CHALLENGES WITH REMOTE AVALANCHE CONTROL SYSTEMS (RACS)

TROMS COUNTY, NORTHERN NORWAY

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ABSTRACT: Troms County Council (TFK) operates two different Remote Avalanche Control Systems (RACS). Along County Road 7768 in Grøtfjorden, 11 Wyssen towers are installed (Krogh et al., 2022). Along County Road 7940 on Arnøya, 23 O'BellX+ units are installed by MHM AS, supplied by MND Safety (Berger et al., 2024). TFK is generally satisfied with the performance of both systems, and it's clear that RACS works very well as a mitigation method. This article, however, will focus on the challenges encountered, rather than the successful operational outcomes.

In Grøtfjorden, we have experienced occasional failed detonations (duds). The issue was particularly prominent during the 2023/24 season and was caused by faulty detonators. There have been no duds after changing the supplier of detonators. The handling of duds varies depending on operational conditions and the assessed risk level. The occurrence of duds and partial detonations creates additional stress for involved personnel and requires specific mitigation measures before the road can reopen. The incidents in Grøtfjorden have demonstrated that duds can occur, and despite improvements made it is reasonable to assume that a residual risk will always remain. Consequently, there has been a need to develop improved procedures for handling duds in Grøtfjorden.

On Arnøya it quickly became evident that the selected trigger points were far from optimal. As the first winter progressed, several units were increasingly affected by heavy snow loading. In March 2025, a natural size-D3 avalanche destroyed one unit, and two additional units were damaged by other avalanches. Based on our experience, these issues were likely caused by a combination of limited planning time, an incomplete understanding of the design limitations of the system, and an unclear distribution of responsibilities regarding the detailed design of installation points. To avoid similar challenges in future projects, several important steps have been identified and acknowledged. A thorough understanding of avalanche dynamics, and the design limitations of the proposed RACS system is essential. Based on the lessons learned from Arnøya, it is our belief that primary responsibility of the detailed design should rest with the infrastructure owner, rather than the RACS supplier.

KEYWORDS: RACS, Grøtfjorden, Duds, Arnøya, Damaged

1. INTRODUCTION

Troms County Council (Troms Fylkeskommune - TFK) operates two different Remote Avalanche Control Systems (RACS) to keep transport corridors safe from avalanches. In 2022, 10 Wyssen towers were installed in Grøtfjorden along county road 7768 by Wyssen Norway AS, and an additional tower was added in 2024. In the same year, 24 O'BellX+ units were installed on Arnøya along county road 7940 by MHM AS/MND Safety, later reduced with one unit that was destroyed by an avalanche in March 2025.

Prior to the installations, avalanches frequently reached the road, resulting in repeated closures. Since their implementation, no avalanches have affected the road during periods of traffic, and closure times have been reduced by approximately 80%.

However, a few challenges have been encountered, providing valuable lessons for future implementations. In Grøtfjorden, the main challenges were related to failed detonations (duds), during the 2023/24 winter season (Chapter 3). On Arnøya, several units were poorly located, resulting in damage and operational constraints during the 2024/25 season (Chapter 4).

This article aims to provide an objective account of these events, present our findings from the road owner's perspective, and discuss measures that can be implemented to optimize both existing and future RACS installations.

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2. OPERATION SETUP

Both avalanche control systems are located well above the Arctic Circle, where polar night conditions prevail, and the sun remains below the horizon from mid-November to mid-January. Terrain reaches from the fjord at 0 – 700masl at both sites. The 11 Wyssen towers in Grøtfjorden use explosives as their release mechanism, whereas the 23 O'BellX+ units on Arnøya operate using a gas-based system. Due to the northern location and limited daylight during winter, reliable avalanche detection and monitoring systems are essential. Both installations therefore utilize radar-detection, pan-tilt-zoom (PTZ) cameras, and infrared cameras to verify avalanche activity and support decision-making regarding avalanche control missions (Delivered by Geopraevent/Skred AS).

The avalanche forecasting team consists of six forecasters who work closely with local snow plough operators, who continuously report weather, snow, and avalanche conditions. Weather observations are obtained from both nearby official meteorological stations operated by the Norwegian Meteorological Institute (MET) and dedicated RACS-weather stations. These stations measure key parameters such as temperature, windspeed and direction. Control missions are performed by local personnel and supervised remotely by the forecaster that's logged in to all monitoring systems.

The suppliers of the RACS have maintenance contracts for up to 20 years, requiring the systems to remain operational 24/7 between 15th of November and 15th of May. Any technical issues arising during this period must be addressed and taken care of by the supplier.

3. DUDS IN GRØTFJORDEN

3.1 Challenges

Wyssen uses two-component explosives (Wyssen 2K), where the charge only becomes an explosive after being dropped from the system. For a partial detonation the blasting caps have detonated, and the explosives cannot longer be ignited. But for a dud, the charges are mixed and the blasting caps have not detonated and therefore the explosives can theoretically be ignited by accident.

Since operations commenced in Grøtfjorden in 2022, a total of 228 successful detonations has been carried out. During the same period, three duds and five partial detonations were recorded, primarily during the 2023/24 winter season (Table 1). Fortunately, none of the duds reached the road. According to Wyssen, the incidents were caused by defects associated with blasting caps supplied by a new manufacturer. Following the implementation of corrective measures, only one partial detonation occurred during the 2024/25 season, and no duds or partial detonations were reported during the 2025/26 season.

Tabell 1: Summary of detonations, partial detonations and duds in Grøtfjorden four seasons.

Season	Detonations	Partial Detonations	Duds	Sum
2025-26	22	0	0	22
2024-25	35	1	0	36
2023-24	81	4	3	88
2022-23	90	0	0	90
TOTAL	228	5	3	236
Part %	97 %	2 %	1 %	100,0 %

3.2 Identification

The technical requirement in the tender was that all systems must be able to automatically detect and notify if a detonation was successful or not. In the Wyssen deployment box, a geophone records the shaking of the system that is caused by a successful detonation. If a successful detonation is not detected, the system automatically notifies the blaster, both in the WAC.3 software and by SMS.

As the detonation of a blasting cap itself does not provide sufficient pressure to shake the deployment box, the geophone is not able to distinguish between a partial detonation or a dud. In such cases the blaster had to manually assess the situation using visible smoke, the presence of a audible detonation or pictures/binoculars to determine if it is a dud or partial detonation. Bad visibility due to fog and precipitation can make it challenging to determine this. In case of uncertainty, the event is treated as a dud until otherwise can be determined.

Prior to the 2025/26 season, Wyssen installed a pressure sensor on all deployment boxes. This sensor is able to measure the pressure wave from a blasting cap and therefore is also able to distinguish between a partial detonation and a dud independently of the weather conditions.

3.3 Management

If a failed detonation is identified as a partial detonation the charge has been destroyed, and there is no risk for uncontrolled detonation. The system is reset and a new blast is executed. If a failed detonation is identified as a dud, TFK's procedure for dud management is used to manage the situation:

After a dud has been identified and it is still hanging in the tower, it must always be released and dropped into the snow below. In the worst-case scenario, a hanging dud may become entangled in the deployment box, making helicopter transport impossible since transporting explosives beneath a helicopter presents a significant safety risk and is strictly prohibited.

After the dud has been dropped, a new detonation attempt shall always be carried out. Leaving a dud beneath the tower can create a hazardous situation if a subsequent natural avalanche transports the dud onto the road. Even when the probability of an avalanche reaching the road is low, a new detonation attempt is justified because the avalanche hazard could increase within the next 10 days while the dud remains an active explosive.

The next step is to locate the dud. This can be done either visually or by using a RECCO search device, as all charges are equipped with RECCO reflectors. Although RECCO reflectors have been used on charges in Grøtfjorden since the start of operations, no formal procedure has existed for accessing a RECCO search device or training personnel in its use. At present, TFK does not possess either a RECCO search device or the expertise required to neutralize a dud and therefore relies on Wyssen for these services. Given the low probability of a dud, a response time to been on site within maximum 48 hours, has been considered acceptable for our operation.

If a dud cannot be located, or if it is lying in steep and inaccessible terrain, the area will be closely monitored until the charge has become inert after maximum 10 days.

Following a repeated detonation attempt, the location of the dud should be monitored as accurately as possible. If visibility permits, multiple images should be collected using the PTZ camera. As each situation can differ and must be evaluated specially, the following most common scenarios have been identified after performing a new detonation:

- No avalanche is triggered, or the avalanche stops before reaching the road (most common scenario) - The road may be reopened before the dud has been neutralized.
- The avalanche reaches the road - The road shall remain closed until the dud has either been located and neutralized, or located in the terrain and assessed as no risk to open the road before neutralizing.

3.4 Discussion and Conclusion

The occurrence of duds and partial detonations creates additional stress for personnel involved in avalanche control operations and requires specific mitigation measures before the road can be reopened. Although the probability of a dud detonating spontaneously in steep terrain is considered very low, there remains a realistic possibility that a natural or controlled avalanche could transport a dud downslope toward the road. Such a scenario could create significant operational challenges, as the charge would need to be located and either recovered or rendered safe before the road can reopen.

Of the 236 attempted detonations carried out since operations began, only eight resulted in either a dud or a partial detonation. Subsequent corrective measures have been implemented to address these issues and reduce the likelihood of recurrence. Nevertheless, the incidents have demonstrated that duds can occur. Despite the improvements introduced by Wyssen, it is reasonable to assume that a residual risk always will remain.

Consequently, there has been a need to develop improved procedures for handling duds. These procedures must be well known and understood by all personnel involved in avalanche control operations in order to minimize the risk of blasting accidents and always ensure road safety.

In Grøtfjorden luckily no dud reached the road, and operational, financial and safety impacts have been small, or even negligible. With further technical improvements by the supplier, and continued collaboration with the parties involved, we believe that both the likelihood of new misfires will be reduced. Nevertheless, if they do occur, improved procedures will keep safety high and reduce stress for the personnel involved.

4. MISSPLACED AND DAMAGED INSTALLATIONS ON ARNØYA

4.1 The selection of trigger points

Deciding where to place the units in the terrain is generally challenging, as it's a trade-off between efficiency to trigger the desired avalanches, and at the same time keep the unit safe with respect to avalanches, cornice falls, rockfall, creep and getting buried in the snow. Additionally, good geotechnical conditions for installing, and the need for helicopter access during operation must be considered as well (Venås et al., 2025).

During the planning phase, the following steps were undertaken to determine the locations for the installations, the same procedure both in Grøtfjorden and Arnøya:

1. Desk studies of satellite imagery, topographic maps, and other relevant data sources.
2. Avalanche records along the road.
3. Collection of local knowledge and operational experience from snowplough operators.
4. Snow-depth measuring and mapping using photogrammetry over one winter-season.
5. Several site visits both on foot and by helicopter.
6. Review of documentation from a handful of helicopter-based avalanche control missions using DaisyBell (Heli-based gasexploder).
7. Initial proposals of trigger points in tender documents.
8. Joint field campaigns with the RACS supplier, to reach a consensus on location trigger points.
9. Detailed design by the RACS supplier, including calculations of all loads and forces that the installation could be exposed to, ensuring that design limits would not be exceeded.
10. Final approval of all trigger points by TFK.

4.2 Challenges

At Arnøya during the first winter, it quickly became evident that the expected snow depths had been underestimated. This resulted in both operational challenges and damage to several installations caused by avalanche activity, see summary in *Table 2*.

The first units began experiencing significant snow accumulation in mid-January. Nevertheless, operations could continue because the units were not completely buried, and communication with the towers remained possible. However, to prevent overpressure during firing and potential equipment damage, a new operating procedure had to be implemented in consultation with the supplier. Under this procedure, an initial test shot was carried out using only a 2-second gas filling time. If the test was successful, a standard shot with a 21-second filling time could be executed. Although this approach reduced the risk of damaging installations, it increased operational complexity and resulted in longer road closures than normally required.

The most significant challenges occurred in March2025 after several major snowstorms and a substantial increase in snow depth. On the 20th of March, a controlled size-3 avalanche bent the mast of the unit Grasryggen1. The damage was not discovered until the end of the season, as the mast remained supported by the surrounding snowpack and the unit continued to operate normally despite deformation (figure 1). Three days later March 23rd, weather conditions changed and temperatures increased significantly from -4 degrees to +10 degree in 48hours (at 285masl.). The rapid warming triggered a natural size-3,5 avalanche that struck and destroyed the unit of Blåbærdalen Vest2 (figure 2), which later was found in the runout sone, about 200meter from the road. Fortunately, the dense avalanche deposits stopped just short of the road, preventing any direct impact on traffic.

The event on the 23rd, occurred despite having done as many as 5 control missions, after each snowstorm prior to the event (the 10th, 13th, 16th, 18th and 20th of March). At the time, it was believed that a deep persistent weak layer (DPWL) had become active due to the rising temperatures. Nevertheless, a control mission was also performed in the evening after the incident but did not trigger any avalanche. The temperature had again dropped substantially, probably stabilizing the snow cover.

Following the incident on the 23rd, and the idea that a potential DPWL had developed, it was decided to remove three additional units that were considered vulnerable to similar avalanche impacts, or close to being totally covered in snow. However, snowfall continued and didn't allow any helicopter-access to the mountain. By the 28th March, as many as 7 units were nearly buried by snow. During a gas refilling campaign on the 9th of April, the units Grasryggen, Reingjerdet, and Blåbærdalen Øst 2 were therefore removed from their masts as a precautionary measure. The objective was to prevent further equipment loss.

With several units not in operation, the safety of the road was compromised. Fortunately, the remainder of the season, no avalanche threatened to reach the road, and no further avalanche control missions were required that season. In late spring however, warm temperatures on May the 12th caused the collapse of a large cornice, which triggered a Size 3 wet-snow avalanche, that stopped some 200m before the road. The avalanche destroyed the mast at the unit of Reingjerdet. Fortunately, the trigger-capsule itself had been removed from the mast, preventing it from being destroyed as well.

After the season of 2024/25, MHM/MND delivered a damage report showing that the forces experienced by the installations far exceeded the design criteria. The three damaged units displayed a similar failure pattern, with structural failure occurring at the same location just above the base connection (Figure 1).

Table 2: Summary of operational challenges winter 2024/2025

Date	Status rapport	Units not in operation	Units with operation restrictions.
13 Jan.	2 units close to being covered in snow.	0	2
20 Mar.	The mast of Grasryggen1 bent by avalanche (Not discovered until end of season).	0	2
23 Mar.	Blåbærdalen vest2 completely destroyed by natural D3,5 avalanche.	1	2
28 Mar.	5 more units close to being covered in snow.	1	7
9 Apr.	3 units removed, due to risk of avalanche and damages.	4	4
5 May	1 more unit close to being covered in snow.	4	5
12 May	Wet avalanche damaged the mast at Reingjerdet.	4	5

Figure 1: Damaged installations during the season of 2024/25.

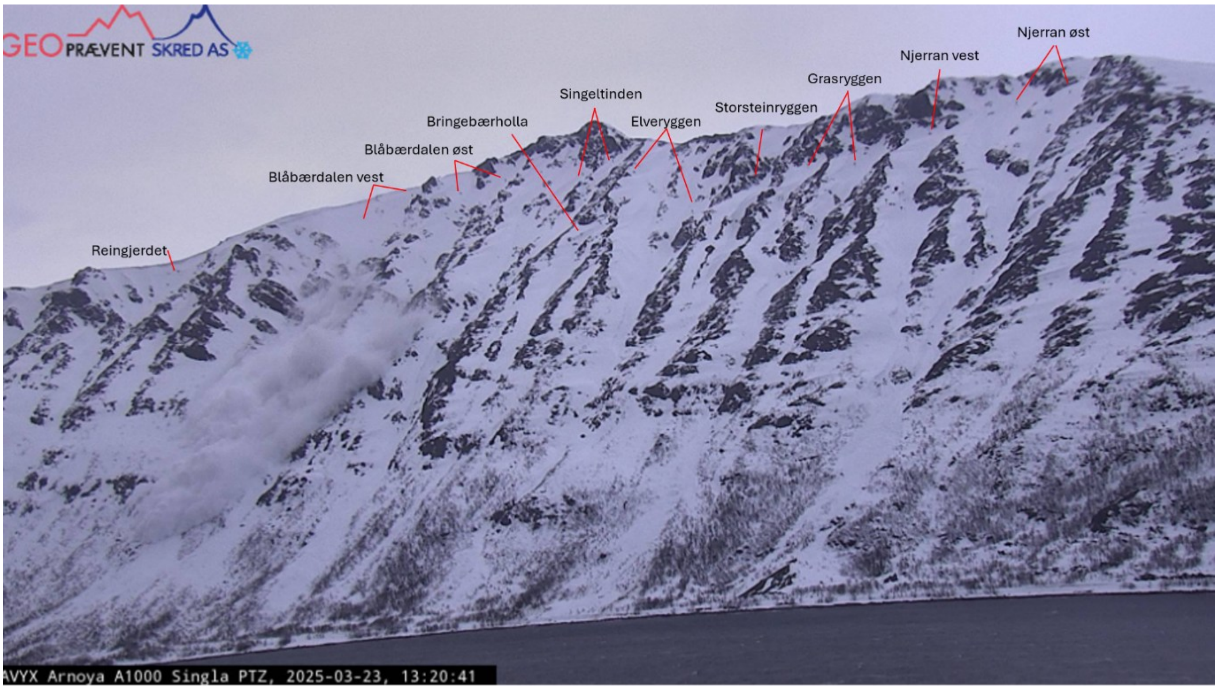

Figure 2: On March the 23rd. after several major snowstorms, temperatures increased significantly and triggered a natural size-3,5 avalanche that struck and completely destroyed the unit of Blåbærdalen Vest 2, which later where found in the runout sone, about 200meter from the road (figure 1).

4.3 Relocating units

Following the 2024/25 season, it became clear that several installations would need to be relocated to reduce their exposure to extreme snow loads and avalanche impacts. During the summer of 2025, the four most critical units were moved: Reingjerdet, Blåbærdalen Vest 2, Blåbærdalen Øst 2, and Grasryggen. As Blåbærdalen vest 2 had been destroyed, it also had to be replaced. It was decided to use another unit; one believed not to trigger any avalanches anyway. So, the system was reduced from a total of 24 to 23 units.

The selection of the four new trigger points was based on several additional sources of information and analyses (11-16), that are described in Chapter 4.1 (1 – 10):

11. Detailed photographic documentation from the PTZ camera system collected during the season of 2024/25.
12. Radar detections of avalanches season 2024/25.
13. Measurements and mapping of maximum snow depths obtained through laser scanning and photogrammetry in May 2025.
14. Development of an improved 3D terrain model.
15. A joint field campaign with MHM/MND in August 2025.
16. Simulations of avalanche loads (RAMMS), to ensure that the new locations would remain within the design limits.

These investigations provided a much more comprehensive understanding of local snow accumulation patterns, and avalanche behavior. As a result, the relocated units are expected to experience significantly lower exposure to avalanche impacts, and snow loads.

Additional relocations for 2 to 8 less critical units are planned for 2028, giving two additional winter seasons of observations and operational experience, before optimizing the overall system layout and establishing a long-term configuration.

As for season of 2025/26 there was much less snow, and the only problem regarding snow depths where one-unit Bringebærholla, which was covered in snow in the beginning of February. By march, spring came early and snow level decreased again, returning the unit to normal operation again. No damages to installations that season occurred.

4.4 Discussion

It is evident that several of the units on Arnøya were installed in locations that proved to be more exposed to avalanche activity than anticipated, and that maximum snow depths were underestimated. A damage assessment conducted by MHM/MND shows that the forces acting on the installations significantly exceeded their design capacity. Based on our experience, these issues were likely the result of a combination of limited planning time, an incomplete understanding of the system's operational limitations, and an unclear distribution of responsibilities for the detailed design of the installation sites.

Due to the short period between project funding approval and the required operational start date, snow depth measurements were limited to a single winter season. This provided an insufficient basis for the analyses required to determine optimal installation locations.

The tender documents and contract specified that the supplier, in cooperation with TFK, was responsible for determining the exact locations of the trigger points prior to installation (Chapter 4.1). Two joint field campaigns were conducted with the objective of agreeing on the final trigger point locations. The first campaign took place in early June 2024, when snow cover remained extensive, making it difficult to adequately assess terrain features and geotechnical conditions. The second campaign was too brief to allow for a thorough evaluation of all 24 proposed trigger points.

Site conditions further complicated the assessment process. The terrain was steep and difficult to access, requiring considerable time to reach each proposed location. In addition, persistent low cloud cover frequently restricted helicopter and drone operations, limiting both mapping activities and access to the mountain. At the same time, installation personnel and drilling crews had already been mobilized and were prepared to commence construction, making any postponement both costly and operationally challenging.

Furthermore, the contract clearly states that detailed design is the responsibility of the supplier, including calculations of all relevant loads, such as snow creep and avalanche forces. However, it is our understanding that no such calculations were carried out for the Arnøya installations before drilling and construction commenced. On the other hand, TFK has approved all installation locations, under the assumption that the selected sites would withstand avalanche forces and snow loads.

TFK's rationale for assigning responsibility for detailed design to the supplier was that the capabilities and limitations of the RACS system are best understood by the manufacturer. Conversely, local snow conditions, avalanche behaviour, and site-specific operational challenges are best understood by the infrastructure owner and the local forecasting team. The intention was therefore to combine the expertise of both parties in order to achieve the best possible outcome.

However, this collaborative approach may have differed from practices used in other RACS projects outside Norway and may not have aligned with the supplier's previous experience. In addition, the supplier had only approximately eight months from contract signing until the expected operational start date, which was a relatively short timeframe given the scope of the project. During this period, units had to be manufactured and transported to Arnøya, field investigations and detailed design work had to be completed, and installation of all 24 units had to be carried out.

4.5 Conclusion

Based on the lessons learned from Arnøya, it is reasonable to conclude that primary responsibility for the detailed design should rest with the infrastructure owner rather than the RACS supplier. Accordingly, TFK should initiate the process of collecting the necessary site-specific data well in advance of the planned operational start date. A thorough understanding of local snow and weather conditions, avalanche dynamics, and the design limitations of the proposed RACS system must be fully integrated into the assessment process. ¨

To avoid similar challenges in future projects, several important steps have been identified and acknowledged as essential during the planning and detailed design phases. These recommendations build upon the planning and evaluation steps previously described in Chapters 4.1 and 4.3 (1 – 16):

- Secure funding and planning resources at an early stage. Snow and avalanche conditions should be documented over multiple winters, including avalanche release areas, fracture lines, runout distances, and maximum snow depths.

- Allocate sufficient time for field investigations. Planning schedules should account for weather delays, poor visibility, and difficult terrain, and critical locations should be visited multiple times before final decisions are made.
- Select trigger-point locations that remain effective under a wide range of snow conditions, including both exceptional snow years, early- and late-season avalanche scenarios.
- Develop a thorough understanding of the capabilities and limitations of the different RACS, including robustness, design loads, effective trigger range, and evaluate whether these characteristics are suitable for the intended site.
- Evaluate the need for several different setups of trigger points, based on the specific properties and performance characteristics of the selected RACS technology.
- Perform site-specific calculations of snow, avalanche, wind, and terrain-related loads to verify that expected forces remain within the design limits of the chosen system.
- Engage an independent third party to review both the desk-study phase and field-based assessments before installation locations are finalized.
- Define the exact trigger locations optimally before releasing the tender documents or at least allow enough time for the detailed design before installation to avoid any stress-affecting decisions.
- Consider the supplier's recommendations for installation points, but the responsibility of the detailed design and final placement of trigger points must be the infrastructure owner.
- Clearly define responsibilities and decision-making authority in contracts and project documentation.

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