Modeling Soil-Pile Interaction for Nonlinear Analysis of Structural Systems under Lateral Excitations

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ABSTRACT

For many years, civil engineers have considered that piles could only support loads applied in line with their central axis. As a result, piles required to resist lateral forces, were installed at a batter. However, it is now realized that the lateral resistance of vertical pile is considerable. Obviously, interactions between the pile and the surrounding soil should be considered both in the design and analysis of the structural system (superstructure and pile-foundation) subjected to lateral actions. In this paper, a displacement-based frame fiber model with continuous lateral deformable soils is used to represent the pile-foundation of frame buildings. The proposed model is simple, computationally efficient and capable of representing the salient features of the soil-pile interaction. The example of an end-bearing cast-in-place pile embedded in the cohesionless soil (sand) is used to investigate the effects of soil-pile interaction on the response of pile-soil systems. An inelastic finite element analysis is performed to investigate the effects of model parameters on the pile-soil response. Several model parameters (e.g. pile length, pile cross-section geometry, pile and soil nonlinearities) are examined. The parametric studies show that the nonlinearity of the surrounding soils and geometric properties of the pile greatly affect the responses of the pile and the position of the plastic hinge in the pile. Under cyclic loadings, the dragging and gapping features of the surrounding soil are crucial in describing the hysteretic behaviour of the pile-soil system.

KEY WORDS: Pile-Soil System, Nonlinear Analysis, Reinforced Concrete, Cyclic Loads, Cast-In-Drilled-Hole Pile.

INTRODUCTION

Nowadays, structural engineers are challenged to design and investigate expensive and strategic structures (e.g. high-rise buildings, offshore platforms, multi-story highways etc.) for extreme lateral loadings (e.g. earthquakes, gusty winds, terrorist attacks, etc.). Usually, pile foundations are used to support these structures. Consequently, the inclusion of the soil-pile system into the numerical model is crucial for design and analysis of these structures under extreme events. It is desirable that the pile foundations remain elastic under these extreme loadings. Such desire is to avoid the difficulties of subsurface inspection and high cost of repairing the foundation damage. Nevertheless, the bending moment induced by the design seismic activity can be adequately large to cause flexural damage in the pile. Post earthquake investigations in recent earthquakes have confirmed that pile foundations are prone to flexural damages from earthquake loadings (Sitar, 1995). The flexural damages in pile foundation can reduce both stiffness and strength of the foundation; hence affecting its serviceability and existing loading-capacity of the structure. Furthermore, it is imperative to consider the effects of soil-foundation system on seismic demand and structural response when the performance-based methodology is used in seismic design of structures The main objectives of this paper are to present the newly developed pile–soil frame element and to investigate the effects of several model parameters (e.g. pile length, pile cross-section geometry, pile and soil nonlinearities, and dragging-gapping effects of the surrounding soil) on both monotonic and cyclic lateral responses of the pile–soil system. The so-called "*Winkler Foundation*" is employed to represent the surrounding soils (Winkler, 1867). Furthermore, it is crucial to note that this study emphasizes only on soil-pile interaction in firm non-liquefiable soil induced by the inertia of the superstructures (inertial interaction). Kinematic interaction related to scattering of incoming seismic waves and effects of soil liquefaction are not included in this study.

FRAME ELEMENT WITH LATERAL DEFORMABLE SUPPORTS: DISPLACEMENT-BASED MODEL

The displacement-based formulation is summarized in the Tonti's diagram of Figure 1. The element used in this study comprises a 2-node frame with top and bottom soil-interfaces (Figure 2). The 2-node element has a linear axial displacement field, a cubic transverse displacement field, and cubic soil-deformation fields along the interfaces. The details of this model formulation can be found in Limkatanyu and Spacone (2006). The general-purpose finite element program, FEAP (Taylor, 2000) is used to host this proposed element.