Appendix D

ANALYSIS OF CPT SOUNDINGS
AND COMPARISON WITH BORINGS
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Ameren Missouri Labadie Power Plant  
Utility Waste Landfill Detailed Site Investigation  
Summary of Geotechnical Investigation  

Appendix D – Analysis of CPT Soundings and Comparison with Borings

The Cone Penetration Test (CPT) data, which appear in Appendix C, have been processed using the program CPT-Pro by GeoSoft in order for the soundings to be easily interpreted visually. This processing includes smoothing the raw data and interpretation for both geologic and geotechnical parameters. The raw data generated by the cone penetrometer include: the cone tip pressure ($q_c$), skin friction ($f_s$), and porewater pressure measured behind the cone tip ($u_2$). The tip pressure and skin friction are corrected by CPT-Pro to account for static pore water pressure ($q_t$ and $f_t$ respectively).

A smoothing function is used to clean up the raw data, to correct for the sensitivity of the CPT equipment and the normal errors that are generated during penetration. This smoothing function removes any erroneous data, and evens out any micro-scale features such as those caused by individual gravel fragments or thin layering which are beyond the ability of the cone penetrometer to reasonably detect due to the probe geometry. By smoothing the data, we ensure that it represents the soil behavior of a soil stratum and not individual anomalies. This smoothing of the data has been shown to have little impact on the soil stratigraphy that is created from the data.

After the data has been smoothed, interpretations can be made. Based upon the pore water pressure data, the ground water depth is approximated manually. Knowing the depth to ground water, the software calculates the static pore water pressure ($u_0$). From the smoothed data of $q_t$ and $f_t$, CPT-Pro automatically calculates the friction ratio ($R_f$), which is defined as ($f_t/q_t$) or alternately as ($f_s/q_t$). In general, a high $R_f$ is indicative of fine-grain and low sensitivity soils. CPT-Pro also calculates the pore pressure ratio ($B_q$), which is defined as ($u_2-u_0)/(q_t-\sigma_v$). In general, higher pore pressure ratios correspond to more sensitive soils, that is, soils which lose significant undrained shear strength when disturbed. Very sensitive soils are typically found in marine deposits in saltwater environments, not in the St. Louis area.

The soil stratigraphy can be determined with this base information, which is derived solely from the data collected from the cone penetrometer as it is pushed, because there are no soil cuttings or soil samples. The primary classification system that we used is the “$R_f$ and $q_t$ based Robertson 1986”, which determines the soil type based upon the corrected cone tip pressure and the friction ratio. The chart used for this method is shown in Figure D-1, which we copied from the CPT-Pro manual. This method is one of 5 that are part of the CPT-Pro program. Coarse-grain soils generally have high $q_t$ and low $R_f$, and fine-grain soils (silds and clays) have low $q_t$ and high $R_f$. These relative values are the basis of soil classification under the $R_f$ & $q_t$ method. In order to account for the limits of data acquisition due to probe geometry, a minimum layer thickness of 6 inches was used for soil classification.

In some cases, we used a second classification system where unexpected or anomalous classifications were produced by the $R_f$ & $q_t$ method – specifically where either “sensitive fine grained” or “organic material” classifications were selected by CPT-Pro. The term “sensitive fine grained” was not useful as it does not descriptive of a soil type. A few CPT logs were developed in our initial analyses using the
$R_f$ & $q_t$ method that had very thick layers (greater than 5 feet) of “organic material.” None of the standard borings on the site encountered anything more than laminations of organics, so we questioned the validity of this classification. The second classification system employed was “$B_q$ and $q_t$ based Robertson 1986,” which determines the soil type based upon the corrected cone tip pressure and the pore pressure ratio. The chart for this classification method is shown in Figure D-2, also from the CPT-Pro manual. A reasonable soil classification resulted using the $B_q$ & $q_t$ method in each case where a questionable classification from the $R_f$ & $q_t$ method was re-analyzed. Our engineering judgment, and CPT soundings correlated with geotechnical borings with soil samples on this project and from other projects, led to our choice of the above two methods of the 5 available in CPT-Pro. We tried the other methods of analyses in the CPT-Pro program, but this yielded the best results.

Five extra temporary geotechnical borings were made next to selected CPT soundings to verify that the CPT sounding produced similar or better results than a standard boring. The pairs of CPT logs and boring logs are depicted in Figures D-3 through D-7. Some logs, specifically C-100 and B-100 in Figure D-6, demonstrate that the CPT probe can detect finer soil layering than a standard geotechnical boring in which soil samples are taken at intervals. In addition to the geotechnical borings, we made CPT soundings next to 3 selected piezometer borings. These are depicted in Figures D-8 through D-10. The general soil classifications in each of these pairs of logs are very similar for practical purposes, with the exception of laminated soils. Laminated soils have been identified in the CPT logs as an average of the soil types in that interval because of the scale limitations of the probe’s size and geometry.

Nine extra confirmation CPT soundings were made next to the planned CPT soundings to demonstrate the repeatability of the results. These comparisons are depicted in Figures D-11 through D-19. The distance in feet between the soundings is shown at the bottom in each figure. The results for each pair are very similar.

Based on the soil type and generated parameters ($B_q$, $R_f$, etc.), geotechnical soil parameters were then developed by CPT-Pro. These parameters include: undrained shear strength ($s_u$), internal effective friction angle ($\phi'$), a pseudo corrected SPT blow count ($N_{60}$), relative density ($D_r$ or $I_D$), Young’s modulus ($E_s$), and wet unit weight ($\gamma$). Some of these are calculated by CPT-Pro using internal equations, and some are calculated with user-input equations from other sources. The references for the equations used are listed below. The data are plotted on the CPT sounding logs and/or are listed in the CPT reports. The CPT reports list the means of data and calculated parameters within each 2.5-foot depth interval. Each CPT report follows the corresponding CPT log in Appendix C.

We noted that the $N_{60}$-values from the standard borings were drastically different from the $N_{60}$-values which were calculated by CPT-Pro for the pairs of borings and CPT soundings. Therefore, the $N_{60}$-values from CPT-Pro have been corrected with factors developed by Reitz & Jens for this site. The factors depend upon the soil type. The corrected $N_{60}$-values are listed in the CPT reports. The correlations which we used are plotted in Figure D-20.
REFERENCES USED IN ANALYSES


Soil classification method based on $R_f$ and $q_t$. Robertson 1986.

Source paper.

Robertson, P.K., Campanella, R.G., Gillespie, D. and Greig, J.

*Use of piezometer cone data.*

Proceedings of the ASCE Specialty Conference In Situ ‘86: Use of In Situ Tests in Geotechnical Engineering. ASCE. 1986.

Also quoted in:


*Cone Penetration Testing in Geotechnical Practice.*

Blackie Academic & Professional.

Classification system from CPTU data (quoted after Lunne, Robertson and Powell, 1997).

<table>
<thead>
<tr>
<th>Zone</th>
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<td>1</td>
<td>Sensitive fine grained</td>
<td>7</td>
<td>Silty sand to silty clay</td>
</tr>
<tr>
<td>2</td>
<td>Organic material</td>
<td>8</td>
<td>Sand to silty sand</td>
</tr>
<tr>
<td>3</td>
<td>Clay</td>
<td>9</td>
<td>Sand</td>
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<tr>
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<td>Silty clay to clay</td>
<td>10</td>
<td>Gravely sand to sand</td>
</tr>
<tr>
<td>5</td>
<td>Clayey silt to silty clay</td>
<td>11</td>
<td>Very stiff fine grained *</td>
</tr>
<tr>
<td>6</td>
<td>Sandy silt to clayey silt</td>
<td>12</td>
<td>Sand to clayey sand</td>
</tr>
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* Overconsolidated or cemented.
Source paper.
Robertson, P.K., Campanella, R.G., Gillesie, D. and Greig, J.
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LOG OF BORINGS
Labadie Power Plant UWL DSI

REITZ & JENS, INC.

Figure D-3
LOG OF BORINGS
Labadie Power Plant UWL DSI
Vert. scale 1:50
Horiz. scale 1:35
Figure D-20

CPT-N_{60} vs Boring N_{60}

- GP-SP Soil: \( y = 0.6829x \)
- CH Soil: \( y = 1.0929x \)
- SM Soil: \( y = 0.6441x \)
- SP Soil: \( y = 0.5072x \)

Standard Boring N_{60} Values vs CPT-Pro N_{60} Values

Line of Perfect Agreement