The external events are hence analyzed in collaboration with experts in structural mechanics, who can help the PRA-staff to interpret the deterministic analyses. By involving experts in structural mechanics, the probability of collapse to specific buildings can be estimated more realistically. These estimations still include uncertainties, but to a lesser extent than in the old analysis.

Each building is considered separately and hence a large number of analysis cases arise. The other important part of the project is therefore to structure the analysis cases better in the PRA-model by modelling the buildings using fault trees. This approach, on the other hand, demands that the analyst is aware of the challenges of modelling events with high probabilities in commercial PRA-software.

The result of the updated analysis is an improved quantification of external events in terms of reduced conservatisms and uncertainties.

Keywords: PRA, External Events, Fukushima, Regulations, Uncertainty Analysis.

1. INTRODUCTION

External events, such as extreme snow or wind, contribute significantly to the overall core damage frequency for the Ringhals NPP. The main reason for this is that several external events challenge the availability of the offsite power grid and in many cases also affect the alternative AC-sources such as diesel generators and gas turbines. One single event, such as extreme snow, may hence affect several barriers against core damage. Since extreme snowfall of such magnitude that buildings and structures may collapse is very rare the uncertainties are large. This paper presents how the Ringhals NPP has used recently performed structural mechanics calculations in order to improve the assumptions in the PRA-model. The paper also gives examples of how to model the events in practice.

2. DETERMINISTIC EVALUATION OF BUILDINGS

External events can challenge the integrity of buildings or other structures of importance to safety. Before quantifying the external events in the PRA-study it is important to know and understand how the different events challenge the structures in a deterministic way. Relatively new regulations from the authorities in Sweden (SSMFS 2008:17 §14) require that buildings containing safety relevant equipment should be verified to withstand loads from external events, using state-of-the-art deterministic structural mechanic methods. The current PRA-study is based on old building evaluations using design specification rather than verifying structural calculations. The new regulations require that building structures should be able to withstand extreme external events with loads corresponding to a return period of 100 000 years. Hence, deterministic structural evaluations have been made for such loads. Also loads with a return period of 50 years are evaluated based on requirements from a Eurocode (e.g. for snow SS-EN 1991-1-3. Eurocode 1 is used) and EKS 8 which is the Swedish application of the Eurocodes issued by the National Board of Housing, Building and Planning, i.e. same load that are used for conventional building structures. In addition, a research report from the Swedish Radiation Safety Authority called Design Guide for Nuclear Civil Structures (DNB) is used to adapt the requirements to nuclear facilities, [1]. DNB describes design provisions for concrete structures at nuclear power plants and other nuclear facilities in Sweden. The scope of DNB includes provisions regarding design and analysis of loadbearing concrete structures covering reactor containments as well as other safety-related structures. The main aim of DNB is to complement the regulations given in EKS 8 for application at nuclear power plants and other nuclear facilities in Sweden. Thus, DNB is based on the partial factor method and the principles of design in limit states, as specified in the Eurocodes including the Nationally Determined Parameters chosen by Swedish Authorities. ASME Sect III Div 2 is applied in DNB for the containment and ASCE 4-98 is used for related to earthquake.

Evaluations for all buildings related to safety have been done for all possible external loads using DNB. In the following subsection the evaluation of snow load is described. Based on these evaluations some reinforcements of building structures are in progress at Ringhals, e.g. the roof of the service building containing diesel generators are to be reinforced.

2.1. Evaluation of snow

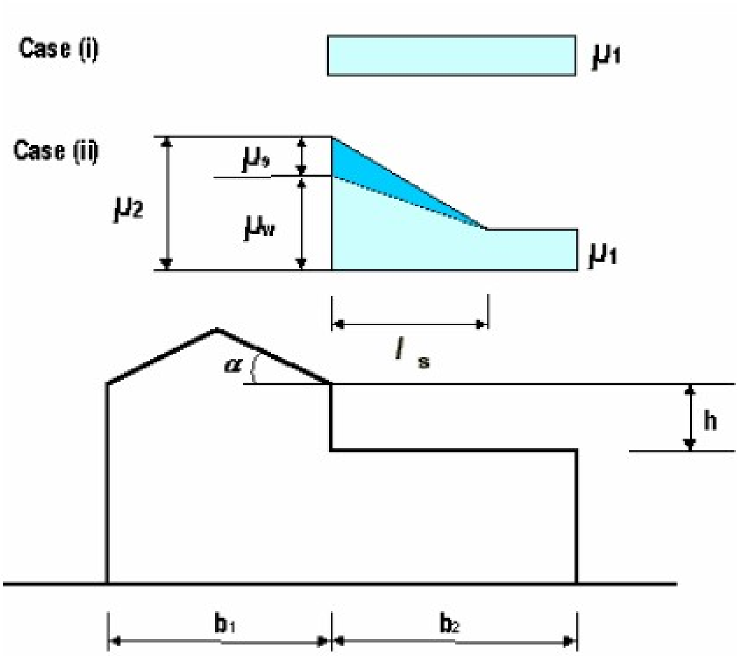
Two different snow loads, denoted “s”, are analyzed using the following expressions based on Eurocode.

Return period of 50 years: $s=\mu\times1.5$ kN/m^2

Return period of 100 000 years: $s=\mu\times3.0$ kN/m^2, corresponding to 100 cm of snow (Ringhals conditions)

where μ is a form factor depending on the properties of the roof. The form factor is depending on the possibility of drifting snow accumulating on higher structures on the roof. In figure 1 the form factor for roofs without (case i) and with (case ii) drifting of snow is shown. Hence, the load will be higher on the part of a roof that is in connection with an adjacent building structure that is higher. For flat roofs $\mu=0.8$.

Figure 1 Form factor for roofs without or with drifting of snow. The figure is from SS-EN 1991-1-3, Eurocode 1.



All roofs and walls are evaluated for the snow loads as well as the total stability of the buildings. The evaluation with respect to the load corresponding to a return period of 50-years are made with more conservative methods than the evaluations of the loads corresponding to a return period of 100 000-years.

The evaluation is made by calculating a utilization factor (UF) for each affected structure. The UF is expressed as the ratio between the load and the resistant of the structure. Hence, in a deterministic analysis a UF >1 means that the structure cannot withstand the load and UF ≤ 1 means that the structure can withstand the load. The result from the evaluation can be:

- Total collapse of building
- Roof cannot withstand load
- Part of roof cannot withstand load (e.g. drifting snow)
- Roof beams cannot withstand loads

From a deterministic point of view none of these results are acceptable and the building has either to be reinforced or other measures such as clearing of roof before critical snow load is reached need to be considered.

In order to quantify the results from the deterministic evaluation into the PRA-study all conservatisms need to be considered and also the value of the UF needs to be carefully considered. PRA-experts in co-operation with structural mechanical experts have been trying to quantify the results. As an example, it is more likely that a roof with a UF of 20 will collapse than a roof with a UF of 1.01. To fully quantify the results into the PRA-study a fragility curve for all loads and buildings structures would be useful. However, no method to develop a fragility curve based on deterministically evaluations have been found.

3. PRA-modelling

The scenarios to be modelled were selected in a detailed external events analysis. The update presented in this paper doesn't address the general screening criteria of which events to analyze, but rather the principles of how to determine the impact on the building structures from the events related to severe weather (strong wind, extreme snow and ice storm).

The following scenarios involving single (S) and multiple (M) external events have been included in the PRA model and quantified:

S01. A01/ Strong wind causing Loss of the external grid and damage to building structures

S02. A07/ Extreme snow causing Loss of the external grid and damage to building structures

S04. W10/ Organic material in water causing Loss of the ultimate heat sink due to clogging of screen house 4

S06. A26/ Ice storm causing Loss of external grid and impact on ventilation to electrical building

M01. A01/Strong wind (affecting external power supply) AND A07/ Snow (affecting ventilation)

M02. A01/Strong wind (affecting the external power supply) and W10/ Organic material in water (affecting the ultimate heat sink)

During the last years a simplified analysis of earthquake has been performed for the Ringhals NPP. The purpose of the analysis is to show that the seismic risk at Ringhals NPP is sufficiently low even if a very conservative approach is taken and the intention is not to include it in the regular PRA. Hence the earthquake evaluation is not included in the update of external events presented in this paper.

One large challenge when modelling external events is to determine the effect on the plant. In some cases, it is straightforward to model the consequences, such as the event S04 – Clogging of screen house. For this event the analyst simply disables the normal cooling path, and investigates if there are alternative ways of providing cooling water to the salt water pumps, or other countermeasures, which should be modelled. However, it can still be a challenge to determine the frequency of an event of such magnitude that the screen house is completely clogged.

For other events the impact of the external event is more difficult to predict. The events S01, S02 and S06 described above are all difficult to analyse but as described in previous sections, by using state-of-the art structural mechanics calculations the uncertainties in the assumptions may be reduced.

As an example, the modelling of the event *S02 - Extreme snow causing Loss of the external grid and damage to building structures* is described in more detail below. The other events mentioned above have also been thoroughly analyzed but the treatment of these will not be described in this paper.

Two different scenarios are modelled, one event representing a snowfall with a 50 year return period and one a snowfall with a 100 000 year return period. The general impact on the plant will differ between the events, but in both cases a loss of offsite power is assumed. There are two separate power grids available at the Ringhals NPP. Usually the power plants at Ringhals are connected to the 400 kV grid, but there is also a 130 kV available.

There are instructions available for removing snow from roofs before critical loads are reached. If this instruction is followed no buildings will be damaged by the load from snow.

Damage levels for different buildings due to snow load for different return periods are summarized in Table 1 based on structural calculations.

Table 1: Damage on different buildings due to snow load for different return periods

Building structure	Structural damage and consequence	
	50-year	100 000-year
Auxiliary building	Part of the roof not resistant against snow load. No components used in PRA are located in this part of building.	Part of the roof not resistant against snow load. No components used in PRA are located in this part of building.
CST (Condensate Storage Tank)	Damage to roof beams and roof can collapse. UF=1,01 meaning low probability of damage to roof.	Damage to roof beams and roof can collapse. Possible loss of CST.
RWST (Refuelling Water Storage Tank)	No damage.	Damage to roof beams and roof can collapse. Possible loss of RWST.
Turbine building	Roof sheet not verified for snow load. Equipment in turbine building not protected by floor assumed to be damaged. Roof beams in parts close to intermediate building cannot withstand load from snow pockets. No damage to pipes from system 715 and 762 to 327.	
Service building (Diesel Generators)	Possible loss of diesel generators. Which diesel generators that may be affected is dependent on where they are located in the building, since some parts of the roof is more vulnerable due to the layout (as described in chapter 2.1). Part of the roof may be damaged only in case of snow pocket. Part of the roof may be damaged.	
Screen house 4 (SWS intake)	Part of the roof cannot withstand snow load due to snow pocket against the screen house 3.	
Screen house 3 (Main Cooling Water intake)	Not verified for external loads. Loss of normal feed water.	

The evaluation of buildings shows that the turbine building roof is not verified for snow loads which means that there is a large risk for damage within the building. There are not many safety classified components such as pumps located in the turbine building but there are cables and cabinets that may be damaged. To capture the effect on the plants safety it is therefore important that cable routing etc. are properly modelled since there may be domino effects leading to reduced barriers.

A set of different analysis cases is defined for snow loads. Since the impact of building structures is different for the 50-year return period and the 100 000-years return period two different main analysis cases are defined. For the 50-year return period short term loss of 400 kV and 130 kV is assumed and for 100 000-year return period long term loss of 400 kV and 130 kV is assumed. In both cases screen house 3 is assumed to be lost. These analyses cases are then divided based on possible structural damage to the buildings.

For a return period of 50 years the following different damage levels are defined:

- Due to the fact that the structural evaluation of the buildings is made with conservative assumptions no damage at all is assumed with a probability of 90%.

- In consequence, the probability for reaching a critical snow load is 10 %. The degree of damage (number of buildings damaged) has great impact on the resulting risk, and has been assumed to be the following.

- Since there is an instruction available for removing snow the probability for not reaching critical snow loads at all is judged to be 90 % (out of 10%) for all the buildings listed in Table 1. Table 2 lists the individual damage levels for buildings if removing of snow fails.

Table 2 Damage level for snow load with return period of 50 years.

Building	Consequences	Conditional probability given critical snow load
Turbine building	Loss of all equipment on level D-1 and above. Steam and water release from systems in building.	100 %
Service building (Diesel Generators)	Loss of one diesel due to snow pockets. Loss of auxiliary equipment in some rooms in the service building.	90 %
	Loss of two diesels due to snow pockets. Loss of auxiliary equipment in some rooms in the service building.	10 %
Screen house 4 (SWS intake)	Loss of screening equipment and loss of electrical room.	100 %
CST	Loss of CST	10 %
	No damage to CST	90 %

In addition, another set of analysis cases is defined, with a return period of 100 000 years with the following different damage levels:

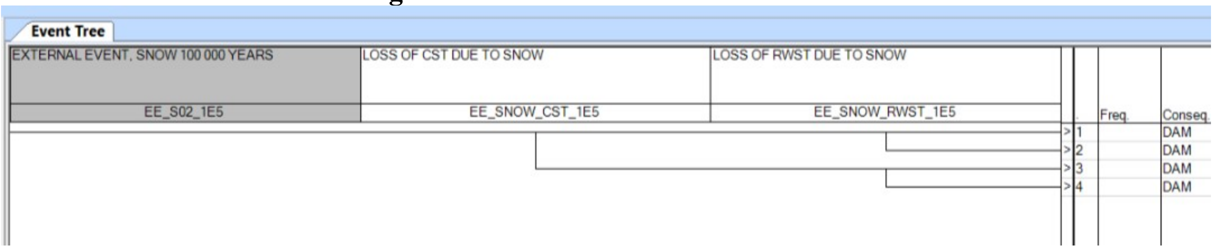
- The weather during when the 100 000-year snow load occurs is assumed to be very severe hence the possibility to manually remove snow is lower than for the 50-year return period. The probability for not reaching critical snow loads at all is judged to be 50% for all the buildings listed in Table 2. Table 3 lists the individual damage level for buildings if removing of snow fails.

Table 3 Damage level for snow load with return period of 100 000-years.

Building	Consequences	Conditional probability given critical snow load
Turbine building	Loss of all equipment on level D-1 and above. Steam and water release from systems in building.	100 %
Service building (Diesel Generators)	Loss of one diesel due to snow pockets. Loss of auxiliary equipment in some rooms in the service building.	90 %
	Loss of two diesel due to snow pockets. Loss of auxiliary equipment in some rooms in the service building.	10 %
Screen house 4 (SWS intake)	Loss of screening equipment and loss of electrical room.	100 %
CST	Loss of CST	80 %
RWST	Loss of RWST	80 %

To reduce the number of analysis cases the different scenarios have partly been handled by using event trees. Instead of creating one analysis case for each possible combination of events presented above the consequences have been handled in event trees:

Figure 2 Event Tree for Extreme Snow



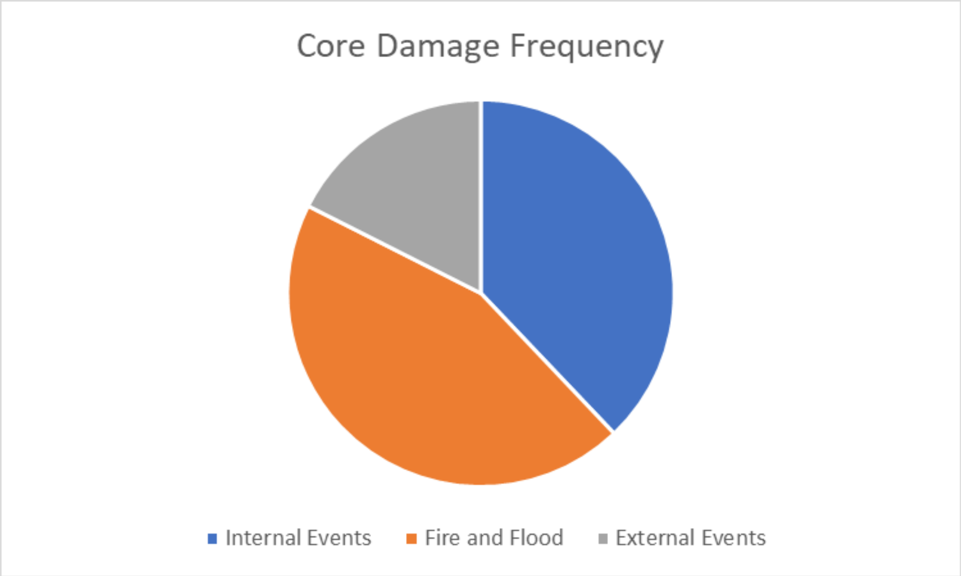
The structure shown in figure 2 makes it possible to analyse four different consequences at once (failure or not of CST and RWST). However, one has to be careful when defining these kinds of analyses when involving events with high probabilities. In the example above both the probability of failure for RWST and CST is set to be 0,8. The probability that the CST or RWST is intact is thus low and it's important to make sure that the "success probability" isn't approximated to be 1,0. The software used in this analysis allows for taking these kinds of considerations into account, but the analyst needs to carefully adjust the analysis settings in order to obtain the correct results.

In the example above (extreme snow) it would have been possible to include also the loss of diesel generators (either one or two diesels) but in this particular case it turned out to be difficult to model the different scenarios without increasing the complexity of the modelling further. It is important to consider that the model must be transparent enough for engineers, other the ones that have developed the model, to easily understand the modelling principles.

4. RESULT AND CONCLUSION

In figure 3 below the contribution from different initiating events are presented for Ringhals 3 NPP. These results are preliminary since the model is not fully reviewed yet. Previous versions of the PRA-model also included an analysis of external events, in fact no major changes have been made in the definition of events (apart from the inclusion of a new event "Ice Storm"). The contribution of the external initiating events has not dramatically changed, but the main improvement is that the uncertainties have decreased since the assumptions regarding the impact on the plant from external events are better informed. Most assumptions regarding the integrity of the buildings are based on relevant structural mechanics calculations.

Figure 3 Contribution from Initiating Events



Still, it is undoubtedly a fact that the uncertainties from the analysis of external events are larger than from the analysis of many internal events, such as common transients. When analyzing a transient such as “loss of feedwater” the initiating event frequency is based on actual events, often plant specific, and the barriers such as the auxiliary feedwater can be analyzed using solid failure data.

In chapter 3 some details about the modelling of extreme snow were given. The evaluation of the structural mechanic calculations led to the assumption that one or two diesel generators (out of four) may be affected. The choice of which diesel generators that are lost is not arbitrary but instead based on where the diesel generators are located in the service building, since the geometry of the buildings may lead to snow pockets forming above certain rooms. That is, two particular diesel generators may be affected and the other two will not be affected. Nevertheless, since the diesel generators obviously are important during external events the assumption of which diesels that may be lost are of great importance. Also, due to the configuration of the plant, two of the diesel generators are more important than the other two and in the example presented in this paper one of the important diesel generators is placed in the service building so that it may be damaged by a collapsing roof. A sensitivity analysis shows that the core damage frequency for external events would decrease by about 60 % if one of the affected diesel generators is assumed not to be damaged. In conclusion, the analysis of the impact on the service building must be very carefully addressed.

The discussion about the uncertainties in the PRA-results, often in terms of uncertainties in the results of area events and external events in comparison to uncertainties for the analysis of internal events, sometimes leads to a debate on which events that should (or can) be included in risk based decision making. Since many analyses in general are conservative the overall result can often be used to prove that a plant fulfills a safety criterion (such as core damage frequency below a certain limit) but the situation is more complex when risk informed decision making is addressed. For such applications the results mustn’t be biased or blurred since parts of the PRA-model are very conservative, for example.

Of course, the work presented in this paper has not ended the discussion about the degree of uncertainties for different analyzed events but important steps have been taken to strengthen the credibility to the overall PRA-result.

References

[1] Dimensionering av nukleära byggnadskonstruktioner (DNB), Strålsäkerhetsmyndigheten 2014:06 (updated version in 2015:24 ISSN: 2000-0456). 2014