

ENVIRONMENTAL SITE CHARACTERIZATION USING IN-SITU TESTING METHODS

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ABSTRACT

Proper environmental site characterization is not limited to an evaluation of water chemistry; it involves assessing the stratigraphic, geotechnical, hydrogeological and geochemical nature of the site in a manner which best represents actual in-situ conditions. In-situ testing methods offer the best available technology to achieve this representative characterization for many site conditions. The key in-situ tools available for this characterization are the piezocone, resistivity piezocone and the BAT water sampling system.

RÉSUMÉ

La caractérisation des sites environnementales n'est pas limitée par des chimiques dans l'eau; l'évaluation du stratigraphie et qualités du milieu géotechnique, hydrogéologique et géochimique d'un site en manière qui représente les conditions "in-situ" est nécessaire. Des méthodes "in-situ" utilisées se présentent la technologie la plus avancée à réaliser cette caractérisation représentative pour plusieurs des conditions du site. Les outils les plus importants pour cette caractérisation sont la piezocone, le "resistivity piezocone" et le BAT système pour la prélèvement de l'eau.

INTRODUCTION

Environmental site characterization refers to the surficial and subsurficial representation of the site that approximates actual in-situ conditions. This representation is typically developed by both surface and subsurface characterization. The United States Environmental Protection Agency (US EPA, 1989) note the following site specific requirements for environmental site characterization:

- stratigraphy;
- water-level data;
- hydraulic conductivity;
- chemical distribution and source(s)/receptor(s) for potential or existing contaminants

Several of these requirements can be met accurately and economically with available in-situ testing methods.

For example, in-situ testing methods such as the resistivity piezocone provide an excellent representation of actual in-situ conditions at selected locations. Stratigraphic, strength, hydrogeological and specific geochemical parameters are provided on a specific and/or screening basis. The use of in-situ testing can often lead to the best possible representation which tends to make the large assumptions required in an overall environmental characterization effort as accurate and defensible as possible.

This paper presents a very brief review of selected in-situ test methods for environmental site characterization. The methods include the piezometer cone penetration test (or piezocone), the resistivity piezocone and the BAT water sampling system.

ENVIRONMENTAL SITE CHARACTERIZATION

Environmental, or geoenvironmental, is a relatively new term to the geoscience/geotechnical engineering field. There are several interpretations of what an environmental site characterization program constitutes. As both the authors and the projected audience of this paper are primarily of geotechnical or geoscience background, the recommended definition is:

"The field of study that links geological, geotechnical and environmental engineering, and the corresponding sciences, to form an area of interest that includes all environmental concerns within natural or processed geological media."

Detection and assessment of groundwater contamination and its approximate transport velocity is an excellent example of an area of interest within the scope of environmental site characterization.

IN-SITU TESTING

Piezocone

The piezometer cone penetration test (CPTU) involves pushing into the ground a 60° apex and typically 35.7 mm diameter (10 cm² area) piezocone on the end of a series of rods of the same or lesser diameter as the piezocone. The pushing is carried out at a constant rate of 2 cm/sec, or roughly a metre per minute. Pushing is achieved by hydraulic force supplied typically by either a drill-rig or specially outfitted cone pushing vehicle. Most any drill-rig with a minimum pushing capacity of 5 tonnes and a hydraulic ram stroke of 1.5 metres or more can be used to successfully push cones in most soils. Davies and Campanella (1995) list typical pushing capabilities for clay and sand soils.

The piezocone measures tip resistance (q_c), friction sleeve stress (f_s), and pore pressure response at up to three locations; on the cone tip face, immediately behind the cone tip and immediately behind the friction sleeve (referred to as U1, U2, and U3 respectively). Most correlations and direct calculations assume measurement at the U2 location. Temperature (t) and inclination (i) are also measured simultaneously as the piezocone is advanced into the ground. All channels are continuously monitored and typically digitized at 25 mm intervals. Campanella and Robertson (1988) outline the piezocone's main advantages, limitations, and standard testing and recommended interpretation procedures.

Resistivity Piezocone

The resistivity piezocone (RCPTU) provides the ability to measure the resistance to current flow in the ground on a continuous basis. This ability is extremely valuable due to the large effects that dissolved and free product constituents have on soil resistivity (conductivity). The RCPTU consists of a resistivity module, which is added behind a standard piezocone. Davies and Campanella (1995) give an overview summary of the RCPTU and its perceived application areas.

Measurements of bulk resistivity trends indicate whether some form(s) of dissolved or free product constituent(s) exists at or above background values. Background values are established either from on-site experience or from similar geological environments. The areas where background values are exceeded are then further evaluated with appropriate groundwater sampling at discrete depths for detailed chemical analyses. Of considerable practical value is the fact that the measured resistivity is almost totally governed by the pore fluid chemistry and the pore volume. In other words, particle chemistry has a limited effect in most circumstances.

A schematic of a resistivity piezocone is shown in Figure 1. The smallest electrode spacing is useful for detection of thin layers of contrasting bulk resistivity, whereas the largest electrode spacing measures an average resistivity over a larger depth and a greater lateral penetration of the electric field into the undisturbed soil. Davies and Campanella (1995) note that the depth of penetration from this type of logging device is roughly twice the electrode spacing.

BAT Water Sampling System

A modification of the commercially available *BAT* System (named after the inventor, Bengt Arne Torstensson, 1984) is recommended for obtaining in-situ pore fluid samples. The original system consists of a sampling tip that is accessed through sterile evacuated glass sample tubes and a double-ended hypodermic needle set-up. The tube sampler is lowered either by cable or electrical wire depending upon whether a pore fluid sample is taken with or without a pressure test being carried out. The modifications made at UBC include using a stainless steel sampling carrier of approximately 120 ml volume and replacing the hypodermic needle system with Swagelock fittings. This latter modification allows much more accurate and feasible sampling in higher TDS environments as experienced, for example, during water sampling in metallic mine tailings. The equipment is hydraulically pushed with the same equipment used for cone penetration testing. The modified BAT sampling tip consists of a probe slightly larger in diameter than the resistivity module (50 mm versus 37 to 44 mm). This sampling tip can be pushed on its own or down the same alignment as the smaller diameter CPTU sounding. Standard AW drilling rods work well for the BAT system.

A schematic of a typical modified BAT system is shown in Figure 2. The US-EPA and other high conformance requirement groups have adopted BAT technology as appropriate and preferred for many environmental characterization applications. The attraction of no drill cuttings and the repeatability of the data are cited as the key reasons for this preference. BAT technology has been scrutinized by many investigators and has met with widespread acceptance (e.g. Zemo et al., 1992).

After BAT water samples are retrieved to the ground surface, preliminary chemical tests should be conducted on-site and then the sample can be stored for further laboratory analyses. Field measurements should, at a minimum, include conductivity, temperature, and pH. Once enough sampling is carried out at a specific depth, the BAT probe is then pushed to the next depth and the procedure repeated. There is no limit to the number of samples that can be taken at one location.

USE OF IN-SITU TESTING IN ENVIRONMENTAL SITE CHARACTERIZATION

As summarized by Davies and Campanella (1995), the resistivity piezocone can be used to evaluate the following environmental/geotechnical parameters:

- soil stratigraphy;
- soil density;
- undrained shear strength;
- hydraulic conductivity;
- in-situ hydraulic gradients;
- drained strength; and relative geochemical nature

The geochemical nature comes from evaluation of the continuous bulk resistivity signature from the resistivity piezocone compared with chemical analyses on samples obtained from the BAT sampling system.

Table 1 presents a small sampling of typical RCPTU bulk soil resistivity measurement values and corresponding measurements of pore fluid resistivity.

TABLE 1 -Summary of typical resistivity measurements of bulk soil mixtures and pore fluid (saturated mixtures only) (adapted from Davies and Campanella, 1995)

Material type	Bulk Resistivity $\rho_b, \Omega\text{-m}$	Fluid Resistivity $\rho_f, \Omega\text{-m}$
Deltaic sands with saltwater intrusion	2	0.5
Drinking water from sand	>50	>15
Typical landfill leachate	1-30	.5-10
Mine tailings site (base metal) with oxidized sulphide leachate	0.01-20	.005-15
Mine tailings site (base metal) without oxidized sulphide leachate	20-100	15-50
Arsenic contaminated sand and gravel	1-10	.5-4
Industry site-inorganic contaminants in sand	0.5-1.5	0.3-0.5
Industrial site - creosote contaminated silts and sands	200-1000	75-450
Industrial site - wood waste in clayey silts	300-600	80-200

The relationship between total dissolved solids (TDS) and bulk resistivity is global and linear. Specific ion correlations with RCPTU bulk resistivity values are most commonly site-specific in nature although sulphate anions and divalent iron have shown remarkable global correlation in our experience to date.

EXAMPLE CHARACTERIZATION PROJECT

As noted in the closure to this paper, a wide range of environmental characterization projects are amenable to the in-situ technology summarized herein. To demonstrate a specific application, the characterization of a base-metal mine tailings impoundment in Western Canada is briefly introduced.

The site, which consists of tailings from a sulphide ore-body, had several geotechnical, hydrogeological and geochemical concerns. The resistivity piezocone and BAT sampling technology were selected for characterizing the site for the specific concerns.

Figure 3 shows a typical resistivity piezocone sounding from the site. From the continuous record of tip bearing stress and dynamic pore pressure, the strength and drainage characteristics

of tailings could be accurately assessed. With the additional information from the sleeve friction, and hence friction ratio (a percentage value of sleeve friction by tip stress), the tailings were shown to be largely contractant, silt-sized and possessing a high susceptibility to static or dynamic triggered liquefaction. This strength characterization work was used to optimize remedial works (berm) deemed necessary.

Geochemically, the BAT sampling program provided site-specific relationships between bulk resistivity piezocone values and specific ions include sulphate, iron and copper. A tentative pH-bulk resistivity relationship was also established.

The resistivity piezocone data was also used to delineate an ionic rich plume whose sampled characteristics includes pH values as low as 1 and sulphate concentrations to 60,000 mg/l (ppm). Figure 4 shows the three-dimensional representation of resistivity piezocone values, converted to conductivity units, from 17 soundings. Figure 4 represents only one depth from each sounding; 5.0 metres. Similar plots were chosen every 0.5 metres for the project to delineate the plume. The delineation from the resistivity piezocone allowed optimal spatial placement of regulatory required monitoring wells; both in plan and to accurately locate discrete well screens with depth.

CLOSURE

Recent environmental characterization projects by UBC using the tools described include:

- DNAPL and dissolved creosote contaminated site in B.C.;
- sulphide mine tailings impoundments in Ontario;
- mine tailings geotechnical and groundwater evaluations at several mines in B.C.;
- arsenic contaminated sands and gravels in B.C.;
- salt-water intrusion to a fresh-water aquifer in B.C.; and
- regional hydrogeological evaluation in major aquifer in B.C.

Other recent activities include combining the presented in-situ tools with surface geophysical techniques to provide enhanced site information.

Commercially available resistivity piezocone work is readily available in Canada for roughly \$25 to \$30 per metre in most instances. Many environmental characterization projects are carried out each year in materials well suited to the technology presented in the paper and it is recommended that more of these projects choose what is likely the best available technology and the most economic for those footing the bill.

This paper has briefly summarized the main in-situ tools available for environmental site characterization. Under the broader, and more correct, definition of what such characterizations entail, the resistivity piezocone and BAT sampling technology are establishing themselves as the premier tools where ground conditions are appropriate.

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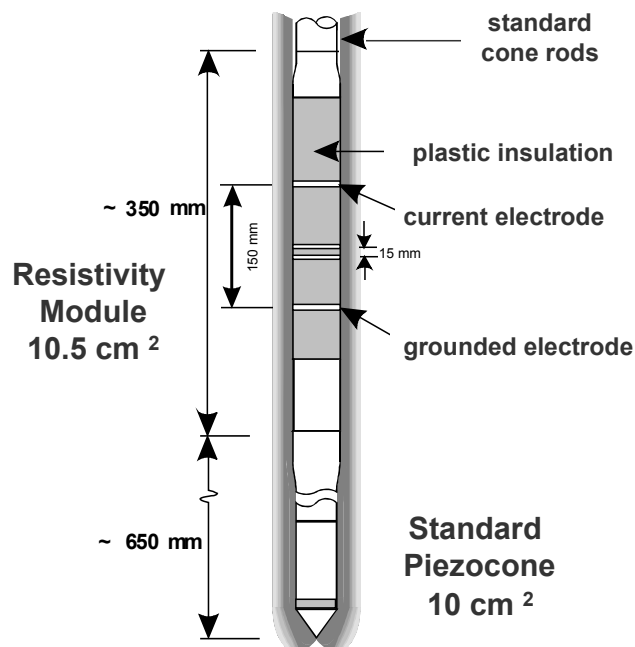


FIGURE 1 - Typical Resistivity Piezocone

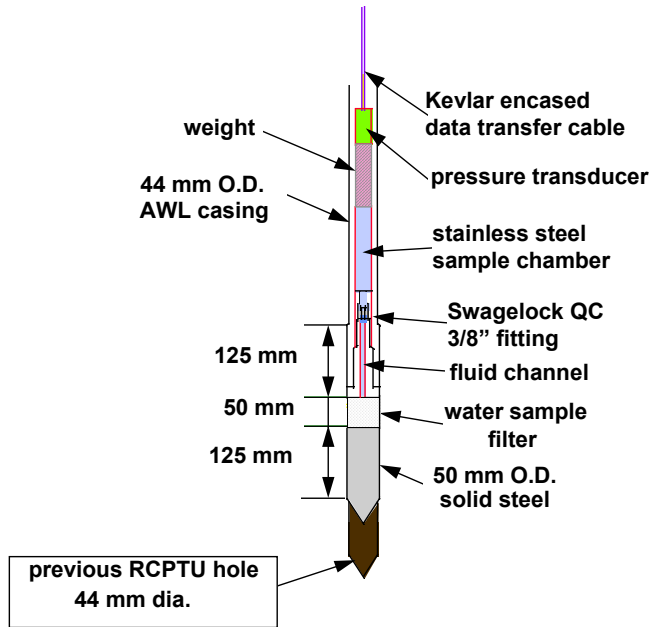


FIGURE 2 - Modified BAT Discrete Depth Water Sampler

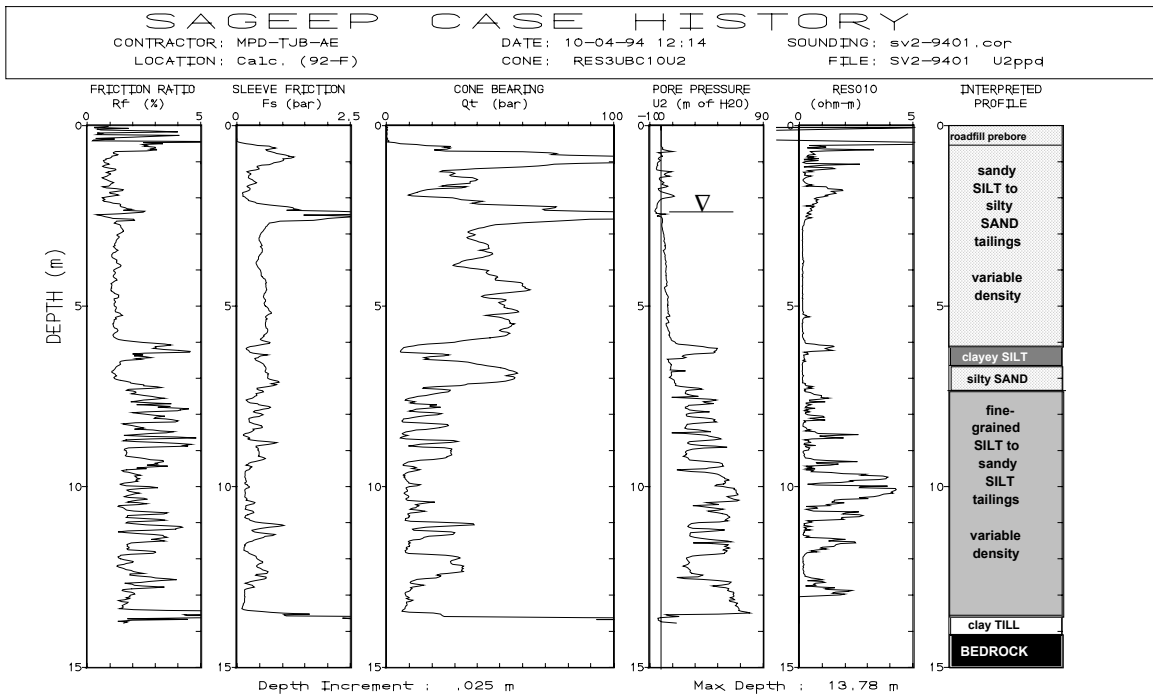


FIGURE 3 - Typical Resistivity Piezocone Sounding Profile from

Base-Metal Mine Tailings

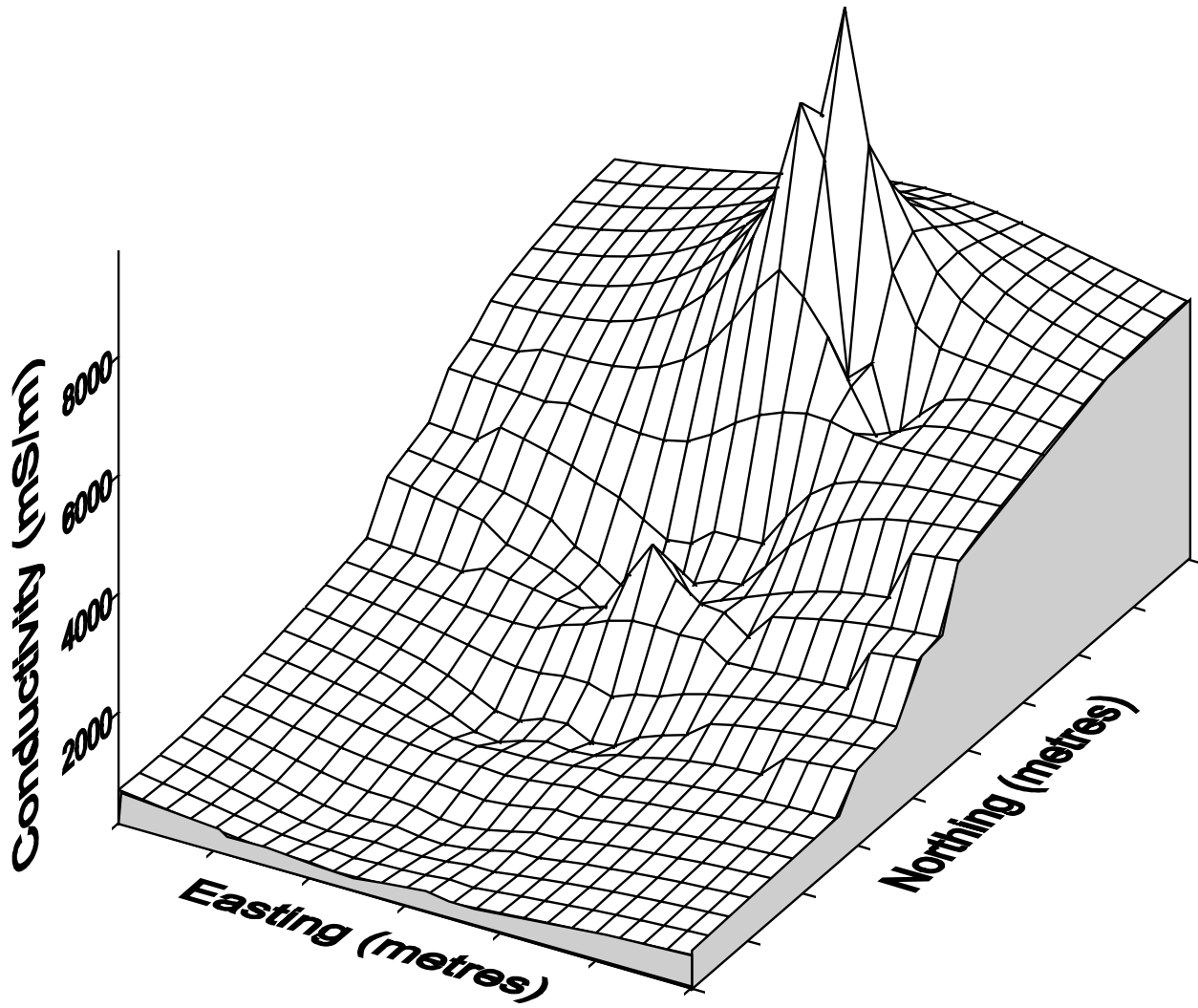


FIGURE 4 - Compilation of Resistivity Piezocone Conductivity Measurements in Base-Metal Mine Tailings