Detecting Underground Penetration Attempts at Secure Facilities

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The protection of secure facilities such as forward operating bases (FOBs) and theater internment facilities (TIFs) is an emerging issue in light of the successful and nearly successful underground breaches at overseas bases, along our borders, and at prisons in foreign countries where suspected terrorists are held. The armed forces are now investigating sensor modalities to protect secure facilities, because covert tunnels can conceal and protect terrorist activities, weapons of mass destruction, command and control facilities, and other functions. The technological sophistication observed in some of the tunnels (such as uses of power conduits; heating, ventilation, and air-conditioning [HVAC] systems; reinforced concrete; and other metallic objects) shows a high degree of engineering skill and financial backing. But seismic and acoustic technology that is currently available can be used to span the underground protection gap within our force protection strategy.

During studies conducted at a base camp in Iraq from July-November 2005, the most promising technology used an array of acoustic and seismic sensors placed at various depths to determine the characteristic signatures produced by underground tunneling, as well as signatures produced by personnel and equipment typically located within a base camp (such as generators, vehicles, and heavy equipment). Subsequent analysis determined that local geologic characteristics were of primary importance in governing both surface and subsurface signals of interest.

Site Geology and Test Facility

The general geologic setting of the base camp consists of various layers of fine-grained sediments from surficial windblown silts and sands to compacted silt and clay-bearing layers with varying amounts of gypsum and unconsolidated coarse to fine sands at a depth of 7 meters. All sediments are damp below about 1 meter.

The windblown material is typically well-rounded quartz grains that are 1 millimeter or less in diameter. This mixture of small mineral grains becomes cemented at a depth of about 30 centimeters, apparently due to precipitating gypsum minerals. This top layer gives way to between three or four distinct layers of buff or tan layers that are intermixed with gray-green layers of compacted silts and clay minerals (Figure 1). These layers vary in depth and vertical extent, depending on the location within the camp. Gypsum is present in the upper layers.

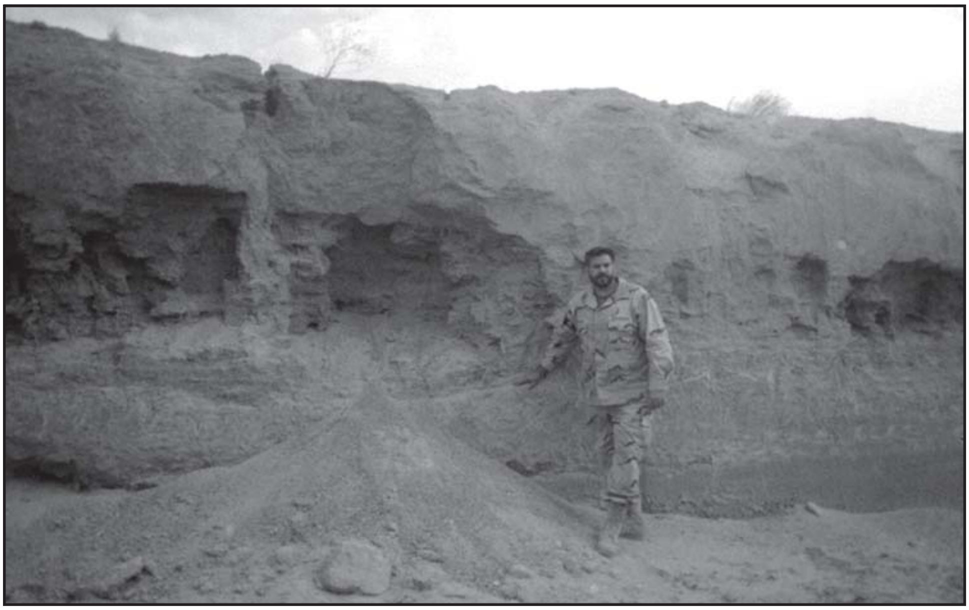

Figure 1. A typical strata sequence in the study area. Note the subtle color changes and weathering differences.

Within the base camp, the natural topography has been disturbed by extensive leveling and building. However, throughout most of the area, an unconsolidated layer of sand is encountered at a depth of about 6.5 to 7 meters. The sand layer has visibly distinct bedding planes occurring at all angles. The overlying silt slumps into the sand layer so there is not a distinct boundary between the two layers.

To validate sensor performance, an 8-meter vertical shaft with an interior side dimension of 1.2 meters (4 feet) was designed and constructed. Camp personnel excavated a pit with a vertical wall (Figure 2) where the shaft was placed so the tunnel would be right at the silt-sand contact (about 7 meters deep at this spot). This allowed about 1 meter of the shaft to stick up aboveground. A pulley system attached to a head frame allowed the spoil to be removed at about 0.25 cubic feet per bucket (about one-third of a 5-gallon bucket).

Figure 3. A look down the tunnel to the working face.

The tunnel leaving the shaft was about 1.2 meters in height and width, and the shoring consisted of vertical posts with 2 by 6 lumber on the top and sides (Figure 3). The tunnel began in the sand layer, and almost immediately, the silt layer slumped into the course of the tunnel from the right, leaving only about one-third of the working face as unconsolidated sand. Thus, the back and sides of the tunnel were constructed in hard silt, which made the tunnel extremely safe. However, it took about 3 days to dig the tunnel to the desired length (6 meters) before testing was initiated. The data collection was initiated at this length in an attempt to minimize any backscatter problems from the digging operations and unwanted clutter noise coming down the shaft and into the tunnel. Analysis of the data could not detect any such spurious acoustic or seismic contamination.

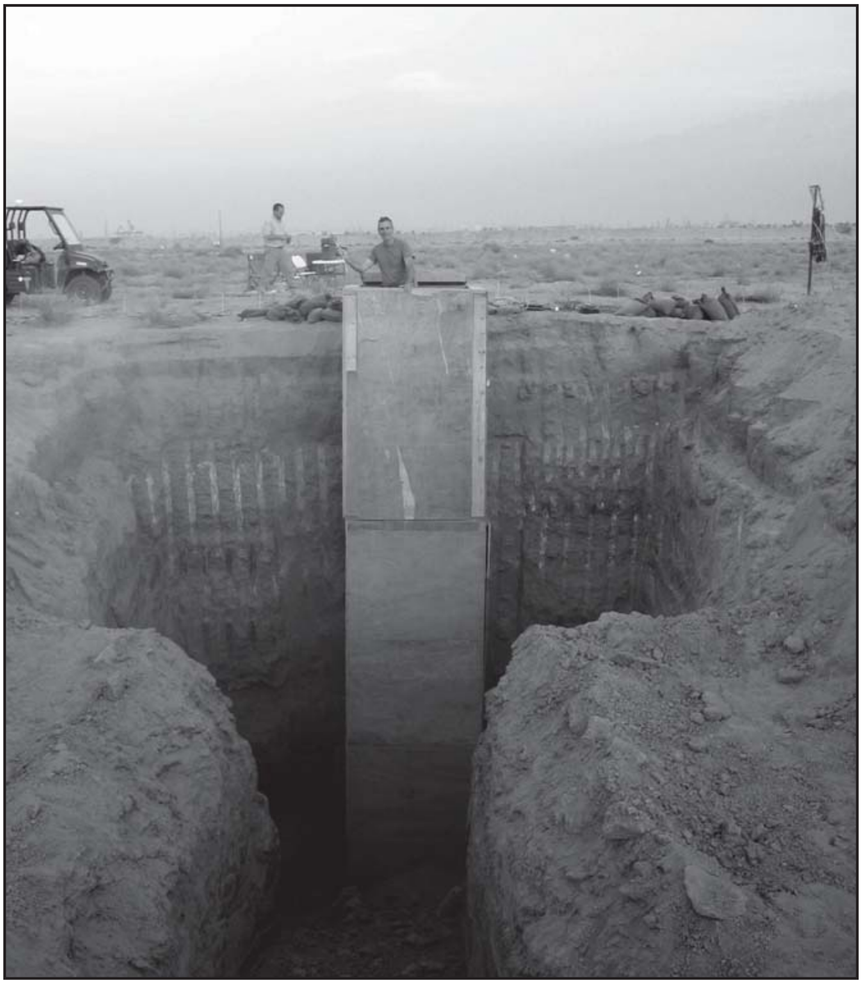

Figure 2. The shaft in place. Note the various layers of compacted silt.

Geophysical Data

The data collection sensors were placed along the line of the tunnel and perpendicular to it. The sensors were also placed at varying depths to determine the attenuation capabilities of the layers for sounds generated at the surface and in the tunnel (such as from trucks, generators, walking, and digging). A variety of data was collected during underground digging operations, which was completed with tools similar to those used by detainees to construct tunnels. After a series of signal-processing algorithm are implemented, it is possible to automatically differentiate signals underground at the 90 percent confidence interval or better (Figure 4).

It is important to note that the near-surface environment is dynamic: changes in the soil conditions in the upper few meters of soil can influence sensor performance dramatically. For example, after the initial series of data was collected, a 36-hour rain occurred. After the rain stopped, a second series of tests was conducted, using the same collection parameters. The particular signature of a source signal did not change, but the amplitudes increased significantly. The increase in the amplitude of the measured data varied from 10-15 decibels (dB) up to 450 hertz (Hz) (Figure 5). This is interpreted to be the infilling of interstitial voids by water, providing a better medium for wave propagation than grain-to-air and grain-to-grain interface. These types of evolving sensor-soil interactions illustrate the need for multisensor protection models and also illustrate why simple threshold detection methods invariably have high false-alarm rates.

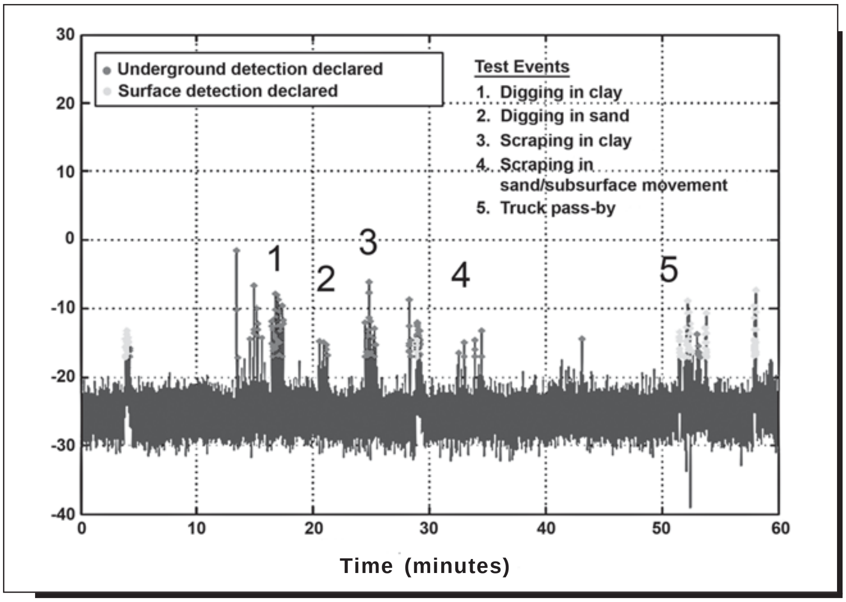

Figure courtesy of BBN Technologies

Figure 4. Results of signal processing to automatically classify signals originating from the surface and underground.

Force Protection Models

Analysis of the test data indicate that passive seismic and acoustic collection arrays will detect and classify active digging operations near a protected facility after advanced signal processing is performed. Emplacement of a seismic/acoustic array will cause a minimal surface footprint or impact to the facility operations. Five concerns need to be addressed to take full advantage of this technology:

- Designing and integrating the seismic/acoustic array into the overall security plans of the facility.
- Constructing the array in conjunction with the facility to minimize costs and maximize effectiveness.

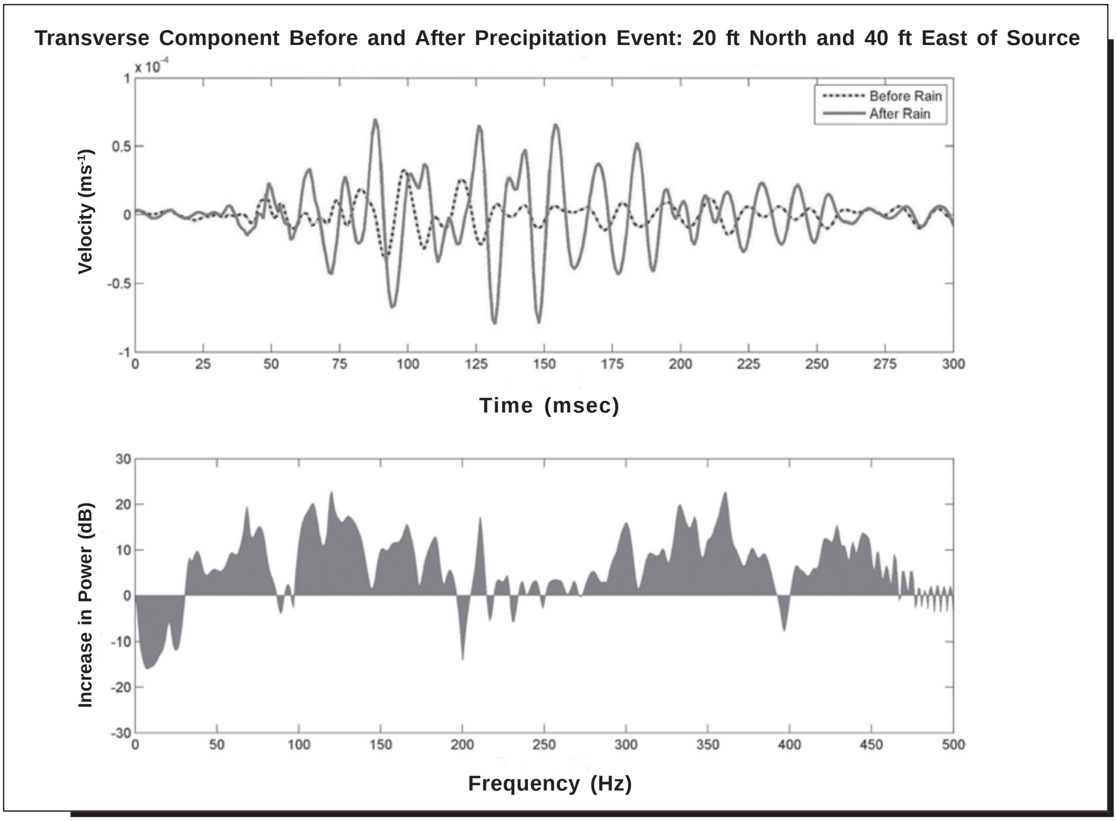

Figure courtesy of Dr. Jason R. McKenna

Figure 5. Example of the increase in seismic amplitude after a steady 36-hour rain (same source and location).

- Collecting enough data to categorize the cultural signatures within and near the facility in order to integrate these signatures into the detection algorithm.
- Training the facility managers on the system and how to recognize anomalies (for example, if actual tunneling occurs).
- Maintaining reachback to the system administrator to provide expert interpretation, troubleshooting advice, and additional upgrades as situations change.

The working system that is envisioned contains the sensor array along the perimeter, continuously collecting data that is fed into a central data processing or monitoring site at the facility. This is where incoming signals are compared to test modules. Any detection of targeted frequencies or modules alerts the on-site system managers. At this point, the data stream with the module or frequencies of interest can be sent to a reachback service for confirmation and/or further analysis. The key to a successful interception operation is continued surveillance of incoming underground data and triangulation of the source in reference to depth and direction. Most of the tunnels take time to construct, particularly if they are constructed by hand. Commanders then make decisions on the best method to intercept the perimeter intrusion.

It is important to realize that during this study, the TIF operations focused on detecting outgoing tunnels. However, there is a significant need to detect incoming tunnels that could bring explosives or weapons into a secure facility. A tunnel used to breach the security perimeter of an outpost along the Israeli border contributed to the military operations that were conducted this past summer in Lebanon between the Israeli Defense Forces and Hezbollah.

Another important aspect of the system data analysis is to ensure that the false positive rate is kept to a negligible rate. One solution is to provide the facility with its own tunnel, where periodic testing of the sensor array would originate. This negative Z detection capability provides commanders confidence in their force protection technologies.

To illustrate the usefulness of such a force protection model globally, consider the Otay Mesa tunnel discovered on 26 January 2006. The tunnel, one of four located within a two-week period between Tijuana, Mexico, and San Diego, California, is the longest (approximately 731 meters, or 2,400 feet) and most sophisticated tunnel ever found under the southern border of the United States. Beginning in a warehouse near the Tijuana Airport in Mexico, it follows a northeasterly route to a warehouse in Otay Mesa, California. The entrance on the U.S. side was concealed by the tile floor of an office in the warehouse.

Soil sampled in the tunnel was very moist and sandy and contained large (at least 4-centimeter) clasts of volcanic tuff. Layers of clay were interbedded with the sandy material, and white concretions were visible throughout. In the Otay Mesa area, the geology is very similar to that encountered overseas. The seismic-acoustic signals from digging appear very similar to those detected overseas, but here, the ambient noise is much more intense. However, despite the presence of numerous trucks idling near the sensors, the signals of interest are clearly visible.

Conclusions

Protecting underground perimeters is the next capability gap to be bridged in the force protection arena. The potential underground penetration of secure facilities needs to be addressed in our current force protection models and capabilities. A system for protection of these facilities must be planned during the earliest phase of facility construction and integrated into the construction scheme. The system must be able to monitor or detect attempts at underground penetration; use current technologies for immediate operational employment and upgrades; and be easily monitored by personnel at the site, with constant technical reachback ability. The use of seismic and acoustic sensors provides the facility commander with an excellent passive data collection capability that can readily distinguish tunneling activities from the surface-originating sounds encountered on a base.

Acknowledgments: The authors wish to thank the Soldiers of the 18th and 43d Military Police Brigades and their subordinate units for supporting the study and KBR (formerly Kellogg, Brown and Root) for their support. Additionally, we wish to thank BBN Technologies for support during OCONUS field collection and subsequent analysis. The United States Army Rapid Equipping Force, Joint Task Force North, and the United States Army Engineer Research and Development Center (ERDC) TeleEngineering Operations Center provided support to this study. The Director of the Geotechnical and Structures Laboratory at ERDC granted permission to publish this article.

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