USE OF GEOPHYSICAL SURVEYS FOR FILL CHARACTERIZATION AND QUANTITY ESTIMATION AT BROWNFIELD SITES – A CASE HISTORY

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Abstract

New building construction planning typically includes site characterization with standard geotechnical drilling and sampling methods under the direction of a professional engineer. For project sites with the potential for variable types and thicknesses of fill materials, including contaminated wastes that pose a possible environmental hazard, this traditional site characterization approach can result in under sampling and lead to an unrepresentative site characterization. This can also result in significant cost overruns and other surprises. In recent years, as reuse of 'brownfield' properties has increased, the need for better, more reliable site characterization methodologies has grown. The combined use of geophysical surveys and standard drilling and sampling methods during the project planning phase has been shown to be a valuable approach to meet these needs.

This paper presents a case history of an actual construction project in which geophysics was combined with traditional drilling and sampling at a brownfield location where a 70,000 cubic yard excavation for two commercial building basements was planned. Historical information combined with the initial drilling results and geophysical testing revealed a potential two-dimensional bias to the fill distribution. Closely-spaced, 2-dimensional resistivity profiles were independently acquired and inverted, and then jointly interpolated in 3-dimensions to render a 3-dimensional image of the fill materials. The 3-dimensional imaging allowed for the quantification of fill types and quantities for proper management during excavation, and the development of estimates for transportation and disposal of the materials. In addition, it also allowed the construction management team to plan for proper segregation and handling of these materials to minimize total construction costs and schedule delays while maintaining safe working conditions.

Introduction

The goal of this geophysical survey was to provide an estimate of the variability of the thickness and characteristics of the fill and native soils at a specific brownfield site. Electrical resistivity imaging has been used successfully at several locations (e.g., Mundell and Byer, 2002) to achieve this goal. It has been found that the resistivity method generally has a robust response to the fill and native soils, especially when fill materials are placed within a sand and gravel setting.

Moisture content (degree of saturation), porosity, permeability, and water chemistry are the major controlling variables of the resistivity of soils and rocks, and resistivity generally increases as porosity and permeability decrease. In unsaturated materials, particularly soils, moisture content strongly influences resistivity. The electrical conductivity of the water in the pores has a strong influence on resistivity as well. However, variations in apparent resistivity at the site are likely to be attributed to variations in subsurface physical characteristics (i.e. moisture content, porosity, and permeability) rather than significant changes in pore water chemistry. Because clays and many typical types of fill observed such as ash, cinders, organic matter, and wood tend to adsorb moisture and tend contribute soluble ions to pore waters (particularly in the case of clays, ash, and cinders), fill materials often tend to have very low resistivity relative to natural sand and gravel soils. The sand and gravel soils tend to not absorb moisture and contribute soluble ions to pore waters, making this type of soil a resistive material. Thus, a strong resistivity contrast is often found to exist between most fill materials and granular soils. This contrast is very useful for delineating fill and native soil boundaries.

The ultimate goal of this project was to provide tangible data, in conjunction with soil boring data, necessary to derive an estimate of the relative quantities of fill and native soil to be encountered during excavation of basements and foundations at two proposed building locations. The following briefly summarizes the technical aspects of the geophysical survey, our interpretation of the survey results with respect to the existing fill variability, and estimates of fill and native soil quantities based on the survey results.

Site History and Geological Setting

The site is located in a former industrial area of a medium-size Midwestern city. At the time of the study, the 3-acre site was situated within a modern commercial building complex, and covered with landscaping, grass, and an asphalt-parking lot. Review of historical information revealed that the area was once used as a stockyard from the 1940s to the 1970s, and that a slaughterhouse and processing plant may have been present near this location. An undated 1970s aerial photograph indicated some type of liquid-filled channel sluiceway, situated in a slightly northeast to southwest orientation, extended away from the processing plant area to the south-southwest. Based on the general location of known points of reference, this sluiceway appeared to pass through the area beneath the new footprint of two proposed buildings, a North Building and a South Building (**Figure 1**).

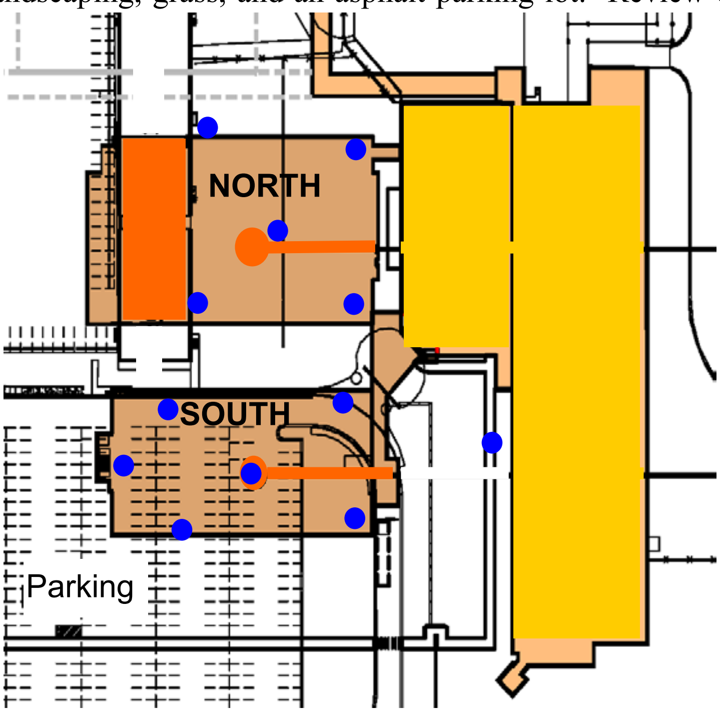


Figure 1. Site Map showing location of North and South Buildings and geotechnical engineering borings (blue circles) used to perform the initial site characterization.

The proposed construction consisted of the excavation of over 70,000 cubic yards of material in order to construct a complete basement for each of the two buildings. The depth of excavation was planned to be from 20 to 25 ft below ground surface. Soil borings completed as part of a geotechnical engineering study revealed the presence of variable thicknesses and types of fill materials consisting of black sands, cinders, wood fragments and occasional miscellaneous metallic debris. In addition, a gray, “waxy”, high moisture content waste material thought to be associated with the animal rendering process was also indicated.

The site is located within a large sand and gravel outwash sequence near a major river. The undisturbed geologic profile in the area typically consists of an overlying thin layer (5 to 15 ft) of alluvial silts, sands and clays covering a well-graded sand and gravel deposit that extends to a depth of more than 100 ft. The top of the unconfined groundwater table is at a depth of about 25 to 28 ft below the ground surface.

Field Investigation

2-D Resistivity Profiling

The 2-dimensional resistivity imaging was completed with an *Advanced Geosciences, Inc. Sting Model R1* resistivity meter and a *Swift* automated electrode switching system. Thirty-three (33) stainless steel electrodes were driven into the ground at an equal spacing of five (5) feet with an anticipated total effective depth of the electrical field penetration of 30 to 35 ft below the ground surface. In paved areas, pilot holes were drilled to make proper contact with the subsurface. A concentrated sodium chloride solution was applied to each electrode location to assure that each electrode was electrically coupled with the subsurface. Once the electrodes were emplaced and properly electrically coupled to the soils, the automated data acquisition system was programmed to acquire electrical resistivity readings using a standard dipole-dipole array. This array configuration was chosen because it is most sensitive to lateral changes in electrical resistivity, and might better detect changes in subsurface material type. Once the initial dipole-dipole array was acquired, additional electrodes were moved down-line (a procedure termed “roll-along”) to increase the line length where necessary. The resulting apparent resistivity data set was subsequently downloaded to a laptop computer for inversion analysis.

Six initial resistivity lines, *Lines A1*, *A3*, *B*, *C*, *D*, and *E*, were completed, as shown on **Figure 2**. The arrowheads on the lines indicate the direction of data collection, i.e., the lowest numbered electrode is at the start of the line. Distance along the lines is noted at 20 ft intervals.

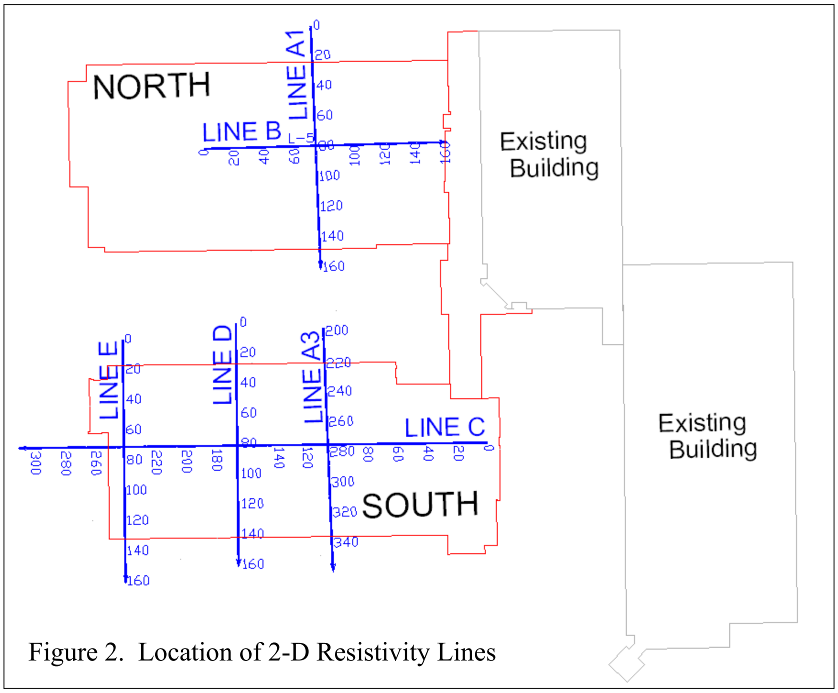


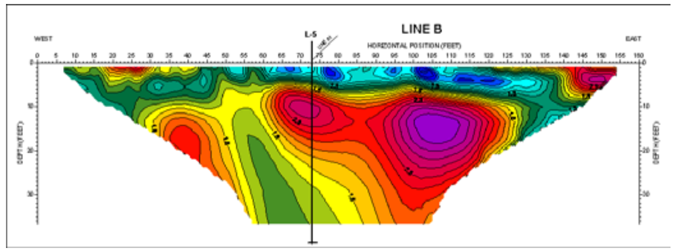
Figure 2. Location of 2-D Resistivity Lines

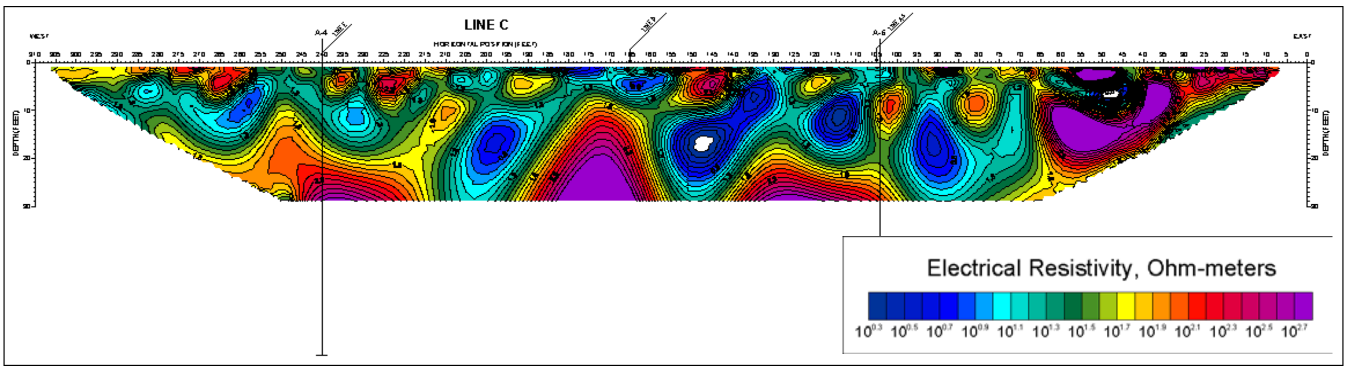
The six profile lines were laid out relative to the proposed building outlines to obtain reasonable coverage of the areas of interest. Note that the western portion of the proposed North Building was obstructed by existing trailers. The intent was also to pass the resistivity lines through selected previously drilled soil borings, the locations of which are shown on **Figure 1**. Referring to **Figures 3** and **4**, for the North Building, *Lines A1* and *B* intersect at Boring L-5, the location of which is shown on the individual cross-sections. For the South Building, *Line C* passes through Borings A4 and A5, and *Line A3* intersects *Line C* at the location of Boring A5. *Line D* passes near Borings A-3 and A-7, and *Line E* passes through Boring A-4 where it intersects *Line C*. The placement of these five soil borings along the resistivity lines provided the opportunity to correlate the resistivity results with the soil boring results.

Resistivity Data Processing

Once each of the six, 2-dimensional resistivity data sets were gathered, the data were transferred to a computer for processing and interpretation. These data were modeled in the using RES2DINV, a resistivity data inversion-modeling program. The resulting model cross section are contoured values of "true" resistivity depicting features in the proper spatial positions (within the constraints of the 2-dimensional assumptions. Surfer Version 8.0 was used to grid and plot the final resistivity model results.

Figure 3. East-West Resistivity Cross-Sections





Data Interpretation

Two detailed electrical resistivity cross-sections, one east-west and the other north-south, both 160 ft in length, successfully imaged electrical resistivity variations in the subsurface in the proposed North Building location. Within the South Building location, four detailed electrical resistivity cross-sections were acquired, three of which were 160 ft in length and oriented north-south and one 310 ft in length and oriented east-west. Final plots of five of the six resistivity cross-sections are provided in **Figures 3** (*Lines A1*, *A3*, and *C*) and **4** (*Lines B*, *D*, and *E*).

The first step in the interpretation is to summarize the results of the soil boring and resistivity correlations and the observed patterns in the resistivity data. Based on our evaluation, the following observations were made relative to these correlations:

1) The ***fill material*** generally possesses a relatively low resistivity value corresponding to the blue to green range of the color scale (i.e., from about 2 to 20 ohm-meters). Note the color scale in the legend is a logarithmic resistivity scale.
2) The ***natural sand and gravel***, in contrast, has a resistivity range generally from orange to red to purple (i.e., from about 80 to over 630 ohm-meters).
3) The general ***vertical profile*** begins at the ground surface with a mixture of primarily low resistivity and much lesser amounts of high resistivity fill.

4) The ***thickness of this fill material*** varies dramatically over the site. The range in fill thickness observed in the soil borings is from 10.5 to 20 ft. The resistivity data suggests, however, an even more dramatic variability from about 5 ft to over 25 ft in thickness.
5) Invariably ***the low resistivity fill material*** is underlain by high resistivity natural sand and gravel soils.
6) Correlation with the soil borings indicates that ***the boundary between the fill and native granular soils*** falls approximately at the yellow color value (i.e., about 50 ohm-meters).

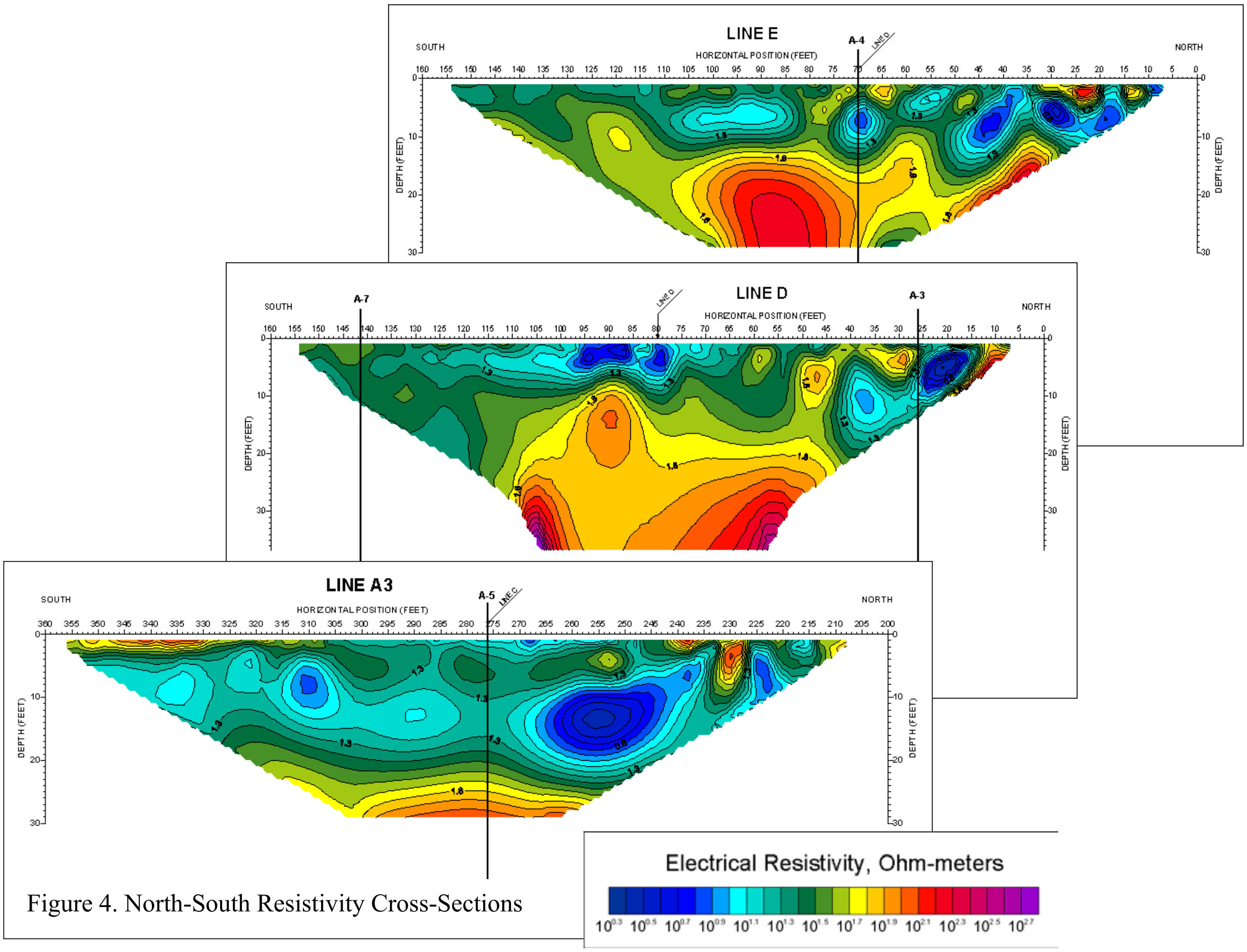


Figure 4. North-South Resistivity Cross-Sections

Our interpretation of *Line C,* which is an east-west line crossing beneath proposed South Building, is that deeper than normal fill is present between line coordinates of about 215 on the west and 67 on the east. It is our interpretation that this thicker zone of fill, which is about 148 feet in apparent width on *Line C*, is possibly within the channel found on the historical aerial photograph. *Line A3,* which crosses *Line C* with the thick fill zone, has consistently thick fill, in excess of 20 feet, and is very uniform in appearance. This suggests that *Line A3* is oriented along the length of the channel. Our interpretation of the position of this channel, noted as a zone of generally very deep fill, is shown on **Figure 5**. In the channel fill thickness may exceed 30 feet, although there appears to be thinner fill accumulations within this structure as noted on **Figure 3**. In the South Building area, the channel appears to be bounded on either side by a variable fill of moderate thickness, perhaps 10 to 15 feet. Of particular interest because of waste disposal implications in the proposed South Building area, several soil borings encountered a gray, "waxy" high moisture content substance in the fill, which may be related or derived from the processing plant. Generally this material is found in or near the channel. This substance does not appear to have a reliable resistivity signature, and little is known about the distribution of the waxy substance beyond what was found in the soil borings.

The channel structure appears to narrow and split towards the north in the proposed North Building footprint as shown on **Figure 5**. In this area there appear to be a couple of narrow, deeper channels, outside of which the fill is generally thin, i.e., about 5 to 10 feet in thickness. No "waxy" material was noted in this area.

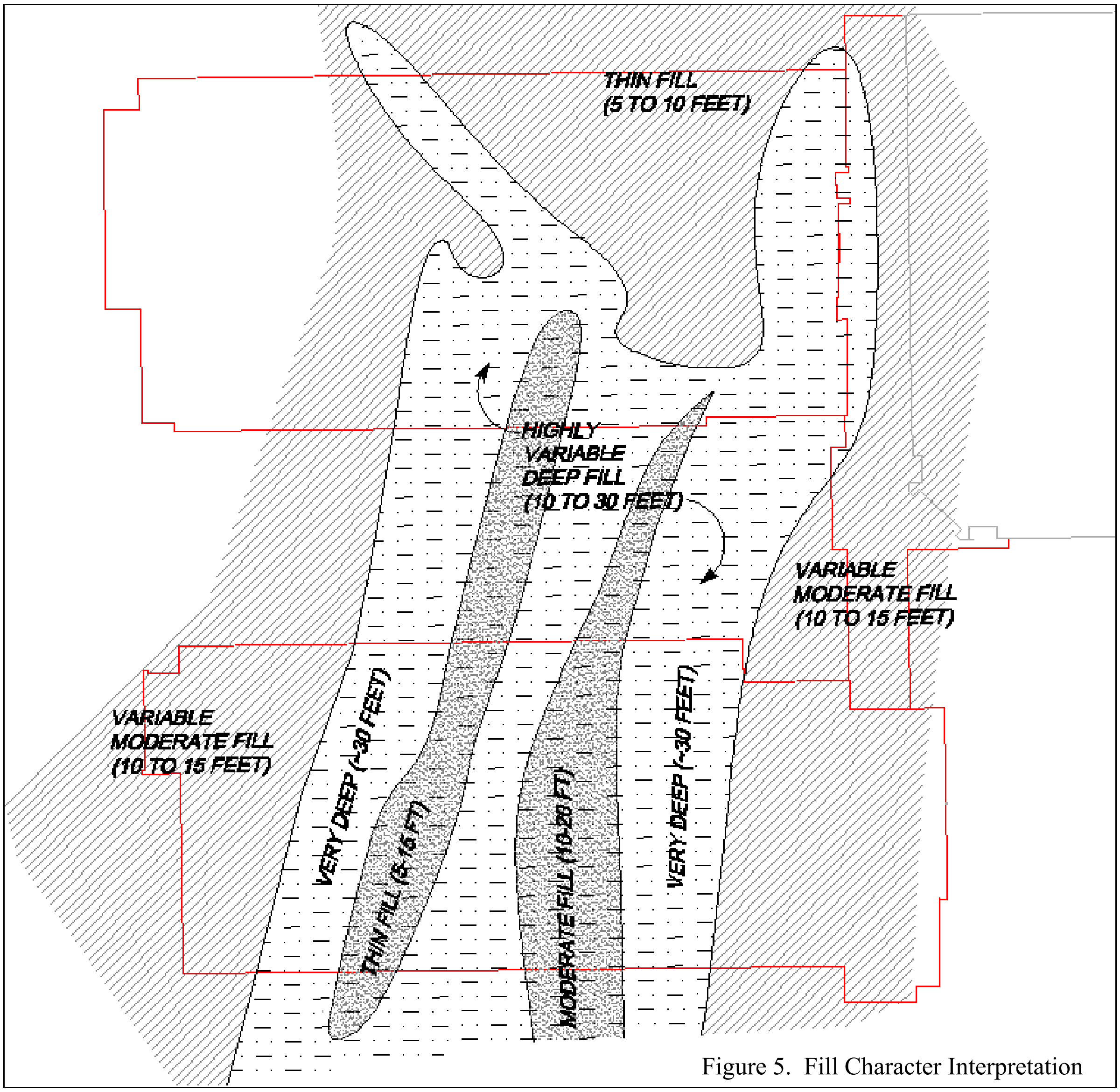


Figure 5. Fill Character Interpretation

Fill Quantity Estimates

Interpretation from Geophysical Data

From the interpretation of the boring and resistivity data, the following initial estimates of the relative quantities of fill and natural soil (by volume) were made based on an excavation depth of between 20 to 25 ft:

- 22.5 to 33 % clean soil (generally sand and gravel);
- 51 to 56 % construction debris fill (black sands, cinders, brick, concrete, wood pieces, metallic debris);
- 16 to 21 % special processing waste fill.

The following fill and natural soil quantities were also estimated for various depths within the excavation as a way to aid segregation efforts and develop an overall excavation plan:

0 to 10 ft depth	-	100 % fill (80 % construction, 20 % special);	0 % clean soil
10 to 15 ft depth	-	60 % fill (60 % construction, 40 % special);	40 % clean soil
15 to 20 ft depth	-	50 % fill (70 % construction, 30 % special);	50 % clean soil
20 to 25 ft depth	-	25 % fill (90 % construction, 10 % special);	75 % clean soil

It should be noted that the actual degree of segregation that can be accomplished during excavation will be affected by the manner in which the contractor chooses to proceed with the excavation. For example, in some instances, excavating from the 'top down' (all the way to the base of the excavation) will likely result in a greater mixing of both clean soils and fill materials, causing higher quantities (and costs) for fill disposal.

These estimates were provided with the excavation bid documents, along with the interpretation of the distribution of fill materials (as shown in **Figure 5**). Discussions were held between the building owner, the general project manager and contractors during the pre-bid meeting and prior to the start of excavation activities concerning approaches to maximize segregation efforts to the extent practical in order to realize an overall project cost reduction.

Monitoring Actual Fill Quantities

Excavation monitoring for the purpose of documenting the materials encountered and to aid in segregation and disposal activities was completed over a six week time period. In general, the results of the geophysical fill characterization were very accurate, and allowed the work to proceed on schedule without significant surprises during construction. At the end of the excavation, the quantities of materials managed were as follows:

- 9.3 % clean soil (generally sand and gravel);
- 72.3 % construction debris fill (black sands, cinders, brick, wood pieces, metallic debris);
- 15.3 % special processing waste fill.

In comparing the actual with the estimated quantities, it can be seen that the actual quantity of clean soil generated was on the order of 13.2 percent less than the lower end of the estimated range. Construction debris fill, on the other hand, was 16.3 percent greater than originally estimated, with special waste materials on the order of 0.7 percent less than the ranged provided. A detailed review of the resulting discrepancies indicated that while the actual quantities of various materials encountered were close to those estimated, the degree of segregation able to be achieved was not ideal. If any fill materials were mixed with clean soils, the entire quantity of material was then classified as a fill material. As such, the effective degree of segregation became the controlling factor for final material classification.

Conclusions

Three-dimensional interpolation of closely-spaced, two-dimensional resistivity profiles provides an effective tool when used in combination with conventional drilling to characterize and estimate fill quantities at sites allowing for sufficient contrast in electrical properties. This approach is an improved method for environmental planning at sites where the excavation and disposal of fill materials results in real construction costs and potential schedule delays that must be anticipated prior to the start of site development.

References

Mundell, J. A., and Byer, G. B. (2002), "Geophysical Characterization of Brownfield Sites for Better Development Evaluation and Construction Planning," In Proceedings: SAGEEP 2002, Environmental and Engineering Geophysical Society, February, Las Vegas, Nevada, Paper 13ESC12.