January 2005

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TUNNEL DETECTION ALONG THE SOUTHWEST U.S. BORDER

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Abstract

The U.S. Army Engineer Research and Development Center (ERDC) has worked with U.S. Law Enforcement Agencies (LEAs) since 1995 to address the problem of clandestine tunnels beneath the U.S./Mexico border. ERDC has performed tunnel-related research, equipment development, or tunnel-detection missions at the request of the LEAs, coordinated by Joint Task Force 6 (JTF-6, Fort Bliss, TX, now known as JTF-N for Northern Command, US Army). This support to LEAs has revealed the importance of understanding the geologic context of a suspected tunnel site as a basis for selecting the appropriate geophysical tools and interpreting anomalies indicated by geophysical data. Tunnel detection missions always involve multiple tools and techniques. A combination of geophysical instruments is used to record data based on different physical principals. When interpreted in a regional geologic context, the combined geophysical methods improve the likelihood of success for tunnel detection.

A variable-frequency electromagnetic survey tool was developed in the 1990s as part of tunnel-detection research, and proven at a tunnel test bed near Otay Mesa, CA. Also at the Otay Mesa site, an ERDC-led team installed and tested a prototype passive-seismic fence, a system that can detect machine and impact noise during the tunnel excavation process. This seismic fence concept has strong potential for deterring tunneling in geographic areas where tunnels have been found most frequently and where cultural clutter limits the usefulness of surface geophysical techniques and tunnel detection.

Current ERDC tunnel detection efforts (March 2005) are coordinated with the National Geo-Intelligence Agency (NGA, formerly NIMA) to combine electromagnetic and radar methods with emerging technology in microgravimetry.

Introduction

Clandestine tunnels are being found with increasing frequency along the border between the U.S. and Mexico. These tunnels are known pathways for illegal drugs and people, and potential pathways for even worse threats to the security of the U.S. For the past 10 years, U.S. Law Enforcement Agencies (LEAs) have requested assistance from the U.S. Army to locate clandestine tunnels and deter tunneling activities. Joint Task Force-NorthCom (JTF-N) at Ft. Bliss, TX, serves as the liaison between LEA requests and military technologies applicable to civilian issues. JTF-N has tapped the geosciences expertise of the U.S. Army Engineer Research and Development Center (ERDC) to search for geophysical indications of tunnels at locations where human intelligence (HUMINT) indicates a tunnel. International military experience beginning with tunnels under the Demilitarized Zone (DMZ) of the Korean Peninsula prepared ERDC researchers to lead tunnel detection missions, to perform tunneling likelihood assessments, and to determine the applicability of emerging technologies by field trials of geophysical equipment at tunnel test beds established in discovered tunnels. This paper summarizes the ERDC tunnel-detection experience in domestic law-enforcement settings. Because of the security sensitivity of the subject, individual tunnel-search missions are not described.

Geological Context of Tunnels

As no geophysical technique was developed exclusively for finding underground openings, it is critical to understand the geologic and cultural context of geophysical data and to use site characterization and other data sources as part of geophysical interpretation.

Site Characterization: The Context for Geophysical Interpretation

Reconnaissance and site characterization of the area of a suspected tunnel include gathering information on the subsurface geology and the surface conditions, both natural (e.g., geologic setting, water table) and manmade or cultural (buildings, traffic, and electromagnetic signature of power lines or generators). Knowledge of the natural and cultural conditions establish good data collection and allow the geophysicist to determine the best tools and collection methods for the site, perform quality control while collecting data, and minimize noise in the data during the processing and interpretation phase. Site characterization includes local geology, utility maps displaying locations of possible cultural effects (fences, pipelines, power lines, etc.), accessibility, and human intelligence that help narrow down the survey area. The ERDC team always performs site reconnaissance prior to border-related tunnel-detection missions, to identify problematic cultural features and gather other essential cultural information.

Tunnels can be engineered for any shallow subsurface environment, but the geologic setting of the area will control the depth of tunneling, the tunneling method, and the likelihood and type of reinforcement used to keep the cavity from collapsing. Much of the geologic information necessary for border tunnel missions is available from published or on-line sources (state geologic surveys, USGS, utility companies, state highway agencies, etc.).

Capabilities of each geophysical method can be severely affected by the geological setting. For example, investigation depths by the ground-penetrating radar (GPR) method can become severely limited (less than 1 m) in settings with large amounts of clay or water-saturated soils, but in favorable settings, such as ice, the investigation depth may penetrate to greater than 100 m.

Geophysical data are interpreted in the context of what is geologically likely. Various combinations of geologic material can create near-identical geophysical output from one instrument. A combination of geophysical instruments is used to record data based on different physical principals. When interpreted in a regional geologic context, the combined geophysical methods improve the likelihood of success for tunnel detection.

Geophysical Anomalies Provided by Tunnels

When performing a search mission to locate and delineate cavities or tunnels, the investigator concentrates on the detection of features recorded by the instruments due to a contrast in physical properties between the target and the host geologic material, or anomalies. Subsurface cavities, natural or man-made, produce anomalous effects caused by the cavity space itself, secondary effects around the cavity (sometimes referred to as a halo zone), and materials within the cavity. Anomalies caused by the main cavity void space can include changes in density, seismic velocity, electromagnetic wave velocity, and electrical properties. Anomalies caused by secondary effects around the tunnel are caused by stress redistribution, cracking and fracturing, subsidence, and induced ground water flow. Effectively, this halo effect enhances the target by making the feature appear to be larger (Figure 1). Of prime importance is stress redistribution caused by the actual tunnel construction process.

Geophysical instruments on the surface detect or measure the anomaly caused by the physical differences between the tunnel and host material. Materials within man-made tunnels are drastically different from the natural host material. They include support systems made of metal, wood, concrete, or plastic in

Figure 1.: An example of what an anomaly recorded with geophysical measurements may look like in relation to the host material (Butler 1994).

addition to the power lines, rails, and motors for powering lighting and ventilation within the tunnel complex (Figure 2).

Tunnel Detection Tools and Field Tests

The construction activities, spoils disposal, and noise of tunneling are easily hidden in heavily urbanized areas. Most clandestine border tunnels are very near Ports of Entry, which are heavily used areas with continuous heavy-truck traffic, new construction, earth-moving, and other human activities. Construction always begins on the Mexico side hidden under a building, and proceeds toward and under the border, to emerge in another innocent-looking building or partially constructed surface facility. The following section describes evaluation of geophysical methods for their ability to detect and delineate tunnels in this complex cultural zone along the U.S./Mexico border.

Douglas, AZ and Otay Mesa, CA Test Sites

The Douglas drug tunnel was discovered by HUMINT in May 1990. It was a reinforced concrete-lined tunnel approximately 30 ft deep and 300 ft in length, originating at a residence in Mexico connecting to a warehouse in Douglas. This site was used to evaluate several surface geophysical techniques. The Otay Mesa drug smuggling tunnel near San Diego, CA, was discovered on May 31, 1993 (also by HUMINT). Although the tunnel was never completed, it is the longest tunnel yet discovered, covering a distance of more than 1450 ft with the tunnel floor at a depth of 65 ft at the point of entry on the Mexican side to a depth of 35 ft at the northern end of the tunnel on the U.S. side.

Due to the easy accessibility to the Otay Mesa site and the possible existence of similar clandestine tunnels along the border, the Otay Mesa tunnel was chosen as a test bed to evaluate more than 20 geophysical methods for detection capability over the tunnel, including both surface and borehole

Figure 2.: Drug tunnels found with anomalous features, which provide possible targets for selected geophysical surveys.

methods. Methods that successfully detected and located the tunnel included seismic, electrical resistivity, and surface and borehole EM (Mahrer and List 1995, Ballard 1997). Numerous other techniques have been tested at both Otay Mesa and the Douglas sites. Figure 3 shows the effectiveness of each method.

Surface Magnetic Surveys

Magnetic surveys were conducted along six east-west lines perpendicular to the Otay Mesa tunnel and one north-south line above the tunnel axis with an EDA OMNI-PLUS proton precession magnetometer/gradiometer. Noticeable anomalous features were attributed to flood-control structures, culverts, and culvert casings on the boreholes used to access the tunnel. Smaller anomalous features were noted where the tunnel contains 0.5-in.-diameter rebar reinforcement on the floor and walls. Overall, the magnetic data provided no notable anomalies related to the tunnel without prior knowledge.

Figure 3.: Effectiveness of geophysical methods to detect tunnels from Douglas and Otay Mesa test sites, dependant on site geology and conditions (Dunbar 2002).

Borehole Magnetic Surveys

Borehole magnetic log surveys were recorded using a Schonstedt MAB-51B fluxgate magnetic gradiometer. Significant anomalies were recorded at tunnel depth from two boreholes that entered the tunnel within the reinforced rebar area. In addition, borehole surveys were recorded at a borehole located 10 ft east of the tunnel and 6 ft west of the tunnel. An anomalous response at tunnel depth (-34 to -39 ft) was insignificant at 10 ft east but was noticeable at 6 ft west. No other borehole magnetic surveys produced significant anomalies related to the tunnel, leading to the conclusion that the magnetic detector must pass very close to (within 6 ft) reinforced steel for a strong response at tunnel depth.

Very-Low-Frequency and Time-Domain Electromagnetic Surveys

The very-low-frequency (VLF) method uses the radiated field from powerful VLF remote radio transmitters set up around the world for military communications. These radio transmitters produce an electric field powerful enough to induce electric currents in conductive bodies thousands of miles away. The induced secondary magnetic field can be measured along the surface of the earth, providing a useful reconnaissance tool.

VLF electromagnetic data were collected along east-west lines crossing the tunnel axis with useful signals recorded from the Jim Creek, WA (21.4 kHz) and Annapolis, MD (24.8 kHz) stations. There were no noticeable response signatures attributable to the tunnel recorded by the Jim Creek station, because its bearing is nearly parallel to the tunnel axis. The Annapolis station, being nearly perpendicular to the tunnel axis, yielded notable anomalies representative of the tunnel axis. One major drawback of the VLF method is anomalies recorded from unwanted sources such as swamp edges, creeks, and topographic highs.

Time-domain electromagnetic (TDEM) surveys were conducted with the Geonics PROTEM® system along grid lines crossing the tunnel axis in addition to borehole surveys. Utility wires that were

used in the tunnel during operation had been intentionally severed at both ends upon discovery. The first survey was made with the lines severed. For the second survey the tunnel wires were grounded at both ends to make a continuous circuit. The method yielded anomalous features indicative of the tunnel only when the tunnel lines were grounded. This indicates that the TDEM method can effectively delineate tunnels when a continuously grounded conductor such as steel rails or a grounded cable is present in the tunnel.

Induced-Polarization (IP)/Resistivity Surveys

A six-channel Androtex resistivity/IP receiver and Phoenix Geophysics IPT-1 transmitter were used to record data along east-west survey lines crossing the tunnel axis. Through field experiments a dipole-dipole array with 20-ft spacing was determined appropriate to illuminate a target at depth of 40 or 50 ft. The small size of the tunnel precluded the use of larger dipole spacing.

The resistivity/IP and metal factor (MF) were presented as pseudosections and profiles. Pseudosections are plots of the measurements as a function of position and electrode separation. Current flowing perpendicular to the tunnel axis will deflect around the tunnel causing an altered upper layer response (higher chargeability layer overlying the tunnel) thereby recording an anomalous peak in the IP profile over the tunnel. The MF was expected to produce anomalies with greater amplitudes over the tunnel because relatively small decreases in apparent resistivity enhance the IP effect in the MF calculation (equation 1). IP/resistivity surveys recorded a weakly defined double-peaked anomaly in the IP and MF measurements over the known tunnel that is neither prominent nor significant but offers reconnaissance capabilities where notable anomalies can be checked by more detailed methods (i.e., seismic).

$$MF = \frac{M_{(Chargeability)}}{\rho_{(resistivity)}} * 1000 \quad (1)$$

During the IP/resistivity surveys the spontaneous potential (SP) between the array's potential electrodes also was recorded and analyzed. Tunnels act as a groundwater sink that can create an SP anomaly from fluid flow. SP profiles traversing over the tunnel recorded noticeable anomalies from groundwater flow interaction with the known tunnel. However, a number of similar SP anomalies also occurred on the profiles (possibly related to the geology) and were not distinguishable from the tunnel-related anomalies.

Seismic Surveys

Three types of surface-seismic surveys were conducted over three profiles perpendicular to the Otay Mesa tunnel axis:

- a. Common-midpoint (CMP) compressional-wave (P-wave) reflection.
- b. CMP horizontal shear-wave (SH) reflection.
- c. Polarized shear-wave (S-wave) refraction.

All three methods indicated the presence of the tunnel with varying clarity along each profile. Indications of the tunnel from the reflection data were displayed as disruptions of the reflector continuity. These tunnel signatures were offset 8 to 15 ft east from the center of the known tunnel location. The shift from the known tunnel location is attributed to the offset from the source point to the first geophone. The tunnel location from the polarized S-wave data was characterized through variations in phase, amplitude, frequency, and

velocity of the seismic waves. All three types of wave reflection indicated the tunnel along some, but not all, survey lines. Proximity of the metallic Border Patrol fence confounded some of the data.

A cross-borehole seismic tomography survey was performed at the Otay Mesa Tunnel to evaluate the effectiveness of the Bureau of Reclamation's CORRSEIS cross-hole seismic system for tunnel detection capabilities. Seismic tomography surveys involve multiple scans recorded through different combinations of transmitter and receiver locations. For this study, the transmitter and receiver were placed in separate boreholes straddling the tunnel axis (also known as cross-hole surveys). Cross-hole seismic scanning was performed traversing the tunnel between 11 panels with varying widths between the transmitter and receiver boreholes (25 to 50 ft).

The rock at the site was poorly consolidated altered vitric tuff (a crumbly volcanic rock with glassy particles). This soft rock attenuates the seismic signal so that data recorded along longer cross-hole distances and at relatively steeper angles are of a much poorer quality than data from shorter travel distances. In addition, the higher frequencies were attenuated more strongly than the lower frequencies. These environmental conditions created a poor signal-to-noise ratio and low frequency content, limiting the accuracy of the results when compared to data from comparable surveys in harder and less porous geologic material. Despite the limitations that created anomalous features attributed to geologic variations, cross-hole seismic tomography successfully revealed and located the tunnel at the Otay Mesa site with low-velocity and high-attenuation values. Figure 4 displays a smoothed velocity tomogram for panel B employing curved ray analysis to enhance the tunnel signature (lower velocity values). Also, the CORRSEIS seismic system generated data for each of the 11 panels in approximately 2.5 hours, a rapid data-acquisition time for this method.

This seismic investigation at the Otay Mesa test bed indicated that for these site conditions, a higher power source with a center frequency around 2.0 kHz would have been more efficient. Also, for similar site conditions with a small target size (2.5 by 5 ft), hole-to-hole distances should not exceed 30 ft with the CORRSEIS system.

Other Ground-Penetrating Radar (GPR), Acoustic, and EM Surveys

ENSCO ground-penetrating radar (GPR) and acoustic survey were run at Otay Mesa. Radar energy was attenuated so rapidly in the soil and rock types at the test bed that the GPR surveys did not indicate or locate the known tunnel from either surface or borehole data. Rapid attenuation of the acoustic signal at this site also severely restricted the applicability of ENSCO acoustic surveys for tunnel detection in this type of geologic setting. Similarly poor results are expected from other porous, soft, or glassy geologic materials.

RIMtech, Inc. of Denver, CO (now known as Stolar Research Corporation) conducted three electromagnetic field procedures: surface-to-surface, borehole-to-surface, and borehole-to-borehole EM surveys. The surface-to-surface and borehole-to-surface methods focused on mapping the secondary radiation induced on the electrical cabling within and running the length of the tunnel, to detect and delineate the tunnel. The borehole-to-borehole method mapped the signal variation created by transmissivity variations of the tunnel void compared to the background geology (Mahrer and List 1995). All three methods recorded noticeable anomalies attributable to the tunnel.

The Otay Mesa surveys evaluated two configurations of the surface-to-surface method: fixed transmitter and fixed configuration. For fixed transmitter, the transmitter was placed directly over the tunnel while the operator traversed the tunnel with the receiver. For fixed configuration, the transmitter and receiver were at a fixed distance from one another and both were moved during data acquisition traverses. Figure 5 shows recorded values from one survey for each configuration. The shape difference in Figure 5 implies that the fixed configuration can be used for broad-area data collection. Once a notable anomaly has been recorded and marked, the fixed transmitter configuration can narrow down the location. Surface-to-borehole and/or

borehole-to-borehole measurements then could be used to delineate the depth of the tunnel (Mahrer and List 1995).

Figure 4.: Smoothed velocity tomogram for panel B (Block 1993).

Subsequent Equipment Trials

In November 1997 surveys were conducted by ERDC along a suspected tunnel area near Otay Mesa using only EM and magnetic noncontact geophysical instruments, specifically a GEM-2H and G-858 magnetometer. Three anomalous high-conductivity zones and one low-conductivity zone were found within the study area. Exploratory borings identified the presence of a buried streambed as the cause of the highly conductive anomalies recorded by the EM instruments (Ballard 1997).

Stolar Research Corporation (formerly known as RIMtech Inc.), under contract to the ERDC, successfully confirmed results from the earlier surface-based EM gradiometer survey over Otay Mesa. The surveys were conducted over the surface of the Otay Mesa tunnel using the Stolar Resonant Electromagnetic wave Gradiometer Antenna system (REMGA) in conjunction with a local 52.5 kHz transmitter placed at optimal locations along the tunnel. The primary survey technique used was the fixed transmitter survey method which involved placing the transmitter over the tunnel's known centerline for maximum coupling to

Figure 5.: Two surface-to-surface surveys with 102 kHz signal and 5 m gradiometer receiver separation. The gradiometer moved perpendicularly across the tunnel 242 m north of border. For fixed transmitter, transmitter was located directly above the tunnel at 211 m north of the border. The transmitter also traversed across the tunnel at 211 m north for fixed configuration (Mahrer and List 1995).

the conductors in the tunnel. The REMGA was then placed in an east west traverse perpendicular to the centerline of the tunnel. Figure 6 shows the EM gradiometer response data from the Otay Mesa tunnel in conjunction with the tunnel centerline. Response data delineate the tunnel where the measurements peak, null, and peak again (a pair of increased magnitude peaks centered by a trough in the profile). These results confirmed that low-frequency scattering from electrical conductors increases as frequency decreases. Therefore, tunnel detection sensitivity improves as the frequency is reduced toward the low kilohertz frequency band (Stolar Research Corporation, 2001).

The project also evaluated the feasibility of cross-hole tunnel detection between boreholes and maximum effective spacing. Analysis of the data showed that maximum distance between borings is determined by the attenuation rate. At 612.5 kHz, the attenuation rate was 2.3 dB/ft. At a separation distance of 75 ft, the total path loss is 172.5 dB, which approaches the maximum dynamic range of 175 dB for the system. As a result this system can successfully delineate the tunnel at 612 kHz with a 75-ft separation distance. Based on the results from this study, 100-ft spacing could be used if the operation frequency was reduced to 466 kHz (Stolar Research Corporation 2001).

Figure 6.: Otoy Mesa tunnel with recorded EM gradiometer data (Stolar Research Corporation 2001).

During August 1998, the ERDC participated in another mission near Calexico, CA to demonstrate specialized geophysical equipment designed to locate and delineate clandestine tunnels. Data were collected with a magnetic gradiometer and a variable-frequency electromagnetic induction instrument, GEM-2H. The GEM-2H, commercially available from Geophex Inc., was developed under contract to ERDC in the tunnel-detection research program. Interpretation from the collected data identified a number of anomalies. Anomalies that were located farthest from known cultural effects and indicated strong north-south trending features were prioritized for further investigation (Llopis and Ballard 1998).

Current Activity

The frequency of ERDC support to LEAs by way of the JTF-N connection has increased from one or two a year in the late 1990s to current activity that required geophysical surveys at six different geographic locations during four months of winter 2004-05. ERDC has developed a rapid-response team in conjunction with JTF-N and several LEAs, now incorporated in the Department of Homeland Security. Activity in 2005 involves close coordination between the ERDC and NGA with application of their new microgravimeter. The southwest border experience has led to ERDC support to requests from military in-theatre operations

and geographic areas along other international borders. We regret that we cannot provide details of recent tunnel-detection missions, due to the law-enforcement or military sensitivity and of the subject.

Deterrents to Tunneling

During September 1999, the ERDC Tunnel Detection Team conducted a field study at the Otay Mesa tunnel to evaluate the feasibility of using a linear passive seismic array, or subterranean fence (Figure 7), to detect tunneling activity along the U.S./Mexico border. Six, 4-in.-I.D., PVC-cased-and-grouted borings were drilled at varying distances to a depth of about 100 ft perpendicular to the existing tunnel (Figure 8). The 100-ft depth was chosen to allow experimental determination of the optimum depth needed to eliminate seismic noise originating from surface activities. The tunnel test bed is only about 150 ft from a heavily traveled international Port of Entry used principally by 18-wheel tractor-trailer rigs.

Recognizing that surface traffic generates primarily Rayleigh waves (which will not penetrate to depths much greater than 50 ft) rather than body waves (which will penetrate to great depths), we theorized that sensors placed at depth rather than on the ground surface would be minimally affected by surface activity. To validate the subterranean fence concept, personnel from the Colorado School of Mines (CSM) were contracted to enter the existing tunnel via the southern-most shaft and construct an addit using the types of tunneling techniques that would be used in the real-life construction of a tunnel in this type geologic setting.

Figure 7.: Passive seismic fence setup.

The primary objectives of the study were to: (1) verify validity of the concept of listening for tunneling activity; (2) determine optimum sensor depth and distance necessary to record tunneling activity with a minimum of false alarms; (3) evaluate the possibility of differentiating tunneling activities; and

(4) assess the complexity of algorithms which might be developed to recognize and identify subterranean activity in near-real time.

Figure 8.: Subterranean fence concept.

First-line sensors during the experiment were high-frequency (100 Hz), 3-dimensional geophones. The 100-Hz units were chosen because their low-frequency cut-off would occur below about 60 Hz, thus further filtering surface activity that is represented in the 30-to-50-Hz frequency band. Data were then acquired by ERDC researchers using a commercial off-the-shelf (COTS) digital data acquisition system while the CSM team in the tunnel generated mining activity of five different types: picking, delayed-charge blasting, pneumatic hammering, hammering a star drill, and pneumatic drilling. During the experiment, six of the high-frequency, 3-D, spring-clamped downhole geophones were lowered into six borings located 25, 50, and 75 ft on each side of the tunnel centerline. Data were collected at depths of 25, 55, and 100 ft.

Data processing was rudimentary. Digital mining activity signals were converted to analog audiotape for quick-look demonstrations, and the audible signals were played through a loudspeaker system. Geophone recordings at all depths detected seismic activity caused by the mining equipment (Llopis 1999). However, it was readily apparent that the quietest and most distortion-free data were obtained at the lower depths. The only attempt to enhance data quality was to square the data. This resulted in marked improvement in signal-to-noise ratio. Tunneling activities were easily identifiable by the human ear listening to the recorded data. Before processing (squaring), background noise was easily discernible, although it did not mask the true seismic signals. Once squared, the background noise almost disappeared. By nature, noise is random and true repetitive signals are coherent. When squared, noise amplitude diminished and the seismic signal was amplified.

The tunneling-noise experiment revealed that tunneling activity could be detected, located (if the 3-D sensors are properly oriented), and identified (provided a data base is constructed). Optimum sensor depth

placement would be about 75 ft deep with borings placed about 100 ft apart. Algorithms constructed to identify subterranean activities and trigger an alarm system could provide a real-time “subterranean fence” network. Ideally, locations for subterranean fences would be carefully chosen on the basis of a tunneling likelihood study. Optimum deployment of the equipment would be in urban areas where repeated tunneling has been documented and geophysical surveys are difficult to conduct.

Conclusions and Recommendations

ERDC experience with detecting clandestine tunnels revealed research questions about the technology of tunnel detection that were successfully addressed in field trials at tunnel test beds. Electromagnetic (EM) and seismic surface high-resolution methods have strong potential for improvement and widespread application to tunnel detection. Recent technology advancements have improved depth of signal penetration, and ease of deployment and data acquisition. Software with links to global-positioning systems (GPS) and geographic information systems (GIS) has improved positional accuracy and data utility. With additional development, overhead instruments can be placed on various platforms with increased resolution. Likely candidate methods for rapid improvement and deployment are variable-frequency EM, magnetometer, hyperspectral, and thermal instruments.

Geophysics-based tunnel deterrents have the best potential to improve border security. Clandestine tunnels tend to be constructed in built-up areas with extensive cultural clutter, where it is easier to hide the physical and sound evidence of tunnel excavation, and to disguise tunnel openings within buildings. These highly built-up areas, often near Ports of Entry, are multiple lines of metallic fences, reinforced concrete channels, buried utilities, rail lines, and truck traffic. They are nearly impossible to survey using surface geophysical techniques. Passive-seismic tunneling-activity detector systems, or subterranean fences, can listen continuously beneath the surface noise and clutter, to reveal the sound of active tunnel excavation and thereby deter construction of additional tunnels. The deployment of subterranean fences at likely locations for new or renewed tunneling activity would provide an entirely new tool for LEAs. The tool also has potential application at military facilities, and other critical and sensitive infrastructure elements worldwide.

ERDC continues to support LEAs with border security issues, most recently with three detection missions in Arizona and California in December 2004 and at additional locations in March 2005. Applications in military operations and humanitarian assistance also continue, and advance the state of practice in tunnel and cavity detection.

Acknowledgements

The work described here benefited from support or participation by Joint Task Force-6 and its successor JTF-N, the Counter-Drug Technology Development Program Office, the U.S. Border Patrol, the U.S. Customs Service, the U.S. Drug Enforcement Agency, the U.S. Bureau of Reclamation, the Colorado School of Mines, the Kansas Geological Survey, and the National Geo-Intelligence Agency (NGA, formerly NIMA). ERDC team members who have contributed to tunnel detection research and tunnel missions include: Robert F. Ballard, Troy R. Brosten, Dwain K. Butler, Maureen K. Corcoran, Joseph B. Dunbar, Jose L. Llopis, William L. Murphy, Ryan E. North, Janet E. Simms, and Eric W. Smith. Permission to present this work was given by the Office, Chief of Engineers.

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