Fiber Optic Strain Experiment (FOSE): Deployment of a Run-of-Mine Distributed Strain Measurement Network

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Opportunity

Fiber optic measurement systems based on time domain optical reflectometry and Fabry-Perot diffraction interometry make it possible to measure distributed and localized strains over kilometers of distance. The accuracy of the distributed system is currently two microstrains over a one-meter resolution distance. Experimenter-selected lengths of fiber can be anchored point-to-point and strung along or across mine drifts in a network of chords that function as extensometers. A three-dimensional network could be constructed through a subset of the 500-km of drifts in the 10 km^3 volume of the former Homestake mine. It is reasonable to think in terms of tens of kilometers of access within whose volume various loads will occur on times scales from days to years: barometric and earth tide, mine dewatering, seasonal water table changes, long-term creep from existing drifts and shafts, and new excavations. The magnitude of the strain signal will not be observable at the largest scales in all cases. Nonetheless, as DUSEL is anticipated to operate over several decades, a run-of-mine fiber optic monitoring and measurement system would provide robust baseline deformation information over large volumes. The distributed and localized strain measurements will provide a crucial infrastructure data base for several geomechanics, hydrology, and geoengineering experiments. The large volume of coverage makes it ideal for calibrating a mine-scale finite element model of deformation. As such, the fiber optic strain experiment will contribute to design and construction of large rooms and to mine safety. Specifically, the fiber optic strain deployment will contribute to: (1) understanding how rock masses deform as a function of spatial scale over long times, (2) interpreting mine seismicity experiments, (3) testing of the coupling between fracture flow and deformation, and (4) safety as it provides a large-volume indication of the mine “breathing” and it can be deployed with a common measurement protocol for shaft and cavern monitoring.

Technique

Long baseline fiber optic measurements of distributed strain and temperature have been utilized in several geotechnical projects, including dam foundation measurement and landslide monitoring with reported lengths up to 50 kilometers. The same technology has been used in monitoring bridge deformation and in petroleum industry boreholes. Several advantages of distributed fiber optic measurements include: daisy chaining (no big bundle of electrical cables), time stability, combining fiber-as-sensor with short-gage-length sensors. Fiber optic devices are highly versatile. They can be used in configurations that run from using armored cable itself as extensometers of any length to strain gages made of fiber Bragg gratings (FBG). These systems can be run in parallel so that displacements over baselines of meters to tens of meters can be compared with localized measurements across discontinuities or inhomogeneities to provide cross checks and context for measurements at these different scales. A separate temperature fiber can be run, which gives 0.1 ^{o}C accuracy over a one-meter resolution length. Temperature might be useful for sensing fluid flow in fractures. Temperature measurement also acts as a safety device for detecting anomalous heat sources (fire).

Cost

Preliminary discussions with vendors Micron Optics and Omnisens lead to the following cost estimates. The distributed, Brillouin system for distributed strain and temperature requires an analyzer that costs about $150,000. This provides a single channel with a sampling rate of approximately one minute depending on the length of the fiber. Several channels can be multiplexed using an optical switch ($30,000). Individual strain sensors, which operate analogously to old-fashioned electrical resistance strain gages, cost several hundred dollars apiece, and the FBG analyzer, which can be used for a large number of daisy-chained sensors, costs $30,000. Armored fiber costs $4/meter. The total equipment cost will depend on configuration, of course, but the capital cost for a reasonable experiment covering several kilometers of drift would be approximately $300,000 - $500,000.