Horizontal principal stress measurement & determination of stress gradient at the New Afton Mine, Kamloops, British Columbia

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Abstract

Knowledge regarding the variability of stress magnitude and orientation at depth is vital to the successful design of large underground excavations. A series of accurate in-situ stress measurements can reveal zones of heightened risk and instability, allowing mine operators to plan for and implement appropriate control measures. In October 2018, New Gold, Inc. contracted Agapito Associates, Inc. (AAI) to perform downhole in-situ stress testing at their New Afton Mine, located near Kamloops, British Columbia, Canada. AAI used the Sigra In-situ Stress Tool (IST), a displacement measurement overcoring tool developed by Sigra, Pty. (Sigra) of Brisbane, Australia. The test hole was collared approximately 706 meters (m) below ground surface and drilled to a depth of 451 m, with 17 stress measurements evenly distributed to the total depth (TD). The campaign objective was to measure the horizontal stress field below the current mining operations and to determine a stress gradient down to the future planned mine level. Measurements obtained ultimately contributed to definition of the long-term geotechnical mine design at the New Afton Mine. This paper serves as a case study for the application of stress measurement methods when employed in succession down a vertical hole and the resultant implications regarding the local stress gradient.

1 Introduction

The magnitude and orientation of horizontal stresses, their relationship with lithostatic forces, and the mutual influence on and by underground excavations are primary factors contributing to ground instability. A critical prerequisite when planning appropriate ground control in an underground mine is accurate and thorough data regarding the local stress field. New Gold, Inc. commissioned AAI to perform downhole in-situ stress measurements at the New Afton Mine (New Afton).

New Afton is an underground, block-cave operation near Kamloops, British Columbia, Canada, approximately 240 kilometers (km) northeast of Vancouver. Figure 1 depicts the location of the New Afton Mine. Primarily a gold and copper producer. New Afton is situated in the southern Canadian Cordillera and hosted by late-Paleozoic and early-Mesozoic volcanic and sedimentary rocks of the Quesnel terrane. The drill hole for IST operations (Figure 2), UAC-07, was collared 706 m below ground surface and drilled vertically down to a depth of 451 m, with 17 stress measurements evenly distributed throughout. UAC-07 was strategically placed above a zone of the New Afton deposit designated for future mining operations.

Drilling operations and stress measurement activities at New Afton occurred during October of 2018. Atlas Drilling of Kamloops, B.C. was contracted to perform two 12-hour shifts per day. AAI Rock Mechanics Technicians supervised the core drilling operations, including picking test depths, conducting IST tests, and assessing preliminary results while on-site.
AAI employed the IST measurement tool and downhole techniques developed by Sigra of Brisbane, Australia. The Sigra IST operates in conjunction with a wireline coring system which permits stresses to be measured at depths up to 2,000 m (Sigra 2017). The IST measures the diametral deformation of a small-diameter
(25 millimeter [mm]) pilot hole using a series of six strain gauge pairs. When overcored by a larger (61-mm inside diameter) HQ3-size bit, stresses acting upon the pilot hole are relieved and recorded by the IST as radial displacement proportional to the initial stress level. In addition, three-component magnetometers and accelerometers record the orientation of the tool with respect to magnetic north and the tool inclination within the hole. An additional sensor monitors the downhole temperature. Subsequently, the core containing the pilot hole is recovered and, with the IST still in place, the elastic properties and Poisson’s ratio are measured. The IST overcoring data, in conjunction with these rock properties, are then used to calculate the in-situ stress magnitude and orientation in a plane perpendicular to the drill hole.

### 1.1 Geologic setting and regional horizontal stresses

The New Afton Mine is a gold and copper deposit hosted by intermediate to mafic volcanic rocks of the Triassic Nicola Formation. Regional-scale fault zones serve as the principal controls for the emplacement of the batholithic rocks and related porphyry-style mineralization (New Gold, Inc. 2019). The drill hole for IST operations, UAC-07, was collared 706 m below ground surface and drilled vertically down to a total depth of 1,157 m below surface. Upper drill hole lithology was predominantly propylitic-altered fragmental polylithic volcanics and transitioned to potassic-altered crystalline volcanics between 140- and 160-m down hole.

Knowledge of prevalent regional stress regimes, along with their history and causation, can lend added understanding to local results. To understand the predominant regional stresses acting upon south-central British Columbia, and the New Afton area, it is critical to first consider the regional and continental tectonics that formed and continue acting upon the Western Cordillera of Canada. Regional-scale horizontal stresses throughout British Columbia are a direct remnant of past and ongoing tectonic activity along the western coast of North America. Beginning in the early-Mesozoic era, a series of allochthonous terranes on the Pacific Plate approached the continental margin in a northeastwardly direction of movement before being accreted onto the North American plate. The Quesnel Terrane, which hosts the New Afton deposit, was fully amalgamated on its east and west margins by the late-Jurassic period (Silberling and Jones 1984). Although the continental margin along western Canada now exhibits a combination of strike-slip and subduction, measured horizontal stress tensors throughout British Columbia overwhelmingly maintain a north to northeasterly orientation as shown in Figure 3 (Heidbach et al. 2016).

### 2 Stress measurement procedure

The downhole Sigra testing method is performed in the following sequence, as shown in Figure 3.

The vertical drill hole is advanced to a predetermined depth (Figure 4A). The core tube is retrieved via wireline. Inspection of the HQ3 core can reveal either competent rock suitable for testing or a heavily fractured zone leading on-site personnel to further advance the drill hole in search of competent rock. Upon reaching a suitable test horizon, the core tube downhole is replaced with a customized countersink tool (Figure 4B). The countersink assembly locks into the outer core barrel, allowing it to rotate with the drill string. The countersink tool grinds any core stump left behind by the HQ3 bit and then produces a tapered counterbore to center the pilot hole within the HQ3 96-mm-diameter bore.

The countersink assembly is then retrieved via wireline and replaced with the pilot hole assembly. A water-pressure-actuated piston provides thrust on the 25-mm pilot hole thruster bit. The locking mechanism used with the countersink is again used to transmit rotation to the center string. When the thruster bit advances the 25-mm pilot hole beyond 50 centimeters (cm) depth, the piston mentioned above advances past water-bypass ports initiating a drop in water pressure. The water pressure drop signals pilot hole completion (Figure 4C).
Prior to removing the pilot hole tooling, the hole is flushed to clear drill cuttings. The pilot hole assembly is then retrieved via wireline and the Sigra IST is lowered downhole. The IST placement device is accompanied by a substantial setting weight, which ensures the IST sets fully into the pilot hole. The leading point of the IST is equipped with a brass-configured triple-wedge system which locks the tool into the pilot hole (Figure 4D). The setting weight and placement device are then retrieved from the hole.

The drill rods are lifted 5 m off the hole bottom (Figure 4E). The rods are held in this position for a minimum of 5 minutes, eliminating any magnetic interference from the metallic rods while three-component magnetometers and inclinometer-accelerometers record the orientation of the tool with respect to magnetic north along with tool inclination.

After lowering the drill rods and pumping the inner core tube downhole, overcoring of the IST proceeds (Figure 4F). To minimize vibration during overcoring, rotation and feed rates are maintained at lower levels relative to typical coring operations. The portion of the IST responsible for measuring diametral deformation of the pilot hole (Figure 4D) is equipped with six pairs of pins; each pair is offset 30° from the pair above or below. An internal data logger records diametral measurements and downhole temperature at a rate of once per 4 seconds.

Upon completion of the overcore run (Figure 4G), the inner core tube is retrieved via wireline, carrying with it the cored interval and the IST locked into the pilot hole. The core and IST are extracted from the core tube, then measured and photographed. The battery powering the IST is then removed and the tool is connected to a personal computer (PC). The magnetometer and accelerometer data, the downhole temperature readings, and the diametral measurements are downloaded to the PC (Figure 4H).
If the core adjacent to the IST pin zone remains unfractured, the battery is reinstalled, and the core and IST are placed inside a biaxial chamber, also called a Hoek Cell (Figure 5). With the IST measuring pilot hole deformation, the biaxial chamber is pressurized incrementally, yielding the Young's modulus of elasticity. If fractured core prevents use of the biaxial chamber on-site, a representative sample of HQ3 core can be recovered from near the overcored zone and tested for rock properties in a laboratory setting.
Figure 5  Biaxial compression chamber, or Hoek Cell, used to measure elastic properties of the tested zone

3  Data analysis and results

Borehole diametral deformation measurements combined with the elastic properties of the host rock may be used to determine the magnitude and orientation of stresses acting within a plane perpendicular to the borehole axis (Bickel 1993). Data compiled to assess stresses at the New Afton Mine included:

- Diametral deformation measurements from 17 Sigra IST tests spaced over one vertical borehole
- Orientation data collected by magnetometers and inclinometer-accelerometers within the Sigra IST and prior to each stress measurement
- Elastic properties of host rock gathered through on-site testing of intact core using a biaxial compression chamber; when not possible due to fractured core, samples of adjacent core were tested at AAI’s rock properties laboratory

Figures 6 and 7 illustrate the calculated major (P) and minor (Q) stress magnitudes in the horizontal plane and their azimuthal orientations with respect to depth. Also shown in Figure 6, the vertical stress gradient was estimated to be 0.025 megapascals per meter (MPa/m) of overburden due to gravity loading.

The magnetometer and inclinometer data were used to determine the orientation of the downhole instrument relative to magnetic north. The orientations were then converted to true north bearings using a magnetic declination of 16.0°E. True azimuths of the principal horizontal stress ranged from 276.2° to 33.1°. The average principal horizontal stress orientation is 345.5° (N14.5°W). The average secondary stress orientation is then east–northeast, or 90° from the principal stress.
Figure 6  Secondary principal horizontal stress magnitudes relative to depth

Figure 7  Secondary principal horizontal stress orientations relative to depth
The major secondary principal horizontal stress ranges in magnitude from 13.0 to 56.1 MPa, and the minor secondary horizontal stress ranges from 7.5 to 41.6 MPa. The measured stresses were compressional. It is apparent that these ranges provide a challenge when discerning a predictable stress trend with depth. However, the range and trend of the measured stress relates to the elastic modulus values (shown as ‘E’ in Figure 6) obtained from biaxial testing. The data suggests stress heterogeneity from material property contrasts along the drill hole. Therefore, stress characterization should not primarily focus on a representative linear stress tensor but consider the details of spatial variations within the rock mass due to tectonic straining.

4 Discussion & Conclusion

An accurate and thorough assessment of the stresses acting upon a rock mass or civil structure is vital to the success of numerous engineering and safety objectives. Whether used as a stand-alone component or as input to numerical models, stress measurement data sets would be key components in any of the following:

- Determination of excavation methods
- Ground support design
- Orientation of large-scale underground excavations
- Stability of underground structures (tunnels, caverns, shafts, etc.)
- Prediction of rock response (heaving, rock bursts, conjugate shearing, etc.)
- Joint and fracture propagation and prediction

Furthermore, a one-time assessment of stresses as a precursor to planning and action would often be short-sighted considering how the planned excavation itself will alter the native stress field. Long-term monitoring and/or periodic re-measurements are usually necessary to adapt accordingly (Ljunggren et al. 2003).

In October of 2018, over the course of twenty-five 12-hour shifts (12 days/13 nights), 17 overcore measurements were attempted at New Afton Mine of which 14 measurements proved successful. Data quality from the 14 successful stress measurements is considered good, with a high level of confidence given to the calculated results. With detailed stress characterization, it is recommended to integrate results from different methods. New Afton has utilized CSIRO Hollow Inclusion Cells (Worotnicki and Walton 1976; Worotnicki 1993) within current mine workings, along with Sigra IST biaxial stress measurements at depth to obtain stress measurements where no current tunneling is present. This has allowed the New Afton technical team to update geotechnical studies on deeper mining levels, such as numerical models of cave profile growth, ground support design for development and large excavations, and mine footprint design with respect to principal stress orientations and magnitude.

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References


