Assessing Drilled Shaft Quality Based on Cross Hole Sonic Logging Data[i]

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Drilled Shafts are a frequently used deep foundations solution, often being designed to sustain high loads. Cross Hole Sonic Logging (CSL) evaluates the concrete quality and construction adequacy of drilled shafts. It is performed in an attempt to identify poor quality concrete due to mixing with drilling slurry, honeycombing, necking, soil intrusions, and soft toe conditions.

Figure 1: *Drilled shaft with built-in access tubes for CSL testing*

When construction specifications require this type of quality control, the drilled shafts that will be tested (usually a percentage of the total number of shafts on the site) are built with 4 or more access tubes (Figure 1). Cross Hole Sonic Logging is performed by lowering a transmitter into one access tube while simultaneously lowering a receiver into a second tube. The transmitter generates ultrasonic pulses that travel through the concrete to the receiver. Received signals are processed and displayed by specialized equipment and evaluated by a test engineer, using appropriate software. The CSL procedure is repeated for each pair of tubes. Figures 2 (signal energy versus time at 2 different points along a pair of tubes) and 3 (shaft profile for a pair of tubes) show some of the information that a test engineer would see on the equipment display.

Cross Hole Sonic Logging is standardized by the USA-based standard ASTM D6760 (ASTM, 2002) and the French norm NF P94-160-1 (AFNOR, 2000) - Vietnam and China also have their own CSL standards. Various regulatory and industry entities around the world mandate, recommend, or, at least, accept that drilled shafts be inspected by this method (Beim and Likins, 2008).

In the United States, the most common criterion for evaluating CSL data is the First Arrival Time (FAT). FAT is defined as the time elapsed between when the signal is generated by the transmitter and when it is first sensed by the receiver. The concrete wave speed is calculated by dividing the distance between tubes by FAT. A higher-than-expected (or delayed) FAT is indicative of a lower concrete wave speed, and concrete wave speed is directly related to concrete quality.

Although First Arrival Time analysis gives an indication of concrete quality, it may not be sufficient to make a complete assessment of a drilled shaft. One problem with using FAT only as a method of interpretation is demonstrated in Figures 2 and 3, from a 12-m-long shaft purposely built with a defect at 5 m.

Figure 2 shows the strength of the received signals versus time (time 0 at the left end of the plot corresponds to the time when the signal is generated by the transmitter) at two different depths along the shaft. While both plots show well-defined, and nearly identical, First Arrival Times (first dotted red line), the signal on the bottom has significantly lower strength or "energy". This is an indication of an interruption on the transmission path or of transmission through contaminated concrete.

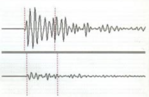

Figure 2: *Signal from location with good concrete (top) and signal from location of known defect at 5-m depth (bottom)*

CSL equipment will create a plot such as the one shown on Figure 3 for each pair of tubes, showing FAT increase and signal energy reduction for the entire length of the pair of tubes (a profile). The bold line on the left side of the figure plots FAT, and the thin line energy, both versus depth. While there is little FAT variation - less than 10% - over the entire length of the shaft, the energy decreases by 8.4dB at 5 m (red horizontal line). The waterfall diagram on the right side of the figure confirms the existence of a signal of low energy at about 5-m depth. A FAT-only evaluation would classify this shaft as "Good".

Likins *et al* (2007) proposes that an improved drilled shaft evaluation criterion be used in the United States, where some Departments of Transportation use a FAT-only-based defect classification. The proposed criterion distinguishes Flaws from more serious Defects, and adds a quantitative Energy Reduction criterion to the evaluation. Likins cites Chinese and French (AFNOR, 2000) standards that, as his proposed criterion, consider not only FAT, but also the reduction in signal energy in assessing the quality of the concrete between transmitter and receiver. Each shaft profile would be evaluated as in Table 1:

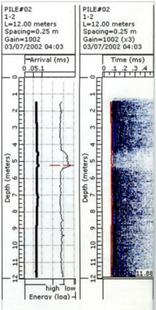

Figure 3: *Output of a CSL test between tubes 1 and 2 of the same 12-m-long defective shaft*

Evaluation	FAT increase		Energy reduction
(G) Good	*0 to 10%*	***and***	*< 6 dB*
(Q) Questionable	*11 to 20%*	***or***	*6 to 9 dB*
(P/F) Poor/Flaw	*21 to 30%*	***or***	*9 to 12 dB*
(P/D) Poor/Defect	*> 31%*	***or***	*> 12 dB*

Table 1: Proposed evaluation criterion for drilled shafts

With a FAT- and Energy-based evaluation the 8.4-dB energy reduction at 5 m places the knowingly defective shaft at the upper end of the "Questionable" evaluation, closer in fact to an evaluation of Poor/Flaw.

Likins *et al* (2007) recommends that shafts with a P/F evaluation in more than half of the profiles be further investigated. The more serious evaluation of P/D should trigger further investigation whenever present in more than one profile. Further investigation of a shaft with a potential flaw or defect should include tomography evaluation and could require excavation (if near the top of the shaft), core drilling, or pressure grouting. Defects or flaws present over the entire cross-section usually require repair or shaft replacement.

This proposed evaluation refines FAT-only classifications by distinguishing Flaws from more serious Defects, and by adding a quantitative Energy Reduction criterion to the evaluation. By contributing to a more positive identification of defects, this criterion enhances CSL based quality control practices in drilled shaft construction. ■

References:

- Likins, G. E., Rausche, F., Webster, K., Klesney, A., February, 2007. Defect Analysis for CSL Testing. Geo-Denver 2007 New Peaks in Geotechnics: Denver, CO. (CD-ROM).
- ASTM. (2002) Standard D6760-02 – "Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ul-trasonic Crosshole Testing." ASTM International, West Conshohocken, PA, www.astm.org, USA.
- AFNOR. (2000) Association Française de Normalisation. NF P94-160-1 Sols: reconnaissance et essais - Auscultation d'un élément de fondation - Partie 1 : méthode par transparence, France (in French).

i. This paper was adapted from Beim, G. and G. Likins (2007) Criteria for Evaluating CSL Data, PDI and GRL Newsletter, issue 55, Cleveland, OH, USA, available at www.pile.com/newsletter.

يتمّ استعمال العواميد الحفرية في الأساسات العميقة وهي عادةً ما تكون مصمّمة لتتحمّل الأعباء الثقيلة. يقوم التسجيل الصوتي المقطعي CSL بتقييم نوعية الخرسانة وصلاحية العواميد الحفرية إذ يُطبّق بهدف إيجاد أيّ خرسانة متدنيّة النوعية نتيجة الإنخلاط مع روبة الحفر أو التصميم النخروبي أو التخصير أو بسبب مواد دخيلة في التربة وظروف أخرى.

عندما تفرض معايير الإنشاء هذا النوع من مراقبة النوعية يتم بناء العواميد الحفرية التي سيتم فحصها. لتتضمّن أربعة أو أكثر أنابيب وصول. يتم القياس بالتسجيل الصوتي المقطعي عبر إنزال جهاز إرسال في واحد من أنابيب الوصول في حين يتم انزال جهاز تلقّي في أنبوب آخر. يصدر جهاز الإرسال نبضات فوق صوتية تعبر الخرسانة وتصل الى جهاز التلقي. يتم من بعدها معالجة الإشارات المتلقّات وعرضها على معدات متخصصة ليتمكن المهندس من تقييمها عبر الإستعانة ببرنامج معلوماتي مناسب. يتم تكرار عملية التسجيل هذه لكل أنبوبين في العواميد الحفرية للحصول على صورة شاملة حول نوعية الخرسانة هناك.