Application of Risk Management and Barrier Management for Structures in Cold Climate

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Abstract— **Wind turbines and other tall structures in cold areas are prone to ice accumulation, which constitutes hazards for people, animals, infrastructure and assets adjacent to the installation. An effective risk management system for monitoring and controlling the risks associated with the installation must be applied to ensure adequate safety.**

The suggested method combines risk analysis and risk controlling barriers. The risk analysis can be used prior to construction or during operation and can be conducted with the help of simulations and barrier analysis. The barrier analysis supplements the simulations to visualise how preventive systems and technical barriers prevents and mitigates relevant incidents.

It is imperative to identify the maturity, vulnerability and effectiveness of the implemented barriers to ensure that the barrier performs as intended. Supportive elements and support systems must further be identified to ensure that the barrier management system is robust and resilient. This will ultimately be the barrier strategy, and to operationalise the barriers you implement a barrier management program. This is the day-to-day activity that ensures that the functionality is there when demanded and performance is within its operating criteria.

Further, you want to ensure effective communication of the barriers such as signs, lights etc. towards third-party (public) and that the communicated message is perceived as projected. The human factor is all about the interaction between the human and the system, such as barriers. Facilitating for effective communication and reducing discrepancy in risk perception for the stakeholders, is the key factor.

Keywords— ***Risk management, Barrier management, Barrier effectiveness, Human factor, Communication, Ice fall, Ice throw, Forecast, Warning system, Turbines***

TABLE I. LEGEND AND ABBREVIATION

DSB	The Norwegian Directorate for Civil protection
NVE	The Norwegian Water Resources and Energy Directorate
PSA	The Norwegian Petroleum Safety Authority

I. INTRODUCTION

The method in this paper has been used for the Tryvann broadcasting tower, a 209-meter-tall tower located at Tryvann in near proximity to Oslo in Norway, to investigate whether the risk for ice fall from the tower is at an acceptable level or not. The method applied for the case at Tryvann is aligned with the recently released guide Ice fall from wind turbines by from The Norwegian Water Resources and Energy Directorate (NVE) [1] and International Recommendations for Ice Fall and Ice Throw by the International Energy Agency Wind Technology Collaboration Programme [2]. Further, it is built upon ice throw modelling and own experiences with ice fall [3][4][5][6]. The methodology used for the Tryvann case is presented in this paper which also reflects findings from a selection of our own studies in Norway regarding the associated risk from telecom towers, power lines and wind turbines [3][4][5][6][7][8][9].

It is key to combine simulated data with barriers in an integrated approach to validate the safety, design and the effectiveness of the barriers.

II. CONTEXT

Adjacent to the broadcasting tower, there exist a ski resort, kindergarten, cross-country ski tracks, and their activity may be in risk during periods when there is risk of ice fall. The ski resort and cross-country ski tracks are popular during the winter, see Fig 1.

Reference [3] refers to Norwegian regulations and responsibilities an owner must comply to, e.g. liability for damages, liability for compensation, criminal liability, and the directors' liability. The implication of these liability legislations is that the owner is required to conduct a risk assessment and to mitigate risk to an acceptable level. Acceptable level is either defined by the government, by the company or as an alternative it may be adopted from other industries; however the most stringent requirement applies.

III. METHODOLOGY

The international recommendation for ice fall and ice throw risk assessment provided by the International Energy Agency Wind Technology Collaboration Programme [2] suggests using mathematical models to simulate ice fall and ice throw for wind farms by combining wind and ice data. Reference [3] presents the methodology for simulations which has been conducted for the site discussed in this paper. This quantitative analysis will provide as input to the qualitative analysis which elaborates on measures to mitigate the risk.

The acceptable risk levels have been adopted from the guideline developed by Lloyd's Register [11], which is based on DSBs requirements for operations handling dangerous substances in Norway [10].

The guideline from The Norwegian Water Resources and Energy Directorate (NVE) presents the risk assessment methodology in addition to suggesting a few measures to mitigate risk of ice fall from wind farms, which also can be adopted for tall structures [1]. Additionally, principles for barrier management have been adopted from the Norwegian Petroleum Safety Authority (PSA) [12].

Fig. 1 Overview picture of Tryvann area. Red dot indicates location of the Tryvann broadcasting tower. Ski resort located North of the broadcasting tower, which has its main road located west of the broadcasting tower. Ref. Norgeskart.no

IV. Risk assessment

Risk assessment is a term used to describe the overall process or method where the aim is to identify hazards and risk factors that have the potential to cause harm, and analyse and evaluate the risk associated with that hazard.

Risk assessment process is included as one of the elements of systematic risk management in any business or business activity, and provides support for both safety and security-related decisions. A risk analysis gains valuable input prior to construction as to optimise design and helps identifying issues related to construction and potential operational issues, this to optimise design. Relevant issues from similar designs or other sites will contribute to the decision makers as to make the optimal decision. Alternatively, a risk analysis may be conducted for an operational site. Valuable experience will then be brought into the risk analysis as to modify design or optimise barriers.

Risk contours are calculated by combining possible events with associated probability of fatality. The risk contours thus show the geographical distribution of individual risk, by displaying the expected frequency of events that can cause fatality at a given location. This is irrespective of whether people are actually in the place or not. Thus, the risk contours show the geographical distribution of individual risk, by displaying the expected frequency of events that can cause fatality at a given location, regardless of whether or not they are actually located at that location. Therefore, the presence of the number of persons, i.e. how many and the duration any persons may be within the affected area, should not be considered [11].

The risk level within each consideration zone indicates what kind of objects and activities are accepted in the zone. For example, a walking route with only short-term passers-by of walkers could go through the "Inner zone" with a significantly higher risk than can be accepted for a kindergarten, which must be placed outside the "External Zone", see Fig 2. Fig 3 presents the contours for the broadcasting tower at Tryvann.

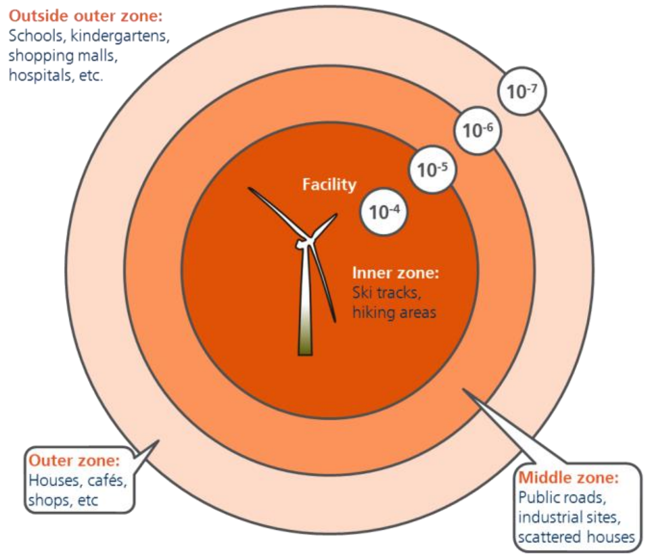

Fig. 2 Zones with special considerations around installation that may case risk of ice throw or ice falls as suggested by Lloyd's Register. The numbers indicate the risk contours for localised individual risk (LIRA), the probability that an average unprotected person, permanently present at a specified location, is killed per year due to ice fall or throw from the facility.

The principle defined by the Norwegian Directorate for civil protection (DSB), states that the facility should not add unacceptable risk to the public significantly compared to the daily risk in society [10]. However, one must accept that there may or will be introduced additional risk to third-party due to the activity one introduce, thus there will be an increased risk to parties adjacent to the facility.

In Norway, there are requirements set by the government that assets shall be sufficiently secured so that ice and snow cannot fall on areas where people and animals may stay. It will probably never be possible to eliminate the risk of damage due to ice falls, and therefore criteria for which risk can be accepted must be set.

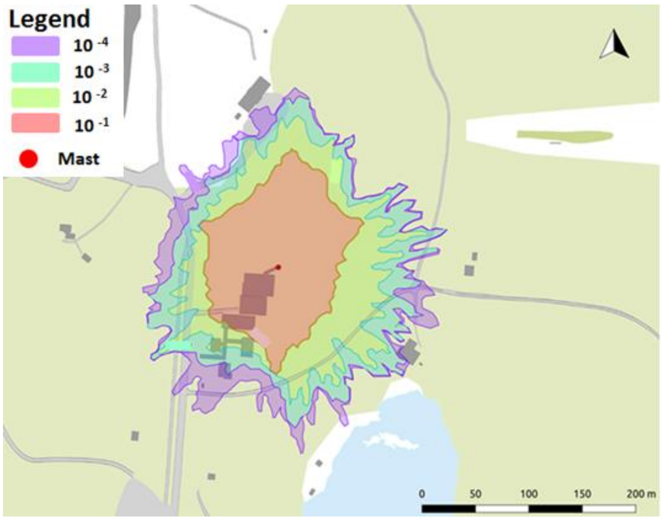

Fig. 3 Risk contours for Tryvann broadcasting tower, red dot indicates centre of tower.

V. Barrier Management - Maturity, Vulnerability and Effectiveness

The barrier analysis supplements the simulations to visualise, through e.g. a bow-tie, how preventive systems and technical barriers prevent and mitigate incidents. These analysis should also be based on best practise for the industry as guidance, which give recommendations on how to manage the risk of ice throws from wind turbines and avoiding third-party injuries resulting from ice, or the IEA Wind TCP Task 19: Wind energy in cold climates, which is the international recommendations for ice fall and ice throw risk assessments, which provides best available recommendations for assessing risk of ice fall/throw as well as reducing the uncertainties in such assessments.

The PSA states that “The objective of barrier management is to establish and maintain barriers in order to handle the risks faced at any time” [12]. Organisations should acknowledge the need for, and maintaining the various forms for barriers; operational, organisational and technical, as to ensure best practice for barrier management. Further, organisations that seek to validate the maturity, vulnerability and the effectiveness of the barriers, have the opportunity to continuously improve the barrier effectiveness during the barrier lifecycle.

Barriers may exist as procedures and technical barriers amongst others, however the goal is to achieve inherent safe design which avoids risk or to remove the risk exposure.

It is imperative to identify the maturity, vulnerability and effectiveness of the implemented barriers to ensure that the barrier functionality performs as intended. Further, identify the current preventative and mitigating barriers to visualise the risk picture and the measures which mitigates the risk. The focus should be on preventative measures to reduce the likelihood of the risk to occur, and if needed, identify additional barriers in addition to identifying the effectiveness of these barriers. This is an iterative process until you meet acceptable level of risk or as low as reasonably practical (ALARP). Support systems must further be identified to ensure that the barrier management system is robust and resilient. This is the day-to-day activity that ensures that the functionality is there when demanded and performance is within its operating criteria. A lean response plan must also be developed for the most critical incidents, with clearly defined responsibilities and tasks, and to ensure that you are not dependent on one person to be able to have an effective barrier.

Identifying the barriers that prevent and mitigates an accident is an accommodating activity to risk management to ensure that there are sufficient measures that prevents an event to occur, or in case it happens, what mitigates the impact of the event.

A. *Preventive barriers*

There are various ways to mitigate the likelihood of impact of any event, for this project the preventive barriers have been represented in Table II. There exist no mitigating measures that reduce the risk of ice fall at this specific site, however there exists several methods to prevent ice accretion.

TABLE II. Preventive Barriers

Preventive Barrier	Robustness/Vulnerability
Ice monitoring and warning system	Effective to monitor ice accretion and risk of ice fall. The service is robust, reliable and continuity plans for delivering the service exists.
Sign and light warning	There is some uncertainty whether the audience respects the signs and light warning or not. People have been observed in the area even when the lights have been turned on.
Text message warning service	Good experience, however not all users respond that they have received the message as intended
Alternative path for pedestrians, see Fig. 4	Alternative pathway is maintained (removal of snow) by the municipality
Perimeter fencing of site (critical area)	Fence is low with regard to height and it is easy to enter the area. The gate and the boom are not locked. This can be improved. The area is marked "Access prohibited"
Notification in the media	There are uncertainties about who the media notification reaches
Information meetings with the users	Information meetings have proved to be effective to communicate risk and to facilitate Q&A sessions
Websites with information about ice fall	Must be posted on the websites of the users and the Ski Association. Little experience with this yet in use
Security guard service	The use of security guard in periods when there is an increased risk of ice fall have proved as an effective measure to reduce the number of pedestrians entering the area. The public shows respect for the guard and have provided positive feedback on the guard service as well as the information about ice falls
Tenants at site	Contracts with tenants are terminated and residences at site are not in use

Risk control is ensured by ice monitoring with cameras and weather forecasting models. This is the most significant driver to ensure control of both ice accretion and risk for ice fall.

Risk avoidance is ensured by altering the pathway towards the ski resort. This concludes that there are no preventive barriers that reduce the risk of ice fall.

B. *Mitigating barrier*

If the event is to occur, mitigating barriers are to reduce the consequences, whether it is HSE related, reputational or economical.

For this case there are three mitigating barriers, see Table III, however they do only relate to people working on-site. The use of personal protective equipment and understanding of risk can only be credited the workers on site as it could be assumed that they have the necessary training in understanding the risk of ice fall. This concludes that there are no mitigating barriers that reduce the impact of ice fall for third parties, however only for personnel on site.

TABLE III. CONSEQUENCE REDUCING BARRIER

Mitigating Barrier	Robustness/Vulnerability
Ice protective wire web	Wire web over the site area, below tower on site. Works well and protects against ice falls. The net must be cleaned manually in case of heavy snow load
Personal protective equipment	Workers use personal protective equipment such as a safety helmet and clothing when at site during winter
Contingency plans	Covers accidents for both first, second and third person

VI. HUMAN FACTOR

Facilitating effective communication and reducing discrepancy in risk perception is key in ensuring risk mitigation against the risk of ice from high structures. This can be in the forms of information meetings, signs, lights etc. The human factor is all about the interaction between the human and the interfacing system, such as barriers you put in place to avoid harm, this can especially be important when manging risk to the public.

One must be cautious with leaving signs exposed for a longer duration of time, whereas the human fall into the trap of habituation. Habituation is the habit of ignoring repeating stimulus, i.e. signs, lights, noise.

VII. SUGGESTED RISK REDUCING FACTOR

Crediting risk reducing factors must be done with due care. Careful considerations on what the measure is being credited against is vital, and it is better to be on the conservative than incautious. The credit must be evaluated carefully for the context of the organisation and the location the facility is located.

Currently there are no measures on the site that reduces the likelihood of ice falling, nor for reducing the consequence of impact when it comes to ice fall against third-party. However, removing or reducing the exposure is the identified measure for the case presented in this paper.

There are currently no existing data on the effectiveness of the security guard at such sites to guide third-party to alternative pathway, see Fig. 4. However, for this case and context, the security guard is assumed to be effective for 98% (risk reduction factor 50) of the time, two percentage points has been reduced to be conservative. There is currently no experience that third-party does not respect the security guard, and all third-party do follow the guidance provided by the guard to use the alternative pathway.

If one assumes that 98% of all persons, that intend to walk the main road in the area during periods of risk of ice fall, follow the instructions and stay well away from the risky area, one can multiply the risk given in Fig. 3 by a factor of 0.02 and all the risk contours value is reduced. This is a violation of DSB's acceptance criteria for hazardous substances in the industry, which states that one should assume that there are people at all points all the time.

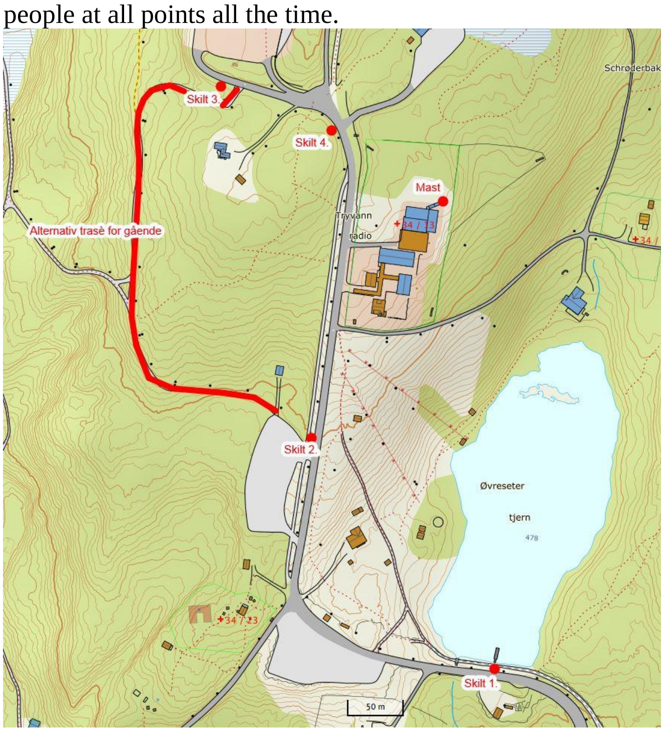

Fig. 4 Alternative pathway.

It can be said that the risk is reduced to an acceptable level in relation to the eligibility criteria, which apply to individual site-based risk with permanent residence.

Table IV presents the new legend for Fig. 3 whereas the risk reduction factor has been multiplied with the old legend.

TABLE IV. NEW LEGEND

Legend	New legend
10-4	2,2*10-6
10-3	2,2*10-5
10-2	2,2*10-4
10-1	2,2*10-3

VIII. SUGGESTED MEASURES FOR FUTURE

Table V proposes additional measures to implement for future to reduce risk and optimise design.

TABLE V. SUGGESTED BARRIER

Suggested Barrier	Robustness/Vulnerability
Develop illustrative signs to visualise the hazard of ice fall by moving into the hazardous area which can be interpreted independently of the language background	Provides a better understanding of the risk independent of the third-party originate
Perform new simulations which includes the latest years with weather data, as well as includes the uncertainties with ice impact fatality, e.g. include uncertainties with energy that drives crushing of ice	Provides better understanding of the current weather picture
Cooperation on notification with relevant third, such as Oslo Vinterpark Tryvann located north of broadcasting tower	Increased situational understanding among third parties through increased communication on current risk in the area. Look at the use of warning through use of social media
Mount polyethylene foam pipes around specially exposed areas to reduce ice accretion. When using polyethylene foam pipes, the ice will build up in larger pieces, as it is now that the ice can build up over a larger area and thus operate with the wind over a longer distance	Different opinion of the goodness of the suggestion. Tower owner should obtain information on the measure and test on parts of the mast for experience building
Hide warning signs during summer period, to reduce risk habituation during high risk periods and make sign stand out	Prevents habituation and ensures communication to third party
Net with mesh above the parking space and walkway area near the café	Good experience with protecting against persons below net. The challenge will be maintenance and removal of dense snow
Net with mesh above the main road	Good experience with protecting against persons below net. The challenge will be maintenance and removal of dense snow
Agree with the municipality to remove pathways and not to maintain pathways in risk zones around near site and increase radius of perimeter fencing	Removes exposure for risk
Move site to another location	High costs involved and highly unlikely to carry out. Reduces radio communication drastically

IX. SUMMARY

There is no guarantee that ice cannot travel longer than simulated with gusts. Models and simulations are a simplification of reality and uncertainties will always be related to these. Today's technology and methods for calculating ice falls give good indications of what can happen and prove to be relatively reliable and precise.

The red contour area, ref. Fig 3, has a frequency for ice fall one-time per square meters per years with ice that has energy that can be fatal for people. The outermost risk contours in the figure represent a frequency of 10^{-4} per square meter per year or once every ten thousand years.

If one compares the hazard associated with ice falling from Tryvann broadcasting tower with consideration zones around an industrial plant, the risk appears to be very high in the inner area. An important difference, however, is that consideration zones calculated around industrial plants assume that there is an equal probability of an accident occurring throughout the year. The danger that arises relating to ice accretion on the tower, however, occurs only during limited periods [11]

The result from modelled data indicates that on average it is approximately four annual episodes of dangerous ice fall and the text message log which alarms on risk of ice fall confirms that this is correct. Four days divided by 365 days is a factor of 0.011 or 1.1% of the year.

The warning service from service provider and Owner appears to be very robust. In addition, weights are used during periods where there is a risk of ice falls. The guards inform the public about the danger of traveling in the area and guiding people to the safe area. It is uncertain how much one can quantitatively credit this measure in relation to the risk contours. The consequences of ice fall are still that ice hits unprotected people and will be able to do great damage and in the worst-case result in fatality. The most important thing people can do is to stay away from the area where the risk is greatest. Tower owner has established a good system to facilitate alternative pathway as to remove exposure from risk including other barriers. The barriers must however be operated and maintained in the future.

The measures implemented provides good risk reduction for third parties as the measures reduce the likelihood that people will be injured by any ice falls from the tower. The uncertainty in the measures lies in whether the public relate to the warnings and guidelines that are given.

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