In-theater seismic acquisition: operational examples from a tunnel detection team

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Summary

Near-surface seismic data were collected at multiple sites in Afghanistan to detect and locate subsurface anomalies, including clandestine tunnels. Examples shown here include data collected over the escape tunnel discovered at the Sarposa prison in Kandahar, Afghanistan, that allowed over 480 prisoners to escape (data were collected post-discovery), data from another shallow tunnel recently discovered at an undisclosed location, and a couple of subterranean infrastructure examples. The data were processed without prior knowledge of target locations and, in the case of the second example, directly contributed to the tunnel discovery.

Introduction

The use of subterranean tunnels has been around for thousands of years with applications ranging from perimeter infiltration to more modern applications of drug smuggling. Most historical examples are related to military applications, whether it be using a tunnel to build a fire beneath the exterior wall of a castle to facilitate structural failure or digging a tunnel into enemy territory to execute a behind-the-lines attack. There have been multiple examples in the last century, including dedicated tunneling companies in World War I that constructed tunnels beneath No Man's Land in Flanders, Belgium, the Cu Chi tunnels in Vietnam in the 1960s, and cross-border tunnels beneath the de-militarized zone (DMZ) in Korea in the 1970s through 1990s. More modern examples include drug-smuggling tunnels along the United States-Mexico border, tunnels between Egypt and Gaza that circumvent restrictions placed on the import and export of goods from Gaza, and tunnels from Gaza into Israel purportedly for carrying out tactical strikes.

One of the most famous examples is the tunnel nick-named "Harry" that became the basis of the movie The Great Escape. This tunnel was dug during World War II as an escape route from a Nazi-run prisoner-of-war internment camp. The tunnel measured 102 m long, was 8.5 m deep, and had several novel features including ventilation ducts made from powdered milk tins and a pump used to push fresh air through the tunnel. Four tunnels have also been discovered beneath the DMZ between The Democratic People's Republic of Korea, commonly called North Korea, and the Republic of Korea, also referred to as South Korea, between 1974 and 1990 with multiple others suspected to exist. Depths range from approximately 1 m beneath the surface and reinforced with concrete slabs to 350 m deep. These tunnels are blasted through granite using explosives, running well into the 4-km wide DMZ and south of the demarcation line. Another example includes a tunnel reported in 2006 that was dug from Gaza into Israel which was used to attack an Israeli military position and kidnap a soldier who was subsequently held hostage for over 5 years.

The conflicts in Iraq and Afghanistan have also produced examples of clandestine tunneling; however, the purpose of those has been to escape a secure facility instead of moving illegal drugs or tunneling into a facility. In 2005, a tunnel was discovered at the largest American military prison in Iraq at Camp Bucca that was 4.6 m deep and 109 m long (Fainaru and Shadid, 2005). The walls of the tunnel were smoothed and cemented with milk while the spoils were spread out over a soccer field used for detainee exercise. Detainees worked five-minute shifts, digging with tools made from tent poles. A similar incident occurred six years later near Kandahar, Afghanistan, in 2011 where a reported 488 Taliban prisoners escaped from the Sarposa prison, which is the largest prison in southern Afghanistan (Shah and Rubin, 2011). The tunnel took approximately five months to construct, running over 300 m long and 1 m wide with electricity and ventilation throughout (Figure 1).

Figure 1. Photograph of the inside of the tunnel discovered at the Sarposa prison in southern Afghanistan in 2011 that facilitated the escape of more than 480 prisoners.

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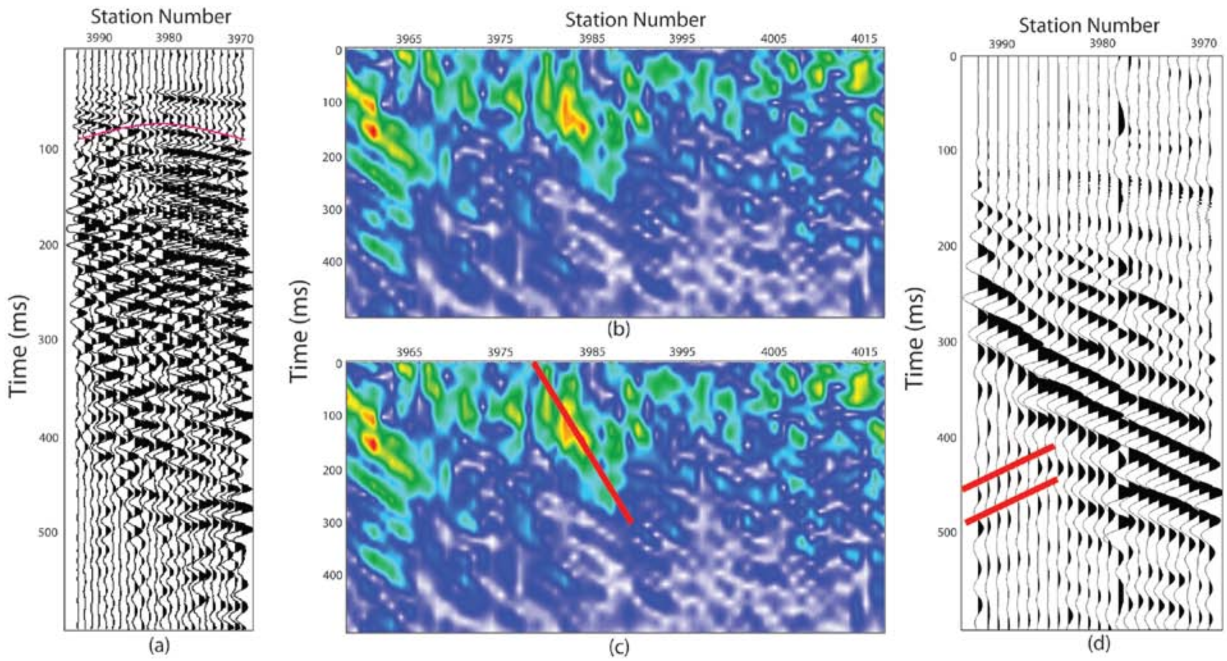

Figure 2. Seismic data collected over the Sarposa prison escape tunnel discovered in Kandahar, Afghanistan, in 2011. (a) is a shot gather with a diffraction interpreted to be from the tunnel indicated by the pink-colored hyperbola. (b) and (c) are both surface wave backscatter cross-sections indicating the interpreted signature arising from the tunnel. (d) is a raw shot gather showing a back-scattered event prior to any applied processing.

There are numerous examples of both general void detection (Branham and Steeples, 1988; Dobecki, 1988; Inazaki et al., 1998; Peterie et al., 2009) and tunnel detection (Belfer et al., 1988; Rechtien et al., 1995; Llopis et al., 2005; Tucker et al., 2007; Walters et al., 2007; Walters et al., 2009) using shallow seismic methods. Seismic techniques intuitively make sense based on the large contrast in material properties between an air-filled cavity and the surrounding geologic medium. Although theory and models suggest this to be a straight-forward problem, this has rarely proven to be true in real-world operation.

Sloan et al. (2012) presented ongoing research at the 2012 SEG Annual Meeting showing the results of seismic studies conducted over an actual tunnel at a test site representative of a desert environment. Similar methods have been used by the Department of Defense in Afghanistan since the Sarposa prison break in 2011 for various applications, including the monitoring of various US, NATO, and Afghanistan facilities. The paper presented here shows various examples of anomalies that have been encountered, including shallow tunnels and historical infrastructure.

The geology in Afghanistan varies widely, ranging from hard rock and very rugged mountainous terrain at high altitudes, to thick sections of loess, to sand dunes and unconsolidated alluvium. Given that the physical properties vary to such a degree, it is no surprise that the geophysical properties are also wide-ranging. Seismic velocities can span an order of magnitude from one site to another and, coupled with what can be very complex geology, makes data processing much more complicated. What works at one site may not work at all at another and processing flows must be tuned to each individual site. Further complicating both the data acquisition and processing are the heavily populated urban environments with dense infrastructure and numerous noise sources, such as cars, trucks, motorcycles, tractors, mule-drawn wagons, pedestrians, and the typical noise added by curious onlookers who have never seen a seismic crew or equipment before.

Methods

Data were acquired using an accelerated weight drop as the source and a 24-station land streamer that included 4.5- and 40-Hz geophones at 1.22-m spacing pulled by a tow vehicle. Three shots were acquired and stacked for each source location. Data were recorded by Geometrics Geode seismographs with 24-bit A/D conversion, 2-s trace lengths, and a 0.5-ms sampling interval. Data were post-processed to produce enhanced diffraction and backscatter sections by reducing coherent noise and increasing the signal-to-noise ratio. Data processing routines are described in more detail by Walters et al. (2007) and Sloan et al. (2011) and the methods in general, along with previous test results, are described in Sloan et al. (2012).

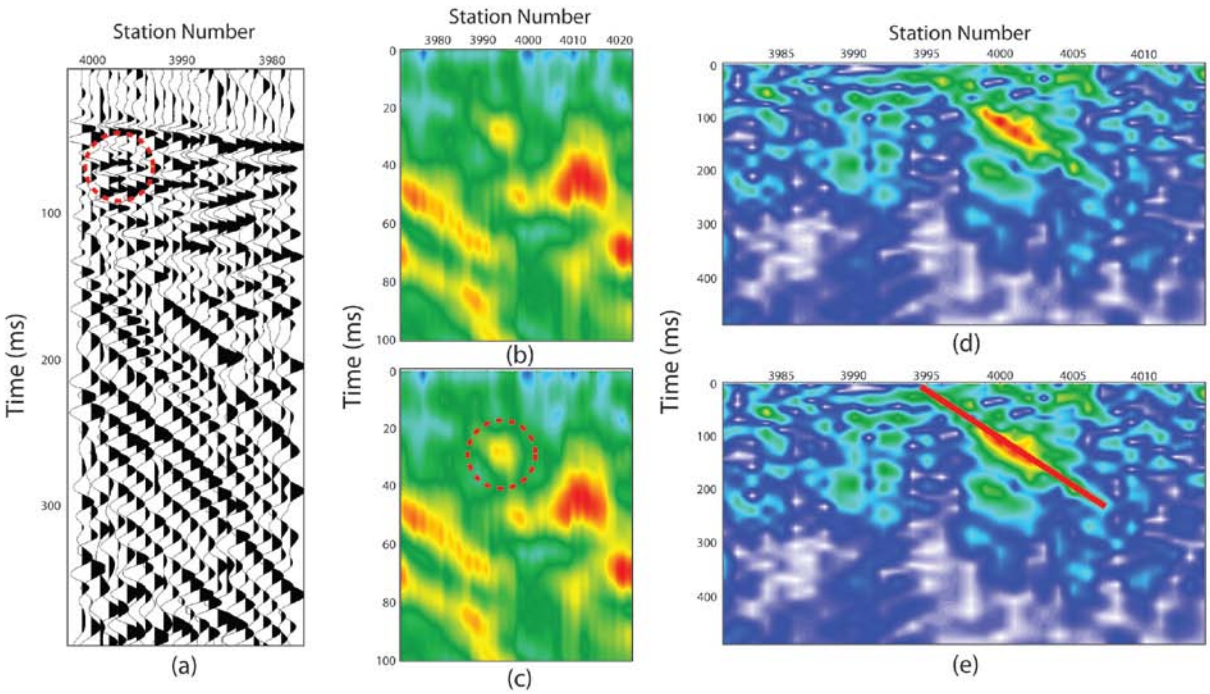

Figure 3. Seismic data collected over a recently discovered tunnel in Afghanistan. (a) is a shot gather with a diffraction interpreted to be from the tunnel indicated by the red-dashed circle. (b) and (c) are enhanced diffraction sections with the interpreted tunnel location indicated by the red-dashed circle. (d) and (e) are both surface wave backscatter cross-sections indicating the interpreted signature arising from the tunnel marked by the solid red line

Results & Discussion

Figure 2a-d shows data collected over the known target discovered at Sarposa prison in 2011. Data were collected shortly after the discovery by a team of geoscientists. Figures 2a and 2d show common source gathers with the interpreted diffraction (a) and backscatter events (d). Figures 2b and 2c display the uninterpreted (top) and interpreted (bottom) backscattered surface wave cross-sections. Although the station numbers of the interpreted anomalies do not match exactly, they are within a two-station spread (2.4 m) which is consistent with the ranges we have seen in previous testing (Sloan et al., 2012). Estimated depth of the tunnel based on two-way traveltime and the diffraction moveout velocity (625 m/s) is approximately 4.5 m deep, which is very close to the actual depth of approximately 3.9 m. Multiple lines were collected in both directions, oriented within 20 degrees of perpendicular to the target. The tunnel was eventually filled in with cement slurry to prevent future use and to ensure the integrity of the overlying roadway, which is a main thoroughfare in that area.

Figure 3 displays data from a recent, previously unknown discovery at an undisclosed location. Figure 3a shows a raw shot gather (with AGC applied for display purposes) indicating an interpreted diffraction. Although subtle, the diffracting event is consistent across multiple records and stacks constructively in the enhanced diffraction section in Figure 3b and c (uninterpreted and interpreted, respectively). The two-way traveltime and estimated velocity (565 m/s) yields an approximate depth of 7 m, which is comparable to the measured depth. Figure 3e is the interpreted surface wave backscatter section. The surface wave data indicated that the target was located at station number 3994, which is within one station of the interpreted diffractor location in Figure 3c and separated by 1.2 m. The intercept location was selected as the difference between the two and the target was confirmed by excavation to be within 1 m of the interpreted location.

Several interesting examples of historical infrastructure have also been detected and excavated. Figure 4 shows an MASW plot displaying changes in shear-wave velocity (Vs). The high-velocity feature located at approximately station 1005 was determined to be a stone and mortar drainage canal that has subsequently been buried approximately 2 m deep over time. At some point the feature was filled in with clay bricks, creating a relatively solid feature approximately 2.5 m wide and 0.75 m thick. An increase in Vs would be expected with such a feature compared to the surrounding loess and unconsolidated sands and gravels.

Karez, or underground tunnels used to transport groundwater from mountain sources to agricultural areas to

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irrigate crops, are found throughout Afghanistan with subterranean passageways often stretching for tens of kilometers. Figure 5 shows a surface wave backscatter section with an interpreted feature located at station number 1171, indicated by the solid red line. No diffractions were observed with the feature, but the backscatter signature is relatively strong and coherent compared to other sources of noise that we often encounter. The location was excavated to determine the cause of the seismic anomaly and was determined to be a collapsed section of a karez passageway approximately 4 m deep. It is interpreted that, although collapsed, the disturbed cross section was well enough defined along the walls (such as a trench that has been loosely backfilled) to produce a backscatter event, but was not distinct enough to generate observable diffractions.

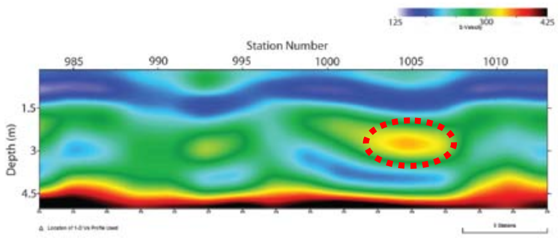

Figure 4. MASW Vs plot with an old stone canal feature indicated by the red-dashed line.

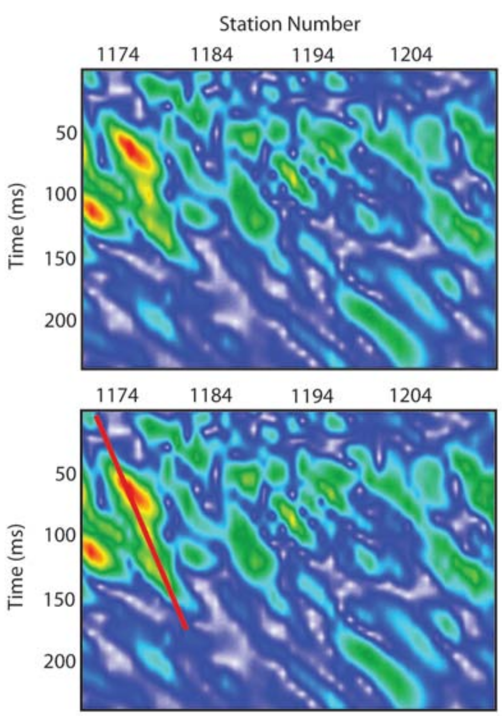

Figure 5. MASW Vs plot with an old stone canal feature indicated by the red-dashed line.

The real strength of the methods described here is the use of multiple techniques, including the analysis of body-wave diffractions, backscattered surface waves, and multichannel analysis of surface waves (MASW). This is further supported by the two examples presented here where the backscattered surface waves played a more prominent role in one example and a more or less equal role in the second example. MASW results were not a major contributing factor in either of these examples; however, that is not necessarily a reference to the usefulness of the technique for this application since it has been used previously to successfully detect and locate a shallow test tunnel (Nolan et al., 2011). There is no silver bullet or one-size-fits-all solution to this complex problem and the use of multiple methods increases the chances of success and improves confidence in interpretations by having more than one coincident data set to cross-reference “hits” and reduce the number of false positives.

Conclusions

Identifying small-scale subterranean features, such as a tunnel, has proven to be a challenge in itself in ideal conditions. It becomes much more difficult when looking for such subtle signatures in an operational environment where noise sources are plentiful and data acquisition parameters may be compromised due to mission requirements, less than ideal conditions, and the notion that some data, albeit noisy, is better than no data at all. Despite the challenges, we were successful in detecting and locating a known tunnel that had been previously discovered, as well as a completely unknown target that was subsequently confirmed by excavation and found to be with one meter of the interpreted location. Both data sets were processed without any prior knowledge that the targets were present or their locations.

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EDITED REFERENCES

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