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Review

Design basis for Arctic infrastructure facilities

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Abstract: A discussion related to the selection of a proper design basis for Arctic infrastructure facilities is presented. The design basis, which must be sufficiently robust to ensure safe operations of the facilities during their planned lifetime, should include relevant information available from the local and indigenous people of the area. The need to properly document all data and assumptions made when preparing the design basis is highlighted, and it is emphasized that, in the case of the upgrading of the facilities, all new data collected must be included in the database. Documentation of all updating is necessary and must be available to all involved during maintenance activities and for possible later upgrading of the facilities. This database must be available digitally, as access to the basics for the design may be of particular concern in the sparsely populated Arctic region, where the distribution of paper copies takes a long time, particularly in the case of emergency situations. Therefore, this database must be protected from cyberattacks. A "Plan B" is needed to ensure that a backup of the fully updated design basis documents, as well as documentation of the "as built" facilities, is available at any time.

Keywords: design basis; infrastructure facilities; Arctic; digital database; design basis updating; cyberattacks; indigenous people

1. Introduction

In order to properly plan the technical conception and development of infrastructure facilities, a design basis is needed [1]. All aspects of the design of the facilities must conform with the premises established in the design basis, which, therefore, should include all data and information related to the actual physical environment; information needed to design the facilities, including the design premises for the foundation and structures; and requirements for the safe operations of the facilities [2]. The collection of design data and premises must be sufficiently robust to ensure safe operation of the facilities during their planned lifetime. Battery limits, existing infrastructure and restrictions related to layout, selection of materials and anticipated future facilities should be given as a base. The selection of standards for the design and preparation of operational procedures represents an important part of the design basis.

For project development in new regions, it is important to understand local conditions and restrictions on how projects should be managed in the area, considering all limitations imposed on the project caused by the physical environment and the resources available. These conditions and limitations should be included in the design basis. In the case of Arctic infrastructure planning, aspects related to the cold climate must specifically be considered [3]. These aspects include expected extreme temperature variations, snow and ice conditions and the specifics of the foundations, which are potentially placed on melting permafrost. It is particularly challenging to ensure the long-term safe operations of facilities in the Arctic, as the climate is changing, with increasing average temperatures and more frequent extreme cold and warm periods. Of interest is how the local and indigenous people of the Arctic have survived in the region; lessons could be learned from their approach to adapting to the specific Arctic conditions [4] and implementing the rights they have, to continue their lifestyle in the area [5,6].

The scope of this paper is to highlight considerations required to establish a proper and robust design basis for Arctic infrastructure facilities. The specifics of the Arctic conditions are considered, and the uncertainties in the design basis document are reviewed. Furthermore, it is suggested to incorporate local and indigenous knowledge whenever relevant. It is underlined that the design basis always must be available and accessible, leading to a strong emphasis on cyber security to protect the database and its updates from cyber threats.

The discussion regarding needs for a modern design basis incorporating ongoing processes like global warming, while taking traditional knowledge into account, and emphasizing modern methods to secure data is considered to represent a contribution to existing research on infrastructure criticality.

The methodology chosen for this investigation is to consider available published information related to infrastructure criticality, to study available literature and to interpret news regarding information related to cyber security.

2. The design basis

2.1. The specifics of the design basis for Arctic infrastructure facilities

2.1.1. The complexity of the development of the Arctic

To prepare the design basis for Arctic infrastructure facilities, a key question relates to the specifics of the Arctic: the additional aspects that must be covered, compared to the design basis for projects in temperate and warm regions. The complexity of integrating all required aspects should not be underestimated.

First and foremost is the description of the conditions of the *physical environment*; this includes the design values of lowest temperature (and the highest temperatures if cooling effects from the environment are needed). Furthermore, specific wind and wave conditions, for example, in Polar Low situations [7], must be listed, as well as design conditions for snow and ice accumulation. The challenges of designing for the effects of climate change are huge, as scenarios must be developed to ensure safe design during the expected lifetime of the infrastructure [8]. Furthermore, the influence of the temperature on permafrost melting must be assessed for safe foundation design [9,10].

The Council of the European Union [11] has defined critical infrastructure as *an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions* (p. 3).

This definition covers both physical and cyber-based systems which provide vital societal functions, like transportation, water and electricity, but also search and rescue services. Reliable and safe operations of critical infrastructure depend on a healthy cyber ecosystem. Critical infrastructure and related facilities are visualized in Figure 1. The complexity of the Arctic also goes beyond the physical environment, as the Arctic is an underexplored region of great political interest to the countries in the High North. This relates to the resources, both fishery resources and mineral resources, as well as to the political ambitions of the Arctic states. The offshore borders between the countries are under negotiation, and territorial claims are being evaluated by the United Nations' Commission on the Limits of the Continental Shelf [12]. Additionally, many countries have strong research activities in the Arctic. Among these, China [13], AWIPEV (the German Alfred Wegner Institute) and the French Polar Institute Paul-Émile Victor have staff on site at Ny-Ålesund (at latitude 78.9° N) throughout the year [14]. In total, 52 countries are engaged in research in the Svalbard archipelago [15]. The research focuses on the effects of climate change, geophysical phenomena related to the auroral light, biological aspects of the cold climate and Arctic infrastructure considerations. The complexity of the High North's interrelationship with critical infrastructure and technological dependence can be visualized as in Figure 1.

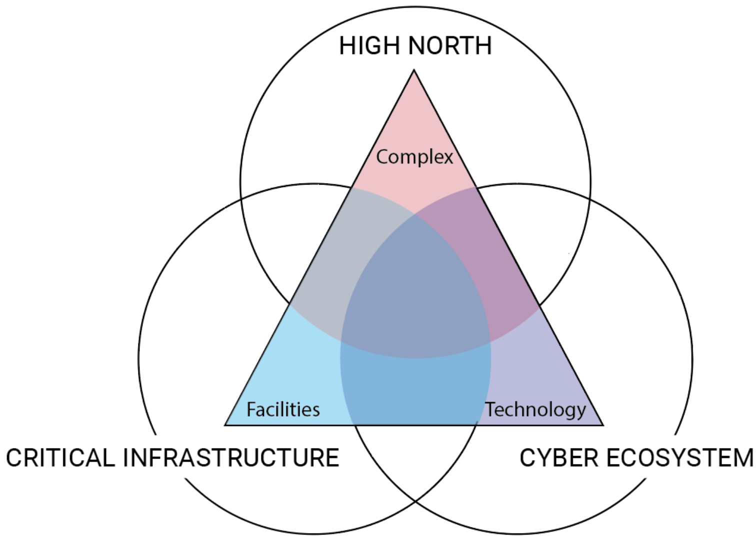

Figure 1. Effects influencing Arctic infrastructure.

Of grave concern in a world that is becoming more and more dependent on digital solutions is the security of the cyber ecosystem [16,17]. Cyber security is most important for Arctic cities and rural areas, as the Arctic region is very dependent on safe communication, due to its limited infrastructure and very long distances between populated locations. Cyber security is under pressure, as the technology for hacking and jamming is growing, and the vulnerability in the case of loss of information and communication technologies (ICTs) is becoming more and more serious because of the total dependency on safe systems for communication, data storage and data collection. Cyber systems in turn depend upon critical infrastructure like electricity, and a complete blackout will stop most activities, including the banking system, communications, and construction work. Therefore, contingency plans must be in place for access to the most important information should the cyber ecosystem fail. In other words, the risk picture that covers the overlapping interactions illustrated in Figure 1 must be understood. Adding the complex and vulnerable Arctic High North to this interdependent web of systems increases vulnerability, as unwanted events can have severe consequences in this area.

In addition, the rights of the indigenous people in this area must be taken care of. In the past, the indigenous people of the north have been under hard pressure from the ruling authorities to be assimilated into the mainstream society by attempts to curb their indigenous culture. This is well known in Norway, where the Sámi culture has been under pressure. Recently, the scandal of the Catholic Church's abuse of indigenous children has been made public [18]. The role of the indigenous people of the Arctic in the discussion of interdependencies between critical infrastructure and the cyber ecosystem is an example of how the experience and knowledge of the inhabitants in the High North can be integrated as valuable information when establishing the design basis for critical infrastructure in the Arctic. It is an important part of the complexity of the situation in the High North; note the survivability and how the local and indigenous people in the Arctic have practiced adaption to the climate conditions. Furthermore, everybody living in the Arctic is becoming more and more dependent on a well-functioning cyber ecosystem [16].

2.1.2. Discussion of the uncertainties in the design basis

It must be realized that, at present, there is large uncertainty with respect to establishing a design basis for Arctic infrastructure facilities, due to trends caused by a warming climate. The question of how to handle this uncertainty has not been solved, and accounting for uncertainty factors will cause large increases in investments in infrastructure [19]. The term "resilient design" covers a design that can withstand the impact of extreme weather and other disturbances. Another important term to consider is "robust design" [20].

Of particular concern are the effects of increasing coastal erosion. As the ice cover is reduced during the Arctic summers, the fetch length increases, and the fall storms generate larger storm surges and larger waves, which increase the erosion [21]. It is also expected that the occurrence of Polar Low (PL) pressures will be found increasingly further north, and the occurrence of PL north of Svalbard (at 80° North) has already been recorded. Note that the paths of PLs are very difficult to forecast and that waves in PLs could increase over a very short time, making it difficult for vessels to stop ongoing activities and leave the location. PLs are also associated with the occurrence of sea-spray icing and snow, endangering the stability of vessels [7].

Whether the design waves in the open ocean will increase is uncertain. [22] concluded that a 57-year NORA10 hindcast dataset "does not suggest any specific temporal trend in the historically significant wave heights in the Barents Sea locations." Other researchers (for example, [23]) conclude that “there seems to be evidence in the data for a notable increase in the extreme wave heights for both of the future scenarios that have been considered, compared to the historical period.”

Another concern is related to the thawing permafrost. With high temperatures during the summer, the permafrost melts to larger depths, and foundations supported by the permafrost sink in, causing extreme damage to facilities [9,10,24]. Furthermore, terrestrial transport is being limited, as winter roads can be used for a shorter time throughout the year. The establishment of a design basis for the foundation design of buildings is therefore based on very uncertain information. Rather than prescribing very conservative figures resulting in costly facilities, facilities should be designed with an option to retrofit the foundation design. However, for the construction of roads and railway lines on permafrost, care must be taken to avoid the melting of the permafrost, using insulating materials, gravel pads and proper drainage to lead melting water away from the infrastructure [25]. In order to carry out this design, a carefully developed design basis is required. In addition, the construction of infrastructure has an impact on local inhabitants, and large-scale projects can cause controversy and resistance.

The political ambitions of many nations and the need for minerals mined in the Arctic may lead to enhanced construction of infrastructure facilities. The preparation of a proper design basis in new areas is particularly challenging, and, if it does not consider the need for robust design, this could lead to unsafe facilities and loss of assets. An example is the transport of minerals from the mines, for which safe vessel transport to the market must be considered [26].

Maritime infrastructure is particularly vulnerable to climate and political changes. Considerations relevant to the design basis for Arctic transport facilities were presented by [27]. Furthermore, much research has focused on polar search and rescue; see, for example, [28–30] and [31].

3. The benefits of implementing traditional[1], indigenous and local knowledge

The value of traditional, indigenous, and local knowledge must be acknowledged. This knowledge reflects studies, biophysical observations, norms, and the development of skills collected over generations [32] and is often seen in contrast to the idea of science as knowledge discovered by scientists in a laboratory. The elders of the indigenous community see it as their responsibility to share knowledge with the younger generation [33]. There is no Sámi word for “science,” but importing traditional, indigenous, and local knowledge into an existing scientific framework can enrich the design basis and also identify and interpret climate change data [34].

One effect of climate change is that extreme conditions appear more often than before. Local knowledge is bound by its place and includes, among other things, information about rare physical phenomena, often overlooked, particularly when such phenomena are local, like information about landslides and avalanches. Knowledge about the local geotechnical and geological conditions should be considered, as they can change within meters, so to say. If critical infrastructure is built in locations of expected danger, sufficient mitigating measures should be implemented.

Another example is that civil engineers can learn about the expected thickness of snow during the winter from mapping the vegetation, as different vegetation requires a thick layer of snow during the winter to survive in the cold. Information from local inhabitants and reindeer herders who still maintain a mobile way of life (nomadic pastoralists), in combination with satellite imagery, could provide valuable information. Also, the expected locations of flooding are identified from studying the

[1] Note: “Traditional knowledge (TK) is knowledge, know-how, skills and practices that are developed, sustained and passed on from generation to generation within a community, often forming part of its cultural or spiritual identity” [35].

vegetation. By implementing this information in the design basis, operational costs can be reduced throughout the lifetime of critical infrastructure projects.

Traditional, indigenous, and local knowledge also includes survival strategies in the case of extreme weather conditions. The combination of traditional clothing, based on reindeer products, knowledge of local conditions and even belief in weather signs being emphasized with respect to survival has not been fully understood, and only a few studies analyze this subject. However, in the emergency department at the University Hospital in Tromsø, a city located in the Norwegian Arctic, "they have never received a Sámi person to be treated for hypothermia." These shortcomings can be overcome by analyzing successful strategies for adapting and building skills for survival.

4. Availability of and accessibility to the design basis for critical infrastructure in the Arctic

The final design basis should provide all necessary location and geotechnical data and premises for the successful construction of infrastructure and must always be fully updated, available and accessible. This means that updating the design basis must include all as-built information, so that maintenance, upgrading, or retrofitting is possible. The challenge to keep the design basis available and updated must not be underestimated, as it will require information and data management efforts and safe data storage. In many projects, considerable work must be undertaken to identify the quality of and the accurate placement of equipment, such as underground piping and cables. As data are handled and stored electronically, cyber security is of key importance for the accessibility of the data [13]. The remoteness and long communication lines in the Arctic region have made cyber communication particularly welcome in this region, and the vulnerability is higher in this region than in populated areas. A group of Ukrainian scientists [36] has underlined the importance on focusing on cyber security efforts.

Although international efforts are ongoing to design safe networks, in order to absolutely ensure access to the design basis, backup data storage must be available. It is not possible to eliminate all threats, but disconnecting this storage from the cyber ecosystem can prevent effects of cyberattacks like hacking or jamming. This, however, does not reduce the need to prepare safe systems that are easily accessible. Several efforts have been made to expand the framework of improving cyber security in the maritime sector [37], and classification societies (like [38]) have issued guidelines for cyber risk management for land-based facilities. Refer to ISO's family of standards for the overall management of information security [39].

5. Concluding remarks

The Arctic region is one of the least populated areas in the world. Although the Arctic population comprises only one tenth of the total population in Norway, it occupies large areas of the country's remote areas. Well-functioning critical infrastructure is key for Arctic societies, and incorporating climate change considerations into the planning of infrastructure in this area is an engineering challenge. The selection of a proper design basis and technical requirements for Arctic infrastructure facilities can have a significant impact on the future development in the area.

The authors have demonstrated the importance of integrating traditional, indigenous, local knowledge and express the hope that this paper will stimulate critical discussions that will respect the participation of local and indigenous communities in making decisions and establishing a design basis. The collection of data from traditional, indigenous, local sources can enhance Arctic communities' adaptation to the challenges that critical infrastructure faces due to climate change. Top-down institutional processes with no recognition of traditional, indigenous, and local knowledge can hinder the capacity to adapt to challenges like climate change stressors.

Furthermore, the need to maintain an updated design basis, which is always accessible yet safe, is underlined in the paper. This includes measures to ensure that backup versions are safely stored, so that cyber threats cannot cause irreparable damage to the design basis.

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Conflict of interest

The authors declare no conflict of interest.

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