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ORIGINAL PAPER

# Pile Head Cyclic Lateral Loading of Single Pile

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**Abstract** This paper presents an elastic continuum model using an extended nonlinear Davies and Budhu equations, which enables the nonlinear behavior of the soil around the long elastic pile to be modeled using a simple expression of pile-head stiffness method. The calculated results were validated with the measured full-scale dynamic field tests data conducted in Auckland residual clay. An idealized soil profile and soil stiffness under small strain (i.e. shear modulus, $G_s$ and shear wave velocity, $V_s$ of the soil) determined from in situ testing was used to model the single pile tests results. The predictions of these extended equations are also confirmed by using the three-dimensional finite-element OpenSeesPL (Lu et al. in OpenSeesPL 3D lateral pile-ground interaction: user manual, University of California, San Diego, 2010). A soil stiffness reduction factor, $G_s/G_{s,max}$ of 0.36 was introduced to the proposed method and model. It was found to give a reasonable prediction for a single pile subjected to dynamic lateral loading. The reduction in soil stiffness found from the experiment arises from the cumulative effects of pile–soil separation as well as a change in the soil properties subjected to cyclic load. In summary, if the proposed method and model are accurately verified and properly used, then they are capable of producing realistic predictions. Both models provide good modelling tools to replicate the full-scale dynamic test results.

**Keywords** Pile head · Cyclic loading · Lateral loading · Single pile · Soil-foundation structure interaction

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## 1 Introduction

The dynamic response of a pile subjected to external excitation is a complex phenomenon resulting from the interactions between the pile and the surrounding soil. Common dynamic forces in engineering practice that are of interest include forces produced by machine vibration, wind or earthquake loading. The understanding in this field has advanced extensively and has received much attention from researchers for more than three decades. Researchers have conducted a variety of small scale model tests, and developed several analytical approaches for simulating the effect of pile–soil interaction on static and dynamic lateral response. These approaches are usually characterised by the treatment of the soil medium. The rationale of the tests conducted are to identify the nonlinear behaviour of the soils at high strain levels, slippage and development of a gap between pile and soil near