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Probabilistic Analysis of Laterally Loaded Pile-Soil System using Monte Carlo Simulation

Mohammad Kamruzzaman Talukder
Faculty of Engineering and Applied Science,
Memorial University of Newfoundland, Canada.

Leonard M Lye
Faculty of Engineering and Applied Science,
Memorial University of Newfoundland, Canada.

ABSTRACT

Pile foundations are often subjected to horizontal loads. There are several deterministic techniques to analyze single piles under lateral loading. This paper implements a computationally inexpensive technique called Winkler approach to model the soil-pile system as vertical beam supported by a series of discrete springs. Beam and spring elements in structural analysis software, ABAQUS, are used in this study to predict response of a single pile under a horizontal load. It is known that soil properties, pile properties, and load systems dominate the performance of a pile and each has a different extent of uncertainty. It was found that the soil properties, lateral subgrade modulus of soil and ultimate soil resistance, in addition to the elastic modulus of pile material, and horizontal load were the most important parameters influencing the performance of piles. Random variation in these factors is studied using Monte Carlo simulation. It is shown that the likelihood of exceeding a specific level of maximum bending moment and pile head displacement for a given horizontal load can be used to construct failure probability curves to study the performance of piles due to the uncertainty in the aforementioned factors in the soil-pile system.

KEY WORDS: Pile; lateral modulus of subgrade reaction; Winkler approach; Monte Carlo Simulation; probability of failure; maximum bending moment; soil spring; probability density function.

INTRODUCTION

Civil engineering structures, such as high rise buildings, bridge piers and offshore platforms are often subjected to horizontal loads. To support those structures, piles that are designed to carry horizontal loads are needed. Two aspects of interest which should be considered in designing a laterally loaded pile are the lateral pile head displacement and the maximum bending moment in the pile (Tandjiria et al, 2000). A pile is said to provide good performance if these two aspects are satisfied. The probability of failure of the pile can be defined as the likelihood of exceeding a specific level of pile head displacement and bending moment in the pile for a certain level of horizontal load applied at the pile head. Chakrabortty et al (2007) used a Monte Carlo approach to investigate the effects of soil spatial variability on foundation settlements and rotations underneath tower structures. They showed the results of the Monte Carlo simulations in terms of fragility curves which are a suggestive method for illustrating the probability of exceeding a certain degree of structural damage as function of load intensity. This paper adopts a similar Monte Carlo approach in combination with a finite element method to evaluate and quantify the probability of failure of the pile.

The Monte Carlo simulation has several components. They are:
• defining the problem in terms of all random variables concerned
• generating values of random variables
• evaluating the problem deterministically for each set of realization of all random variables
• extracting probabilistic information in terms of PDF of response random variables.

Defining the problem requires a mathematical model that relates all random inputs and response parameters of a system. A pile-soil system under static load comprises the following input random parameters:
• Elastic modulus of pile material, E
• Lateral soil modulus of subgrade reaction, K_h
• Ultimate soil resistance at any depth below the soil surface, P_u
• Lateral load applied at the head of the pile, H

The response of the pile-soil system to the load H can be quantified by observing the following responses:

• pile head displacement, Y
• and maximum bending moment, M_{max}

FINITE ELEMEMNT ANALYSIS OF PILE

A finite element model of a pile foundation was developed using finite element program called ABAQUS, version 6.7. The schematic diagram