Implementation of geomechanical instrumentation based on extensometry for pillars monitoring at Esmeralda mine Block 2 extraction level, El Teniente division – Codelco

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ABSTRACT

The deformation and displacement of the rock mass sometimes causes serious geomechanical instabilities which affect operational continuity and personnel safety. As a result of this, and to improve the understanding of the behavior of the primary ore, digital extensometers were installed in the Esmeralda Block 2 mine in a 9,000 m2 polygon. The intent was to monitor the deformations and internal displacements of the rock mass before, during and after the undercutting. Block 2 in a sector whose exploitation method is Panel Caving Conventional with Hydraulic Fracturing.

The designed configuration has 72 extensometers of different lengths and a series of anchors to measure the vertical and horizontal components of deformation and/or displacement. The information obtained is compared with mining operations of the environment.

A dashboard platform was created internally for the visualization of data remotely and online. The main focus of this study is to calibrate the instrumentation information with the internal deterioration process of the rock mass affected by mining to establish admissible deformation thresholds prior to an instability event.

1 MINING CONTEXT

The Teniente mine stands as one of the foremost global producers of copper-molybdenum, distinguished by its underground mining operations. Presently, it boasts a production output nearing 140,000 [tpd].

The Esmeralda Block 2 mine is one of the primary productive sectors of El Teniente, consisting of 15.75 [Mton] of mineral reserves averaging 0.7 [%Cu]. It is currently mined through Conventional Panel Caving and massive implementation of hydraulic fracturing, utilizing a triangular extraction mesh (Teniente type) with dimensions of 15x24 meters.

The geomechanical instrumentation plan detailed further ahead is conceived within a sector of this mine, with the objective of monitoring the condition of the extraction level (EL) pillars as mining advances southward, as shown in Figure 1.

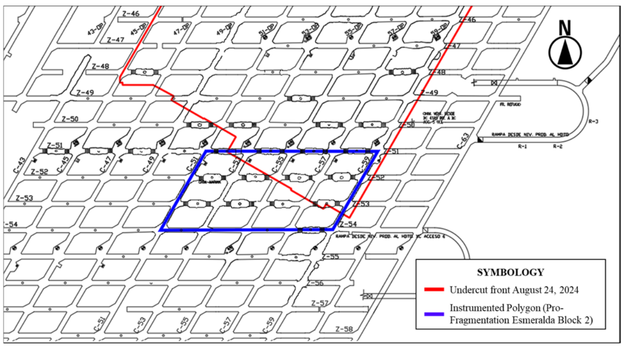

Figure 1 Industrial Test Polygon Batea Pro-Fragmentation at Esmeralda Block 2 Mine, situated in tonalite rock, with the projected caving front as of August 28, 2023.

2 WORK METHODOLOGY

The working methodology of deformation monitoring plan at Esmeralda Mine is presented in Figure 2, indicating that once geomechanical instrumentation is completed in the area of interest, a continuous analysis will be conducted. This analysis considers the information from the deformations data registered by the extensometers and the mining activities in the sector, which are limited to production blasting for drawbell opening and undercut level blasting for the caving propagation. From this analysis, some representative case studies of what is observed in the area are highlighted, accompanied by descriptive statistics, to finally establish a conceptual understanding model up to the current date.

The analysis of seismicity is outside the scope of this paper and will be approached in future studies once more robustness is obtained in the information collected by the instruments.

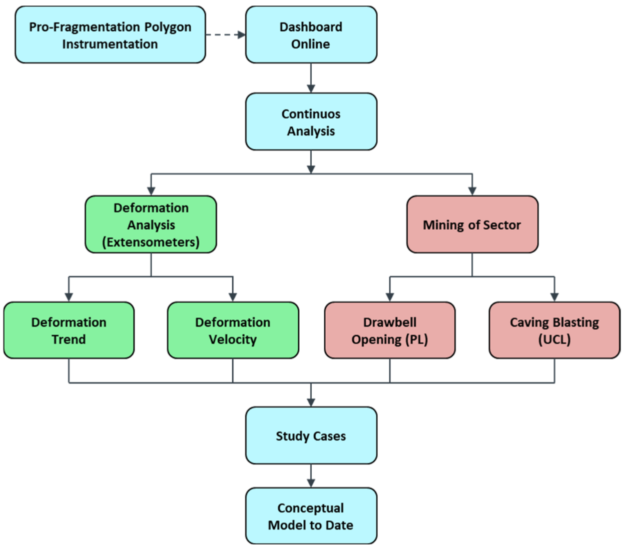

Figure 2 Methodology of analysis for this document.

The reliable capture information from extensometers was initiated in August 2023, until the end of January 2024.

3 INSTRUMENTATION PLAN

The Geomechanical Instrumentation Unit of El Teniente Division defines comprehensive instrumentation plans to monitor the stability of its various productive sectors. For Esmeralda Mine, a global plan includes installations of HI cells, extensometers, load bolts, markers, cave trackers, inclinometers, among others. Specifically for this sector and study, a geomechanical instrumentation polygon is defined to examine the effect of mining on deformations generated in extraction level pillars, particularly focusing on the effect of production blasting. For this purpose, extensometers will be installed.

Based on the above, the design focuses on:

- Extraction level pillar.
- Production drift/drawpoint drift.

These instruments are used to monitor the displacement or deformation of measurement points (anchors) positioned within the rock mass relative to a reference point (instrument head). The movements captured by the extensometers indicate displacement in the blocks within the rock mass.

The installed instruments, ranging from 7 to 10 meters in length, feature between 3 and 4 anchors. An important aspect to consider is that the instrument head is located inside of the drilling well. Therefore, the drilling must include an additional 1 meter to ensure it is fully embedded in the borehole, thus avoiding exposure to equipment in the area or secondary blasting. Figure 3 displays the referential spatial arrangement in a tunnel through a cross-sectional view. The installed extensometers have a precision of 0.3 [mm].

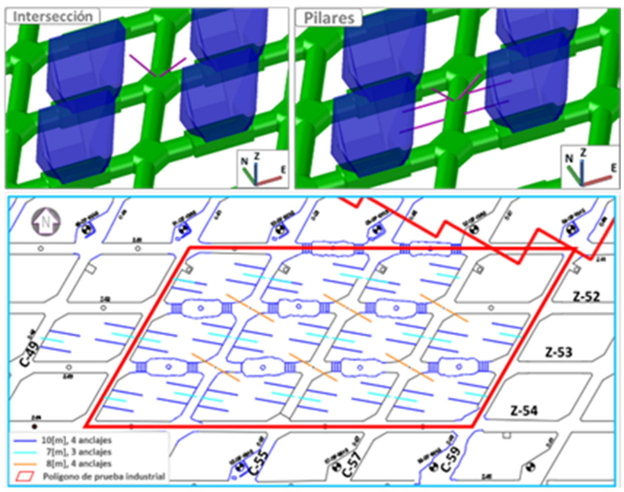

Figure 3 Instrumentation design for deformation monitoring.

4 STUDY SCENARIOS

Below, are some representative scenarios based on the information captured by the instruments installed in the sector, and their relationship with drawbell opening and caving blasting, which are established as key events in the mining production cycle.

Figure 4 illustrates the drawbells opened and the caving front (in colors black and blue, respectively) as of August 2023; also, it shows in red the drawbell opened between August 2023 and January 2024, as well as the caving front as of January 2024.

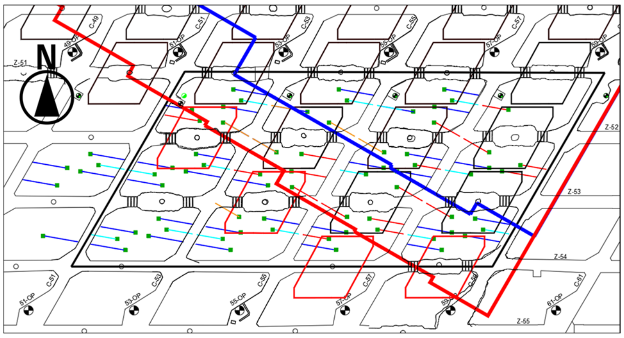

Figure 4 Advancement in drawbell opening and undercut front, during the analysis period spanning from August 2023 (blue line) to January 2024 (red line).

This period is chosen to analyze the behavior of the extensometers in response to these blasts, particularly to the advance of the undercut front, and the abutment stress phenomenon over the instrumented pillars:

4.1 Study Stage No. 1: Pillar ahead of the undercut front

The farthest pillar from the subsidence front within the instrumented polygon corresponds to number 9 (see Figure 5), where we observe the case of extensometer 61816-1. As shown in Figure 6, starting from October 2023, it begins to record a slight deformation rate of 0.01 [mm/day], reaching a maximum of 1.3 [mm] by the end of January 2024. To date, it maintains a transitional deformation trend (constant deformation velocity) in its four anchor points. Additionally, it is worth noting that the drawbell north of the pillar where the extensometer is located has not been opened, with the undercut front being approximately 30 [m] behind. Therefore, so new deformation peaks are expected to be recorded during the coming months as a result of the advancement of mining in the extraction level.

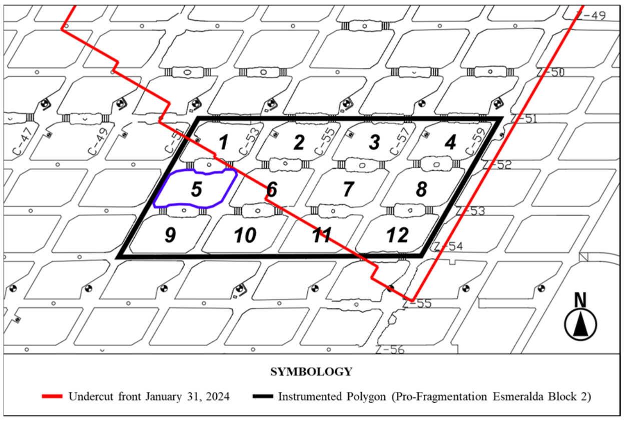

Figure 5 Location of pillar 5 (blue line) and 9 of interest in stage study No. 1.

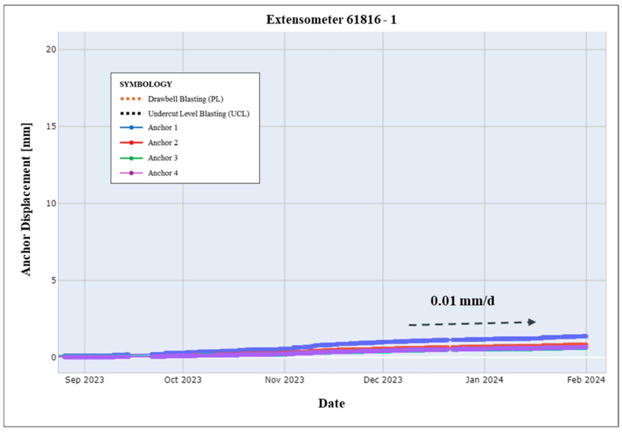

Figure 6 Deformation curves in extensometer anchors 61816-1.

Another example is pillar 5 (see Figure 5), which has been affected by the opening of the drawbell to the north of the pillar, as well as caving blasting, at a distance of approximately 20 [m], without yet reaching the pillar's area.

The behavior of the deformations registered by extensometer 62011-1, shown in Figure 7, indicates a slight increase in the deformation rate since November 9th, 2023, attributed to the advance to the south of the front. On November 3rd and 9th, 2023, the drawbell located at Ditch-52/Drifts-51/53 is opened in two stages, which is reflected in abrupt deformation peaks of 5.6 and 7.9 [mm], respectively.

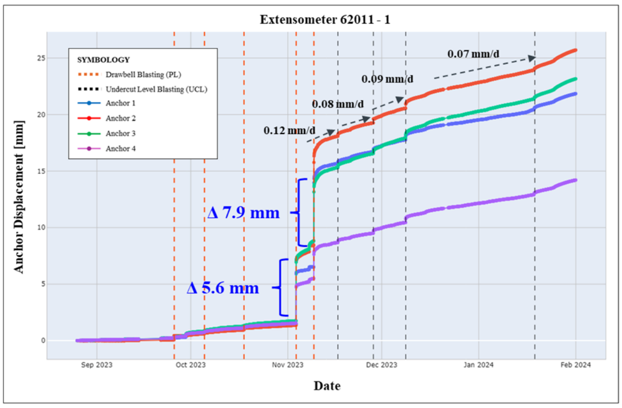

Figure 7 Deformation curves in extensometer anchors 62011-1.

After these dates, the undercut front has continued its growth towards the south, reflected as small abrupt increments in deformation. Subsequent to these, a transitional deformation trend is observed up to the date of January 31st, 2024, maintaining a constant deformation rate of 0.07 [mm/day].

The greatest displacement is recorded at anchor number 2, located 8.5 meters inside the pillar. Conversely, the smallest displacement is recorded at anchor number 4, which is closest to the gallery.

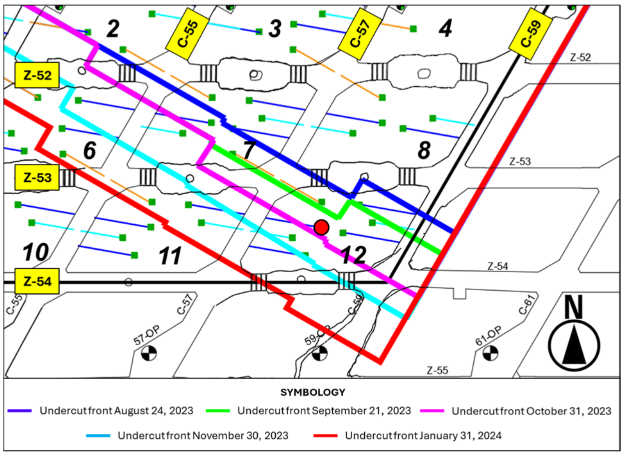

Figure 8 Passing of the undercut front over Pillar 12, highlighting with red circle the extensometer 62097-1.

This extensometer still needs to capture the deformation generated by the drawbell opening blasting to the south of Pillar 5, in addition to the perturbation generated by the advance of the undercut front over the pillar. Therefore, the recording of new deformation peaks in the surrounding instruments is expected.

4.2 Study Stage No. 2: Undercut front over the pillar

In this case study, the impact generated by the passage of the undercut front over a pillar located at the production level is analyzed.

At the start of data capture by extensometer 62097-1 around August 24, 2023, the undercut front was entering the area of Pillar 12, whereas by the end of January 2024, it is already at the southwest end of the pillar, exiting its area, see Figure 8.

In the deformation graph presented in Figure 9, the effect of the drawbell opening located at Ditch-54/Drifts-57/59 (south of the pillar) between August 17th and August 29th of 2023 is observed. Deformation peaks close to 2 [mm] are registered, along with an upward trend in deformation, which gradually decreases as the caving blasting moves to the southern end of the pillar (away from the pillar).

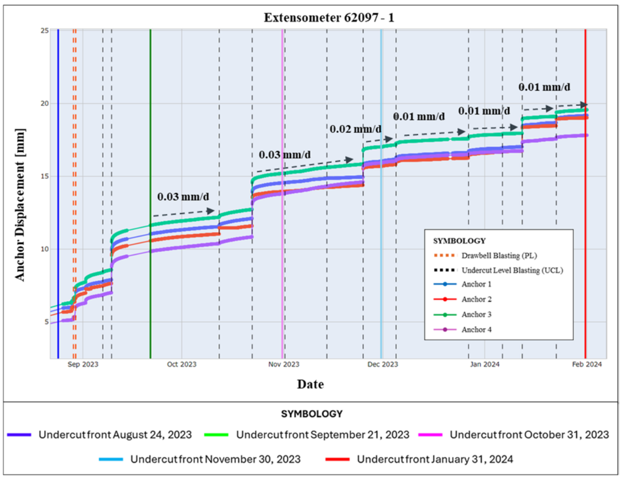

Figure 9 Deformation curves in extensometer anchors 62097-1.

In the center of the monitored polygon, the displacements registered by extensometer 61755-2 (pillar 7) are taken as an example (see Figure 10), which at the start of monitoring was ahead of the undercut front, with the drawbells to the north and south of pillar No. 7 opened. This device captures the deformations caused by the passage of the front, which can be observed in Figure 11. It is noteworthy that since January 2024, the curve tends to decrease its slope, with the movement of the front towards the south.

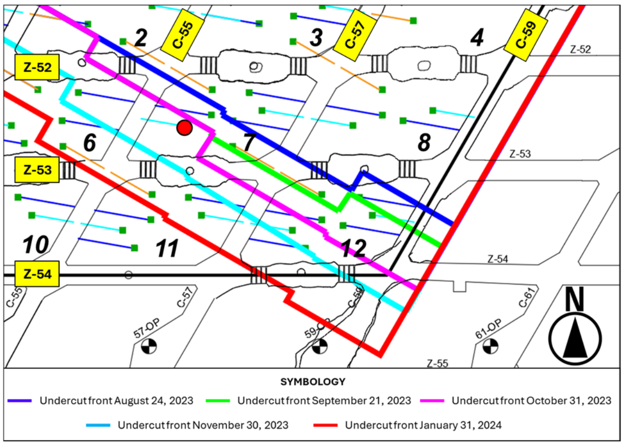

Figure 10 Location of extensometer 61755-2 with respect to the undercut front.

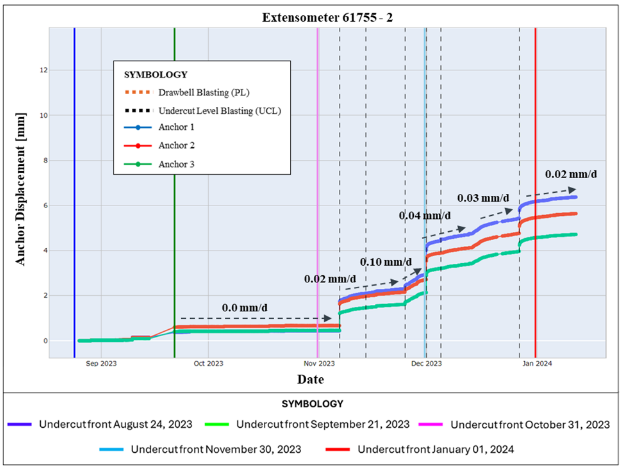

Figure 11 Deformation curves in extensometer anchors 61755-2.

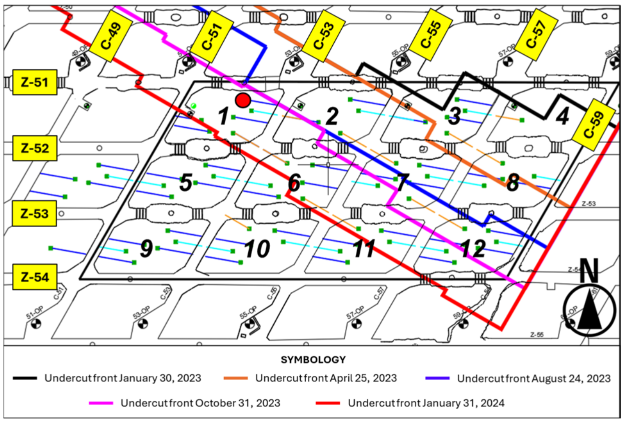

Figure 12 Location of the extensometer 61728-2 with respect to the undercut front.

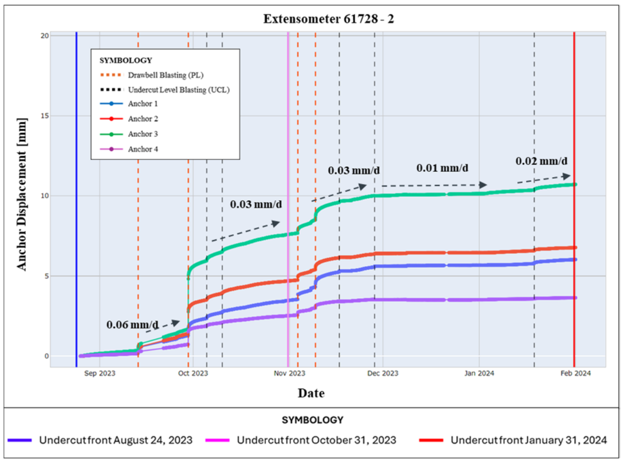

Figure 13 Deformation curves in extensometer anchors 61728-2.

In the northwest corner of the instrumented polygon, the behavior of extensometer 61728-2 (pillar 1) is illustrated as an example, highlighted in red color (see Figure 12). Also, in Figure 13, the behavior since August 2023 can be observed, with the peak deformation corresponding to the opening of the drawbell south of the pillar. Subsequently, it maintains an upward trend due to the advancement of the undercut front, until finally, starting from January 2024, it tends to stabilize, as it is already in a relaxed zone. Here, a regressive deformation trend is observed, indicating a systematic reduction in deformation rates.

4.3 Study Stage No. 3: Undercut front ahead of the pillar.

In this case, the deformation condition is observed in the pillars over which the undercut front has already passed to the south of their respective area.

In Figure 14, the location of extensometer 61926-1 (pillar 6) is presented in relation to the undercut front, highlighting that at the time it was activated (August 2023), this device was in a relaxed zone, with the trays of the north and south of the pillar open. In this scenario, Figure 15 displays the deformation graph of this device, showing a maximum displacement variation close to 0.2 [mm], serving as a clear example of the behavior observed in those extensometers that were behind the undercut front at the time of their activation. These extensometers do not register the disturbances generated by the blasting of drawbell opening and subsidence, given their distance from the latter.

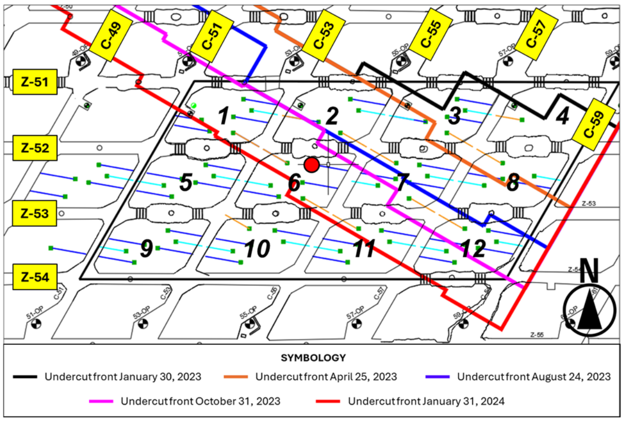

Figure 14 Location of the extensometer 61926-1 with respect to the undercut front.

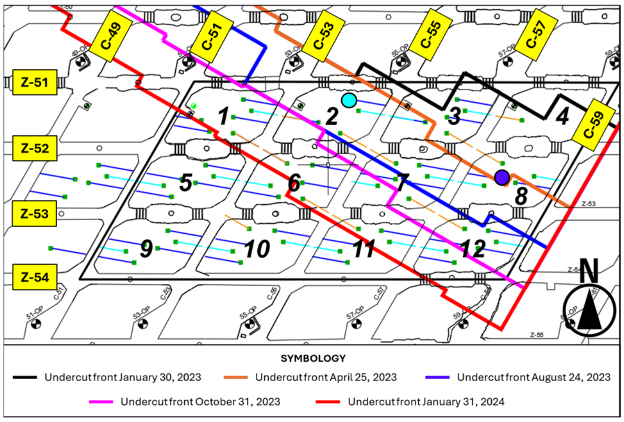

Figure 16 Location of the extensometers 61964-1 and 61805-1 with respect to the undercut front.

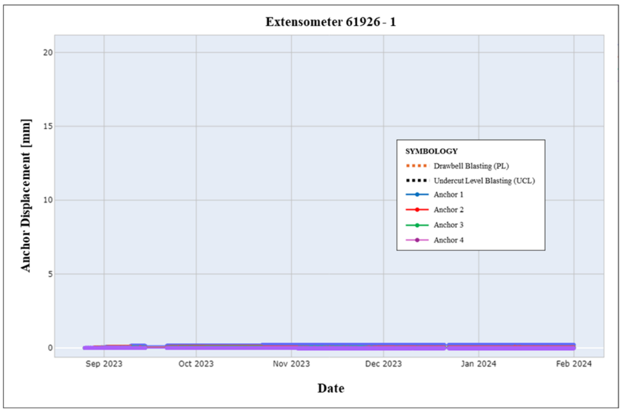

Figure 15 Deformation curves in extensometer anchors 61926-1.

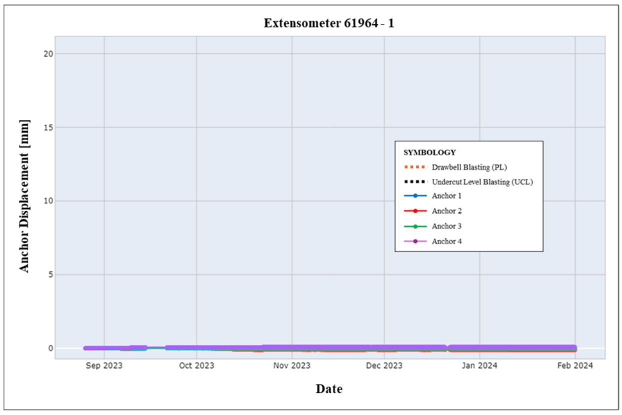

Figure 17 Deformation curves in extensometer anchors 61964-1.

A similar situation occurs with extensometer 61964-1 (highlighted with a blue circle in the pillar 8) and extensometer 61805-1 (highlighted with a cyan circle in the pillar 2), as seen in Figure 16. The behavior of these extensometers clearly shows the relaxed zone, indicating that little to no displacement (<0.5 [mm]) is expected after the passage of the undercut front, until January 2024.

5 STATISTICAL ANALYSIS

The present study focuses on analyzing the disturbance of the rock mass in the mining operation of Esmeralda Block 2, considering the blasting carried out between August 2023 and January 2024. The spatial distribution of these events relative to the instrumented polygon is shown in Figure 19.

Additionally, a distinction is made between two main types of blasts: Those aimed at advancing the undercut front, characterized by high undercutting with advances of 2 meters and carried out from the undercut level (UCL), and the drawbell opening blasts, which are executed in two stages from the production level (PL).

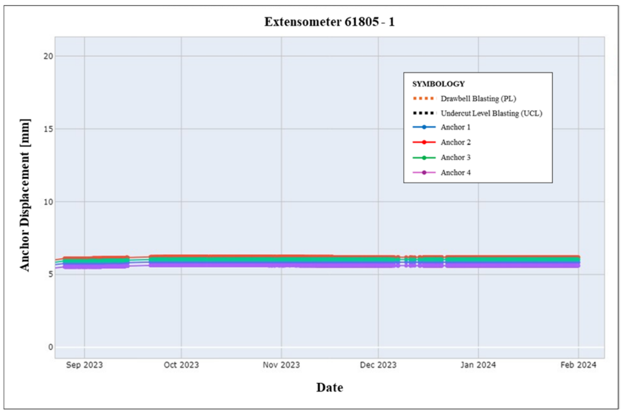

Figure 18 Deformation curves in extensometer anchors 61805-1.

With the georeferenced information of each blast, the distance to each anchor points of the extensometer inserted in the rock pillars of the production level is calculated. Subsequently, the magnitude of the jump in the displacement curve recorded by the extensometers, attributable to the corresponding blast, is determined.

This approach allows examining the degree of disturbance of the rock mass in relation to the distance from the blasting origin point.

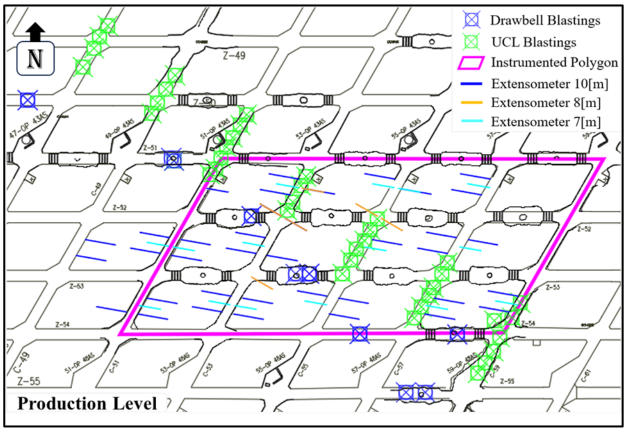

Figure 19 Spatial distribution of the blasts recorded in the pro-fragmentation polygon of Esmeralda Block 2 mine between August 2023 and January 2024.

5.1 Caving Blasting Analysis (UCL)

For the analysis of caving blasts, a sample of 39 blasting events registered during the aforementioned time period was considered.

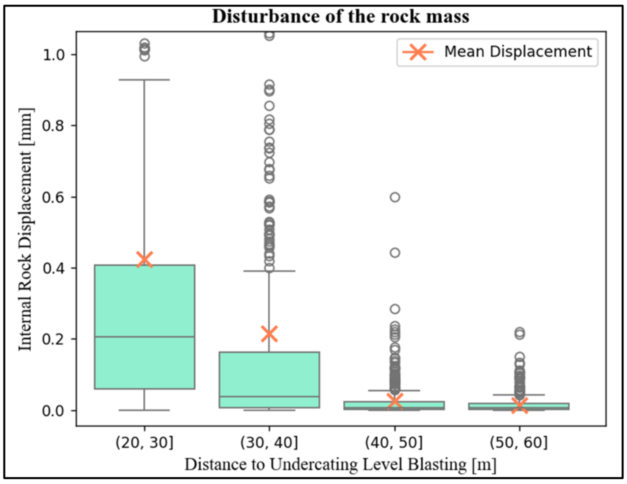

Figure 20 Boxplot of caving blasting events recorded by the instruments between August 2023 and January 2024.

The graph (Figure 20) represents the distribution of displacement peaks registered by the instruments, resulting from caving blasting events, as derived from the statistical analysis. The graph does not include the maximum values, as they are outliers, and including them would make it impossible to observe the average behavior of the disturbance based on the distance.

On the other hand, Table 1 contains the results obtained for the descriptive statistics of the undercut blasting events.

Table 1 Descriptive statistics of undercut blasting events (August 2023 - January 2024)

Range Distance [m]	Minimum [mm]	Maximum [mm]	Mean [mm]	N° Data
(20,30]	0	4.41	0.42	143
(30,40]	0	3.96	0.22	550
(40,50]	0	1.10	0.03	417
(50,60]	0	0.22	0.015	474

It is observed that the greatest displacements are concentrated in those extensometers closest to the blasting event, while those instruments further away tend to record less disturbance, due to the dissipation of the energy generated by the blast.

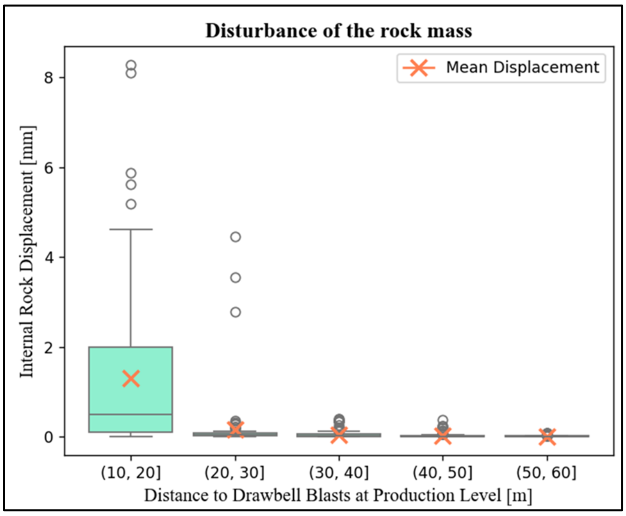

Figure 21 Boxplot of drawbell blasting events recorded by the instruments between August 2023 and January 2024.

5.2 Drawbell Opening Blasting Analysis (PL)

For the drawbell opening blasting analysis, a sample of 15 events was considered. The graph containing the distribution of the registered magnitudes is presented below.

Table 2 contains the statistical results obtained for the recorded data of the drawbell opening blasting.

Table 2 Descriptive statistics of drawbell opening blasting events (August 2023 - January 2024)

Range Distance [m]	Minimum [mm]	Maximum [mm]	Mean [mm]	N° Data
(20,30]	0	8.23	1.30	90
(30,40]	0	4.45	0.16	101
(40,50]	0	0.40	0.05	214
(50,60]	0	0.38	0.02	227

It is observed that drawbell opening blasting generates higher displacement peaks compared to caving blasting. This is primarily because the former are closer to the extensometers. Additionally, the energy released by a drawbell opening blasting will have a greater impact on the instruments located in the adjacent pillars, as they will have a smaller surface area to dissipate the released energy.

In general terms, the findings reveal an inverse relationship between the induced disturbance and the distance to the blast source, with the highest displacement peaks observed within the first 50 meters from the blast point. These results provide a significant understanding of the rock mass behavior in response to blasting in the mining context, contributing to the optimization of blasting practices and the mitigation of associated risks.

6 UNDERSTANDING MODEL

Considering the cases studies presented earlier, in addition to the descriptive statistics, we proceed to consolidate the understanding to date of the extensometers behavior in the mining context of a mine using Conventional Panel Caving Method with hydraulic fracturing (HF). The above is reflected in a conceptual model, which is divided into 3 zones (see Figure 22):

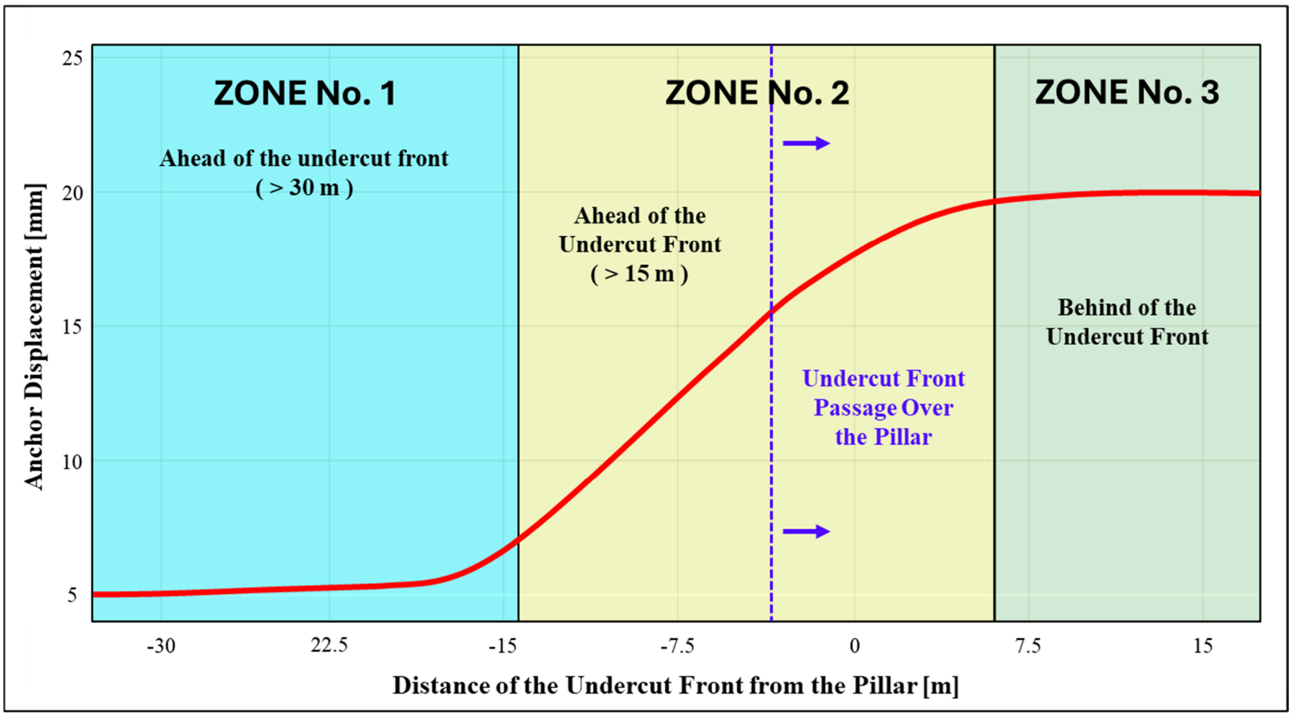

Figure 22 Conceptual model for geotechnical instrumentation of the study polygon in Esmeralda Block 2 Mine. Displacement scale values are reference.

Zone No. 1: Null or minimal deformation (< 2 [mm]), detected in the extensometer graphs located at a distance of > 30 [m] from drawbell opening or caving blasting. Regarding the deformation curve, it is characterized by being horizontal, and starts to take a slight positive slope before the beginning of Zone No. 2.

Zone No. 2: High disturbance (3 – 10 [mm]), begins with the opening of the drawbell adjacent to the north of the pillar, blasted in 2 phases, presenting deformation peaks that can reach 10 [mm] with each phase. Following each of these blasts, a transitional trend occurs. As the undercut front passes over the pillar, the extensometers record small deformation peaks, accompanied by a change in the deformation trend transitioning to a relaxed state (overall slope less than 0.5 [mm/day]).

With the opening of the drawbell located south of the pillar under study, and the advance of the undercut front, an upward trend in displacements is detected, totaling approximately 20 [mm] throughout Zone 2.

Zone No. 3: After the complete advance of the undercut front over the pillar, this stage begins, where the deformation trend is regressive, with the deformation curve tending towards horizontality, which would be explained by being in a relaxed zone. A significant decrease in deformation rates is observed.

7 CONCLUSIONS

The implementation of a displacement study polygon within extraction level pillars at Esmeralda Block 2 Mine and its relationship with production blasting allows for the capture of relevant information for understanding and decision-making in a geomechanical and productive context.

The various reviewed case studies allow us to understand the behavior of displacements in the rock mass and their relationship with drawbell opening and caving blasting, and consequently, the passage of the undercut front.

It is possible to identify 3 behavior zones: Pre-undercut front zone, advance of the undercut front over the pillar, and post-undercut front zone. In the first zone, the detected movements tend towards 0.0 [mm], while in the third zone during the advance of the undercut front, a total of 20 [mm] can be reached.

Drawbell opening blasting have a greater impact on the displacement peaks recorded by the extensometers compared to undercut blasting, within a maximum study radius of 50-60 [m].

This information is useful for understanding the response of the pillars at the extraction level to the dynamic disturbances induced by blasting and the advance of the undercut front, leading to an expected behavior, from which thresholds or alert criteria will be sought to be established in the future in the event of geomechanical instability.

The information recorded by the instruments may be used in future numerical modeling.

Finally, the technical specifications of the extensometers installed in the polygon of Esmeralda Block 2 meet the necessary requirements to be able to register the disturbances induced in the pillar, resulting from the mining operations.

8 RECOMENDATIONS

It's recommended to install instrumentation in Pre-mining zone to monitor the total impact generate because mining activity (Pre-mining zone, Abutment Stress, Relaxed zone).