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Numerical Analysis of Rock-Socketed Piles under Combined Vertical-Lateral Loading

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Abstract

This paper presents the results of numerical analysis carried out using PLAXIS 3D on behaviour of rock-socketed pile subjected to independent and combined loading. The numerical procedure adopted in the analysis was validated by comparing the load test results reported in the literature. After validation of the numerical analyses, the parametric analysis were performed on the rock-socketed pile subjected to independent loading and combined loading for different rock conditions, soil cover depths and socketing lengths. From the results of parametric study, it is found that the vertical and lateral load capacities under combined loading are not significantly affected, when the soil cover depth is high. However, if the soil cover depth is low, then the behaviour of rock-socketed pile under combined loading is found to be significantly different, compared to its behaviour under independent loading. It is also seen that the rock conditions and socketing length have profound effect on pile behaviour under combined loading.

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Keywords: Rock socketed pile; Rock; Numerical model; Vertical load; Lateral load; Combined loading

1. Introduction

In the present construction activities, large diameter bored piles are being used to carry heavy loads from super structures. These heavy loads are essentially to be taken to bed rock level and socketed into rock, when top soil is weak. In the piling specifications, socketing in solid/hard rock is usually specified for termination criteria. But, in

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many cases, the depth at which hard rock strata is available is very large such that the termination of pile upto that level becomes uneconomical. Therefore, the capacity of pile needs to be increased by utilizing the shaft resistance provided by the soft rocks. Many researchers [1–9] have studied the load transfer process in rock-socketed piles through model and field tests and theoretical analysis.

Many designers prefer to design drilled shafts to take load in side shear only rather than combined side shear and end bearing because the amount of movement required to mobilize side shear is relatively small, while that required to mobilize end bearing is relatively large [10]. Both empirical and analytical methods have been used to predict the ultimate unit side shear of rock sockets [5]. Empirical methods are generally based on full-scale load tests in which the ultimate unit side shear is back-calculated from instrumentation. The ultimate unit side shear (f_{max}) is then related to the unconfined compressive strength of the soil/rock (q_u) using empirical constants, usually denoted α, β and c as

$$f_{max} = \alpha\beta(q_u)^c \quad (1)$$

Relationships for relating the ultimate side shear to the unconfined compressive strength of the rock follow two major expression i.e. simple linear expression and power function. Whether the relation between f_{max} and q_u is better represented by a power function or a linear function depends mainly on the range of q_u considered. The linear function proposed by Carter and Kulhawy [11] is only applicable for q_u between 1.7 and 2 MPa, whereas the power function applies over a wider range. Zhang [9] concluded that extensive studies of load test data by Williams and Pells [12] and Kulhawy and Phoon [13] indicated that the power-curve relationship is closer to the real case. O.Neill et al. [11] concluded that a unique value of α does not exist and more parameters than just q_u are required to make accurate predictions of f_{max}. Williams and his colleagues [12, 14] developed a semi-empirical method where α reflects variations in the intact strength of the rock and β is an adjustment factor to account for seams of softer material in the rock.

A range of analytical tools are available to foundation designers to consider rock sockets under lateral and moment loading. Several analytical methods falling into two general categories: continuum methods [7, 15] and Subgrade reaction approach [16, 17] have been proposed that attempt to model laterally loaded rock-socketed drilled shaft response. Carter and Kulhawy [15] presented a method to determine the rock capacity by using cohesion and friction angle of rock treating rock mass as a homogeneous and elasto-plastic material, without considering secondary structures of rock mass, such as cracks and fractures. Reese [18] considered the secondary structure of rock mass by using a rock strength reduction factor which can be determined from Rock Quality Designation (RQD). Zhang et al. [9] proposed a method to estimate the ultimate reaction of rock masses per unit shaft length using Hoek-Brown rock strength criterion, in which the effects of RQD and other secondary rock structures were included. To et al. [19] proposed a method to estimate the lateral load capacity of drilled shafts in jointed rock. Yang [20] identified two modes of failure i.e. planner wedge failure mode for rock mass at or near ground surface, and strength controlled failure mode for rock at great depth based on stress and deformation fields around the shaft.

A common application of rock-socketed piles is found in foundations that experience both vertical, lateral and uplift loading simultaneously. Therefore it is important to study the behaviour of rock-socketed piles under the combined action of vertical and lateral loads. Although there are some studies reported on pile behaviour under combined loading in soils, such studies on the response of rock-socketed piles under the combined loading is scarcely reported. The current design practice for piles is to consider the vertical and lateral loads independently. Thus, there is a great need for addressing this problem through research. This paper presents the results of numerical analysis carried out using PLAXIS 3D on effect of combined loading in behaviour of rock-socketed piles.

2. Validation problems

2.1. Validation for vertical loading

Four case studies of vertical load tests on rock-socketed pile were selected for validation, but the results of case study is presented herein (BTP2, reported by [21]).The details of site conditions of a case study and the properties used in the analysis are presented in Table 1. The load-settlement curve predicted from the Finite Element (FE)