Replacement of a Major Ventilation Raise at the Homestake Gold Mine

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ABSTRACT

Few tasks are more important to the Ventilation Engineer than planning major airways. This paper presents a case study of the inception, design, installation, cost and performance of a 253 m long, 4.27 m diameter subsurface replacement exhaust raise and its connecting drifts.

The original raise served as a component of the primary exhaustway (140 m^3/s) and heat rejection sink (8MW) for the deepest production district, responsible for 45% of the mine's total ounce production. The chronology of ground control problems with the original raise and attempts to halt the unraveling are described. Planning for a replacement raise commenced once it was realized that the original raise could not be saved. Computer simulation helped size the new raise and connecting drifts. Selection of the raise location was based on a careful rock mechanics assessment. A temporary ventilation bypass system was designed to minimize production loss in event of a catastrophic failure of the old raise while the new raise was being bored. This failure occurred shortly after the temporary bypass was ready.

The new raise system was completed in February 1995 at a cost of $US 1.475 million. The troubles encountered, resistance measurements, and final costs are given, and a comparison of planned and actual performance is made.

KEY WORDS

Homestake Mine, Airway Failure, Mine Ventilation, Ground Control, Rock Mechanics, Internal Raise, Costs, and Production Loss.

INTRODUCTION

The Homestake Gold Mine, located in the Northern Black Hills of South Dakota, produced 1,325 kt of gold ore per year from underground until January 1998 when the mine was downsized. Prior to 1998, the mine was ventilated by 392 m^3/s via three relatively independent circuits. Of these, the Oro Hondo still provides 217 m^3/s. The deepest portion of this circuit, ventilated by 140 m^3/s, produced 45% of the total ounce production. The exhaust side contains three major components: the old 4.9 m diameter Oro Hondo shaft from the surface to the 3950 foot level, 1430 m of horizontal 5.2 m by 3.7 m drift, and the #31 Exhaust raise system which is composed of nine 4.9 m diameter vent-ilation raises from the 3950 to 8000 levels. (Level designations are considered proper names and are reported in feet below the surface.) A 2240 kW SWSI centrifugal fan ventilates the circuit (with a 932 kW two-stage axial for back-up). Figure 1 shows the mine and #31 Exhaust system. Rock sloughed off the sides of the rough-blasted Oro Hondo shaft and nine raises at a more-or-less steady rate into the 1990s. This rock was periodically removed. The first signs of more serious trouble occurred in the summer of 1992. Large slabs plugged the raise offset on the 6500 level and were only

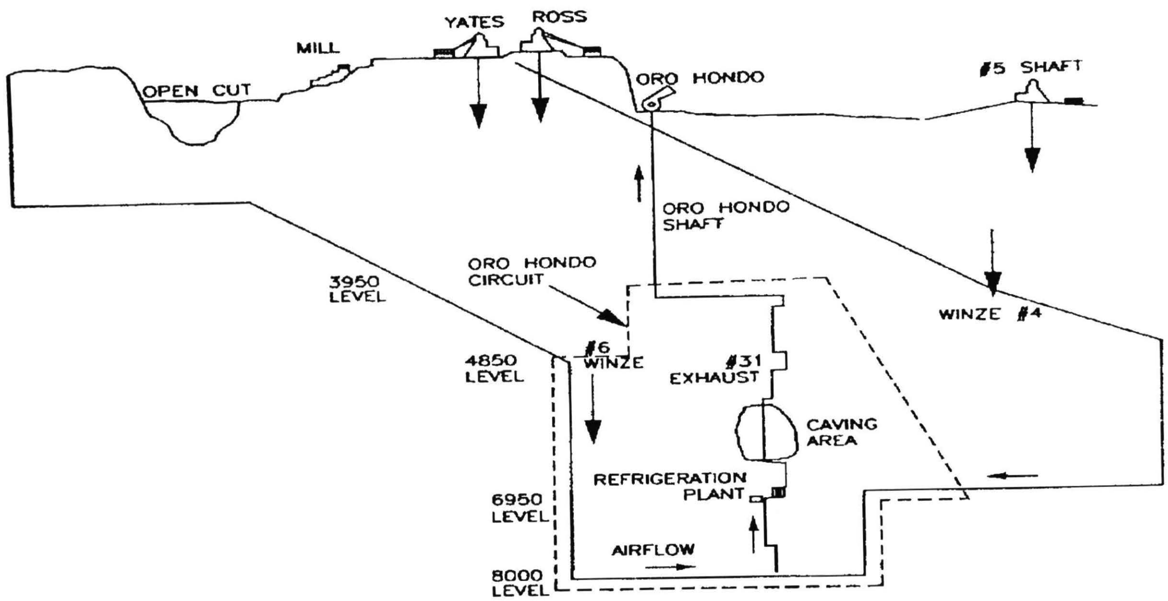

Figure 1. Longitudinal Schematic of the Homestake Mine, Lead, South Dakota.

cleared after two days of blasting. Consideration was first given at that time to either stabilizing that section or replacing it. Contingency plans were also formulated to minimize the impact on production should the caving accelerate. However, the raise seemed to behave itself for the next year. Then in August 1993 a major caving occurred. Slabs plugged the offset once again, and the bottom of that section on 6800 level. Attempts to drill and blast the slabs were only partially successful. The waste extraction hole bored from the 6800 to 6950 levels in 1991 became plugged. A ramp had to be driven nearby the extraction borehole in an attempt to free the hung up raise. Mine personnel were shocked when a visual and cavity monitoring survey revealed large caving areas in #31 Exhaust between the 6050 and 6500 levels. These caving areas are shown in Figure 2. A rock mechanics assessment concluded that the "unraveling" had gone too far and that a replacement raise should be planned. The raise had reached a critical diameter and the spalling was unstoppable.

PLANNING FOR THE NEW RAISE

After much design consideration it was decided to bore a vertical raise. The strong foliation of the Homestake formations imparts much deviation on holes drilled or reamed. With a vertical hole, it is far easier to control deviation. A tentative location was selected far enough from existing mine workings. Diamond drilling was conducted on three different levels to determine whether the proposed site was suitable for raise placement. The drift on the bottom of the raise would have to be driven through a known major shear zone so the raise could be placed to the east of the shear structure. Figure 3 shows the condemnation drillhole layouts and rough geology within the area of the proposed raise. The top of the hole, shown in Figure 4, was on the 5900 level. The borehole chamber is roughly 169 m from the mining areas. The bottom of the hole is roughly 55 m from the mining areas as shown in Figure 5. The new system was designed to have the same resistance as the old system for the deep mine. As the center of mining progresses deeper, controlling the resistance of the Oro

Hondo circuit becomes even more critical. Calculations showed that a 4.27 m diameter raise with 5.2 m by 3.7 m connecting drifts would give a slightly higher resistance than the present system. However, the new system would effectively move the raise away from the mining areas. The proximity of #31 Exhaust to the mining areas is one of the main factors that led to its demise

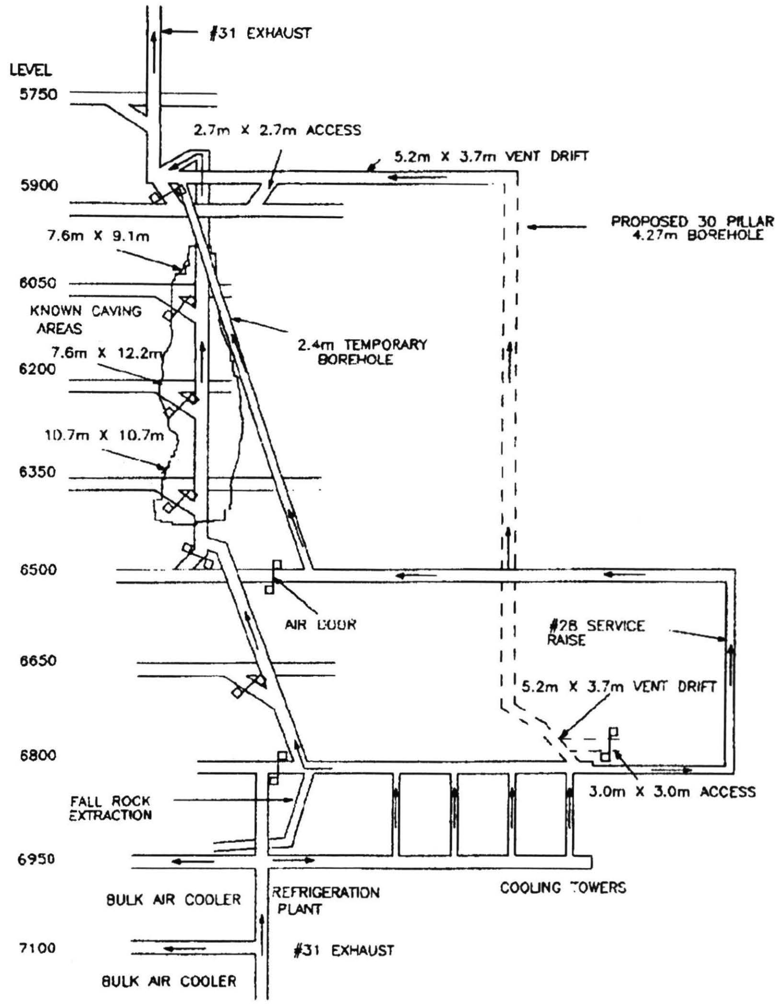

Figure 2. Detail of the #31 Exhaust Area, 5900-7100 levels.

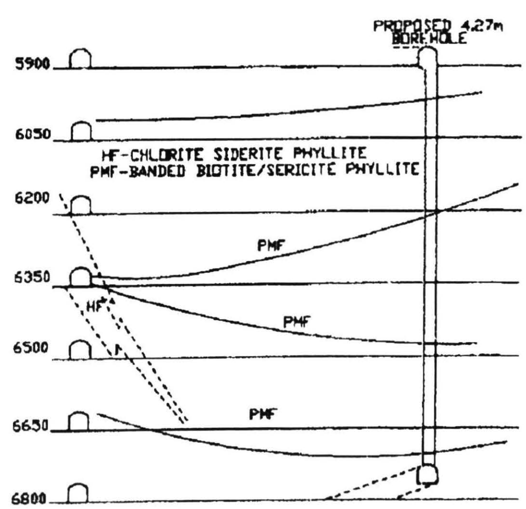

Figure 3. Condemnation diamond drillhole layouts and geology for the proposed raise location.

THE TEMPORARY SYSTEM

An action plan was formulated to prepare for the worst. If caving in #31 Exhaust accelerated, while the new system was being installed, the operation had to have a contingency plan to provide airflow for condenser heat rejection in the Ventilation Plant. This plan centered on using 28 service raise from the 6800 to 6500 and a new 2.4 m borehole to be reamed from the 6500 to the 5900. The contractor prior to setting up on the 4.27 m main ventilation hole completed this 2.4 m hole. In June of 1994 caving in #31 Exhaust accelerated. A major fall of ground occurred the weekend of June 4th. Caving accelerated to the point that mucking could not keep up, even with two extraction points on the 6800 and the 6950. By June 14th the fall rock had filled the 4.9 m #31 Exhaust to within 20 m of the 6650 level. Fortunately, the 2.4 m borehole for the temporary system was completed on June 12th. At this point full crewing and much overtime were devoted to finalizing the system. Drill cuttings had to be cleared from the base of the 2.4 m hole on the 6500.

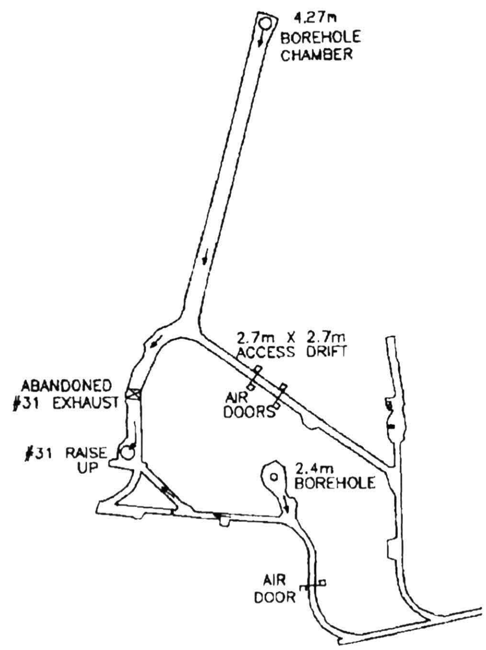

Figure 4. 5900 Level ventilation drift and borehole chamber.

A connection had to be blasted through from the 6500 to #31 Exhaust. An airdoor and a seal had to be erected and two old airdoor frames had been removed. Two reconditioned and shop-tested 93kW fans were installed in a bulkhead at the top of the 2.4 m borehole to help the Oro Hondo surface fan to cope with the higher resistance. While all of this urgent work was being completed, airflow in the lower part of the mine dropped 60%. During this period it was only possible to run a single refrigeration machine in the 6950 ventilation plant, this being a 66% reduction over normal operation. The controlled recirculation fans were left running during this period to provide some air movement.

After the temporary system was completed, initial results were encouraging. The system successfully moved 109 m^3/s through the cooling towers and three refrigeration machines were run. However, this was short-lived. Four 93 kW fans in succession had to be replaced as motors ground faulted and blades were shed. It is still unclear what caused these failures. The falling of rock in #31 Exhaust eventually plugged off even the 6500-access drift in early July.

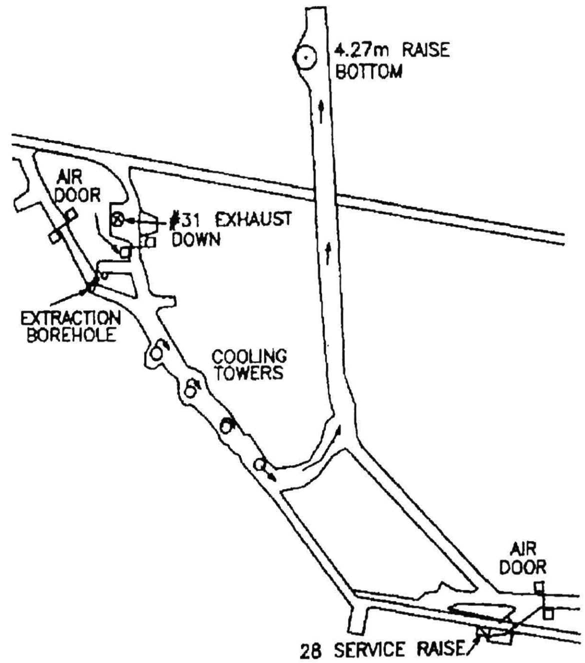

Figure 5. 6800 Ventilation drift and cooling tower comple

This made it difficult for the Oro Hondo fan to pull air up #31 Exhaust in parallel with the 2.4 m bore. Con-sequently, the air temperature passing through the cooling towers spiked from 27.5°C to 31.1°C wet-bulb. Moreover, working faces in the deep mine rose an average of 3.6°C. Stope air temperatures on the 7700 and 7850 levels rose to 32.2°C. This is 2.8°C higher than the design wet-bulb reject temperature of 29.4°C. The 5900 fan bulkhead was then dismantled and new bulkhead erected over the cooling tower dam wall on the 6950. This put the fans in a less hostile environment for operation and from a servicing standpoint. Servicing these fans would no longer require a plant shutdown. The fan bulkhead was completed on July 12th. Immediately following yet another ground-faulted 93 kW fan, two new belt driven fans were purchased on a rush order and installed on the weekend of August 6th. The operation experienced continued troubles in attempts to run three refrigeration machines with the temporary system.

DRIVING THE VENT DRIFTS

The plan on the 5900 level was to connect the top of the borehole to the remaining #31 Exhaust raises by 169 m of 5.2 m by 3.7 m arched ventilation drift. Due to the corrosive nature of exhaust air, resin-rebar bolts were installed after all the primary split-set support was installed. Figure 6 shows a cross-section of the 5900 and 6800 ventilation drifts. A six-man, two-shift crew drove the drift. With a virgin rock temperature of 42°C a 105 kW spot cooler was required during the mining operation. Before the ventilation drift on the 5900 level could be started, a 64 m long 2.7 m by 2.7 m access drift to the main ventilation drift was driven. Over 9616 t of waste were generated on this level from this project. No waste is normally skipped at the Homestake Mine. So this 5900 level waste generation produced some logistic challenges. Most of the rock was car-loaded and then trammed some 1.7 km to the south end of the mine. Mining was accomplished using a MJM 20B-face jumbo and a 1.5 m^3 Load-Haul-Dump. An Atlas Copco LM 56 track mucker was used for the right side of the drift. It was necessary to carry track to the face to facilitate moving the borehole machine and power packs to the cutout.

On the 6800 level the bottom of the borehole had to be connected to the existing cooling towers. The cooling towers serve as heat rejection for the 8MW-ventilation plant, which serves the deep mine. A 114 m ventilation drift 5.2 m by 3.7 m would have to be driven. Connecting to the south end of the cooling tower complex serves to better distribute the condenser heat rejection airstream. Prior to driving this new 6800 ventilation drift, 110 m of 3 m by 3 m drift were driven from the stoping areas. On the 6800 level more than 10,650 t of drift waste and 11,795 t of borehole cuttings would have to be disposed of. Several stopes previously scheduled to be backfilled were "held open" to accommodate this waste. Ore production did suffer to some extent. Mining on the 6800 level was entirely rubber tired; a 2.7 m^3 loader and a MJM 20B face Jumbo. Due to the shorter drive distance a four-man mining crew was used. When the request for expenditure for the replacement raise was approved, work immediately started on the connecting ventilation drifts on both the 5900 and 6800 levels. Drifting was completed in May 1994.

THE BIG VENTILATION BOREHOLE

The borehole contractor moved off the 2.4 m hole and moved to the big hole in mid-July. The 256 m pilot hole was completed on August 2nd. As mentioned earlier, the fact that a vertical hole was drilled, enabled the contractor to hit within 3 meters of his target. The author lost a beer on that wager. The 4.27 m reamer was attached on August 12th and reaming commenced. After reaming just 20 meters, the stabilizer rods got stuck in the pilot hole due to squeezing ground. Fortunately, the modified Robbins RBM7SP was able to generate enough downward thrust to push the rods and reamer back down the hole. Both the contractor and Homestake breathed a sigh of relief. After boring resumed, operations were shut down again at 57-meter mark, when a connection between two of the stabilizer rods broke. Then the stem on the reamer itself broke at the 83-meter mark on September 16th. At this time the contractor and Homestake decided to have the entire reamer assembly redressed. Boring resumed on October 22nd but the reamer twisted off yet again at 160 meters. This time the failure occurred at the first stabilizer rod. Boring resumed in the second week of December. The reamer dropped for the fourth and final time at 219 meters. This time it was decided to remove the wings from the reamer and reduce the hole size to 3.7 meters. The big ventilation hole was finally completed in early February 1995. Following demobilization of the boring machine the new ventilation borehole was visually inspected. Conditions looked good and no spalling of rock was noticed. Two to three weeks later, the 90-degree corner at the top of the raise was blasted off to reduce the shock loss at the top of the raise. This was accomplished using a Boart BCI-2 longhole machine.

FIELD VERIFICATION

During the planning of the new ventilation raise, it was determined that a 4.27 m borehole with connecting drifts of 5.2 m by 3.7 m would give an acceptable resistance for the #31 Exhaust replacement. Resistance for the new raise excluding the connecting drifts would be the sum of the entrance and exit shock losses and the raise itself. There is also a shock loss due to the contraction of the raise about 40 meters from the collar. In the original planning phase, this shock loss for contraction was not anticipated. The equation used to calculate the entrance and exit equivalent Atkinson resistances:

$$R_{SHOCK} = X\rho/2A^2 \ (Ns^2/m^8) \qquad (1)$$

where:

X = shock loss factor
ρ = air density (kg/m^3)
A = area of opening (m^2)

These resistance components were then added to the bored raise resistance, the rational turbulent resistance, dependent solely on geometric factors and having units of m^{-4} and expressed by the following equation (McPherson, 1993).

$$R_t = \frac{fLper}{2A^3} \ (m^{-4}) \qquad (2)$$

Where,

f = Coefficient of friction (dimensionless)
L = length of the airway (meters)
per = airway perimeter (meters)
A = area of the airway(m^2)

The dimensionless coefficient of friction is calculated from the Von Karmen equation. This equation relates the asperity height *e* with the airway diameter *d*. For fully developed turbulent flow the Von Karmen equation gives:

$$f = \frac{1}{4[2\log_{10}(d/e) + 1.14]^2} \quad (3)$$

Using a psychrometric program and the state points for air entering and exiting the raise, the air densities will be 1.066 kg/m^3 and 1.138 kg/m^3 respectively. From these densities and equation 1, the entrance and exit equivalent Atkinson resistances are 0.00052 Ns^2/m^8 and 0.00058 Ns^2/m^8. These are then added to the raise resistance calculated from equations 3 and 2.The asperity is assumed to be .0254 m and the diameter of the airway is 4.27 m. The dimensionless coefficient of friction calculated from equation 3 is:

$$f_{raise} = \frac{1}{4[2\log_{10}(4.27/0.0254) + 1.14]^2} = 0.0080 \quad (4)$$

from this the rational resistance of the raise is calculated from equation 2.

$$R_{raise} = \frac{(0.0080)(252.7\ m)(13.41\ m)}{2\ (14.30m^2)^3} = 0.00464\ m^{-4} \quad (5)$$

This rational resistance is then multiplied by the anticipated mean density in the raise itself. At a mean density of 1.102 kg/m^3, the raise resistance is 0.00511 Ns^2/m^8. The three resistance components are added to give 0.00619 Ns^2/m^8.

After the project was completed and the new system commissioned, the resistance of the raise with the entrance and exit losses was measured in the field. The gauge and tube method was employed. Approximately 274 m of 6mm tube was dropped down the borehole and pulled out towards the cooling towers so that the entrance shock loss would be captured. The total pressure drop was then measured with a digital manometer. The pressure drop measured 256 Pascals and the airflow measured 151.6 m^3/s. From the square law, and solving for the resistance.

$$p = RQ^2, \qquad R = p/Q^2 \quad (6)$$

where,
p = pressure drop (Pascals)
Q = airflow quantity (m^3/s)
Inserting measured field values we get,

$$(256Pa) / (151.6m^3/s)^2 = 0.01114\ Ns^2/m^8 \quad (7)$$

The measured resistance is 80% higher than the estimated resistance. One of the reasons for this is the last 40 meters of the raise is not 4.27 m in diameter but, 3.66 m in diameter. Moreover, the shock loss at the bottom of the raise more closely approximates a branching flow because the pilot hole missed the drift centerline by 8 feet. The drift also extends beyond the borehole so the air may have to double back to enter the raise. However, in planning for the new raise system, we had underestimated the resistance of the old #31 Exhuast raise. Most of this error was due to the constriction on the 6800 level where the air enters the main raise.

COST

The project budget and schedule were submitted in December 1993. The $1,739,000 budget was composed of $15,000 for rock structure analysis, $502,000 for 5900 level development, $443,000 for 6800 level development, $394,000 for the 4.27 m diameter borehole, $228,000 for the temporary system, and $157,000 for a 10% contingency. Work was completed in February 1995 at an actual cost of $1,475,000. The contingency was not needed. Drifting came in under budget while the temporary system was over. Driving 5.2 m by 3.4 m drift cost $1,732 per meter, everything included. The 4.27 m borehole came in slightly over budget. Total borehole cost was about $1,830 per meter which included prepping the machine site, drilling the pilot hole, reaming the bighole, repairing the cutter head when required, and mucking the cuttings.Costs for repairing the cutter head were shared by the contractor and Homestake.

CONCLUSION

Performance of the new 30 Pillar exhaust raise has met or exceeded expectations. Although measured resistance of the raise was 80% higher than estimated, airflow through the cooling towers increased after it was commissioned. This implies that the old #31 Exhaust section had an even higher resistance.

The project came in under budget although completion was delayed by four months. In hindsight, the only thing we would have done differently is to have started earlier. It would have saved additional mucking costs and thousands of ounces of lost production. Once an old raise begins to unravel, it should be either re-supported or replaced. Several factors led to the failure of the original raise. It was too close to existing stoping areas, rough-blasted instead of bored, not bolted or shotcreted, and the exhaust air temperature increased from 29° to 40°C in 1988 after the 6950 Vent Plant was commissioned. There is evidence that even mild thermally induced stresses caused by a temperature change can help destabilize rock mass.

REFERENCES

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