EXECUTIVE SUMMARY

This study was conducted under the Federal Highway Administration (FHWA), Central Federal Lands Highway Division (CFLHD) contract number DTFH68-03-P-00116. The current practice in assessing the integrity of newly constructed drilled shaft foundations, or other concrete structures that contain access tubes, is through the use of nondestructive testing (NDT) methods. Most common NDT methods include crosshole sonic logging (CSL), gamma-gamma density logging (GDL), and crosshole sonic logging tomography (CSLT). Numerous studies and field investigations have been performed to evaluate the accuracy and effectiveness of these NDT methods in detecting defects in drilled shafts. However, most of these studies have fallen short to correctly identify and characterize defects for engineering decision making. Or, as stated by Jerry DiMaggio (2004), FHWA Principal Geotechnical Engineer, *"when using (NDT) methods, the key questions that often must be answered are:* (1*) Is the test result a false negative?* (2) *What are the next steps and who is responsible for incurred cost if a defect is suspected? and most importantly* (3) *Is the discontinuity a defect?"*

The purpose of this study was to address two key issues needed by the foundation engineer to assess the structural integrity of drilled shaft, more specifically:

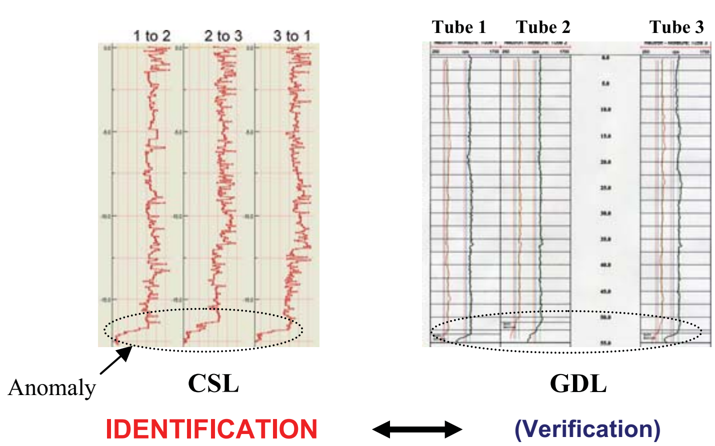
- What constitutes a defect in a drilled shaft? and,
- How to relate observed defect in a velocity tomogram to engineering strength information?

The overall objectives of this study were:

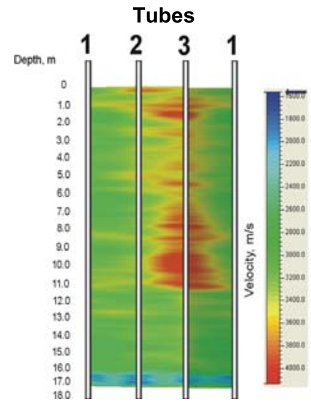
- Review and evaluate the current state-of-practice of NDT methods;
- Use a statistical analysis to define a "defect" in a CSLT image;
- Monitor and model changes in concrete temperature (velocity, density, and moisture) in a drilled shaft after concrete placement;
- Establish empirical relationships that correlate changes in a CSLT velocity image to changes in concrete strength.

To address the above issues and objectives, the study was conducted based on the development of a three-step approach that allows the foundation engineer to evaluate and characterize a defect and assess its effects on the overall integrity of the drilled shaft foundation. The following presents the most significant results:

Step 1. Anomaly Identification and Independent Verification – This step allows the engineer to identify and independently verify suspected "anomalies" in a drilled shaft foundation inside and outside the rebar cage. It is concluded that both CSL and GDL must be used for this initial evaluation.

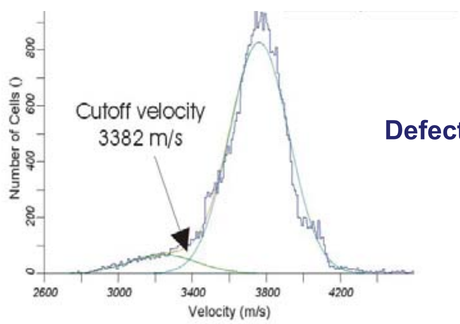


Once an anomaly is identified, three-dimensional CSLT is required for velocity imaging of the anomalous zones. This task is best achieved by using true 3-D tomographic inversion software. The 3-D imaging also requires a velocity equalization to be performed prior to tomographic imaging.



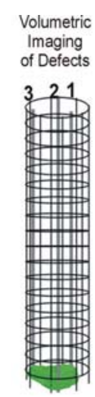
CSLT
IMAGING

Step 2. Defect Definition – In this step, a statistical approach is used to separate CSLT velocity distribution of sound concrete from the velocity distribution of anomalous concrete. With this analysis, a key cut-off velocity is determined that separates this two velocity distributions. As a result, a **"defect"** volume is defined as having a velocity lower than the cut-off velocity.



Defect Definition

Step 3. Defect Characterization – The third step relates changes in velocity values in the defect volume to changes in concrete strength. Using the cut-off velocity, a 3-D strength image is developed to characterize the defect. The velocity-strength correlation is developed in the laboratory using cylinders with the same design mix as the shaft and allowing for maturity. The strength image can now be inputted to the shaft design analysis program to evaluate the effect of the defect on the overall performance of the designed structure. This allows the engineer to decide whether the defective shaft is still serviceable, repairable by remediation, or unacceptable.



<4,000 psi

STRENGTH CHARACTERIZATION

Therefore, this study has evolved onto the development of a basic guideline or "roadmap" that leads the engineer from the initial detected anomalies to the integrity assessment of the drilled shaft foundations. The outcome of this study has provided the foundation engineer and owner agencies with an improved tool in deciding to accept, remediate, or reject a given shaft or a wall structure.

REPORT ORGANIZATION

Chapter One contains a brief discussion of various nondestructive techniques along with advantages and their disadvantages.

Chapter Two describes in detail anomaly identification, independent verification, and imaging. A tomographic modeling study of shafts containing defects is presented.

Chapter Three describes the statistical analysis used for separating sound concrete velocity distribution from anomalous concrete velocity distribution. Using this analysis, a cut-off velocity is determined for volumetric imaging of a defect.

Chapter Four describes defect characterization (or, correlation of velocity to strength). Final tomographic "strength images" are developed for integrity assessment by the engineer. In order to better understand the correlation between velocity and strength, the results of a temperature modeling study is presented. In addition, data from a seven-day field monitoring of two shafts using temperature, velocity, density, and moisture logging is included. A description of the maturity method is presented.

Chapter Five presents data examples where the three-step approach (described in Chapters 2-4) is used. Data from 20 drilled shafts obtained from three (3) different projects are presented.

Chapter Six provides a summary and conclusions of the study.

In order to aid in defining some of the terms used in this report, a glossary of terms is provided.

In Appendix A, seven (7) case histories are presented where dual crosshole sonic logging (CSL) and gamma-gamma density logging (GDL) methods were used for correct identification and independent verification of anomalies in drilled shaft foundations.

Units. All units are expressed in both metric and English. However, when a reference is made to a figure or table which has only metric units, accordingly the units in the text are expressed in metric only.