

## AVALANCHE CONTROL OPERATIONS WITHIN THE FRAMEWORK OF THE WINTER VIABILITY OF ANDORRA'S ROADS.

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**ABSTRACT:** For approximately 15 years, the Government of Andorra has been tendering and contracting (every six years) winter control against the risk of avalanches on Andorra's main road network; currently the company responsible for this control is Nivorisk SL. whose mission is zero casualties due to avalanche risk, both for the population and for the workers executing the contract themselves. The set of actions carried out can be summarized in four main points: 1- monitoring and control of snow and meteorological conditions, with different intensities depending on short- and medium-term forecasts; 2- risk assessment for the road network and for people/infrastructure; 3- Implementation, closure and intervention (if necessary) of the different artificial triggering devices; 4- Analysis and updating of the different PIDAs as well as the avalanche register affecting roads.

The control zones are distributed in areas of the northern and the eastern side of the country. There are 3 major areas of vital strategic importance for the protection of main roads and access to ski slopes, where Gazex®-type preventive triggering systems are available: Les Fonts d'Arinsal (with 3 shelters and 9 exploders), La Guardiola (with 3 shelters and 8 exploders) and L'Hortell (with one shelter and 3 exploders).

Currently all Gazex® systems of the Government of Andorra, operate through new generation communication satellites (Type4), designed to offer communication redundancy (radio and/or 3G-4G), operating by the MyMND/Safety web-based control system, which allows connectivity to work from any Internet access point, giving the safety operator user freedom and flexibility in its daily operation.

This centralization and modernization of the preventive triggering systems (Gazex®) together with the analysis of the historical records and through the modeling carried out with the Swiss 3D numerical model (RAMMS), allow us to optimize the closing and opening times of the different roads, guaranteeing at all times acceptable and residual danger and risk thresholds in terms of probability of loss of human life.

**KEYWORDS:** : winter operations; forecasting, gazex, triggered avalanche

### 1. INTRODUCTION

The objective of this article is to present the methodology and working system operated by the Government of Andorra, with the support of the company Nivorisk, in the winter control and monitoring of the national road network in the Principality of Andorra.

The Government of Andorra and the technicians at Nivorisk have taken on the mission of ensuring zero avalanche-related casualties, both among the general population and among the workers involved in monitoring activities. This goal is increasingly important in the safety protocols for managing natural risks due to incidents that have occurred worldwide during tasks related to avalanche risk forecasting (such as assessing snowpack stability, preventive avalanche release, and mobility in avalanche-prone terrain during crisis situations).

In this regard, one of the key points presented in this article is the systematization and standardization of all preventive avalanche release Gazex® devices in Andorra using new 4G satellite technology. This technology enables the operation on a friendly and reliable manner apart from bringing traceability of operations as well as their control through a dedicated web platform. The satellite communication allows an interesting redundant 4G and radio communication system in case of defect of the 4G local network.

### 2. CRITICAL CONTROL ZONES WITH THE NEW GAZEX® 4G SYSTEMS

The Andorra government responsibility is to ensure that the 275 km road network remain open, safe and accessible throughout the winter and allow approx. the 15 000 (AADT) vehicles originating from Spain and France.

The most critical mountainous areas to be monitored and secured are distributed across the northern and eastern slopes of the country. The main avalanche prone controlled zones are:

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**La Guardiola Avalanche:** A slope that impacts the CG-2 road. It is equipped with a Gazex® system consisting of 8 exploders, 2 mini shelters, and one large shelter (gas control center). Additionally, there is a Nivex sensor for measuring snow depth.

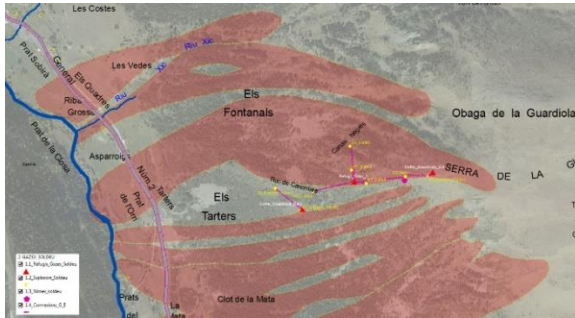


Figure 1: Snow avalanche pattern in La Guardiola.

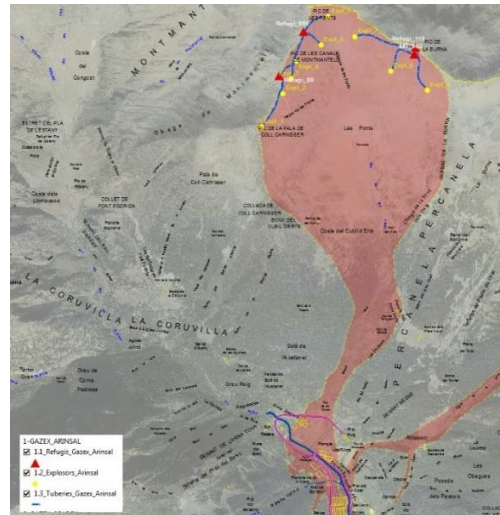


Figure 4: Snow avalanche pattern in les Fonts d'Arinsal



Figure 2&3: Part of the Gazex® Equipment (mini shelter + Gazflex on the photo) in La Guardiola area

**Fonts d'Arinsal:** located near the village of Arinsal and impacting the CG-5 road, is equipped with a containment dam and various Gazex® systems. Specifically, there are 3 shelters (gas control centers) and one mini shelter that powers 9 exploders distributed throughout the entire basin.



Figure 5&6: Part of the Gazex® Equipment (Gazflex on the photo) in Les Fonts area



**The Hortell Avalanche:** located on the CG-3 road in the Arcalís area, affects the section between PK 20+610 and PK 23+050. This area is equipped with a Gazex® system, consisting of one large shelter (gas control center) and 3 exploders. Additionally, a Nivex sensor is installed to measure snow depth.

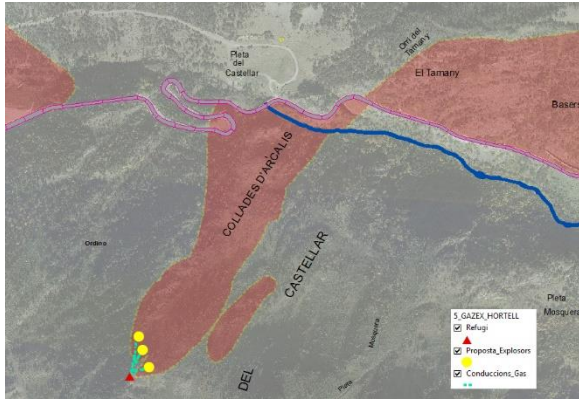


Figure 7: Snow avalanche pattern in Hortell



Figure 8&9: Part of the Gazex® Equipment (Small shelter & Inertia on the photo) in Hortell

The temporary road closure for triggering of the avalanche is either done late in the night (10pm-00) or early in the morning (05-07am) when there is little or no traffic.

### 3. REGULAR SURVEILLANCE

The regular snow and weather surveillance tasks carried out by the technical assistance team involve the systematic and continuous monitoring of meteorological and snow conditions to:

- Forecast potential critical situations
- Intervene during critical situations
- During the surveillance, the following activities are conducted:
- Monitoring and analyzing medium-term weather model outputs
- Tracking daily weather forecasts and regional avalanche danger levels provided by the National Meteorological Service
- Reviewing NIMET records from ski resorts
- Checking data from automatic snow and weather stations and other real-time remote data (e.g., webcams)
- Monitoring PIDAS results at ski resorts
- Reviewing snowpack profiles conducted by the Forest Rangers, CENMA, and ski resorts
- Conducting field assessments of snowpack conditions and signs of avalanche danger

During routine monitoring, the observation of specific indicators is carried out, and their distribution by altitude and orientation relevant to the avalanche departure zones of interest is recorded, as outlined in the following tables (collected in the data logbook of the technical assistance team).

The set of actions carried out can be summarized in 4 phases:

- Phase 1: **Monitoring** and surveillance of snow and weather conditions, with varying intensities depending on short- and medium-term forecasts.
- Phase 2: **Risk assessment** for the road network and for people/infrastructure.
- Phase 3: **Activation**, closure, and intervention (if necessary) of the various Gazex® **artificial triggering devices**.
- Phase 4: **Analysis and updating** of the different PIDAs as well as the avalanche inventory

### 4. ISSUANCE OF PRE-ALERTS / ALERTS

Prior to the controlled triggering of avalanches with Gazex® systems and as a result of daily monitoring tasks, the Government of Andorra and Civil Protection services are informed via email/WhatsApp groups of potential critical situations in the medium term (days ahead) under the designation of "LOCAL DANGER PRE-ALERT." The structure of a PRE-ALERT will include:

- Possible date of the critical situation
- Weather description
- Potential avalanche activity

The goal of this information is to identify potential critical situations in advance to efficiently organize the necessary material and human resources to address them.




<b>GOVERN D'ANDORRA- COEX</b> Servei d'assistència tècnica per a la seguretat enfront allaus de neu amb afectació a la xarxa de carreteres d'Andorra – any 2021		 Innovation and Solutions	 Govern d'Andorra							
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Figure 10: Pre alert frame

From the moment of issuance, the technical assistance team (AT) is activated for monitoring and confirming the risk situation. If the PRE-ALERT is confirmed, the AT team will switch to ALERT mode.

At this point, the technical team prepares a Local Avalanche Danger Assessment form for the areas of interest, which contains the following individualized information:

- Probability of natural triggering: High, Medium, Low
- Probability of impact on road network or infrastructure: High, Medium, Low
- Recommendation for triggering (in any modality): Yes, No
- Prioritization of triggering interventions: Levels 1 and 2
- General assessment.

## 5. INTERVENTIONS AND TRIGGERING WITH GAZEX® SYSTEM FOR AVALANCHE CONTROL

Prioritization of interventions (whether triggering or other protective actions, closures, and assessments) can often be analyzed based on historical data or through simulations performed with the Swiss 3D numerical model (RAMMS) for each avalanche zone of interest. These simulations provide information on snow depth, speed, and dynamic impact pressure in the lower parts of each slope and in areas close to road infrastructure or buildings, considering various snow depths and physical characteristics.

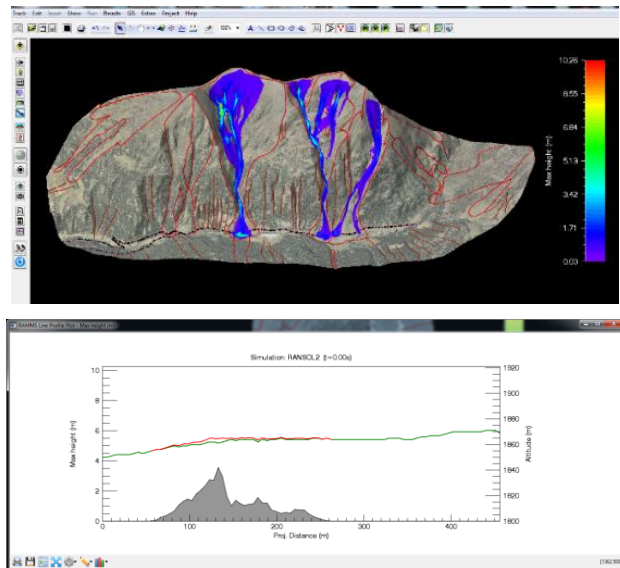


Figure 11&12 - Results of the Simulation with RAMMS: Avalanche Depth and projected height over the distance

The triggering protocols and actions for the various Gazex® preventive triggering systems are agreed upon and coordinated with the manufacturer MND-Group, which provides contractual assistance to the Government of Andorra in auditing and maintaining all installed systems in the country.

The triggering of the different Gazex® devices is carried out in strict accordance with the safety protocols established by MND. During 2023 and 2024, the communication protocols for the Gazex® systems at La Guardiola (Soldeu), Les Fonts (Arinsal), and L'Hortell (Arcalís) have been updated.

These updates include adding and prioritizing access to an IP address, which allows for much faster and less restricted remote access via the internet compared to previous systems. Contingency protocols include GSM phone connectivity and radio links.

This ensures the activation of the exploders at any distance and overcomes obstacles that could cause failures in communication systems.

GOVERN D'ANDORRA Name: ARINSAL - Les Fonts A Address: 2307				CELLULAR Online
Measure		Trig		
Gas	Voltage	Wind	Others	
 O <sub>2</sub> 149 bar	 Battery 13.9V	 Direction 0 °	 Temperature -1.4 °C	
 Propane 0 Kg	 Power 25.9V	 Speed 0 m/s	 Solar Radiation 0 %	

Figure 13 – Extract of Safety-cs interactive platform

In each triggering operation, at least 2 certified technicians authorized by MND must be present. The triggering devices, whether fixed computer systems or portable computers or even mobile phone, are accessible to all responsible technicians 24 hours a day during the winter season.

The shots are carried out following alert notifications and always in coordination with and prior notice to the following government services:

- Responsible and director of COEX
- Police Service (TEDAX)
- Civil Protection Service
- Municipality/ski resort of the parish where the respective Gazex® systems are located (Ordino, Canillo, La Massana).

Each shot is duly recorded in the MND-SAFETY platform, which also allows for the transmission of a copy upon request by any government service.

## 6. AVALANCHE IDENTIFICATION AND INVENTORY OPERATIONS

Following preventive triggering operations and throughout the winter season, avalanche activity is monitored in at least the 16 controlled zones specified in this document. The goal of this monitoring is to gather quality information about the phenomenon in the Principality of Andorra and how it might affect infrastructure, buildings, and other vulnerable elements.

By default, a flight route is scheduled to cover all assigned control zones. The flight planning is done systematically, starting with the Valira del Nord basin and ending in the Eastern sector, taking advantage of the connections between these areas for cartography and analyzing avalanche activity outside urban areas or with potential impact on road infrastructure.

The data is incorporated into a NIVOGIS-GOVERN D'ANDORRA database in GIS ONLINE format. This database should enhance knowledge across various fields, but especially regarding its impact on existing and potential real estate (urban planning) and the road infrastructure network in the Principality.

The observation and inventory of avalanches are carried out following these minimum steps:

1. Take photographs of the avalanche.
2. Complete the minimum description form for the avalanche:
  - Name and location
  - Date
  - Trigger /shot
  - Starting zone altitude /Orientation /slope
  - Size of the event
  - Type of avalanche

3. Map the avalanche and digitize it into a GIS database using Lambert III South-France coordinates, which are official in the Principality of Andorra. An example is shown hereafter



Figure 14 : Example GIS map

## 7. DISCUSSION

We have presented so far a focus on the winter program in progress in Andorra.

Over the last 20 years, the government of Andorra has proceeded an average of 10 operations (Gazex® shooting) per season.

Over the last 6 seasons the operations have not been very significant due to a clear decrease of snow fall (average of average of 5-6 interventions per year).

Each intervention is normally activated with snow accumulations of no more than 40 cm in 24 hours, so the probability of avalanches reaching the road areas is minimal. All the Gazex® operations in the last 6 years have not produced any avalanche deposits on the road, but the aerosol clouds have.

In the last 6 years 4 natural avalanches have come naturally on the road but in areas without protection measures or triggering systems such as RACS or barriers. These avalanches occurred under closed road, and under the effective surveillance plan.

Of all the shots carried out with Gazex® during each winter season, 90-95% cause snow fracture and triggered avalanches.

This system can trigger at any time and especially when then snow is judged to be the most reactive. The system enables the road safety manager to decide when to shoot according to the conditions and to do it automatically, optimizing to the maximum the time of action.

On the other hand, in helybombing operations, the success rate is often much lower because from the time we decide to shoot until we have the helicopter at our disposal, several hours can pass (ski resorts also require the helicopter) and sometimes we have found that several hours have passed before shooting, causing an increase in temperature and a partial settling/stabilization of the snow cap, which means that the shot is not effective and the slope is not clear.

This means that all the snow has accumulated in the upper part of the slope and this creates a certain insecurity in the process of opening the road.

Looking further, other issues need to be addressed and improved in the coming years. From example the need to get data from field monitoring devices and that will really help the safety road managers, in a cost effective way, to be confident but still vigilant in its approach.

## 8. CONCLUSIONS:

During these last 20 years the COEX have been improving its winter roads protection strategy.

Many actions have been undertaken, combining field observations and monitoring on the main critical departure zones with a strong effective surveillance program.

Lastly, the preventive release has been operated based on a modernized Gazex® system, at a cost effectiveness with regards to the risk reduction on the national road network.

## 9. ACKNOWLEDGEMENT

We would like to acknowledge the COEX for initiating this winter program. We also want to thank the partnership between the COEX and the snow safety managers of the ski resorts Gran Valira & Vallnord for their support and help during the engineering design, works and operation of the system presented in this paper.