Improved Analytical Method for Pile Bent Structure based on Nonlinear Characteristics

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Summary

A fundamental study of pile bent structure subjected to combined loads in multi- layered soil is conducted using a load transfer approach. The emphasis is on quantifying an improved analytical method developed by considering pile's plastic hinge. An analytical method of pile bent structure is developed by taking into account the nonlinear behavior of materials and the geometric nonlinearity (P-Δ effect). A series of parametric studies is performed for different soil-pile conditions. It is shown that the developed analytical method is capable of predicting the behavior of a pile bent structure under combined loading. Based on the results obtained, the optimized column-pile diameter ratio can be obtained through the relations between the column-pile diameter ratio and normalized lateral cracking load. Through comparisons with field case histories, the limit depth on the application of minimum steel ratio proportionally decreases as normalized pile length increases, and beyond that the limit depth converges to a constant value (≃0.3).

Keywords: Pile bent structure; Plastic hinge; Optimized column-pile diameter ratio; Lateral cracking load; Limit depth; Minimum steel ratio.

1. Introduction

Recently, pile bent structure (single column drilled pier foundation) has often been used as a foundation for highway, bridge, urban monorail, and many other structures because of its cost-effective and space-saving features. This structural element consists of a column that is continued under the surface as a shaft of approximately the same diameter as the column. Although axial loading is a major consideration in designing such structures, large lateral loads often necessitate the use of large diameter piles (Kerop, 2001).

Regarding pile bent structure, the U.S. Federal Highway Administration (FHWA, 1999) has suggested three types of bridge pile foundation modeling methods: (1) equivalent cantilever model, (2) equivalent base spring model, and (3) equivalent soil spring model. The North Carolina Department of Transportation (NCDOT, 2006) has reported the design criteria of pile bent structure based on the equivalent models. They conclude that the pile bent structure modeling method for the optimal design is of intermediate complexity between the equivalent cantilever model and the equivalent base spring model.

For pile bent structure in which the diameter of the pile is the same as that of the column, traditional design method of pile bent structure based on virtual fixed point theory (Georgia Department of Transportation, 1994; FHWA, 1999; Chai, 2002; NCDOT, 2006) is an approximate analysis. Here, the virtual fixed point is determined by equating the lateral stiffness of the equivalent cantilever to the lateral stiffness of the soil-pile system as a depth associated with lateral resistance. However, the virtual fixed point theory cannot adequately predict the real behavior of pile bent structure, because this design method cannot consider the nonlinearity of materials and nonlinear geometric behavior (P-Δ effect) under combined loading. Moreover, although variable cross-sections in pile bent structure is often adopted, no standards exist yet for the optimized column-pile diameter ratio and minimum steel ratio. The steel ratio of the pile is determined roughly by the virtual fixed point and the maximum bending moment in traditional design (FHWA, 1999). For optimum design of pile

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