**Design of Rock Socketed Drilled Shafts**

**Problem**

Drilled shafts socketed into rock are widely used as foundations for bridges, large signs, transmission towers, noise walls, retaining walls, and buildings. Rock-socketed drilled shafts are also used to stabilize active landslides. Typical loads applied to drilled shafts are compressive axial loads, tension uplift loads, and lateral (moment) loads. Numerous research efforts have been conducted in the past to attempt to determine the magnitude of the side shear resistance in rock sockets along axially loaded drilled shafts.

The lack of field verified specific detailed design methods for laterally loaded drilled shafts embedded in rock subsurface profiles, present a challenging design effort for the engineer. Many of the recent designs were unintentionally prepared very conservatively by providing an excessive rock socket length. A substantial cost saving could be realized, while maintaining an acceptable and safe performance, if a proven rational method was developed for the analysis and design of drilled shafts in such a subsurface profile.

The lack of validated design methods stimulates the need to develop a more rational design approach for laterally loaded drilled shafts in rock. Therefore, a method for predicting the ultimate lateral capacity, predicting deflections of drilled shafts in a rock mass, determining p-y criterion for the rock mass, and utilizing in-situ pressuremeter/dilatometer test information for determining rock properties needs to be developed.
The p-y method has been widely and successfully used for the design of laterally loaded drilled shafts in soils for decades. This method is based on a numerical solution of a physical model based on a beam on a Winkler foundation. The structural behavior of the drilled shaft is modeled as a beam, while the soil-shaft interaction is represented by discrete, non-linear springs. Rock has been given little attention in the p-y method of analysis.

Objectives
This research project was carried out to achieve the following objectives:
(a) Develop and validate a design/analysis procedure for rock-socketed drilled shafts used in bridge applications.
(b) Develop a p-y criterion for rock mass.
(c) Perform full-scale field lateral load tests on fully instrumented drilled shafts to obtain reliable and comprehensive field test data for validating the p-y criterion.
(d) Identify the best field and laboratory test methods for determining rock mass properties to be used in the developed p-y criterion.
(e) Review and recommend a best approach for deriving site specific p-y curves of rock mass from pressuremeter or dilatometer test data.

Description
This project consisted of evaluating and developing design criteria for drilled shafts socketed in rock and subjected to lateral loads. Results from five lateral load tests on rock socketed drilled shafts conducted in Ohio were evaluated. The instrumentation of the drilled shafts in each of the five lateral load tests included vibrating wire strain gages, inclinometers, and dial gages. This permits the measurement of both strain and deflection with depth and the deflection at the jacking point to be obtained. At each of the test sites, soil borings with rock coring was conducted during this research. Rock samples were obtained for laboratory testing.

Field testing included the use of a borehole pressuremeter/dilatometer to obtain measurements used to establish correlations between the rock strength and deformation parameters and potential p-y curves.

A comparison was made between back calculated p-y curves from strain data, p-y curves predicted by using Reese’s method, and p-y curves from the pressuremeter tests in rock.

Conclusions & Recommendations
The major findings and developments resulting from this research study are summarized below.

1. A new hyperbolic p-y criterion for rock is proposed based on the field test data and extensive theoretical work. Validation of the proposed p-y criterion of rock was carried out by comparing the predictions against actual lateral load tests results.
2. A 3D finite element model simulating the response of laterally loaded drilled shafts in rock using ABAQUS was established to develop an empirical correlation equation for estimating the initial slope of a p-y curve for rock. Additionally, theoretical equations for determining the ultimate resistance of the rock mass was derived based on failure modes of the rock mass, a rock strength criterion, and an existing empirical equation for estimating the side shear resistance between the rock and drilled shafts. The failure modes of the rock
mass were identified through a series of 3D FEM studies.

3. A method for predicting lateral capacity of drilled shafts in rock and/or soils was developed. This method can be used to ensure an adequate safety margin for the design of drilled shafts in rock. An elastic solution for predicting the lateral deflections of piles/drilled shafts embedded in a two-layer soil/rock system was proposed. This solution allows a quick estimation of drilled shaft deflections under lateral loads. Furthermore, an evaluation of various existing methods for deriving p-y curves from the results of an instrumented lateral load test was carried out and the most suitable p-y curve derivation method was identified.

4. Finally, the existing methods for deriving site specific p-y curves of soils from pressuremeter and dilatometer tests were reviewed and examined with the lateral load test results of rock-socketed drilled shafts. Briaud et al. (1983) method, with a modification of reducing the p value by 50%, was recommended for deriving p-y curves of rock from the pressuremeter and dilatometer tests.

**Implementation Potential**

Based on the findings of this study, a complete solution for the design of drilled shafts socketed in rock or intermediate geomaterials under lateral loads is provided. The proposed elastic solution for a profile having two layers can be used for a preliminary design of shafts under service loads. The computer program LCPILE developed in this study can be used for limit state design to provide an adequate margin of safety for the design. The proposed hyperbolic p-y curves can be used in conjunction with the existing computer program COM624P or LPILE for the final design. The modified Briaud et al. (1983) method can be used to validate the final design if dilatometer tests data are available.