Pile Cap Interaction with Bridge Pile Foundations under Lateral Loads

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Abstract: The paper presents an analytical pile–cap soil model to determine the lateral resistance of a pile cap in sandy soils and its contribution to the lateral resistance of the bridge pile group–cap foundation system of pinned or fixed pile head connections with the pile cap. The strain wedge (SW) model approach was adopted to incorporate the pile cap in an interactive pile group–cap foundation system. The proposed model allows the calculation of the mobilized passive and side shear cap–soil resistance based on soil, cap, and pile properties. The study demonstrated the contribution of the pile cap in sandy soils to the total pile group–cap bridge foundation system (i.e., the bridge foundation lateral stiffness), which could approach 50% of the total pile group–cap lateral resistance. Such relative contribution varied with lateral deflection and the soil around the cap and pile group as well as the rotational restraint of the pile head–cap connection. The proposed technique was validated through comparisons with full-scale load tests. **DOI: 10.1061/(ASCE)BE.1943-5592.0001408.** © *2019 American Society of Civil Engineers.*

Introduction

Lateral resistance taken by the pile cap in a pile group–cap foundation system is a very important element in the design of the bridge foundation and affects the foundation stiffness and its impact on the lateral response of the bridge superstructure. Proper consideration of the pile cap in modeling the foundation system can significantly enhance the foundation stiffness as well as the passive lateral resistance under seismic loads. The lack of reasonable evaluation of the foundation stiffness could result in a conservative or unsafe design due to the miscalculation of the induced seismic forces. A significant amount of research has been conducted on the vertical and lateral load response of piles and piles in a group, but most of such research has overlooked the contribution of the pile cap to the lateral resistance of the pile group bridge foundation. The relative distribution of load between the piles and pile cap has been assessed in a limited number of full-scale lateral load tests on pile group–cap foundation systems (Beatty 1970; Kim and Singh 1974; Kim et al.1979; Zafir and Vanderpool 1998; Mokwa and Duncan 2001; Rollins and Cole 2006). Other research has been conducted using small-scale pile group–cap systems (McVay et al. 2000; El-Garhy et al. 2009). Furthermore, Dewi and Tjie-Liong (2011) and others have performed a series of analyses using finite-element programs to determine the lateral resistance that is taken by the cap.

Beatty (1970) performed a lateral load test on a six-pile group connected with a pile cap. After comparing the test with the pile group without a pile cap, Beatty (1970) concluded that the pile cap substantially impacts the pile group's total resistance and that additional research is needed.

McVay et al. (2000) performed centrifuge tests at the University of Florida on 3×3 and 4×4 model pile groups in loose and medium-dense sands. Four cases of pile cap foundation system tests investigated the effect of the embedment depth of the pile cap. As expected, lateral cap deflection decreased as pile cap embedment in the sand increased, as did the lateral resistance of the pile group–cap system.

El-Garhy et al. (2009) performed a series of tests on model steel pipe piles in sand to show the effect of pile cap embedment on the deflection of the pile cap. Five different embedment depths involving three different pile groups (2×2, 3×3, and 4×4) with pile spacings of 3 and 5 pile diameters were tested. El-Garhy et al. (2009) concluded that the increase in the pile group–cap system lateral resistance due to increasing the pile cap embedment depth was more than the increase in the pile group–cap system lateral resistance resulting from increasing the pile spacing.

Mokwa and Duncan (2001) conducted a series of full-scale load tests to monitor the lateral load resistance of pile caps. Three different 2×2 pile groups using H-shape steel piles were tested in undisturbed ground, compacted sand, uncompacted sand, and gravel backfill. Mokwa and Duncan (2001) demonstrated that for natural soil found at the site, approximately 50% of the total lateral load applied to the pile group was taken by the pile cap. Rollins et al. (1997) also found that the lateral load taken by the pile cap could be greater than the load taken by the piles. Mokwa and Duncan (2000) developed a design spreadsheet (PYCAPSI) to estimate the pile cap resistance through *p-y* curves using the log spiral earth-pressure theory. The pile cap *p-y* curves were developed using a hyperbolic soil stress–strain formulation established by Duncan and Chang (1970).

Shama and Mander (2004) performed a study from both theoretical and experimental aspects on timber piles connected to a concrete pile cap under lateral loading. The experiment was performed on two full-scale timber piles, each embedded a different length into a concrete pile cap to analyze the ductility and strength of the timber pile connection in the concrete pile cap. Shama and Mander (2004) concluded that by increasing the pile head embedment length, the lateral resistance of the pile cap connection will increase.

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