Employment of the *P*-Multiplier in Pile-Group Analysis

Mohamed Ashour, M.ASCE[1]; and Hamed Ardalan[2]

Abstract: This paper discusses the variation of the *P*-multiplier (P_m) used with the *p-y* curve to assess the response of a pile group under lateral loads, which is a crucial topic for the design of bridge pile foundations. P_m is influenced by the site geotechnical conditions (i.e., soil profile, type and properties), pile front and side spacings, and pile-group deflection. The presented study shows the needs to incorporate these factors with the recommended sets of P_m to avoid any compromise or uncertainty when P_m is treated as a single (unique) value based only on pile spacings. The current study addresses these influential elements using the strain wedge (SW) model technique, suggested P_m values, and data collected from full-scale pile-group load tests. The experimental results show that P_m is not unique and must be assessed based on the site geotechnical conditions along with the pile-row front and side spacings. Because the employed P_m values must be a function of these influential factors, additional full- and model-scale load tests with different pile spacings and soil types might be required. The paper also emphasizes that using other techniques, such as the SW model, in addition to the *P*-multiplier could increase the confidence in the predicted pile-group lateral response. **DOI: 10.1061/(ASCE)BE.1943-5592.0000196.**

CE Database subject headings: Pile foundations; Pile groups; Lateral loads; Strain; Deflection.

Author keywords: Pile foundation; Pile group; Lateral load; *P*-multiplier; Strain wedge model.

Introduction

The design of a pile group under lateral loads is a very common problem in foundation engineering. The most common method is the use of the *P*-multiplier (P_m) with the *p-y* curves, as employed in a number of computer programs. There are other applicable methods, such as the group reduction factor method (Davison 1970) that is based on pile-group tests in sand and recommends a linear reduction factor for the modulus of subgrade reaction [varies from 25% for the three-diameter (3*D*) pile spacing to 100% for the 8*D* pile spacing]. Ooi and Duncan (1994) developed a simplified group amplification procedure for the design of groups of piles and drilled shafts based on the theories of Poulos (1971) and Focht and Koch (1973). The amplifications factors are multiplied by the single pile values of deflection and maximum moment. Comparisons with different methods used for pile-group analysis are presented by Ooi and Duncan (1994).

The pioneering work of Brown et al. (1998) established the approach of the *P*-multiplier and its employment in the analysis of pile groups as a constant reduction factor to reduce the *p*-value (soil resistance, F/L) of the isolated pile *p-y* curve (Fig. 1). The values of P_m are obtained from full-scale load tests of pile groups with (mostly) three-pile diameter spacings in both directions and depend on associated site geotechnical conditions. P_m values obtained from full-scale load tests are empirically determined through a number of trials to match the calculated pile-group deflection with the measured deflection. As a result, P_m is expected to change for the same pile group if installed at different sites (i.e., different types or layer thicknesses of the near-surface soils). This explains the significant variations in the P_m values recommended by different researchers and agencies (Fig. 2). At present, the use of the P_m technique in pile-group design (with no data from a full-scale load test) relies only on the ratio of the pile-row spacing in the loading direction to the pile diameter (S_L/D). However, the suggested *P*-multipliers could be affected by ignoring the influence of (1) pile spacing in the same row (S_T), which is normal to the loading direction; (2) soil type; (3) soil layer thickness and properties (soil profile); (4) level of lateral loading; and (5) pile arrangements. For the same type of soil, the P_m values estimated based on the traditional *p-y* curves could be substantially different from those obtained from site-specific *p-y* curves.

In addition to the experimental data presented by Hughes et al. (1978) for the horizontal stress distribution in the soil around laterally loaded piles, Fig. 3 shows the distinctive variation of the horizontal stress in the soil zone around the pile group based on the finite-element analysis (Rao et al. 1998). The stress zone expands horizontally as a function of pile arrangements and decreases with depth (Fig. 3). The leading work by Brown et al. (1988) established the concept of interaction among closely spaced piles in a pile group (i.e., group action) based on the horizontal shear zone overlap among the neighboring passive soil wedges in the group.

The horizontal passive soil wedge overlap decreases with depth, and the larger the pile-group deflection, the deeper and wider the zone of stress overlapping. Furthermore, the horizontal overlap of stresses among the piles at a certain depth starts with a large value of P_m (close to 1), where overlapped stresses are very small at that particular depth, and then decreases with the increase of group deflection to some extent. As observed in a number of pile-group tests (Ilyas et al. 2004; Brown and Reese 1985; Rollins et al. 2005), the pile-group interaction is very limited at the early stage of lateral loading (small deflection) (i.e., overlapping stresses in the surrounding soil are very small), and the individual piles in the group respond similar to a single pile. Increasing the pile spacing from 3*D* to 5*D* would extend the stage of pile-group deflection with $P_{avg.} = P_{single}$ before the development of the group action and

[1]Associate Professor, Dept. of Civil and Environmental Engineering, Univ. of Alabama, Huntsville, AL 35806 (corresponding author). E-mail: ashour@eng.uah.edu

[2]Graduate Student, Research Assistant, Dept. of Civil and Environmental Engineering, Univ. of Alabama, Huntsville, AL 35806.

Note. This manuscript was submitted on April 14, 2010; approved on November 6, 2010; published online on August 15, 2011. Discussion period open until February 1, 2012; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Bridge Engineering***, Vol. 16, No. 5, September 1, 2011. ©ASCE, ISSN 1084-0702/2011/5-612–623/$25.00.