AN OVERVIEW OF THE CALTRANS BOREHOLE GEOPHYSICAL LOGGING PROGRAM

David Hughes, Geophysics and Geology Branch, California Department of Transportation, Sacramento, California, david_hughes@dot.ca.gov

Abstract

Most geotechnical investigations involve drilling and coring to collect samples, measure subsurface properties, and develop lithologic logs. The California Department of Transportation (Caltrans) supports a statewide borehole geophysical logging program to provide supplemental in-situ borehole data.

A typical Caltrans borehole logging suite consists of measurements obtained from three sondes, and include caliper, natural gamma, resistivity or induction, and in-situ Compression- and Shear-wave seismic velocity logs. Additional borehole tools that are available, or in development, include acoustic televiewer, borehole deviation, full-waveform sonic, cross-hole radar, and in-situ gamma density logging.

Borehole geophysical investigations provide a cost-effective supplement to drilling due to low relative cost, the ability of geophysical methods to look beyond the sidewalls of the borehole, and the collection of in-situ data not available from a standard drilling program.

Introduction

Geotechnical site investigations typically involve drilling and coring to collect samples and subsurface information. This method only looks at materials and properties in the immediate proximity of the boring, and can introduce bias and error. In most drilling environments, even continuous coring does not result in continuous core recovery, and the drilling process may disturb what is obtained. Descriptive logs rely heavily on visual observations. Visual log descriptions are subjective and prone to human bias, sometimes resulting in different descriptions, between loggers, of the same material. Therefore, the potential exists that, with visual descriptions alone, significant features may be missed, incorrectly identified, or improperly placed. In addition, it is not possible to obtain in-situ information through a standard drilling and coring program.

Geophysical logs measure signals that are affected by contrasts in the physical properties of earth materials. Per Keyes (1989), “Because the value of the product justified the expense, almost all of the advances in borehole geophysics have been made for oil-well logging.” These methods, tools and interpretations have been adapted for geotechnical purposes. The science has matured enough so that some tools, such as the P-S Suspension log, have been developed specifically to generate geotechnical information. Borehole geophysical logs provide unbiased continuous and in-situ data, and, in general, sample a larger volume than samples of core and drill cuttings (Williams, 1998). These logs also allow detailed lithologic and stratigraphic information to be obtained from non-sampled boreholes, and identification of geophysical “markers” allows correlation between boreholes (Pullan et.al., 2001).

Borehole geophysical log interpretation is not straightforward, however, as there is usually no unique, unambiguous interpretation of a single geophysical log. Multiple logs are collected and interpreted together, and interpretation should be qualified with direct observation and measurements. In addition, the lithologic log, as well as disturbed and missing core sections, can be corrected by correlation with continuous geophysical logs.

Borehole Geophysics at Caltrans

The California Department of Transportation (Caltrans) supports a downhole geophysical logging program. This program is not designed to replace drilling and coring, but is an effort to increase the quality of the information obtained during the drilling program, obtain otherwise unavailable, in-situ
information, and reduce the amount of drilling necessary for site characterization. The downhole geophysical logging program has been tailored to provide seismic response information for the Caltrans Seismic Retrofit program and the seismic requirements for new construction. Other applications have aided in landslide characterization and mitigation, cooperative seismic instrumentation programs involving the California Division of Mines and Geology and the United States Geological Survey, borings logged only by geophysical logging, construction of cross-sections and correction of lithologic logs, and non-destructive construction inspection.

**The Typical Caltrans Logging Suite**

A typical Caltrans downhole geophysical logging suite includes:

1. Caliper measurements, which mechanically measure the physical borehole diameter at depth,
2. Natural gamma measurements, which record the natural radioactivity of earth materials in the subsurface,
3. Electrical resistivity measurements, which measure the resistivity of earth materials using either a resistivity or an induction probe, and
4. In-situ compression and shear wave seismic velocity logs (P-S Suspension Log).

Additional Caltrans borehole geophysical logging tools that are available, or in development, include acoustic televiewer, borehole deviation, full-waveform sonic, cross-hole radar, and in-situ gamma density logging. The following discussions of tools and interpretations are brief by necessity: more comprehensive information is contained in the references cited.

1. **Caliper**

Mechanical caliper measurements of borehole diameter are collected by sondes with spring-loaded arms. The arms are connected to potentiometers, and the indicated electric potential is converted to diameter. An important use of the caliper tool is to assess the quality of the boring, and is typically run first in the log sequence for that reason. If the hole is going to collapse, it is better (so to speak) to sacrifice the (relatively) less-expensive caliper tool than another, more costly one.

Caliper measurements are useful in detecting the presence of washouts (i.e., unconsolidated sand and gravel, disturbed during drilling), squeeze zones (swelling clays or soft, unstable formations), fractured intervals, and caving or collapsing zones. Boring quality is assessed by measuring the diameter and rugosity (roughness) of the boring, and is also qualitatively assessed by the resistance of the caliper tool to move within the borehole.

Interpretation of the caliper log is typically combined with the natural gamma and resistivity logs, and assists interpretation of the P-S

---

**Figure 1.** Caliper log showing washout of soft material (surface to 35.5 m bgs) and fractured rock intervals below that. Vertical scale is m bgs; horizontal scale is 8 to 20 cm boring diameter. Drill bit diameter was 9.4 cm, 14.7 cm conductor casing above 6 m. See text for additional discussion.
Suspension log. Borehole washouts due to sandy intervals are suggested by increased borehole diameter, relatively low natural gamma counts, and increased resistivity. Squeeze zones due to soft or slaking clay formations are suggested by decreased borehole diameter (sometimes so much the caliper tool is not able to pass down the borehole, with a “soft tag” at the obstruction), relative high natural gamma counts, and decreased resistivity. Fractured zones are suggested by borehole rugosity and low S-wave velocities on the P-S log, as well as, in extreme cases, the inability of the caliper tool to pass down the borehole, with a “hard tag” at the obstruction. Caving and collapsing zones are suggested by low natural gamma counts, low seismic velocity, and high resistivity (indicating granular material).

Figure 1 shows an example of a caliper measurement log. The boring was closed by loose fractured rock at approximately 35.5 meters (m) below ground surface (bgs). The Caltrans drilling crew opened the closed interval with a steel drillpipe, and no information was collected from 35-43 m bgs. During placement of the caliper tool below the steel drillpipe, borehole obstructions were noted at 45.5 m and 48.5 m bgs, and continued logging suggested additional fractured rock intervals down to approximately 50.5 m bgs. This boring was reamed, cased with PVC, and grouted prior to additional logging.

2. Natural Gamma

The Natural Gamma detector is small and relatively inexpensive, and is typically housed with other tools. Natural gamma measurements are collected during the resistivity or induction probe run. This log measures naturally occurring gamma emissions due to the decay of radioactive materials in the subsurface. A sodium-iodide crystal is used to detect gamma rays. This crystal produces a flash of light in response to a gamma ray collision within the detector (Keyes, 1989, Telford et.al., 1990). This flash is recorded as a “count” by the instrument. Counts per second (cps) are recorded on the log.

In nature, the most abundant radioactive isotopes recorded on the natural gamma log are potassium-40 (K$_{40}$), thorium-232 and uranium-238, with the most plentiful of these isotopes being K$_{40}$ (Welenco, 1996a). Clay bearing intervals commonly emit relatively high gamma radiation because clay is a weathering product of potassium feldspar and mica, and clays tend to concentrate uranium and thorium by ion absorption and exchange (Williams, 1998). Radius of investigation for most materials and hole conditions is approximately 0.3 m (Pullan et.al., 2001).

The natural gamma log can be collected through both thermoplastic and steel pipe (although attenuation of gamma rays through steel can be problematic at increasing pipe wall thickness). This is useful while drilling in unstable formations (e.g., loose alluvial sand, and extremely fractured serpentine), as information useful for borehole correlation and geologic cross-sections can be collected.

Figure 2. Natural gamma log showing the difference in gamma counts between upper alluvial (coarse grain) material and lower marine terrace deposits (fine grain) material. Vertical scale is m bgs, horizontal scale is 30 to 150 gamma counts per second (cps).
Interpretation of the natural gamma log is based on the geologic principal that gamma radiation, in general, decreases from shales and clays to clean sandstones and gravels (Welenco, 1996a). This log is useful for stratigraphic interpretation, and provides information on qualitative grain size, lithology and contacts, and unit thickness. Because the natural gamma ray log is a passive, lithologically-dependent measurement of naturally-occurring radioactive elements, it is generally useful in lithologic log correction, and invaluable as a correlation log, both between borings, and for preparation of geologic cross-sections (Welenco, 1996a). Due to the statistical nature of radioactive decay, this log is not repeatable in an absolute sense. Accuracy is greater at high gamma count rates and long measuring times (i.e., slow logging speeds). At high count rates and slow logging speeds the statistical error will be small, and similarity in response and trends can be noted across zones of repeated measurement (Keyes, 1989).

Figure 2 is a natural gamma log recorded in northern San Diego County, California. The contact between clean (relatively clay-free) coarse grained fluvial material with low natural gamma counts, and the underlying finer grained marine terrace deposits with relatively high counts is apparent at approximately 4 m bgs. The layered nature of the marine terrace deposits is apparent from the oscillating trace below 4 m bgs (logged by observation as a relatively continuous monolithic unit).

3. Resistivity

All earth materials conduct electricity to some extent. In a porous material, bulk conductivity is the combined electrical conductivity of the earth material and the pore fluid. If the pore fluid conductivity is relatively low (i.e., freshwater), then the bulk conductivity reflects the earth material. If the pore fluid is highly conductive (i.e., saline fluids) and the porosity is relatively high, the bulk conductivity mainly reflects that of the pore fluid. Conductivity and resistivity are inversely related, and data are usually reported as resistivity on the log. Radius of investigation is variable, depending on the tool and electrode configuration, and can range up to several meters.

Interpretation of resistivity logs is usually combined with the natural gamma log. In general, in fresh porewater conditions, high resistivities are associated with coarse-grained materials (sand and gravel), and low resistivities are associated with silt and clay. This decrease in resistivity is due to an increasing percentage of conductive clay minerals. One exception to this rule occurs with arkosic (feldspathic) sand and gravel. Here, the high percentage of potassium feldspar is associated with increased amounts of K$_{40}$. This results in higher gamma counts associated with increases in resistivity, which is an atypical log response (Keyes, 1989). An example can be seen in Figure 3.

Resistivity probes collect multiple measurements of formation resistivity by current flow between electrodes or between an electrode and ground, and require open, fluid filled boreholes. The simplest measurement is the single-point resistance log. Single point resistance is measured from an electrode on the probe to a ground at the surface. It is affected by diameter of the borehole (larger diameter decreases the apparent resistance) and can only be used for qualitative assessment of formation properties, but it has excellent resolution and is useful for locating bedding contacts and fractures. On a typical resistivity probe, the SP electrode is usually included with a 4-electrode configuration known as a
"normal" array. For normal resistivity measurements, electrode spacing determines depth of investigation. In general, short normal spacing looks at resistivity in the disturbed borewall area, and long normal spacing looks out farther into the formation (away from disturbed zones). Increased radius of investigation typically results in a loss of detail, as resistivities are “averaged” over a greater sphere of investigation. To overcome that limitation, focused resistivity probes, which use special focusing-electrode arrays to drive measurement current into the formation, can be used. Other electrode configurations are available, including microresistivity probes, for very shallow measurement, which utilize small pads in direct contact with the bore wall. Keyes (1989) and Welenco (1996a), among others, provide more detailed discussion of these and other types of resistivity arrays.

Figure 3 is a resistivity log collected in San Diego, California. In general, the earth material consists of interbedded shallow marine and fluvial nearshore deposits. The flat response on the long normal log (which sees deeper into the formation), indicates the natural pore fluids are more saline than the drilling mud. The increase in the natural gamma counts and increase in resistivity and resistance at 27.5-30 m bgs suggests an arkosic sand derived from granite (an interpretation supported by geologic provenance). A more typical log response for coarse-grained material (low gamma counts and elevated resistance) is noted at approximately 26 m bgs.

4. Electromagnetic (EM) Induction

Induction probes measure conductivity by measuring the electric field induced in earth materials by a high frequency magnetic field emanating from the probe (Welenco, 1996a). This probe can be used in PVC cased boreholes and dry boreholes. A single conductivity curve is collected, which can be inverted to produce a resistivity curve. The radius of investigation is tool-dependent and generally ranges up to 1 m from the probe (Hunter et al., 2001).

Interpretation follows the general discussion above for resistivity logs. The resistivity curve produced by the induction probe is most similar to a short normal resistivity curve (Welenco, 1996b).

Figure 4 is an example of induction log data. This log was collected through grouted PVC casing, and is from the same boring shown on Figure 1. (Note the decrease in gamma counts associated with increasing hole diameter between 30 and 20 meters.) The change in strata from the very soft surficial marsh and nearshore clayey and silty deposits to more competent rock is noted at approximately 35.5 m bgs by the increase in resistivity. Here, rock is composed of siltstone and clayey siltstone and is, in places, intensely fractured and intensely weathered. The highest resistivity noted during logging, at approximately 56 m bgs, corresponds with the highest seismic velocity interval noted on the P-S Suspension log (discussed below).
5. P-S Suspension Log

In-situ compression (P) and shear (S) wave seismic velocity logs, or P-S Suspension logs, are collected using a downhole probe connected to a surface seismograph. The probe contains a seismic source and two sets of oriented geophones separated by a fixed (1-meter) distance. The tool measures S-wave velocity in hard rock. In soft rock and soil, equivalent S-wave velocity is obtained through measurement of the dispersive, flexural mode (Schmitt, 1988). (For purposes of discussion, the flexural and shear modes are hereafter considered synonymous in this paper). Measurements can be obtained through a fluid-filled, grouted, PVC casing, but best results are obtained in a fluid-filled uncased borehole. Because the source is at a constant distance from the receivers, interval velocities can be recorded with greater detail and at greater depths than conventional (surface-to-borehole) shear wave surveys.

Currently, P-S suspension data are examined and processed semi-automatically. This allows greater control over identification of events on the velocity records and helps to minimize potential for error. The P and S wave velocities are graphically shown on a plot of velocity versus depth (or elevation). Velocity data are used to calculate low-strain, in-situ values for Poisson’s ratio and shear modulus. These material properties and velocities are used to derive seismic ground response models for structure design. Interpretations of material composition are made in combination with the above geophysical logs.

Figure 5 is a sample P-S velocity plot collected at a proposed bridge pile location (see also Figure 1 and Figure 4 for different geophysical logs from the same boring). Here, saturated (Vp>1500 m/s), very soft soil (Vs<762 m/s) is noted from approximately 16.5 m to 35.5 m bgs. A velocity reversal (decrease in interval velocity) is noted from approximately 42.5 to 50.5 m bgs. Based on the caliper log and field observations, that interval appears to be intensely fractured. A decrease in interval velocity is also noted at the base of the logged section. Based on the P-S Suspension log and other downhole geophysical data, the final design for the bridge pile was a cast-in-drilled-hole (CIDH) pile with a bell (under-reamed) tip.

Figure 5. PS Suspension log plot. S-wave velocity is on left, P-wave velocity on right. Vertical scale is m bgs, horizontal scale is wave velocity (m/s).

Other Borehole Geophysical Tools

Additional Caltrans borehole geophysical logging tools beyond the basic logging suite that are available, or in development, include acoustic televiwer, borehole deviation, full-waveform sonic, cross-hole radar, and in-situ gamma density logging.
**Acoustic Televiewer**

The acoustic televiewer is an imaging tool that uses ultrasonic waves to scan the borehole wall. An open, fluid filled boring is required. Competent rock produces shorter acoustic travel time and a stronger reflection of the acoustic waves. Planar features such as fractures and bedding planes are shown as longer travel time/lower amplitude traces, and can be identified as sinusoidal lines on a false-color acoustic image, oriented relative to magnetic north. Borehole rugosity is shown as a grainy image. The acoustic televiewer also magnetically measures borehole deviation (direction and amount) from vertical. The tool has a very slow logging speed, is very sensitive to borehole diameter and receiver gains, and must be centralized in the borehole.

Interpretation of acoustic televiewer data involves manually picking and identifying best fit sine waves (from bedding and fractures) on the false color image. Image resolution and contrast can be manipulated during interpretation to enhance features. Best results are obtained in rock-like material: the tool does not work in soil. Strike and dip of features, as well as borehole deviation, is computed by the interpretation program. Stereonet plots of selected depth intervals and features can be produced.

Figure 6 is a portion of an acoustic televiewer plot. Bedding appears as low amplitude sine waves, and fractures appear as higher amplitude sine waves that cross other features. The faint vertical white dotted line near the bottom of the amplitude plot outlines a scour mark from an earlier caliper measurement. Also included in Figure 6 is an associated stereonet plot depicting poles to bedding. The stereonet shows a tight grouping of relatively high angle beds dipping to the south and reflecting regional dip of the formation.

**Full Wave Form Sonic**

The full wave form sonic tool measures the travel time for a refracted wave (P-wave) and converted seismic waves to travel to one or more receivers, and also records the
waveform and amplitude of the returning waves. Sound pulses at around 23,000 Hertz are used (Welenco, 1996a). The differential travel time between two receivers is used to determine earth material velocity (Sharma, 1997). The P-wave velocity can be used to calculate formation porosity using predefined relationships. In general, sonic waves travel faster through denser formations. Therefore, an increasing differential travel time for a particular material indicates increased porosity (Welenco, 1996a). In addition, examination of P- and S-wave amplitudes can be used to detect fractures (Telford et al., 1990), and cement bond evaluation of steel- or PVC-cased borings can also be obtained using the sonic waveform.

Figure 7 is a portion of a full wave form sonic log collected during a landslide investigation. Increased porosity is noted at approximately 79.5 m bgs, and decreased porosity is noted at approximately 88 m and 94 m bgs. This corresponds well with the PS Suspension log of this boring (not shown), which shows a seismic velocity decrease with increased porosity, and seismic velocity increase with decreased porosity at these same intervals (interval at 94 m bgs not recorded on the P-S Suspension log due to tool length).

Cross-hole Radar (Under Development)

Cross-hole ground penetrating radar (GPR), consists of antennas set up in transillumination mode, and is used to obtain tomographic images of earth material velocity distribution between boreholes. Both 2-d and 3-d images can be acquired, though 2-d is far more common. This method requires two boreholes in fairly close proximity to each other, with a typical borehole separation in sedimentary environments of five to ten m. Successful tomographic images, however, have been obtained at up to 40 m separation in crystalline metamorphic rock (Sharma, 1997, Greg Johnson, pers. commun., 2002).

Gamma Density Logging (Under Development)

In-situ gamma density logging, also called gamma-gamma logs, are used to assess formation density. A radioactive source bombards the formation with intermediate energy gamma rays. Collision of gamma photons with electrons in the formation produces back-scattered gamma rays proportional to the electron density of the formation. The probe detects these back-scattered gamma rays. Electron density is closely related to bulk density, which for most common soils and rocks is nearly equal to the bulk density of the formation. If grain density is known, total porosity may also be calculated. This probe can be run in either fluid or air filled borings (Welenco, 1996a).

Interpretation

It has been stated that geophysical log interpretation is more of an art than a science because different phenomena can cause similar log responses (Welenco, 1996a). Put more formally, there is no unique interpretation of a single geophysical log. Therefore, multiple geophysical logs are collected and interpreted together in conjunction with the lithologic log and drilling information. The four geophysical logs mentioned in the typical Caltrans logging suite, in conjunction with lithologic logging, sampling and
laboratory testing, provide all of the information necessary to determine engineering properties of earth materials during a typical foundation investigation.

The primary limitation of geophysical logs centers on this lack of a unique interpretation. Geophysical logs do not directly measure engineering properties of earth materials but use various forms of remote sensing to calculate those properties. These logs must be interpreted together, and physical information needed for log calibration must be obtained from sample investigation and testing.

Common factors that affect the collection and interpretation of geophysical logs include the following:

- Disturbed formation due to drilling method impacts (e.g., fracturing introduced by drilling methods or intrusion of drilling fluids into the formation),
- Physical borehole properties, such as borehole diameter, pore water salinity, and inherent formation conductivity,
- Lack of physical data (lithologic logs and samples) to assist and confirm geophysical log interpretation, and
- Assumptions used for geophysical interpretations (e.g., earth materials used for calibrations) that may not match specific site conditions and materials

Finally, most geophysical interpretations are qualitative instead of quantitative. Geophysics, as mentioned above, involves various forms of remote sensing. While these results can be run through the filters of formula and interpretation, it is difficult to replace the hand sample. As stated by Welenco (1996a), “Nature cannot be put into equations in a straightforward manner except through the intermediate process of data collection and statistical studies. Geology is a natural science”.

As an example of the synergistic interpretation of borehole geophysical logs, the following investigation is presented. Borehole geophysics assisted in the interpretation of a major landslide and the design for the landslide stabilization. The deepest boring (100 meter deep) drilled during the investigation was logged with a full geophysical suite. The formation itself, described from the core, consisted of bedded sandstones, siltstones, and claystones. For this investigation, some of the most valuable geophysical information came from the acoustic televiewer. Fracture zones, open fractures, and material changes were noted in the televiewer log. Based on stereonet plots of televiewer data, there appeared to be five distinct landslide blocks above a major failure plane. Important information on rock density correlated to rippability was provided by supplemental P-S log data. Information on fracture density was critical to designing the remedy and controlling groundwater inflow. The televiewer information proved vital in meeting that need.

Figure 8 shows the combined downhole geophysical logs from the landslide investigation discussed above. The interval shown is 80-94 m bgs. The caliper log suggests a large open fracture at approximately 85.5 m bgs. Gamma and porosity logs are not conclusive, but the conductivity log shows an increase in conductivity and the acoustic televiewer log reveals an apparent low-angle fracture. The distinct sine wave feature visible on the acoustic televiewer log at approximately 88 m bgs appears to be a filled or healed fracture, as shown by slight borehole diameter decrease (i.e., softer material squeezing out of the fracture) on the caliper log, increases in resistivity and decreases in porosity. The visual image on the acoustic televiewer suggests this entire area consists of harder rock (higher amplitude colors on the image), and the sonic log also suggests this is a hard rock section, with decreasing porosity in this zone. A decrease in the natural gamma suggests increased sand content. Other apparent healed fractures picked on the acoustic televiewer log are at approximately 90 m and 93-94 m bgs. Separation of the long normal resistivity and the short normal resistivity curves, with the long normal curve more resistive, suggests the formation pore fluid is more resistive (i.e., fresher) than the drilling fluid. This separation disappears above 83 m bgs, suggesting drilling fluid invasion in a more permeable zone (possibly acting as a conduit for fluid movement).
### Downhole Geophysical Logs

<table>
<thead>
<tr>
<th>Caliper</th>
<th>Natural Gamma</th>
<th>Downhole Geophysical Logs</th>
<th>Acoustic Televiewer</th>
<th>Porosity</th>
<th>Full Wave Form</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Resistivity: Normal Point &amp; Lateral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resistivity: Normal Point &amp; Lateral</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8. Combined downhole geophysical logs. From left, the curves are: caliper, natural gamma, resistivity (short normal [blue], long normal [green] and lateral [black]), resistivity (point source, red), induction conductivity, induction resistivity, acoustic televiewer (amplitude plot only, no picks are shown—light colored vertical band is from borehole eccentricity), percent porosity (sonic), and full wave form sonic (near receiver waveform only). Interval is from 80 to 94 m bgs.
Borehole Geophysical Costs

As noted above, a wealth of data critical to gaining a better understanding of the subsurface can be obtained through the use of borehole geophysics. The use of borehole geophysical logging also provides a cost-effective supplement to a drilling program, providing continuous, objective in-situ information. For comparison, most of the cost of a typical geotechnical investigation goes into drilling holes. At Caltrans, it costs approximately $8,000 to drill a 120-foot geotechnical boring (David Thomas, pers. comm.). In the year 2000, average cost to Caltrans for geophysical logging was $646 per hole (Owen, 2000), or approximately 8% of the cost of drilling. Compared to the cost of drilling and sampling a boring, borehole geophysical methods are a cost-effective means of maximizing the information that can be gained from a drilling and sampling program.

Borehole geophysics also complements a drilling program, in that it obtains information not obtainable through laboratory testing of drilled samples alone. Certain types of in-situ information, such as seismic wave velocity and continuous density measurements, are not obtainable outside of a geophysical logging program. When assessing the cost-effectiveness of these in-situ methods, their application to structure design must be considered. In-situ seismic velocity measurements, for example, are used to obtain representative ground response models. In the absence of these models, structure costs may increase up to 20% due to overly-conservative design (Owen, 2000). Of less probability but greater risk is the potential failure of a structure from poor design or underdesign. In that instance, catastrophic structure failure can result in replacement and liability costs in the millions of dollars.

Examples of cost savings due to the reasoned use of borehole geophysics at Caltrans (Jan Rutenbergs, pers. commun., Owen, 2000) include:

- Using geophysical logging only in a mid-boring between endpoints to demonstrate geologic continuity in a sedimentary environment, thereby saving staff and equipment time,
- Reducing the number of borings required for site characterization, and
- Reducing the number of laboratory sample analyses required for site characterization.

Conclusion

Geophysics can be a cost-effective supplement to a traditional downhole logging program. Borehole geophysics, by a relatively minor increase in project cost, increase both the type and amount of data obtainable from a borehole, aiding site characterization and structure design. In some instances, a geophysical logging program can save money by reducing the scope of investigations, the number of lab tests needed or the number of borings required for an investigation. These advantages have been recognized by Caltrans, which continues to support its in-house geophysical capabilities.

References


