ABSTRACT

Due to the growing industrialization and urbanization worldwide in the last few decades, the requirement of constructing structures like high-rise buildings, industrial chimneys, transmission towers, bridges, etc., has increased significantly. Conventional pile foundations with constant cross-section have been widely used in such structures. Under extreme cases (such as storm, earthquake, scour, etc.), failures of conventional uniform cross-section piles have been reported in the past. In such circumstances, piles with a variable cross-section may perform better than the uniform cross-section pile. Under-reamed pile is one of such piles in which one or more enlarged cross-sections (also called bulbs) are present. Under-reamed piles can be used against compression, tension, and lateral loading or when all of these loadings act together (in high-rise structures). Construction of under-reamed piles is generally preferred in clayey soils because of the stability issue and proper formation of bulbs. Many researchers have studied the response of under-reamed piles in clayey soils, but most of these studies were case-specific. Also, limited studies have been conducted on the response of under-reamed piles in nonhomogeneous clay. Therefore, it is intended to study the response of under-reamed piles in such type of clay. Two types of nonhomogeneous clayey soils (1) clay with linearly increasing undrained cohesion and (2) soft clay underlaid by stiff clay are considered. These types of clayey soils exist in many places. Response of under-reamed pile foundations under various static loading conditions such as compression, tension, and lateral loading is investigated numerically. Two types of numerical techniques, namely, lower bound finite element limit analysis and FLAC3D (Fast Lagrangian Analysis of Continua in Three Dimensions), are used. Under axial compression and tension, due to the rotational symmetry about the centre line of the pile, a two-dimensional axisymmetric analysis is carried out by using lower bound finite element limit analysis. In case of lateral loading, since the two-dimensional axisymmetric analysis cannot be performed, a three-dimensional analysis is carried out using FLAC3D.

Unlike the case of homogeneous clay, in nonhomogeneous clay, the bearing and uplift capacities of under-reamed piles are found to be affected by the bulb position and bulb spacing (in case of two bulbs). The bearing and uplift capacities of under-reamed piles are found to increase significantly with increases in the number of bulbs and the rate of increase in undrained cohesion. Under axial tension, two types of pile-soil interface are considered: (1) fully bonded and (2) immediate breakaway at the pile base and bottom surface of the lowest bulb. For the immediate breakaway condition, the uplift capacity is found to reduce drastically due to the pile-soil separation. In case of soft clay underlaid by stiff clay, the bearing and uplift capacities are found to increase remarkably when the bulb is placed in the stiff clay. The bearing and uplift capacities are found to increase with an increase in the ratio of the undrained cohesion of stiff to soft clay. Load sharing and failure mechanisms of the under-reamed pile in nonhomogeneous clay are also studied from axial force distribution, variation of radial stress along the pile-soil interface, and proximity of the state of stress to the yield. The lateral load-carrying capacity is found to increase with an increase in the bulb distance from the base, a decrease in the bulb spacing, and an increase in the rate of increase of undrained cohesion. Deflection in the under-reamed pile is found to reduce remarkably when the bulb is placed near the ground surface. Shear force and bending moment in the under-reamed pile are found to increase at the location of the bulbs owing to higher cross-sectional area and higher moment of inertia. The failure mechanism under lateral loading is studied through displacement contours and induced stresses in front of the pile.

From the previous studies, it is realized that scour is one of the major causes of pile foundation failure in bridges and other water-borne structures. In scour conditions, the load-carrying capacity of the pile foundation reduces due to the removal of soil around the pile. According to various international standards, under-reamed piles can be used in scour conditions for a higher capacity. However, hardly any detailed studies are available on the response of under-reamed piles in scour conditions. Therefore, it is intended to study the response of under-reamed piles in clayey soil under scour conditions, subjected to compression, tension, and lateral loading. The bearing, uplift, and lateral load-carrying capacities of under-reamed piles are found to decrease remarkably with an increase in the scour-hole depth. For a given scour-hole depth, the bearing, uplift, and lateral load-carrying capacities of the under-reamed pile are considerably higher than the pile without bulb. Pile head deflection under lateral loading is found to reduce significantly when the bulb is placed near the scour-hole. At a given applied load, the maximum bending moment and the maximum negative shear force (i.e., shear force opposite to the loading) are found to increase remarkably with an increase in the scour-hole depth. Moreover, the bearing, uplift, and lateral load-carrying capacities of under-reamed piles are found to decrease when the effect of stress history is considered. In scour conditions, the failure mechanism of the under-reamed pile under different loading is studied from displacement contours, displacement vectors, and induced stresses around the pile.

Keywords: Under-reamed pile; Clayey soil; Lower bound finite element limit analysis; FLAC3D; Compression; Tension; Lateral loading; Scour; Failure mechanism