A macro-element for pile head response to cyclic lateral loading

N. M.Sa'don, M.J. Pender, R.P. Orense & A.R. Abdul Karim

Department of Civil & Environmental Engineering, The University of Auckland, Auckland, New Zealand.

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ABSTRACT: The standard method of modelling the lateral load response of a pile head is to use computer software packages. Many of the conventional software packages model the interaction of the pile shaft and the soil using either the linear or nonlinear Winkler springs approach. An alternative way of analysing the elastic behaviour is to use a simple expression for the pile head stiffness. This approach has been extended in this paper to represent the nonlinear pile head lateral response. Numerical simulations showed that this approach is capable of achieving the same monotonic response prediction as the Winkler spring software. Thus, the response of the whole pile shaft can be represented by a simple set of equations focusing on the pile head. This is referred to as a macro-element. This paper presents an analytical technique of the elastic continuum approach used for the cyclic response of the laterally loaded pile problem. This approach will then be compared with the cyclic Winkler calculations and field data obtained from previously published results.

1 INTRODUCTION

Piles are frequently used to resist lateral forces that result from loading of supported structures. The response of pile foundations to lateral forces depends on the interaction between the pile and the soil surrounding. This lateral force at the pile head can be the governing design constraint for a single pile and pile groups supporting different types of structures. The lateral force may be a result of earthquakes, machine vibrations, wave actions, wind, blasts, or impacts and may be transient or cyclic in nature.

Researchers have employed various analytical approaches for the analysis of single piles subjected to cyclic lateral loadings. The approaches can be categorised by the treatment of the soil medium in the analysis.

- The Winkler spring model or modulus of subgrade reaction approach represents the soil supporting the pile by an array of uncoupled springs. These springs can be taken to be linear elastic or nonlinear and the shapes of the load-deformation relationships are described by the *p-y* curves. Finite-element or finite-difference techniques are then be used to determine the response of the pile and spring system to the applied loadings (Matlock *et al*. 1978, Novak *et al*. 1978, and Reese and van Impe, 2001).
- A theoretical homogeneous continuum approach in which the soil surrounding the pile is modelled as a homogeneous elastic continuum (Poulos 1971a, b).
- A finite element or finite difference approach in which the pile and the soil surrounding it are discretised using finite-element or finite difference techniques and desirably using nonlinear representations of soil stress-strain relationships. Examples of this are the studies by Blaney *et al.* (1976) and Kuhlemeyer (1979).

The analysis of the lateral pile head stiffness is frequently carried out by using computer software based on the Winkler spring idealisation of the localised interaction between the pile shaft and the soil such as LPILE (Reese and van Impe, 2001) and RUAUMOKO (Carr, 2005). However, the aim of this paper is to demonstrate an analytical method as an alternative to such software for estimating the