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Nonlinear Behaviour of Laterally Loaded Long Piles Penetrating Soft Clay Below Water Table Subjected to Cyclic Loading—Sensitivity Analysis Part II: Numerical Investigation

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ABSTRACT

This paper is Part II of our previous paper, which contained a theoretical basis of a sensitivity analysis for numerical investigations. This part comprises the results of sensitivities of generalized maximum deflections of long piles due to the changes of the design variables vector. The long isolated pile is embedded in soft clay below the water table. The pile is simulated as a one-dimensional beam element, while the soil is described by a *p-y* relationship. The pile bending stiffness and the soil parameters involved in a *p-y* relationship are taken as the design variables. The variables in discrete-fashion lateral forces are applied to the top of the pile-soil system. The nonlinear behaviour of the adjoint system is demonstrated. The sensitivity integrands are determined and discussed in detail.

INTRODUCTION

Laterally loaded piles have received widespread attention due to their common occurrence in engineering practice. They are of particular interest when used as support for retaining walls, pier fenders, dolphins, various types of offshore structures and drilling platforms (Poulos and Davis, 1980). Offshore structures have been built for oil production and for many other reasons in many parts of the world. Their design involves the consideration of unusually large ratios of lateral to vertical load, particularly in areas where severe storms occur. The exact effect of the cyclic wave loading on the soil response conducted in analytical fashion is very complex. It would be unrealistic to precisely follow in continuous fashion the path of this response. In practice, what is required for design purposes is the quasi-static approximation of a lower bound of soil resistance corresponding to an infinitely large number of load cycles. The existence of such a lower bound for pile-soil systems was demonstrated and incorporated into suitable soil behaviour (Matlock, 1970).

The significance of a quasi-static approach to cyclic loading leads to the conclusion that, no matter how complex the cyclic loading becomes in carrying out a design analysis, it must be possible to represent the soil behaviour at an arbitrary depth by means of a simple *p-y* curve. The successful application of a *p-y* method to the analysis of long piles depends upon the availability of detailed information on a spatial distribution of soil properties that are key factors in the design of laterally loaded deep foundation. The sensitivity analysis of long piles presented in this paper provides the answer to the question of the manner in which the changes of spatially distributed soil parameters involved in a *p-y* relationship and bending stiffness of the pile affect the changes of maximum kinematic quantities of long piles subjected to lateral forces. The investigations are conducted for the collection of long piles. The shortest and the longest pile from the set of long piles are subjected to detailed studies in the framework of sensitivity theory. The sensitivity integrands determined which are associated with the design variables affecting the changes of top lateral deflection, and an angle of flexural rotation for variables in discrete-fashion loadings is discussed.

CHARACTERICTICS OF INPUT DATA

The theoretical formulation of the sensitivity analysis of piles presented in Part I formed the basis for numerical studies. The behaviour of laterally loaded piles depends on their length. The classification of piles into long and short piles implies their different applications. Determining the length of the laterally loaded pile-soil interaction system of a linear elastic type is readily obtainable from the linear theory of a subgrade reaction in which the soil response is modeled by means of a Winkler-type foundation that involves the coefficient of subgrade reaction k. For strong cohesive soils a coefficient of subgrade reaction k has a constant value (Terzaghi, 1955). Then the length of the laterally loaded pile can be determined as a product of a scalar and the characteristic length λ_c that is given (Davisson and Gill, 1963, Das, 1999) as:

$$\lambda_c = \sqrt[4]{\frac{EI}{kb}} \tag{1}$$

where EI is the bending stiffness of the pile, and b stands for the width of the pile.

The laterally loaded pile-soil interaction system in which the soil reaction is characterized by k has a closed form solution (Hetenyi, 1948). However, when the pile is embedded in a soft clay located below the water table that is described by the *p-y* relationship, the closed form solution does not exist.

The evaluation of a length of laterally loaded pile embedded in a soil described by a *p-y* curve can be made by means of the relative stiffness factor T (Evans and Duncan, 1982). It depends on the type of loading (lateral force H_t or the bending moment M_t), type of pile constraints (free or fixed pile-head), bending stiffness of the pile EI and the pile-head horizontal displacement y_T. The relative stiffness factor T is equivalent to the characteristic length of a pile λ_c when analyzed in the scope of linear elastic theory.

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KEY WORDS: Laterally loaded long piles, nonlinear pile-soil interaction, spatial design variables, sensitivity operators/sensitivity integrands.