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Event detection system for monitoring the cliff retreat and undermining of Castellfollit de la Roca village

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ABSTRACT

Castellfollit de la Roca village (Catalonia, NE of Spain) stands on top of a basaltic cliff affected by rockfalls that are causing the retreat of the slope and the risk of undermining the buildings. So far, remote sensing techniques have been applied. They have detected centimetric precursory movements of toppling in basaltic columns, and unnoticed rockfalls of tiny volume as well. However, rockfalls of remarkable magnitude caused by other mechanisms have occurred at the foundation level of some houses, without any precursor movement detected by remote sensing techniques.

In order to gather information from these events, a priority sector has been instrumented with a geotechnical network of crackmeters, tiltmeters and thermistors to monitor the thermo-mechanical behavior of the rock mass. Readings from the sensors have been automated through a wireless network based on Loadsensing nodes and gateway connected by LoRa technology.

Tiltmeters are all-in-one devices of sensor and logger operating in dynamic mode. This system enables the detection of events and sending alert messages in real time. To receive reliable alerts for risk management, suitable thresholds have to be defined, based on the knowledge of the studied phenomena at the particular scenario. This paper presents the system set up and the threshold analysis through the observation of the cliff behavior on the daily and seasonal cycles registered during the first year of operation.

Keywords: Rockfall, Real time monitoring, Wireless, Early warning system.

1. Introduction

In recent years there has been great progress in the knowledge on the instability process leading to rockfall. Thanks to the great detection capacity achieved with the monitoring systems, it has become apparent that this process manifests with some signs. The difficulty lies in the fact that the stiffness of the rock mass can make these early signs of failure very faint. Furthermore, its fragility may cause detectable hints to be concentrated in a short final period prior to the failure. In this sense, geotechnical instrumentation offers maximum precision for measuring these specific indicators and at the same time a continuous measurement. Depending on the velocity of the process, this continuity in time can be considered either with a static reading on a scale of daily behavior (typically from minutes to hours), or even with dynamic readings, below one second of measurement frequency.

This paper presents a case that exemplifies a progressive application of monitoring techniques, from remote sensing systems using discontinuous campaigns, to contact sensor systems with continuous measurement. The wireless sensor network (WSN) is being tested as a warning system in a unique case of geological risk in conflict with a geological heritage to be preserved.

2. Case site presentation

2.1. Basaltic cliff at Castellfollit de la Roca

Castellfollit de la Roca is a small village located 40km inland from Girona, in Catalonia, at the north-eastern end of Spain. Its medieval historical center is located on top of a basaltic cliff. This relief is caused by a Quaternary basaltic formation, formed by the superposition of two lava flows of dated of about 200,000 years (Muruzábal et al. 2023). Between the two there is a decalage of about 25,000 years in which a primitive paleosol was formed, which represents a level of weakness in the rock massif.

Subsequent fluvial erosion at its base (the main river Fluvià to the north flank, and the tributary river Toronell to the south) have sculpted the cliffs to a height of about 1200m all around the hill, with a maximum height of about 40m. This is one of the main geomorphological attractions of the volcanic area of La Garrotxa natural park, with a high value as a natural and cultural landscape.

In this context, there is a rockfall dynamic fenomena with very limited impact, given that there is no occupation of the river banks. Although that, the main risk derives from the retreat of the escarpment, which is creating the risk of undermining the buildings. From the observational landslide activity inventory the larger landslide has involved a total volum of 1500m^3, registered in 1976 (Janeras et al. 2023). In addition, in several documents there are historical references to the progressive loss of yard space located on the edge of the cliff.

To improve both security and preservation of the old town, local and regional government authorities have ordered the ICGC (Institut Cartogràfic i Geològic de Catalunya) to perform surveillance and monitoring works.

2.2. Techniques used for rockfall detection.

This study case is representative of a progressive application of monitoring techniques, which are summarized below.

2.2.1. TLS surveying

Castellfollit de la Roca is a pioneering place in the application of terrestrial laser scanning (TLS) in the study of rock falls. Since 2006, some first experimental campaigns conducted by the University of Barcelona (UB) have ascertained the capability to detect two main changes in the rocky mass in relation to rockfalls. They are the activity of detachments that apparently move the wall away in the laser measurements, and movements of blocks that reduce the distance measurement in line of sight (Abellán et al. 2011 & 2014).

Subsequently, ICGC has continued monitoring with six-monthly TLS campaigns, which have provided a long chronological series of the rockfall activity. These data have allowed quantifying the rockfall hazard by means of magnitude-frequency relationships (Janeras et al. 2023). It has been concluded that the activity is fairly homogeneously distributed throughout the cliff, although it seems slightly higher in the lower basaltic level. Rockfall detected by TLS are shown in this online viewer by ICGC (https://visors.icgc.cat/nuvols-punts-3d/castellfollit-despreniments-tls/) (Pedraza et al. 2022). This fact configures the overhanging profile of the wall and the dynamics of peeling and cracks in the upward direction. The same results have made it possible to estimate, for the whole of the northern cliff of the town of about 2hm^2 of rocky surface above the Fluvià river, an annual probability of occurrence of 0.018 for rockfalls of volume equal to or greater than 1000m^3. This magnitude is on the order of the larger size recorded in the observational inventory and has a high potential to dislodge a building if failure occurs at the top of the cliff. This hazard scenario corresponds to a return period of about 50 years, according to the calculated frequency.

In addition, in some cases of favorable configuration, it has been possible to detect block movements prior to the detachment. This occurs in the central levels of the cliff, which are formed by well-defined basalt columns. In this case, the overturning mechanism of the columns predominates, and involves a progressive toppling movement forward before the failure.

The great limitation of this monitoring system lies in the fact that the measurements are discontinuous according to six-monthly campaigns. On one hand, this system does not allow the detachments to be dated with enough detail to provide an analysis of the triggering actions. On the other hand, precursor movement can be detected only in cases of columns that overturn progressively and slowly with centimetric to decimetric movements over years. In order to be able to progress in the study of the behavior of the cliff, a continuous measurement is needed (Williams et al. 2019, Walton et al. 2023).

2.2.2. Fixed photogrammetric monitoring.

In order to overcome this limitation, as part of the Georisk project leadered by the Universitat Politècnica de Catalunya (UPC), a system of fixed cameras has been implemented to carry out a daily photogrammetric control (Matas et al. 2022). The system is still operational since 2021. The processing of these images has made it possible to cover the same two applications as the TLS: detecting detachments and pre-fall movements in equally favorable cases of overturning of basaltic columns (Núñez-Andrés et al. 2023b) similar to other test sites (Blanch et al. 2023).

On the contrary, no precursory movements were detectable with this system for the event occurred on May 12th 2023 close to the base of a house without damage. This rockfall was of 10.88m^3 in volume, corresponding to an average thickness of 0.8m on a failed surface of 13.6m^2. This level of the cliff, located at the base of the buildings, does not have a columnar structure but massive. Consequently, it was concluded that this photogrammetric monitoring system lacks sufficient precision to detect precursor movements when these are very small (of the order of mm), or if it involves fast evolution (i.e reaches centimetric order in a few hours).

The different remote sensing techniques applied in Castellfollit de la Roca have allowed a comparative analysis of the performances provided by LiDAR and photogrammetric techniques, both on a ground and aerial basis using RPAS (Núñez-Andrés et al. 2023a). It is also important to note two limitations of fixed photogrammetric monitoring:

- While it allows for a continuous daily recording, processing time is required, making it unsuitable for the rapid detection of rockfall events. In this project, with this method, the maximum latency between a rockfall event and its detection through photogrammetry would be about 24 hours.
- Like other remote monitoring methods, it is affected by weather conditions and visibility. It is not a method that can operate effectively during episodes of precipitation.

2.2.3. WS monitoring

Previous remote sensing techniques applied on the largest and more visible parts of the cliff, together with the geological surveillance, have made it possible to focus on sector S3, due to its large breaking potential, described in section 2.2.1 as the 50-years hazard scenario. This area contains an open fracture parallel to the surface of the cliff that corresponds to an upward progression of the largest landslides recorded in the inventory. In this sector, remote monitoring has been complemented with geotechnical in-situ, ground-based sensing using the wireless sensor network (WSN) achieving continuous high-precision and fast response monitoring. The instrumentation covers an approximate area of 500m^2 (20m high by 25m wide) of the upper part of the cliff, just below the foundations of 5 houses.

Regarding remote sensing techniques, these are point-measurements, but of high interpretative value as they respond to potential rupture mechanisms already identified. A single network can contain sensors that read parameters that can be correlated (e.g. speed of the opening of a crack with the inclination of a block). The ability of the system to increase the frequency of the readings when the speed of some of the monitored parameters increases or when a high value from any of the measured parameters is detected, provides a great benefit. If an early warning system is implemented over this Network, this will allow detecting in real time when a certain value has been exceeded and thus taking actions that can minimize the risk that entails a phenomenon of this type. (Lluch et al. 2022, Pérez et al. 2022).

2.2.4. Summary of the Techniques Used for Rockfall Detection

Regardless of the possibilities that the presented methods may offer, “Table 1” provides a summary of the main characteristics of these methods concerning the specific case study, taking into account the existing constraints.

Table 1. Frequency of data collection, precision, area covered, challenges and data output achieved in the study site according to present work and previous studies (Abellán et al. 2009, Janeras et al. 2023, Núñez-Andrés et al. 2023b).

Monitoring system	**Frequency of data collection**	**Precision achieved**	**Area covered**	**Challenges/limitations**	**Output**
TLS surveying	6 months	5 mm	26400 m^2	Certain influences of weather conditions. Vegetation.	3D model to detect changes and quantify the movements..
Fixed photogrammetric cameras	Effectively 1 or 2 per day	10 mm	1500 m^2	Influences of weather conditions. Sun exposure. Vegetation.	3D model to detect changes and quantify the movements.
WSN static (extensometer)	1 hour	0.01 mm	14 points representative of 500 m^2	Physical access with work at heights is required for installation. Specific points	Measurements of displacements at various specific points. Detection of translation..
WSN dynamic (tiltmeter)	3.9 Hz	centidegree			Measurements of inclination at various specific points. Rapid detection of toppling or flexion

3. Installation and description of the automated In Situ Sensor Network

The installation of geotechnical sensors in such natural and vertiginous cliffs is always a great challenge and adds some difficulty and commitment, entailing works at height. But wireless technology has significantly simplified these jobs, which are becoming more and more common. Arantec has been the specialized company in charge of these works with the support of IGCC on field. Thanks to the direct access from the houses but also to the easy deployment and versatility of the system, the installation was completed in only two days. All sensors and nodes were prepared and tested in advance to minimize operations while the installers were hunged up, so they only need to fix the sensors and loggers to the rock at each point.

A total of 9 crackmeters have been installed according to the 3 main faults visible on the slope, grouped in pairs and at two different levels. These instruments are meant to measure the movement across the sliding plane but also to measure the perpendicular displacement. One of those instruments is a wire deformemeter that has been placed covering the two main faults. Thermistors have also been placed on two of the crackmeter sets, embedded on the rock to measure the thermal behaviour of the rock mass (Fig. 1).

All these sensors have been automated by using a total of three Loadsensing vibrating wire loggers.

Figure 1. Lateral view of the sector S3, where WSN was installed to monitor the fracture parallel to the cliff surface. The distribution of the sensors is shown combining crackmeters, tiltmeters and thermistors.

For long-term monitoring and early warning detection, five Loadsensing Tiltmeters configured in Event Detection Mode (codified as C) have been installed in specific rock masses to measure the inclination along three axes.

Lastly, a single Gateway has been installed on the belltower of the ancient church to enable data automatization. All these instruments along with the Loadsensing system compose the Geotechnical Network.

Loadsensing is a system conformed by loggers and Gateways that is able to automate data read by sensors, at the reporting period selected, and transmit it by using a low power and long range radio to a Gateway, providing connectivity from the sensor to a 3rd party Software.

Loadsensing solution allows the coexistence of dataloggers connected to in-situ sensors and other wireless sensor with the Event Detection solution within the same Network (Pérez et al. 2022). This entails versatility on the network configuration and allows the reporting period to be adapted to the requirements of the installation. In this case, the network can be divided into two types of sensors: those that can be configured with a static reporting period that allow control of the measured parameter in almost real time (crackmeters, thermistors) and those that are sampling with a dynamic frequency, that allow real-time alerts when a preconfigured threshold is exceeded.

The EDS solution (Event Detection Solution) has been designed to be an essential component of the early detection warning system. It has three main layers: 1) wireless tiltmeters with event detection ability, 2) Data collector (Gateway) elements that receive messages from the distributed sensors (EDS tiltmeters and other in-situ sensors) and 3) CMT (Connectivity Management Tool) Edge Platform (Pérez et al. 2022).

Tiltmeters are sampling constantly 3 axes inclination data within a 3.9 Hz frequency. Based on this data, the device operates in an exception mode: its normal behavior is changed to an alert mode depending if a certain threshold has been exceeded. Thresholds are defined by channels, an upper one, that is considered to be exceeded when the instant sample is higher and lower one, that will be considered exceeded when the instant sample is lower than the threshold (Pérez et al. 2022).

The system can manage two type of messages: the alert message and the reporting period message. The device in normal state transmits data periodically (which is used as a base line) with a periodicity between (5 minutes and 24 hours) (Pérez et al. 2022). When a threshold is exceeded in any of the axes, the device is set automatically to alert mode, in which different changes are made on its operation:

- At the moment that a continuous measurement exceeds the threshold, an alert message containing critical information (channel and threshold exceeded, excess) is generated and published by MQTT in real time.
- This alert message is followed, some time later, by a reading (data) message equivalent to the periodic reading, but asynchronous (it is generated when it is required and not according to a periodicity) which contains the exact values when exceeding the threshold.
- Increases the rate of periodic measurements while remaining in a state of alert. The new periodicity can take values between 30 seconds and 24 hours (Pérez et al. 2022)

To ensure the radio message reception by the Gateway, the radio communication system has been limited to SF7 and SF8.

When a configured threshold from the EDS is surpassed, the data is sent in real time through MQTT to the 3rd party software. This alert could be distributed through the actors involved on the specific project to enable the action protocols required.

The system-reported latency is under 2 seconds for 10 tiltmeters detecting an event at the same instant and under 5 seconds for 25 tiltmeters detecting an event simultaneously (Pérez et al. 2022).

The battery lifespan from the loggers depends on the reporting period selected on normal and alert mode and the number of events registered. As an approach, we could say that batteries could last around 2 years by using a reporting period of 1h, considering that devices are not in alert mode for a long time.

In this case, the software used for data monitoring is Moncalc which is also able to provide metadata of the monitored network. The solution allows the integration of a geotechnical and topographic monitoring system, dealing with the corresponding geometric adjustments and error control. This software allows Loadsensing integration through MQTT protocol.

4. Data analysis

4.1. Crackmeters and extensometers

When writing this paper, a complete annual register is not still available but data allows having a preliminary idea about the rock mass behavior. The main cracks under surveillance are being monitored by crackmeters F1, F3 and F5, which are measuring movement perpendicular to the fracture plane complemented by crackmeters F2, F4 and F6 that are disposed as parallel as possible to the vertical component of sliding of the fracture. Each data set is shown compared to data of the nearest thermistor (Fig.2 & Fig.3).

In general, we can observe that the displacements recorded by crackmeters have a seasonal behavior correlated with the temperature variations of the rock mass surface and that there is a global recoverable trend of this thermomechanical coupling. When the rock surface is cooled down both main cracks tend to open due to the thermal bending of the rock slab, which also descends. This correlation is particularly noticeable during a specific and sudden episode of rain and thermal decline at the end of August.

It is also worth comparing data recorded by the wire extensometer F7 with the data obtained from the nearest crackmeters that are monitoring the opening of the fractures in the vertical and horizontal plane. Extensometer F7 has been installed crossing the main fractures in inclined direction with 1.38m height difference between both anchored ends separated 3.13m, as can be measured in the 3D model. Therefore, F7 measurements can be compared to the equivalent composition of crackmeters (Fig.4), which show an equivalent seasonal behaviour, despite F7 wire extensometer tends to show higher cumulated movement to positive values (opening of the crack and descending of the slab). It is worth noting that the crackmeters composition does not take into account the existing slight deviation of each crackmeter from the vertical comparing plane defined by F7 direction.

Figure 2 &3. Displacement in mm registered in crackmeters F1, F3 and F5, measuring the perpendicular movement of the fracture (opening) and displacement in mm registered in crackmeters F2, F4 and F6, measuring the parallel movement of the fracture (vertical sliding)

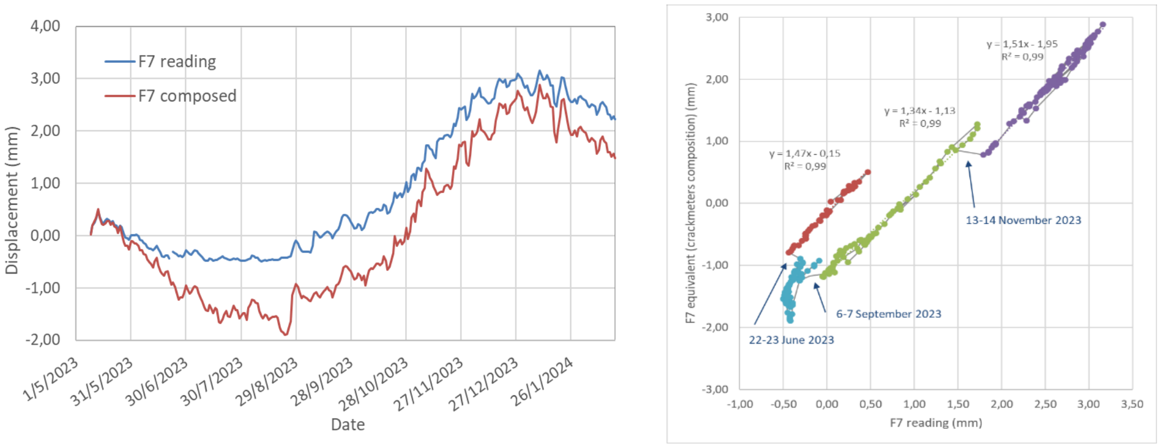

Figure 4 & 5. Daily average data mesured by F7 wire crackmeter compared to the module conformed by crackmeter measuring the perpendicular movement of the different fractures. Daily average data recorded by F7 wire crackmeter and the module conformed by crackmeter measuring the perpendicular movement of the different fractures.

In the correlation diagram (Fig.5), we can see the good agreement between movement measured by F7 and its composition from crackmeters, except some sudden gaps on specific dates, where wire extensometer F7 detects

larger movement not detected by the crackmeters. The sum of these three steps is 1.2mm, corresponding to 32% of the oscillation range along the year. It can be concluded that a wire extensometer can give an integrative measure of the whole movement of the rock mass and could detect if other minor cracks could play some role in stability, allowing to do a cross validation between instruments. Nevertheless, for this analysis is important to consider that due to the instrument mechanics, wire extensometer is more vulnerable to external actions, which can cause false signals of movement.

4.2. Tiltmeters

The surface availability and suitability to install the tiltmeters entails different orientation from the devices attached to the rocky slope. Although the main axes of interest are similar, there are differences on the tilt directions registered, so it becomes difficult to compare the axes registers between them directly.

What makes more sense is to compare the evolution of the records as the differential referred to the date of installation or to the average of the data measured around that date.

Fig. 6 and 7 show differential data from the clinometers on the 3 axes in combination with data from the temperature registered by one of the nodes. In general data is consistent with seasonal movement related to the thermal changes of the rock mass. There are records in some devices with a high thermal influence due to its specific location, as is the case of device C1.

However, device C2, which is located in the upper part of the slope, immediately below the houses where beams protude, does show a period of movement (from the beginning of July to september) between two equilibrium status and this is well marked in the Y and Z axes. We could say that this block has a local behaviour since it is well delimited and shows a great penetration of the vegetation.

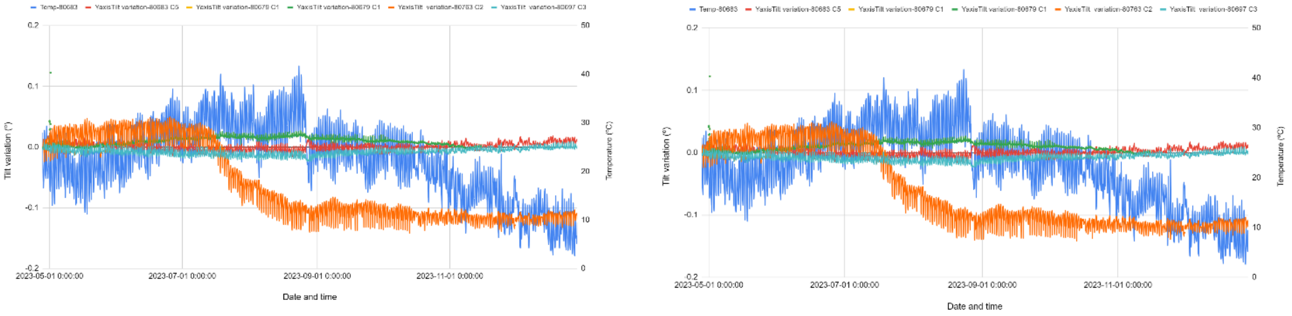

Figure 6 & 7. Tiltmeters incremental measurements on Y axis and Z axis.

4.3. Network performance

An important benefit to enhance from Loadsensing solution is the ability to transmit sensor data through long distances. In general, it is very important to ensure data reception (reliability) for the activities that are being monitored, but when it comes to an early warning system it becomes crucial granting that the potential events that might be registered are being received by the Gateway.

Loadsensing provides information regarding radio data reception messages and allows the control of this parameter through the Node Status Interface from the CMT. This way, the user can control the amount of messages received and lost by the system.

On “Table 2” all messages received by every node, messages lost due to radio communication and messages lost due to the Gateway reboots since their configuration are presented. These last ones are due to power cuts as the Gateway is being powered with the electrical grid from the church where the element is installed.

If we take a look at the total number of messages sent by each logger since the beginning of the installation and consider only losses due to radio communication, the percentage of lost is lower than 0.2% globally and that means an extremely high reliability of reception in any case. These results improve the performances achieved with ZigBee loggers in previous experiences by ICGC (Janeras et al. 2016) under similar challenging conditions, showing the capabilities of LoRa technology solutions offered by Loadsensing for rockfall monitoring.

Table 2. Message reception registered on the Network per node

Node	**messages received**	**messages lost**	**messages lost due to GW reboot**	**Total messages**	**% messages lost**
C5 (80683)	8637	5	118	8760	0.057%
C3 (80697)	8732	6	88	8826	0.068%
C4 (80704)	8597	3	129	8729	0.034%
C2 (80763)	8672	15	98	8785	0.171%
NODE 2	8463	10	56	8529	0.117%
NODE 1	8661	2	79	8742	0.023%
NODE 3	8298	1	78	8377	0.012%

5. Threshold definition according to data sets

Establishing thresholds is something that needs to be done according to the knowledgement of the rockmass behaviour or based in the experience from previous events registered in the area and that can not be defined on a generic way if the mission is to create reliable alerts.

In this case, as it is not possible to set thresholds from a geomechanical model, understanding the station's behavior over the course of a year without rockfall events registered could provide more insights into defining these limits. For the initial definition of the thresholds, the following methodology is proposed for the observation period (April to December 2023) for each tiltmeter in event detection mode (“Table 3”):

- Calculate the average inclination measured for each axis.
- Obtain the angular range (maximum measured value - minimum measured value) for each axis.
- Determine the offset based on the observed maximum angular range (0.036º) and by adding the peak-to-peak noise in continuous sampling of the tiltmeters in event detection mode (0.006º). The proposed offset would be 0.024. This value is calculated by dividing the maximum angular range by two and then adding the peak-to-peak noise.

- Establish the upper and lower thresholds by adding and subtracting the obtained offset from the mean value.

This method has limitations, as can be seen for tiltmeter C2. In this case, as seen in the previous section, movements were detected from July to September 2023, possibly due to the effects of vegetation. In this case, the angle range for the period is up to 0.20º. Since the movements tend to stabilize from September onwards, it is considered more appropriate to obtain a new average of the measured inclinations for values measured from September and apply an offset of 0.036º in this case, higher than the proposed 0.024º offset to be applied to the rest of the tiltmeters.

When configuring the thresholds, it is suggested to set them only for the axes where the measured angle is close to zero. Since the measured inclination is derived from gravity measurements using a triaxial accelerometer, the axis with values close to 90º always has a lower measurement quality than the other two. In fact, the information provided by the inclination measured along this axis is already included in the other two, which have values closer to 0º.

In addition to the thresholds that trigger the alert message from the tiltmeters, it is important to define other thresholds and criteria for activating processes and early warning measures, including the relative displacements measured by the crackmeters.

Table 3. Thresholds proposed for tiltmeters in event detection mode. The axis with inclination measurements closest to 90º, marked with an asterisk, is the one for which no threshold configuration is suggested.

	Incl avg	**Incl max**	**Incl min**	**Angular range**	**Proposed offset**	**Upper thrd.**	**Lower thrd.**
C5_Xaxis	-0.51	-0.50	-0.52	0.024	0.024	-0.49	-0.53
C5 Yaxis	*73.61*	*73.63*	*73.59*	*0.034*	*0.024*		
C5_Zaxis	16.38	16.40	16.37	0.034	0.024	16.41	16.36
C3 Xaxis	-0.23	-0.22	-0.23	0.009	0.024	-0.20	-0.25
C3 Yaxis	*86.51*	*86.53*	*86.50*	*0.033*	*0.024*		
C3 Zaxis	-3.48	-3.46	-3.50	0.033	0.024	-3.46	-3.50
C4_Xaxis	-0.36	-0.34	-0.37	0.029	0.024	-0.34	-0.39
C4 Yaxis	*85.43*	*85.45*	*85.41*	*0.035*	*0.024*		
C4_Zaxis	4.55	4.58	4.54	0.036	0.024	4.58	4.53
C2 Xaxis	*-3.30*	*-3.28*	*-3.33*	*0.047*			
C2 Yaxis	*85.43*	*74.25*	*74.06*	*0.190*			
C2 Zaxis	*15.49*	*15.58*	*15.38*	*0.199*			
C2_Xaxis from Sept	-3.30	-3.29	-3.31	0.019	0.024	-3.27	-3.32
C2 Yaxis from Sept	*85.43*	*74.12*	*74.06*	*0.059*	*0.036*		
C2_Zaxis from Sept	15.55	15.58	15.52	0.060	0.036	15.58	15.51

Beyond absolute thresholds, it may be interesting to define thresholds based on the increases in parameters measured per unit of time, such as velocity. However, being a rock slope, abrupt changes can occur that may be difficult to detect with the velocity of the measured parameter.

These limits could be modified according to the evolution of the records, so in case these are exceeded and being related and compared with the data provided by the crackmeters would allow to understand if there is any trend that indicates activity of the rocky slope.

6. Conclusions

Applying progressive monitoring strategies with the incorporation of different techniques as the knowledge of the rock mass behavior is obtained is convinient.

We can rely on geomatic techniques for quantifying significant rock volumes before their detachment and for having an idea of the activity of the phenomenon on extensive areas, understanding the precision and frequency data acquisition that these techniques can provide.

Wireless sensor networks (WSN) make possible to focus on particular areas that indicate more activity or that according to its nature, no precursor movements have been detected before their detachment with the other techniques, providing higher precision (milimetric) and more frequent data. These techniques can be very useful for obtaining information about the phenomena that trigger rockfalls and their use is even more enhanced in places of difficult access, such as rocky cliffs.

In these cases, a combination of sensors measuring accumulated damage in static mode, such as crackmenters, combined with sensors dynamically registering inclination (in EDS), is very valuable.

The latter make it possible to establish an automatic early warning system on a time scale of seconds that complements the alerts that can be derived from static sensors on a scale of minutes.

Loadsensing system automatization allows a certain flexibility, scalability and versatility and this adds value to this kind of projects, allowing to remotely apply changes in the sampling rates in those cases in which a greater vigilance of the phenomenon is required and even automate this change for those dynamic reading devices.

The use of LoRa technology is presenting fully reliable transmission results and offers many competitive advantages for rock mass and landslide monitoring.

Data provided by the instrumentation shows in general a thermo-mechanical stational behavior of the monitored fractures and blocks and there are not tendencies recorded out of this behaviour. This makes sense since these are wide fractures that allow water drainage and there is no significant action of the vegetation by opening the fractures.

In this type of environment it is of interest applying cross validation between instrumentation as it would allow to understand if there are other minor movements that could play some role in stability.

One of the interesting points of the analisys was to work with yearly (or almost yearly) data sets to define thresholds for the different titmeters in event detection mode, as they constitute the devices that the early warning system is based on.

In this case a methodology based on statistic data analysis allows to establish upper and lower thresholds and define different thresholds according to the unit.

Nevertheless, it is important to define other thresholds and criteria for activating processes and early warning measures where data provided by all the instruments installed play a role.

7. Acknowledgment

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