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Executive Summary Report

Field Instrumentation, Monitoring of Drilled Shafts for Landslide Stabilization and Development of Pertinent Design Method

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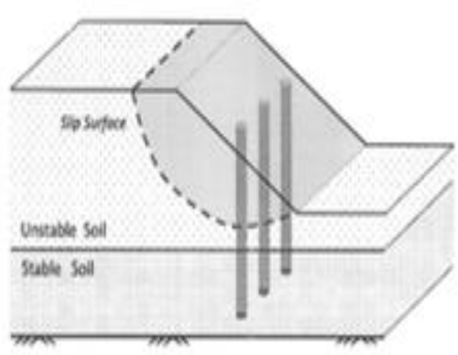
Project Background

The use of a row of spaced drilled shafts to stabilize unstable slopes along the highways offers many advantages compared to other slope stabilization techniques. Some of these advantages may include: (1) various construction techniques are available for installing drilled shafts in almost any type of soil and rock conditions; (2) lateral load test can be performed to verify the lateral load-carrying capacity of the drilled shafts; (3) the use of drilled shafts avoids the need to address the right-of-way issues that may be needed for other types of slope stabilization methods; (4) the drilled shafts offer a reliable and economical solution compared to other slope stabilization methods; and (5) the drilled shafts are typically structurally capable of resisting long-term environmental effects.

Despite a wide application of this slope stabilization technique by highway agencies, there is no universally accepted design method that can yield a safe and economic design outcome. The design process requires engineers to determine optimized combinations of the following key design variables: (1) drilled shafts diameter; (2) spacing between the drilled shafts to ensure the development of soil arching; (3) the necessary socket length of the drilled shafts in the non-yielding rock layer so that the drilled shafts can act as relatively stable structural members against the moving soil; (4) the location of the drilled shafts within the slope body so that the target global factor of safety of the stabilized slope can be achieved using the most economical configuration of the drilled shafts; (5) the forces imparted on the drilled shafts due to the sliding soil mass so that the structural design of the drilled shafts can be performed to meet the structural capacity requirements. Therefore, a research effort to develop and validate a pertinent design procedure is needed.



Study Objectives

- Develop a pertinent design and analysis method, together with the accompanied PC based, user friendly computer program, to enable engineers to design an optimized slope stabilization scheme using a single row of appropriately spaced drilled shafts. Both geotechnical and structural design issues should be considered in a unified approach to yield a safe and yet economic design outcome.

- Validate the developed design method by comparing with field load test results at the ATH-124 project site and the short-term and long-term monitoring data of three ODOT projects involving the use of drilled shafts as a means to stabilize unstable slopes.

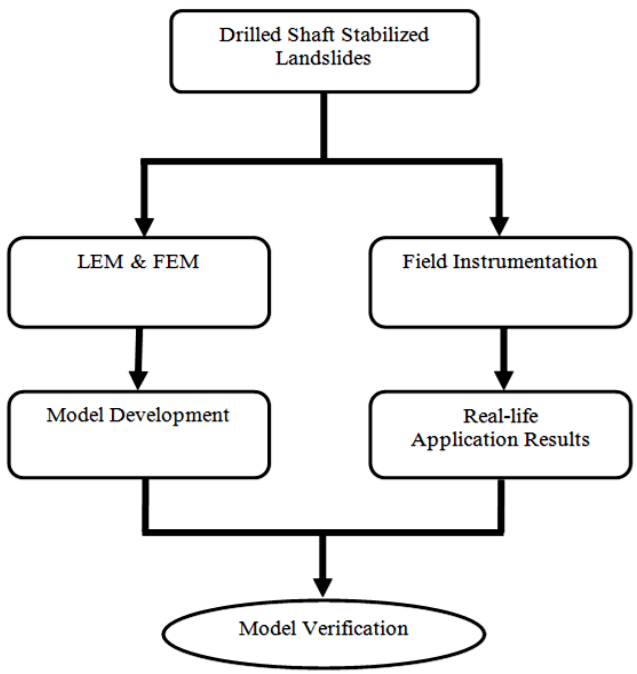
Description of Work

The general framework of the research approach is shown in the diagram and is consisted of the following development work:

- Conducting comprehensive parametric analysis of the soil arching behavior in a slope/shaft system by utilizing three-dimensional finite element models with the strength reduction techniques.

- Developing the general procedure of limiting equilibrium based method of slice approach for determining the geotechnical factor of safety of a slope/shaft system in which the load transfer factor is used to account for the beneficial effects of the drilled shafts in reducing the driving force on the slope.

- Conducting a controlled load test at the ATH-124 project site and collecting both short-term and long-term field performance data through instrumentation and monitoring efforts at three ODOT project sites (MRG-376, WAS-7, and JEF-152) for validating the developed design method and the accompanied computer aided design tool, UA SLOPE 2.1 program.



Research Findings & Conclusions

- The existence of soil arching due to the presence of a single row of appropriately spaced drilled shafts in a slope was ascertained from more than 40 cases of three-dimensional finite element simulations and from field measured data at the ATH-124 test site.

- The soil arching behavior of the slope/shaft system was quantified into a set of semi-empirical equations through the load transfer factor, which in turn was incorporated into the method of slice slope stability analysis program, UA SLOPE 2.1, to compute geotechnical FS and the net force on the drilled shaft in a complex slope/shaft system. The effectiveness of soil arching in a slope/shaft system was found to be mostly influenced by the following factors: soil strength parameters, shaft location, shaft diameter, and shaft spacing.

- The suggested design process involves the determination of optimum design variables, including shaft location, shaft size (diameter and length), shaft spacing for an optimum outcome; namely, finding the drilled shaft configuration to yield the target global FS yet with the least load demand on the drilled shafts. The location of drilled shafts is an integral part of the design variables due to its influence on both achievable global FS and the required shaft length.

- The validity of the UA SLOPE 2.1 program was established by excellent comparisons with the finite element simulation results in terms of both global FS and the net force on the drilled shaft. In addition, the load test data at the ATH-124 project site was used to provide a calibrated and site specific finite element model, from which the finite element predictions and the UA SLOPE 2.1 program predictions for both global FS and the net force were found to be in excellent agreement. The applicability of the UA SLOPE 2.1 program was therefore verified to the extent documented in this report.

- The three ODOT landslide repair projects that were instrumented and monitored by the UA research team showed that the drilled shafts to be an effective means to re-construct the failed slope to its original slope geometry with an enhanced global factor of safety. It was also observed that the post construction movements of the repaired slopes were within an acceptable range and the measured forces on the drilled shafts were substantially below the structural capacity of the as-built structure elements.

Implementation Recommendations

The implementable outcome of this research was the development of a robust and user friendly PC based computer program UA SLOPE 2.1. This computer program, with the necessary verification of its accuracy and range of applicability documented in this report, can be used by the design engineers to analyze complex soil profile and slope conditions often encountered in real world projects. The computer program can also be effectively used for the iterative optimization design process to achieve an optimized combination of shaft location, shaft size, and shaft spacing that would provide the target factor of safety for the geotechnical system (i.e., the drilled shaft/slope) as well as the economic structural design of the drilled shafts with the least construction cost. Adoption of this computer-aided design tool would potentially save ODOT both engineer manpower requirements and construction cost for future landslide repair projects.