24-005

A Surface Geotechnical In-Pit Underground Portal Relocation: An Operations-Based Case Study

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ABSTRACT

Reactivation of highwall slope failures during adverse weather had intermittently impacted haul road access into a previously mined open pit. These impacts ranged from limited access to full closures; however, the greater impact was to an underground mine that was developed within the open pit. Following several significant precipitation events, a rapid snow melts greatly accelerated movements finally closing the haul road and destabilizing other past failures. In addition to re-designing the overall pit access, the decision was made to relocate the primary portal to a more stable highwall. An accelerated surface geotechnical review was required to advance the portal relocation; however, only existing information from past investigation, existing geology model, visual inspections, and slope monitoring data were available for the assessment - no new investigations or data collection could be completed within the allowable timeframe. The evaluation included a review of the geology, an assessment of the current highwall condition and previously observed performance, and a rockfall analysis to evaluate existing catchment above the proposed new portal location.

BACKGROUND

The mine operation discussed in this operational case study is in northern Nevada, USA. Although gold mineralization associated with this deposit was identified in the 1960s, surface mining did not begin until 2004. The open pit was mined in 5 separate, adjacent phases from 2004 until the completion of the final layback in late 2010. Immediately following completion of surface mining, development for an underground portal operation began in December 2010 in the northern end of the pit floor.

The most significant open pit slope instability occurred during the second layback, or phase, which encompassed the southernmost portion open pit slope. Active mining of this phase occurred between 2005 and 2007. The southern highwall was established within a structural zone bound by two defined, typical basin and range faults. In 2006, the region experienced above average spring precipitation which adversely affected highwall stability. The natural topography and run-off essentially drained toward the open pit slope. This highwall proved to be sensitive to rainfall, snow melt, and run-off in the years following mining activity. The south pit slope exhibited continued slope failure after underground operation commenced, during wetter than normal Spring months. These internal failures would impact a laydown yard that had been developed below the pit slope. Remediation activities generally required relocation of materials and equipment, cleaning back of failure material, and building larger containment berms.

Throughout mining of subsequent phases, the pit slope generally performed very well; no significant slope failures that impacted mining activity were observed. There were some local bench-scale failures in the upper most benches which were established in weathered Vinnini Fm. or Rodeo Creek Fm. that were managed with clean-up or contained on existing benches.

However, in December 2015, slope instability began to develop in the west highwall of the final open pit phase (see Figure 1). A slope failure of the lower extent of the highwall impacted the use of the batch plant. Crest displacement included the pit side outer portion of the haul road/access road into the pit.

The slope movement impacted the available width of the haul road. Access was narrowed to signal lane by berming the outer edge. Furthermore, the observational geotechnical risk mitigation approach outlined in a site specific, standard operating procedure (SOP) and trigger action response plan (TARP) specified that depending on

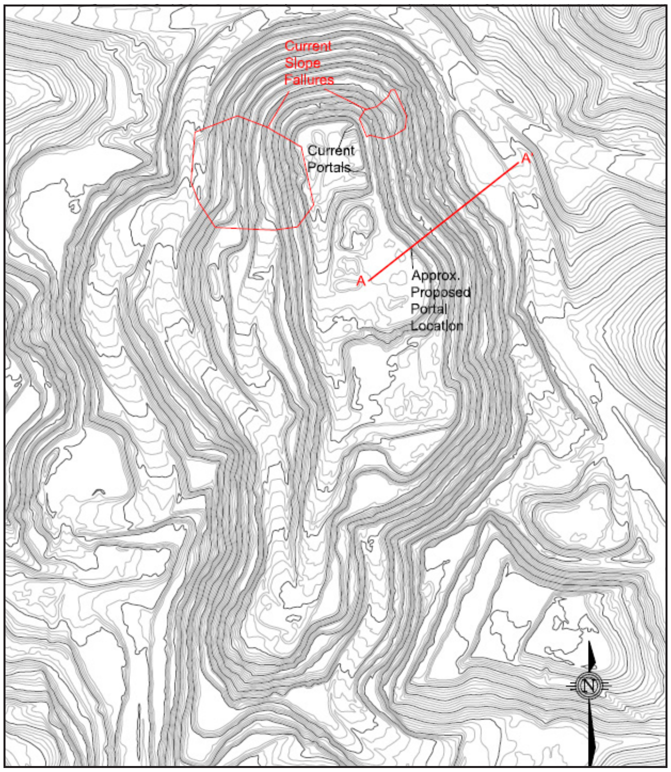

Figure 1. Map of the open pit with the on-going slope failures identified in red. The current portal locations are indicated, as is the location of the proposed new portal.

the measured movement rates or visual observations, the haul road could either only be used with spotters in place or access closed altogether. A secondary, light vehicle access was developed to ensure alternative, safe access in and out of the open pit for personnel. A plan was developed to establish a new primary access to the west of the existing haul road and slope instability; however, when slope movement rates expectedly decreased during the Summer and Fall of 2016 (i.e., drier weather conditions) mining the new access was delayed.

Concurrent to the development of the west pit slope failure that impacted the haul road, a local, previous failure mass that developed within a fault zone exposed in the east highwall also began displacing. This failure mass began filling the catch bench above the portal and eventually spilling onto the pit floor. This led to portal extensions being constructed to minimize the exposure to employees.

During the winter of 2016–17, the region again experienced increased precipitation compared to the previous several years. The resulting snow melt, rain, and run-off infiltrated the failure inducing increased pore pressure. Which in turn destabilized the area and caused the slope movement rates to significantly increase. This increased slope movement again resulted in intermittent closures of the haul road following the SOP and TARP requirements. A large increase during a rapid snow melt and rain event in early February 2017 pre-emptively required the closure and withdrawal of personnel from the underground operation due to the uncertainty of the stability of the access road, and the potential for any slide run-out to impact the portals.

During the middle of February, following the closer of underground operation, mining activity associated with establishing a new primary access has been accelerated by reallocating surface mining equipment to the project. Also, the underground mine engineers developed a plan for a new portal location to be established to the south of the current slope failures. With the shutdown of the underground operation, there was urgency in evaluating all aspects of this project in a timely manner, to identify and mitigate any additional potential risks to begin executing on construction of the new portal. One of the obvious potential risks being continued or new geotechnical slope instability in other areas of the pit.

An internal geotechnical review of the highwall above the proposed location(s) for the new portal was requested and conducted in an accelerated timeframe in support capital funding request for completing the project. The limitations of the assessment defined for the project team were that there would be no new subsurface investigation (i.e., drilling) and there would be no external technical resources (i.e., consultants) due to the required timeline. The evaluation did include a review of the local geology, an assessment of the current highwall condition and previously observed performance during surface mining, and a rockfall analysis to evaluate existing catchment above the new portal location. The remainder of this paper briefly discusses the aspects for the highwall review.

SITE GEOLOGY

Based on the current surface geology model and mapping information, this area of highwall is primarily composed of: Rodeo Creek Formation, Popovich Formation, and Roberts Mountains Formation. The bedding and formation contacts tend to dip toward the northeast around as observed from exposed pit slopes. Since, the proposed portal location would be located in an area of highwall that trends northwest to southeast, the formation contacts are dipping back into the highwall. Typically, this combination of pit slope and structural intersections lead to a more stable configuration (see Figures 2).

At the time of the assessment, there were no major fault structures modeled in this proposed portal location highwall. Inherently, with the basin and range tectonic activity

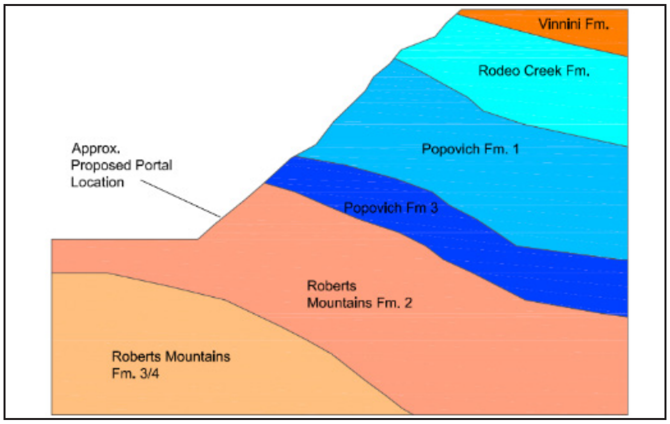

Figure 2. Geologic cross-section through the proposed portal location. There were no major faults according to the geology model; geologic formation contacts are dipping away from the pit toward the northeast.

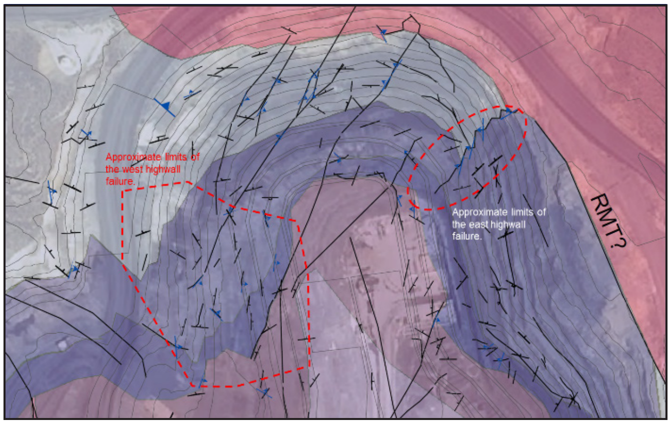

Figure 3. Geologic map of the northern end of the open pit. The observed slope failures were controlled by both geologic formation contacts and known faults.

Figure 4. View of the highwall above the proposed portal location. The catch benches contain material along each bench toe; however, there are no signs of slope movement.

that had occurred, there was potential for minor to moderate faults to be present with the formations. In the several years since surface mining was completed, there had not been deformation in this area of the highwall which would have exhibited deterioration along such secondary structures.

Fortunately, these conditions are different from the geologic conditions that were observed in the north end of the open pit and associated with bounding the ongoing slope failures. The west wall failure had been developing along fault and formation contacts. The contacts between the Rodeo Creek, Popovich, Roberts Mountains Formations are in proximity, with an overall pitward dipping orientation with respect to the highwall. Infiltration from precipitation and surface run-off over time, accelerated deterioration along structures and contacts. The weakening resulted in the instability that began to develop in December 2015. This area is shown in Figure 3.

Similarly, the local failure above the existing portals was occurring along a modeled fault structure that is also the contact between the Rodeo Creek and Popovich Formations. The projection of the fault/contact in the highwall was near vertical above the northern portal. Failure along this structure did begin during surface mining activity of the final phase. Over the past several years, the existing failure and weak material along the contact has continued to deteriorate; particularly when there have been winters or springs with above average precipitation. The area is indicated in Figure 3.

HIGHWALL CONDITION

A visual inspection of the highwall above the proposed portal location was conducted to identify if any major local instabilities had or were developing. Pictures are included as Figures 4, 5, and 6. The upper two benches do exhibit more substantial deterioration and weathering (Figure 4). This was observed in the Vinnini and Rodeo Creek Formations as surface mining was developing each phase of the open pit. There were some localized failures that were the result of weak material not able to remain stable when excavated at 65-degree bench face angles; however, these had been contained on the existing catch benches.

The remainder of the of the open pit slopes had performed very well, considering the local geological and geotechnical conditions exposed in the instabilities. There is, of course, minor ravel and sloughed material that had accumulated at the toe of each bench face; however, when examining photographs of the same area taken in July 2010 (see Figure 7) and January 2011(see Figure 8); it does appear that most of the material accumulated either during

Figure 5. A closer view of the highwall above the proposed portal location

Figure 6. A view looking parallel to the highwall and catch benches above the proposed portal location

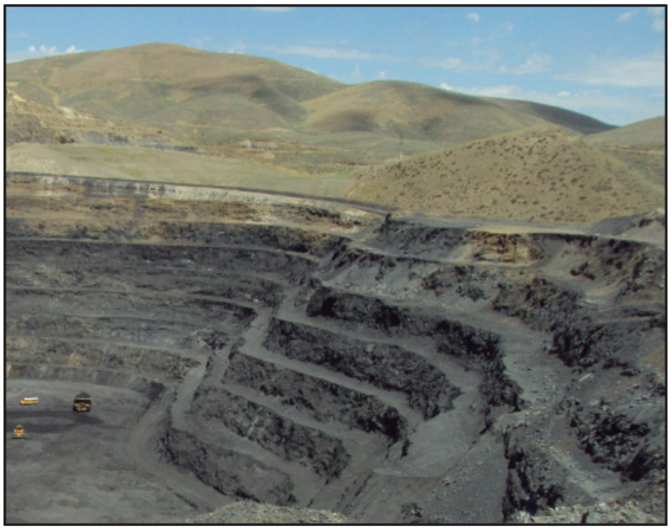

Figure 7. A July 2010, photograph that shows the upper benches of the highwall above the proposed portal location

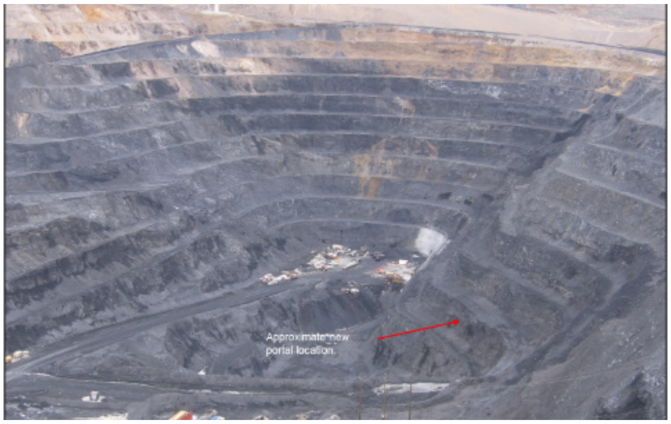

Figure 8. This January 2011 photograph shows the highwall above the proposed portal location. Development of the existing portals has commenced in the northern end of the pit.

or shortly after active mining. Although there had been ongoing material degradation inherent to exposure, it had not induced significant, observable slope movement.

Another local observation was that there were no "large" rocks that have accumulated on these benches. This does not mean that there is never a risk for rockfall in the future. It simply indicated that the rock mass tends to break into smaller rocks/fragments. Overall, when this assessment was completed, the pit slope within which the proposed portal would be located, had performed very well, with no obvious signs of instability.

ROCKFALL ANALYSIS

A rockfall study was conducted using Trajec3D. The highwall geometry was developed from recent laser scan survey data to build a detailed surface on 1-ft contour intervals. The survey data was smoothed to filter collinear and duplicate points, to reduce the number of triangulations to a quantity that could be imported into Trajec3D. The remaining properties are summarized in the Table 1.

The rockfall initiation points were manually selected. In the case of this analysis, 500 initiation points were selected across the open pit slope in the proposed portal area. Since the material that composes the highwall tends deteriorate into small fragments, or small rocks, the minimum allowable rock size permitted in the software at the time, 220-lbs, was determined to be representative of typical rockfall events.

Table 1. Slope material properties

Material	Coefficient of Normal Restitution	Static Friction Angle (degrees)	Dynamic Friction Angle (degrees)	Unit Weight (lb/ft^3)	Simulated rock weight (lb) minimum allowed	Total Rockfall Simulations
Bench Slope Face	0.01	50	45	160	220	500
Bench Surface	0.10	40	35			

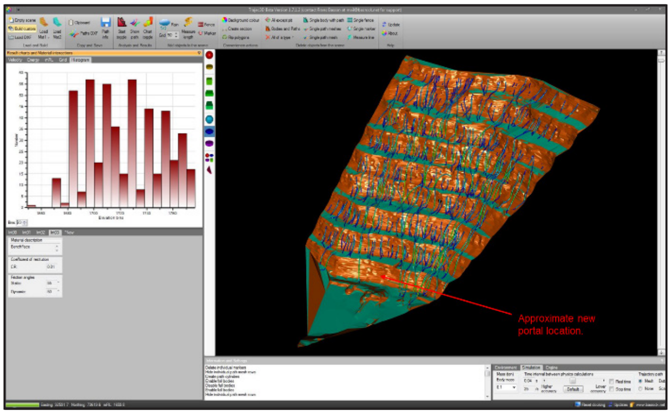

Figure 9. Three dimensional rockfall analysis conducted on the existing highwall geometry

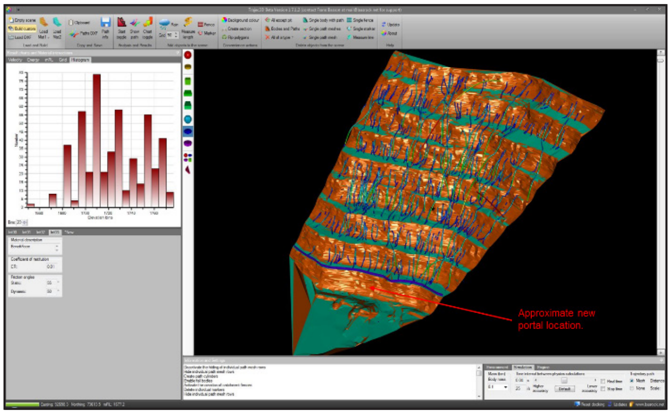

Figure 10. Three dimensional rockfall analysis conducted on the current highwall geometry with a 3-ft barrier along the crest

Two model scenarios were evaluated. The first evaluated the condition of the open pit slope in its current condition at the time of the assessment; these results are depicted in Figure 9. The second analysis was conducted with a 3-ft barrier (berm or fence) along the crest of the catch bench immediately above the proposed portal. This allowed a comparison of the estimated rockfall events that could be retained above the portal and surrounding area, which is shown in Figure 10, with the results of the current condition analysis.

The results of the analyses indicated that:

- A total of 14 rockfall events could reach the floor/toe of the open pit slope (14/500*100% = 2.8%) for the existing conditions.
  - Most of these events occurred at the southern extend of the proposed portal area, where back break during active surface mining reduced athe catch bench width and allowable containment.
- A small barrier (i.e., berm) constructed along the bench above the portal mitigated all modeled rockfall events from reaching the floor/toe of the highwall.

It is important to note that while the Trajec3D software, at the time of this study, indicated a percentage of rockfall events that would or would not be contained prior to reaching the toe of a highwall, variations in the size and number of rocks, and variations in field conditions beyond the assumptions incorporated into the model result in only an approximation of expected outcomes. Nevertheless, the analysis provided a guide to understand the potential risk to personnel working in the area around a portal. In any scenario, vigilance by geotechnical staff to regularly inspect and evaluate work areas is always required to identify changing conditions.

The example scenario below briefly explains the probability of a rockfall passing all the catch benches and causing a harmful event:

Example 1: A person struck by a rock passing catch benches (note: dimensions and time are representative averages; assumes 1 individual walking the length of the impact area once):

$P_{rockfall\ event} = P_{rock\ reaches\ pit\ floor} * P_{area\ exposed} * P_{exposure\ time}$

$P_{rock\ reaches\ pit\ floor} = 2.8\%$ (from the first bullet point above)

$A_{human} = 8.625\ ft^2$ (based on average human dimensions)

$A_{portal\ area\ bench} = 27{,}000\ ft^2$ (approximate area around the portal determined in AutoCad)

$T_{time\ on\ bench} = 0.0178\ hr$ (based on portal bench length, person walking the length & average human walking speed 3.1 mph)

$P_{rockfall\ event} = P_{rock\ reaches\ pit\ floor} * (A_{human}/A_{portal\ area\ bench})*100\% * (T_{time\ on\ bench}/T_{total\ time\ in\ day})*100\%$

$P_{rockfall\ event} = 2.8\% * [(8.625ft^2/27000ft^2) * 100\%] * [(0.0175hr/24hrs) * 100\%]$

$\underline{P_{rockfall\ event} = 0.0065\%}$

As there will be human exposure and that the software cannot predict all possible field conditions or scenarios, even for models that predict all rockfall events would be contained should not assume a 0.00% probability.

DISCUSSION OF FINDINGS

This operational geotechnical review did not identify critical geotechnical issues of concern with the proposed portal location. The geologic contacts are at a more favorable orientation with the geometry of the open pit slope. Furthermore, there are no known major structures visually observed in the open pit slope nor within the geology model.

The open pit slope, in this area anyway, had performed very well for the past several years. This is an example when collecting regular photographs, during visual inspections, of normal conditions are beneficial. Geotechnical staff of course collect photographs of geohazards, slope instabilities, and slope failures as they develop. But the normal condition photographs can be used internally to verify no significant change in conditions. They also can be shared with external stakeholders (i.e., regulatory inspectors, consultants, etc.) when site geotechnical staff are educating external staff of conditions between their "snapshot" observations.

There were no signs of slope instability over the existence of the open pit slope in the proposed portal area. Most rockfall or ravel events had been contained on the existing catch benches. Based on the material characteristics, most of the deterioration develops as raveling of smaller material. Therefore, rigorous rockfall containment is not necessary; however, it would be prudent to construct a berm or place some concrete blocks along the bench immediately above the portal as protection to people exiting the portal and cannot inspect the highwall as people entering the portal can observe changing conditions.

SUMMARY

This geotechnical assessment was required to be completed within a couple week period. The timeliness relied on the continuity of the geotechnical staff to have regularly inspected, documented, and monitored the open pit slopes as mining progressed. The observational data informs engineering judgement only gained by on site experience.

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24-006

Additional Damage to Buildings and Infrastructure Induced by Long-Term Surface Movements Above Longwall Mining

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ABSTRACT

After the systematic closure of Europe's coalfields in the late twentieth century, the emphasis is now clearly on industry's environmental legacy. One aspect of the latter is the long-term surface movement above abandoned coal mines. The analysis of satellite data shows that the subsidence lasts longer than generally assumed. However, a few years after the flooding of the abandoned underground coal mines, a new phenomenon was observed, i.e., the direction of the surface movement was reversed. The phase of upsidence has already lasted for several decades, and only future measurements will tell how long it continues. A key conclusion is that the regions with maximum subsidence do not necessarily correspond to the greatest upsidence. In other words, buildings and infrastructure are subjected to a different loading from this upsidence than during the subsidence phase. The long-term surface movements have an impact on vulnerable structures in the densely populated regions of the former deep coal mining areas in Europe. These movements create additional damage. This new knowledge is also relevant for mines that are still in operation or future mines that are planned.

INTRODUCTION

At the end of the twentieth century, entire coal fields in Europe were closed. In Belgium (Campine coal basin), the five remaining underground coal mines were closed between 1988 and 1992. Coal production in these mines began between 1917 and 1930. These mines applied the longwall mining method (with goaf), and most panels were situated between 500 to 1000 m depth. The average mining height per coal seam was relatively low, i.e., between 1.0 and 1.5 m. The Campine coal basin is characterized by numerous faults, causing a high degree of compartmentalization. This combined with past tectonic movements along these faults resulted in complex mining geometries, i.e., the position of the various longwall panels and their shape. In other words, mining did not follow a regular pattern. Below a given location, the total mining interval covered several hundred meters, and more than 5 seams were mined (even, sometimes more than 10). At both sides of the panels, single gateroads were excavated.

At the end of the coal mine's lifespan, the underground pumping installations were dismantled, and the vertical shafts were sealed. This meant that after the closure, the open tunnels, the collapsed goaf volumes and the surrounding rock mass or strata started to be filled with groundwater and the hydraulic gradient started to evolve towards the original hydraulic gradient. It is generally accepted that after closing the underground access, the surface movements are reversed, i.e., from a downward subsidence to an upward movement (uplift or upsidence). Examples can be found in the reference list in Vervoort 2021a. The link with the flooding of these mines was clearly established by other research (Baglikow 2011; Bekendam and Pöttgens 1995; Caro Cuenca et al. 2013; Samsonov et al. 2013). Although the direction of the additional movements has reversed, the cumulative amount of movements remains downward in comparison to the situation before the start of mining. (Further, an example is presented.) Recently, an analytical framework was successfully presented to better understand the different mechanisms and processes involved (Vervoort 2021b; Vervoort 2022a). Good correlation was observed between the measured and the calculated upsidence values along north-south transects. The crucial aspect for a good match between the two is to take into account the expansion of the goaf material when the water level is increased, but, as important, to also include in the calculations the expansion of all the strata between the excavated panels and around the mined area. It is believed that the strata layers are also drained during mining and that the pore pressure values are increased towards their original values before the mining began. A good fit with the measurements was