The Uncertainty in the Displacement Evaluation of Deep Foundations

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ABSTRACT

Demand for a more economical design and attempts to improve structural safety have resulted in the re-examination of the entire design process over the past 50 years.

A design of a structure needs to ensure that while being economically viable; it will suit the intended purpose during its working life. Limit State (LS) is a condition beyond which the structure, or a component, fails to fulfill in some way the intended purpose for which it was designed. Limit State Design (LSD) comes to meet the requirements for safety, serviceability, and economy. LSD generally refers, therefore, to two types of limit states: Ultimate Limit State (ULS), which deals with the strength (maximum loading capacity) of the structure, and Serviceability Limit State (SLS), which deals with the functionality and service requirements of a structure to ensure adequate performance under expected conditions (e.g. normal expected loads or extreme events).

The ULS design of a structure and its components (e.g. pile) depends upon the predicted loads and the capacity of the component to resist them. Both loads and capacity (resistance) have various sources and levels of uncertainty. Engineering design has historically compensated for these uncertainties by using experience and subjective judgment. The new approach that has evolved aims to quantify these uncertainties and achieve more rational engineering designs with consistent levels of reliability. These uncertainties can be quantified using probability-based methods resulting with the Load and Resistance Factor Design (LRFD) methodology, which became the preferable approach for the AASHTO Specifications. Separation of uncertainties in loading from uncertainties in resistance along with procedures from probability theory allow LRFD to assure a prescribed margin of safety. While the ULS condition is relatively well established, the SLS was never methodologically researched and quantified. The same principles used in the LRFD for ULS can be applied to the SLS substituting the capacity of the component with a serviceability limit (e.g. lateral and/or vertical displacement).

A study under the National Academy of Science (NAS) supported by Geosciences Testing and Research (GTR) is aimed at developing the AASHTO LRFD Specifications for serviceability in the design of bridge foundations. A critical component of such development is the quantification of the uncertainty associated with the displacement evaluation of Deep Foundations. Analyses methods related to single piles and pile groups under vertical or horizontal loads were both investigated and developed. Large databases were assembled and examined mostly via the approach seeking the uncertainty in the prediction of a load required to induce a prescribed displacement.

The uncertainty in the prediction of lateral resistance of single piles and pile groups was established using computer-based software packages (COM624P/LPile, GROUP and the Strain Wedge Method – SWM) in addition to hand-based calculation methods (Broms and Normalized Relations developed in this study). The uncertainty in the settlement prediction of vertically loaded single piles and pile groups was established using elastic solutions (including one developed in the study), load transfer method, equivalent pier and footing methods, and a simplified evaluation of the settlement under design loads developed in this study. The analyzed databases included case histories of load testing related to 85 free-head single piles, 9 pile groups without a cap and 8 pile groups with a cap (additional two caped timber pile groups) subjected to a lateral load, and 165 free-head single piles and 36 pile groups with a cap subjected to a vertical load. The cases were analyzed to both determine the uncertainties in the analysis methods and the source of these uncertainties.

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