Non-Destructive Testing of Drilled Shaft Foundations:

Cross-Hole Sonic Logging & Gamma Density Logging

Presented by
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Design Philosophy of Drilled Shafts

• Drilled shafts provide the capability to support large loads in conditions that otherwise would not be possible.

• Shafts can be designed to support a variety of loading conditions, including downward and upward axial loads, lateral loads and seismic events.

• Loads are transferred to bedrock or more stable underlying soils, making them more resistant to seismic and scour conditions.
Drilled Shaft Construction

• Tests are performed on drilled shafts with access tubes attached to the rebar cage installed during construction.

• One access tube per foot diameter of the shaft with a minimum of 4 tubes.

• Tubes must be filled with water at the time of concrete placement. Water must be present for CSL test and then evacuated for GDL test.

• Tubes are generally tied at the interior of the reinforcement cages in a way that reduces bending when placing the cage and ensures proper bonding of concrete to tubes during concrete placement.

• Tubes can be metal or PVC.

• Bottom, top and joints must be sealed to avoid concrete blockage and water leaking.
Rebar Cage Before Placement
Drilled Shaft Construction
Placing Rebar Cage
Placing Rebar Cage
Wet Construction

• Generally employed in collapsing soils or when drilling below water.

• Fluid level needs to be maintained at or above water level.

Important aspects of the concreting sequence:
- The tremie pipe is lowered with a five foot head.
- First concrete placement can and shall disturb sediments accumulated at the shaft bottom and may even kick up sediments, causing them to stick to the rebar cage in areas such as stirrups and crusher rings. This can also result in mixing that will weaken concrete.
- Sediments may become trapped as they accumulate on top of the concrete column to be moved up, and the concrete and its friction with the side may result in folding soil into the concrete, creating an anomaly.
- Sediments can be forced up where they can stick to the rebar cage or the access tubes.
- Not enough concrete pressure during casing pull can lead to reduced diameter.
- Slurry with sediments may be left or slurry may be too thick and concrete if not placed quick enough.
- Stiff concrete develops friction against the sidewall, creating gaps against the casing.
- Stiff concrete will fail to consolidate properly, resulting in voids or honeycombs.
CSL Process

- Transmitter probe emits an ultrasonic pulse that travels through the concrete.
- Receiver probe is tuned to the same frequency (45 KHz) to detect the pulse. Range of 20 KHz to 100 KHz. Frequency should be correlated to largest aggregate size.
- Signal strength (energy) and arrival time (wavespeed) are affected by the shaft diameter, concrete quality and sonic continuity (bonding or coupling of concrete).
CSL Procedure

- Probes are lowered to the bottom of the access tubes and retrieved according to ASTM D 6970 while data is collected by the data acquisition system until the entire shaft is scanned.

- Distance measurements, sampling rate, record size, gain, trigger level and transmit power level are adjustable.

- Depth encoders record depths that are correlated with ultrasonic pulse readings.

- Each tube combination is tested and recorded for further analysis and reporting.

- Tubes are numbered starting at the northernmost tube going in the clockwise direction.
Equipment is relatively light and portable due to a battery power source.

Water is evacuated from tubes after CSL testing by use of a rigid hose and air compressor to ready the tubes for GDL.
Standard reports include wavespeed, energy and the “waterfall diagram” along with job and drilled shaft information.

Raw data is analyzed and filtered to produce reports with accurate depictions of drilled shaft characteristics.
Initial Debonding VS Concrete Contamination
Gamma Density Logging (GDL)

- Gamma ray photons from a Cesium-137 ionizing radiation source are emitted into the surrounding material, collide with electrons and change direction, also known as Compton Scattering.

- The intensity of reflected gamma ray photons is measured by a Sodium Iodide scintillation crystal detector in counts per second (cps). The intensity of the gamma rays returning to the detector is a direct correlation to the electron density of the surrounding medium.

- The photon count/unit of time is calibrated to measure variations in the unit weight of concrete.
Gamma Density Logging (GDL)

Gamma Density Equipment

Cesium-137 Source

Gamma Density Probe

Diagram:
- Electronic
- Detector
- Spacer
- Source
- To Data Collector
Gamma Density Logging (GDL)

*The percentage of resolution has not been confirmed.*

Extendable to 6” +/- effective with spacer. More space will cause $R_j$ to increase, but resolution will be lost.*
GDL Process

- The volume of investigation is limited to a 5 to 6 inch radius, with 90% of readings originating from within this distance.

- Counts are affected by the density of the material, speed of logging, spacing between source and detector, and source strength.

- Logging speed is adjustable, but typically takes place at approximately 10 feet per minute.

- Tests can be done with or without water in tubes, but are generally done without water to avoid damage to electronic equipment.
GDL Procedure

• Each tube is logged individually, with the first tube being logged twice to demonstrate repeatability of testing.

• Speed is adjustable, with a standard rate of 10 feet per minute.

• Probes range from 30 to 60 inches in length with a diameter of 1.375 inches.

• Equipment consists of probe, cable, motorized winch, microprocessor and laptop computer and generator.
Equipment is heavier and more fragile than CSL equipment.

Radiation source and delicate scintillation crystal increase concern in congested areas.
GDL Data

Data is analyzed to provide mean density and standard deviation details. A standard deviation of 2.5 is used to calculate mean -2, -3 and +3 standard deviations.

<table>
<thead>
<tr>
<th></th>
<th>Tube 1</th>
<th>Tube 2</th>
<th>Tube 3</th>
<th>Tube 4</th>
<th>Tube 5</th>
<th>Tube 1A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Density</td>
<td>154.0</td>
<td>152.4</td>
<td>153.0</td>
<td>154.4</td>
<td>154.9</td>
<td>153.8</td>
</tr>
<tr>
<td>Std Deviation</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Mean - 3XStd.Dev.</td>
<td>146.5</td>
<td>144.9</td>
<td>145.5</td>
<td>146.9</td>
<td>147.4</td>
<td>146.3</td>
</tr>
<tr>
<td>Mean + 3XStd.Dev.</td>
<td>161.5</td>
<td>159.9</td>
<td>160.5</td>
<td>161.9</td>
<td>162.4</td>
<td>161.3</td>
</tr>
<tr>
<td>Mean - 2XStd.Dev.</td>
<td>149.0</td>
<td>147.4</td>
<td>148.0</td>
<td>149.4</td>
<td>149.9</td>
<td>148.8</td>
</tr>
<tr>
<td>Actual Std Dev</td>
<td>1.7</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.5</td>
<td>1.7</td>
</tr>
</tbody>
</table>

- The data profile provides a comprehensive reading of the medium adjacent to the access tube.

- PVC couplers will result in low density spikes and spaced reinforcements will result in a high density spikes. These spikes are easily identified by repetitive patterns and sudden changes in density.
Defects/Anomalies

• Different types:
  o Critical defects: Delineates the construction to be dangerous if not remediated.
  o Important defects: Have serious effects on performance, should be remediated.
  o Defects of little importance: Ones which do not affect performance or safety.

“...While a well-trained and experienced technician may be capable of performing the field work for most NDT techniques, supervision and final interpretation of NDT data generally require the expertise of an experienced engineering professional.”

-S. Scot Litke, Executive Director
ADSC: The International Association of Foundation Drilling
(Excerpt from Nondestructive Testing of Deep Foundations; Hertlein, Bernard)
First Arrival Time (FAT): When the signal first exceeds the simple amplitude thresholds. Wavespeed = tube spacing/FAT.

<table>
<thead>
<tr>
<th>Concrete Quality</th>
<th>FAT Increase (%)</th>
<th>Energy Reduction (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>0 to 10</td>
<td>and &lt;6</td>
</tr>
<tr>
<td>Questionable</td>
<td>10 to 20</td>
<td>and &lt;9</td>
</tr>
<tr>
<td>Poor/Flaw</td>
<td>20 to 30</td>
<td>or 9 to 12</td>
</tr>
<tr>
<td>Poor/Defect</td>
<td>&gt;30</td>
<td>or &gt;12</td>
</tr>
</tbody>
</table>

Filtering functions of software enable quick analysis in most cases.

- If Poor/Flaw results are greater than 50 percent of profile, it must be addressed.
- Poor/Defect in more than one profile must be addressed.
- Tomography can be performed for additional analysis.
Contamination in Concrete VS Initial Debonding
FAT can be manually “picked” to obtain more accurate results beyond what the software filters can provide.
GDL Evaluation

GDL data is compiled and analyzed in spreadsheet software (Excel).

<table>
<thead>
<tr>
<th>Tube1 Depth</th>
<th>Tube1 Density</th>
<th>Tube2 Depth</th>
<th>Tube2 Density</th>
<th>Tube3 Depth</th>
<th>Tube3 Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.118883</td>
<td>162.584</td>
<td>0.227541</td>
<td>159.732</td>
<td>0.172573</td>
<td>160.442</td>
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<tr>
<td>0.282508</td>
<td>162.303</td>
<td>0.391166</td>
<td>163.566</td>
<td>0.336198</td>
<td>164.121</td>
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<td>0.446134</td>
<td>160.301</td>
<td>0.554791</td>
<td>162.303</td>
<td>0.496824</td>
<td>161.885</td>
</tr>
<tr>
<td>0.609759</td>
<td>159.099</td>
<td>0.718417</td>
<td>160.172</td>
<td>0.663449</td>
<td>158.523</td>
</tr>
<tr>
<td>0.773384</td>
<td>156.642</td>
<td>0.882042</td>
<td>158.188</td>
<td>0.827074</td>
<td>154.293</td>
</tr>
<tr>
<td>0.93701</td>
<td>159.722</td>
<td>1.045374</td>
<td>158.598</td>
<td>0.99007</td>
<td>153.976</td>
</tr>
<tr>
<td>1.10064</td>
<td>160.262</td>
<td>1.205299</td>
<td>158.262</td>
<td>1.15433</td>
<td>156.096</td>
</tr>
<tr>
<td>1.26426</td>
<td>160.424</td>
<td>1.372928</td>
<td>159.178</td>
<td>1.31795</td>
<td>157.13</td>
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<tr>
<td>1.42789</td>
<td>161.828</td>
<td>1.53654</td>
<td>158.274</td>
<td>1.48158</td>
<td>157.227</td>
</tr>
<tr>
<td>1.59151</td>
<td>162.26</td>
<td>1.70017</td>
<td>159.135</td>
<td>1.6452</td>
<td>157.814</td>
</tr>
<tr>
<td>1.75514</td>
<td>160.91</td>
<td>1.86679</td>
<td>159.941</td>
<td>1.80883</td>
<td>162.875</td>
</tr>
</tbody>
</table>

Standard reports contain statistics and density profiles for all tubes.
GDL Statistical Analysis

Fundamentals of Statistical Quality Control

- GDL data is also analyzed using traditional statistical analysis.
- Analyzing the Gaussian distribution of the density readings provides data about the quality of the drilled shaft.

Standard Deviation $= \sigma = \sqrt{\frac{\sum(x - \bar{x})^2}{n}}$
GDL Statistical Analysis

Statistical analysis of drilled shafts of varying quality

Poor concrete quality from 3 to 10 feet

Concrete contamination within top 7 feet

Good quality drilled shaft
Correlating information between CSL and GDL tests can effectively determine flaws from other variations (such as debonding).
Correlating Information
Tomography
Coring
Coring
Coring