Computers and Geotechnics 37 (2010) 858–866

Contents lists available at ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo

Mobilized side and tip resistances of piles in clay

Mohamed Ashour [a,*], Gary M. Norris [b], Sherif Elfass [b], Ashraf Z. Al-Hamdan [a]

[a] Department of Civil and Environmental Engineering, University of Alabama in Huntsville, 301 Sparkman Drive, Huntsville, AL 35899, USA
[b] Department of Civil and Environmental Engineering, University of Nevada, Reno, NV 89557, USA

ARTICLE INFO

Article history:
Received 5 January 2010
Received in revised form 12 July 2010
Accepted 20 July 2010
Available online 14 August 2010

Keywords:
Pile
Clay
Axial load
Load transfer
Pile settlement
t–z Curve

ABSTRACT

This paper presents a procedure to assess the mobilized pile side and tip resistance versus pile head and tip settlement under axial load in clay soil. The load transfer (*t–z*) curve is evaluated at any point on the loaded pile based on the combined pile tip/side resistance–displacement mechanisms along the length of the pile. Unlike current methods that assume the pile settlements as a percentage of the pile/shaft diameter, the presented technique determines the side and tip resistance of the pile and the associated pile settlement under existing load based on the current stress/strain level in the surrounding soil up to failure (excessive settlement). The technique employs the concepts of the elastic theory and Ramberg–Osgood characterization of the stress–strain behavior of the clay soil. Case studies are also presented to exhibit the capabilities of the proposed procedure. The good agreement between measured and calculated load transfer curves along the pile and pile tip resistance versus pile head, side, and tip displacements shows the consistency of the proposed procedure. A computer code is developed to employ the presented technique.

1. Introduction

A significant part of research on axially loaded piles has focused separately on ultimate or mobilized bearing capacity of the piles (tip resistance) and vertical shear stress (side shear resistance). Some procedures are available to generate the load transfer (*t–z*) curve along the side of the pile [3,4,8–12,15,16,19,28]. Some of these procedures are empirical and founded on field and experimental data. Others are based on analytical concepts such as the methods presented by Randolph and Worth [21], and Kraft et al. [12], in addition to the numerical techniques adopted by Poulos and Davis [17] and Butterfield and Banerjee [2], and the finite element method [3,11].

Zhu and Chang [28] developed an analytical model for the load transfer (*t–z*) curves with the consideration of shear modulus degradation (nonlinear stress–strain relationship) in clay. The pile displacement (*z*) was calculated by modifying the elastic theory solution to account for the soil shear modulus degradation along the pile [18]. The Zhu and Chang [28] analytical load transfer model was integrated with an experimental load transfer curve for pile tip. The load transfer model developed was based on long term loading analysis of normally consolidated clay (drained conditions), which is not the critical loading condition.

Han and Ye [9] performed a number of axial load tests on small diameter piles in soft clay that were adopted to develop theoretical solutions for the soil bearing capacity, pile load capacity, and tip resistance. The pile tip nonlinear displacement was empirically modeled by using a secant shear modulus of the soil as a function of the initial shear modulus of the tip soil, maximum tip resistance. However, Han and Ye [9] directly used the observed pile side resistance (without modeling) in the presented comparisons.

Using field and laboratory data, Coyle and Reese [4] developed a widely used method of analysis to predict the load–settlement relationship of axially loaded piles in clay. Based on experimental data, Coyle and Reese [4] developed three normalized empirical curves (*A*, *B* and *C*) to predict the load transfer *t–z* curve at different depths (curve *A* for depth from 0 to 3.3 m, curve *B* for depth from 3.3 to 6.6 m, and curve *C* for depth larger than 6.6 m). More focus was given to the topic by O'Neill [15] to address the complicated factors related to the pile–clay response under axial loads, and modeled the side resistance of piles and drilled shafts in clay soil by calculating the peak unit vertical side shear stress (f_{max}) at the pile–soil interface.

Elfass et al. [6] studied the undrained pile-tip displacement response and established a model that accounts for the stress–strain variation and calculates the mobilized tip resistance versus displacement curve. Limited analytical research work has considered the combination of pile settlement and the mobilized pile side and tip resistance under working (existing) loads. Such integral analysis reflects a realistic characterization for the pile load–settlement relationship that can be used to assess: (1) the load transfer (*t–z*) curves along the pile; (2) pile head load–settlement curve; and (3) pile tip load–settlement curve.

* Corresponding author. Tel.: +1 256 824 5029; fax: +1 256 824 6724.
E-mail address: ashour@eng.uah.edu (M. Ashour).

0266-352X/$ - see front matter
doi:10.1016/j.compgeo.2010.07.005