The borehole camera: An investigative geophysical tool applied to engineering, environmental, and mining challenges

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Thousands of shallow holes and wells are drilled each year to assist engineers, geologists, geophysicists, hydrologists, and other professionals investigate, inspect, and evaluate near-surface geologic conditions that may impact surface structures and/or to gain in-situ subsurface information. Drilling is the litmus test to confirm interpretations made on various scientific data sets applied to petroleum, mining, engineering, and environmental challenges. However, traditional drilling and logging techniques can yield residual inconclusive data for rational assessments because small fractures, washouts, thinly laminated layers, minor casing damage, etc., may be too small for standard logging tools to detect. To close this uncertainty gap, borehole camera (BHC) systems can be employed to enhance the investigation and inspection of shallow holes. The capabilities of this simple optical imaging tool have, until now, remained underutilized.

Technological advances in electronic component design and sensing devices in the last decade have enabled the development of cost-effective BHC units that can operate in both wet and dry conditions. The slim-line design allows the BHC to easily operate in small-diameter holes commonly used in near-surface exploration and assessment studies. A videocassette recorder attached to the BHC records the entire survey. The videotape can subsequently be played back in the office for those who were not at the well site to examine the survey results. Real-time video inspection of open and cased wells can be used to determine the success of drilling operations and can also show images of potential problem areas. In some cases, the recorded videotape has served as evidence in court where survey results quickly resolved litigation, thus saving time and money.

Borehole camera. The cost of current slim-line BHC units for near-surface applications varies from the least expensive portable black-and-white

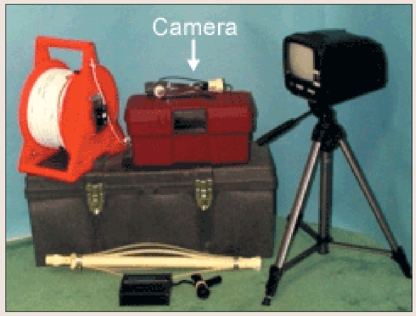

Figure 1. System components of a portable B/W, 1.25-inch diameter camera.

(B/W) to the more expensive motorized-winch color systems. The portable units require two persons to operate effectively in remote areas with limited access. More sophisticated BHC systems can be redesigned and mounted inside a vehicle to help protect the operator and electronic components from adverse weather conditions. Although the depths of most shallow BHC surveys are less than 500 ft, a modified BHC can operate up to a depth of 1600 ft. Borehole cameras designed for petroleum applications can survey at much greater depths. Due to the camera's high sensitivity to light, low-power auxiliary lights attached to the camera head provide adequate illumination for improved visualization of borehole conditions.

Portable B/W, 1.25-inch diameter cameras (Figure 1) are ideally suited to inspect shallow holes and water wells 2- 24-inch in diameter. A tilt feature is incorporated to permit the operator to rotate the camera for side viewing. This simple system has also been used in many search-and-rescue missions in which victims were trapped in wells, caverns, fissures, or collapsed structures. The PVC base permits the attachment of PVC pipe strings to expand its capabilities in horizontal and vertical holes. (A U.S. coal company regularly uses one such system to inspect and map roof rock conditions so that the proper lengths of roof bolts are used to help secure the roof from collapsing, saving time, money, and possibly lives. Other BHC

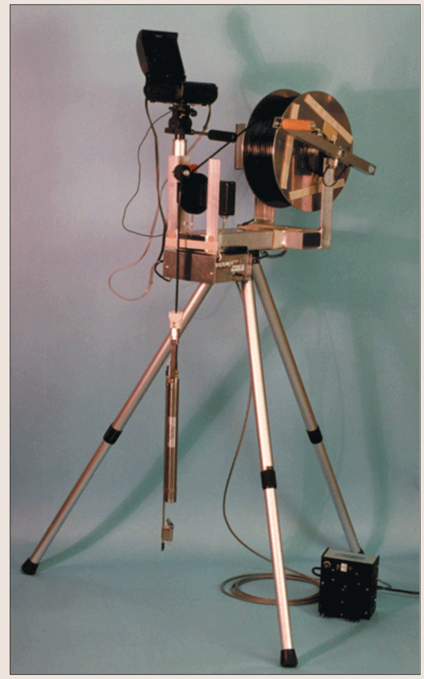

Figure 2. Slim-line prototype color camera system as a portable unit.

units in their inventory have successfully been deployed to address various engineering, environmental, and mining problems.)

Figure 2 shows the prototype of the slim-line color BHC as a portable unit. The camera and electronic components are housed inside a 1-inch-diameter water-resistant stainless steel case. This rugged system can easily be modified to perform up to 1600 ft of surveying depth and modified to operate inside a vehicle. The unit has successfully been employed in boreholes that range in size from 2-inch exploration holes to 15-ft shafts. These BHC systems provide axial views of the holes. Sideviewing is accomplished by a small motor-driven mirror located in front of the camera and tilted 45° from vertical.

Some field results. In cases in which geologic problems are more complex, drilling results may provide partial answers to exploration questions, while at the same time raising new ones. This scenario occurs regularly in

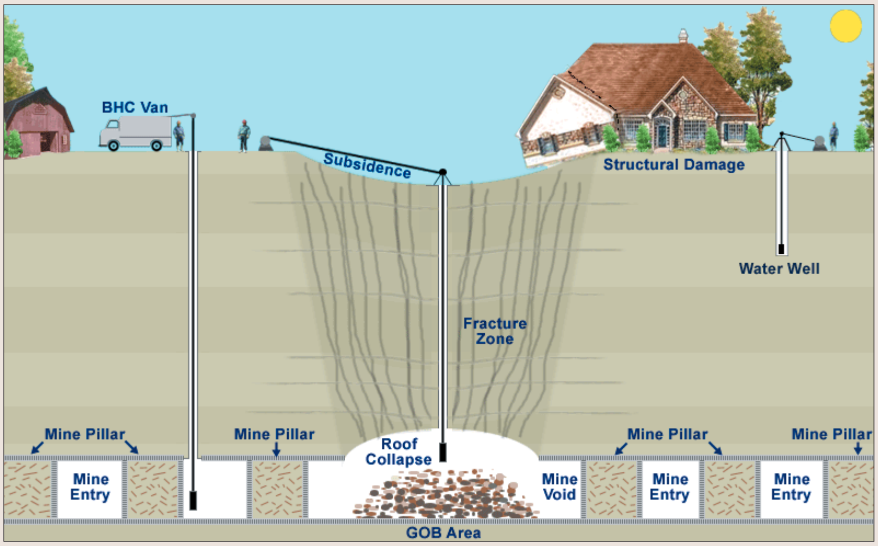

Figure 3. Schematic illustration (not to scale) shows the effects of mine subsidence on surface structures and demonstrates the utility of BHC surveys in enhancing site assessments.

the near-surface environment. When drilling results fail to correlate with the initial interpretation, BHC technology eliminates much of the guesswork by simply showing downhole conditions on the monitor.

In mining operations, voids and cavities are generated when the mineral is extracted (Figure 3). Over a period of time, roof rocks collapse and a fracture zone develops and migrates up to the surface. The ensuing subsidence often damages surface structures. Any plan to properly remediate subsidence problems must first assess the conditions that caused the problems and this requires a thorough onsite surface inspection and subsurface mapping. This is accomplished by drilling shallow holes into the old mine workings and lowering a BHC into each to visually inspect on the monitor pillars, voids, ribs, crib support, and rock piles that may be the source of subsidence.

High-resolution seismic, electromagnetic, and electrical resistivity methods have been successfully employed to detect shallow fracture zones. Cost-effective remediation efforts, however, require more precise subsurface information. Thus, BHC surveys conducted in open holes can facilitate any remediation efforts by showing the location, depth, and magnitude of fractures so that proper backfill operations can be implemented to minimize further subsidence damage. For example, in water wells located near active underground mining operations, lower water tables or dry conditions (assuming normal rainfall and recharge rate) would suggest leakage due to fracturing, as illustrated in Figure 4. The BHC clearly shows a vertical fracture at a depth of 89 ft, an image that would help decide whether to remediate the existing water well or drill a new one.

Unconsolidated rock layers usually create unstable conditions in the borehole because loose rocks could separate from the wall, subsequently

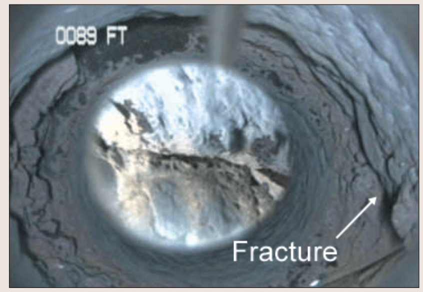

Figure 4. The BHC with a side-looking mirror rotated to the 3:00 position, shows a vertical fracture.

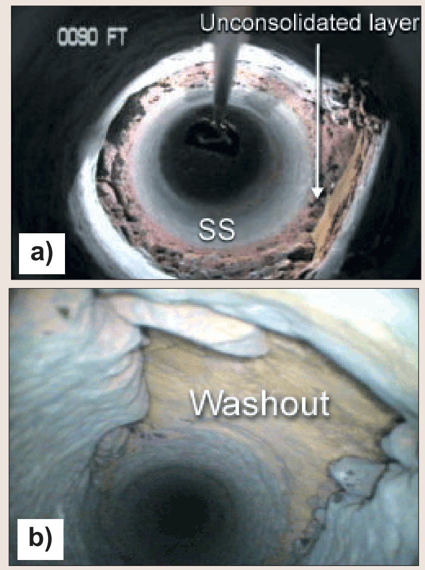

Figure 5. Images of unconsolidated rock layers from boreholes. Washout condition is evident in (b).

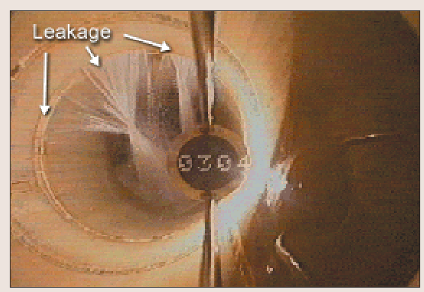

Figure 6. Weak PVC joint is evident at a depth of 304 ft, between 9:00 and 1:00, allowing saline water to infiltrate the pipe (photo courtesy of Welenco).

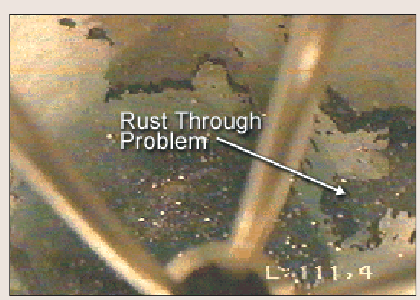

Figure 7. BHC survey shows a rust-through problem (courtesy of Welenco).

filling and clogging the hole. In cases like the washout condition in Figure 5, a BHC survey would normally indicate the need to install such a casing to keep the hole open to support certain operations such as ventilation, dewatering, or other purposes.

BHC surveys are also gaining popularity in increasingly complex and costly well completion operations, in which the companies involved want assurances that their well has no inherent problems. Downhole installations and work (e.g., packers, casing, cementing) are greatly assisted by BHC surveys. In Figure 6, the camera reveals a weak PVC joint that allows saline water from a shallower aquifer to infiltrate a deeper one intended for exploitation. The problem was quickly identified and resolved by a successful well repair job.

Well maintenance is another area in which the ability to visually inspect well conditions is a definite advantage. Figure 7 shows a steel liner in which corrosion has eaten through the liner at some sections. The BHC survey results convinced management not to abandon and replace this old well, but to rehabilitate it at much lower costs because the rust-through problems were found to be isolated.

Conclusion. BHC surveys can complement other geophysical techniques and provide effective solutions when problems or uncertainties are encountered in boreholes. Drilling is still an integral part of geotechnical site assessment, and remediation efforts can be more effective when problems are clearly and properly identified. Even though BHC surveys provide site-specific results in one dimension, the real-time optical images lead to less guesswork; subsequently, assisting engineers and geoscientists develop proactive solutions: saving valuable time, money, and possibly lives.

"Simplicity is the ultimate sophistication"

—LEONARDO DA VINCI

Suggested reading. "Surveying rock structure using a borehole television probe" by Calder et al. (*Canadian Institute of Surveying*, 1972); "Preliminary reports on borehole acoustic televiewer logging" by Lau et al. (Atomic Energy of Canada, LTR-215, 1982); "Subsurface fracture surveys using a borehole television camera and acoustic televiewer" by Lau et al. (*Canadian Geotech J.*, 1987); "Formation evaluation by inspection with the borehole televiewer" by Zemanek et al. (GEOPHYSICS, 1970); "Monitoring of ocean disposal using side-scan radar mosaicing" by Moshier et al. (*TLE*, 1997).

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