

Group and Network Effect in Micropile Design Practice

A. Benslimane, Polytechnic University, 6 Metrotech Center, Brooklyn, NY 11201.

I. Juran, Polytechnic University, 6 Metrotech Center, Brooklyn, NY 11201

D. A. Bruce, Nicholson Construction Company, P. O. Box 98, Bridgeville, PA 15017.

SYNOPSIS: Facing the difficulties in evaluating the group and network effects for different types of micropiles, soils and site conditions and in the absence of sufficient field data, no specifications have yet been established to take into account the group and network effects which are commonly neglected in micropile design practice. This paper summarizes the micropile state of practice assessment (D. A. Bruce and I. Juran, 1995) conducted for the Federal Highway Administration in order to evaluate current design guidelines, quality control, and construction practices of micropile group systems. Available analysis approaches are presented and evaluated through comparisons with experimental data obtained by different investigators on the engineering behavior of micropile group systems and reticulated micropile networks under different loading conditions. Preliminary conclusions are presented along with proposed design guidelines for micropile group systems.

1. INTRODUCTION

The design of micropile systems particularly for underpinning applications usually dictates the need for groups of closely spaced piles. With conventional piles, there is usually a compromise to be resolved between the desire to select a close micropile spacing, thus minimizing the size and cost of the pile cap and, on the other hand, the need to maintain a certain minimum inter-pile spacing so as to avoid the "group effect" necessitating a reduction in the nominal capacity of each pile. Depending on pile spacing, the loading capacity of a group of piles can be significantly smaller and its movement larger than the loading capacity and the movement of a single pile under the same average load per pile in the group. To account for the group effect on the loading capacity and the pile movement, different design codes (e.g. AASHTO, 1992; CCTG, 1993; BOCA, 1990) specify minimum spacing between piles and/or relevant reduction factors (e.g. NAVFAC-DM 7.02, 1982; Canadian Geotechnical Society CGS, 1992; ASCE Committee on Deep Foundations CDF 1984). Ultimately, when piles are closely spaced, interaction between these piles has to be considered.

Several analytical approaches have been proposed to evaluate the group effect in pile systems including the continuum elastic methods (e.g. Poulos, 1968; Poulos and Hewitt, 1986; Poulos and Davis, 1980; Yamashita et al., 1987; Banerjee, 1978; Butterfield and Banerjee, 1971; Banerjee and Davies, 1977) and load-transfer models (e.g. O'Neill et al., 1982; Maleki and Frank, 1994) as well as empirical correlations derived from available data base relating the movement of a pile group to the movement of single piles (e.g. Skempton, 1953; Vesic, 1969; Meyerhof, 1976; Fleming et al., 1985). However, for given loading conditions, the group effect that may develop in the micropile-soil system appears to be highly dependent on a variety of parameters including in particular (i) soil type (i.e. cohesionless, cohesive, rocks, water table) (ii) pile installation technique (i.e. effect of drilling disturbance, type and pressure of grouting) that can significantly modify the mechanical characteristics of the in-situ soil, and the soil-pile interface properties (iii) geometry of the micropile system (e.g. spacing to

diameter ratio, slenderness ratio and micropile inclination) (iv) loading mode (i.e. loading applied directly to the micropiles versus loading applied to the coherent, composite micropile reinforced soil structure) (v) related boundary loading conditions at the pile-cap connection and (vi) relative stiffness of the cap to the soil-pile system. The difficulties involved in the appropriate determination of these parameters and particularly in evaluating the effect of the pile installation technique on the loading capacity and the movement response of the pile group system, create major limitations with regard to the application of the available analytical models in micropile design practice.

Two basically different design concepts which are illustrated in figure 1 have been developed (Bruce and Juran, 1995) for engineering practice of micropiles, namely:

Case 1 referring to micropiles which are designed to transfer structural loads through soft or weak soils to more competent strata. These micropiles are generally used as structural support to resist directly the applied loads.

Case 2 referring to Lizzi's (1978) original "root pile" design concept, relies primarily on using a three dimensional network of reticulated friction micropiles to create in-situ a coherent, composite, reinforced soil system.

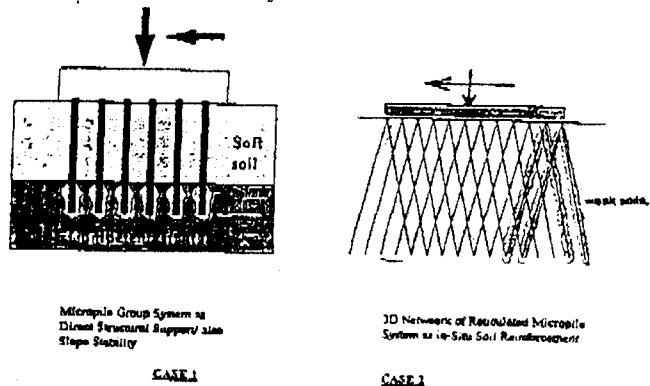


Figure 1. Design Concept of Micropile Systems

For conventional piles, available design codes (AASHTO, 1992; CCTG, 1993) specify minimum spacing between piles and /or relevant reduction factors (NAVFAC, 1982; CGS, 1992) for the determination of the pile group axial loading capacity. AASHTO (1992), following Terzaghi and Peck (1948), recommends the axial group capacity to be computed as the lesser of (i) The sum of the ultimate capacities of the individual pile in the group, or (ii) The axial loading capacity of an equivalent composite pier circumscribing the group, for a block failure of the group. At present, several design codes such as the French CCTG (1993) and the AASHTO (1992) Bridge Specifications still suggest the use of the Converse-Labarre group efficiency equation for friction piles including (in the French code) micropiles in different types of soils.

It is noted that the Converse-Labarre formula relies only on assumed relationships between the pile group geometry and the group efficiency factor with practically no relevant test data available for its justification. In particular, it does not allow for any considerations with regard to different parameters such as installation technique effect, slenderness ratio and soil type. The comparison between experimental and predicted values of the group efficiency factor for driven piles in sand and specifically for the micropile tests conducted by Lizzi (1978) strongly suggests that the Converse-Labarre formula should not be used in micropile design practice.

In the absence of sufficient field data, the FHWA study (Bruce and Juran, 1995) suggests that the French CCTG (1993) recommendations can be adapted for preliminary conservative assessment of the group efficiency factor in micropile systems.

3 MICROPILE GROUP MOVEMENT ESTIMATE

Depending on pile spacing, the movement of a group of piles can be significantly larger than the movement of a single pile under the same average load per pile in the group. Due to the group effect, the contiguous pile creates an increased movement to its neighbors as compared to single pile under an equal loading. Several approaches have been developed in order to predict the movement of group of piles, including: (i) Empirical correlations relating the movement of pile groups to the movement of a single pile (e.g. Skempton, 1953; Vesic, 1969; Meyerhof, 1976; Fleming et al., 1985), (ii) Continuum elastic methods based on Mindlin (1936) equations (e.g. Poulos, 1968; Poulos and Davis, 1980; Poulos and Hewitt, 1986; Poulos (1989), Poulos and Davies, 1990; Yamashita et al, 1987; Banerjee, 1978; Butterfield and Banerjee, 1971; Banerjee and Davies, 1978; Randolph and Wroth, 1979), (iii) Load transfer models and "hybrid solutions" (O'Neill et al., 1977 and 1980; Maleki and Frank, 1994; Chow, 1986, 1987a and 1987b; Lee, 1993a) combining characteristic load transfer "t-z" curves for each pile with continuum elastic solutions to assess interaction factors for estimating the group effect. (iv) Pure shear interface model developed by Randolph and Wroth (1979) assuming that the vertical loading produces pure shear with negligible radial movement.

The group movement can be expressed by the group reduction factor, R_g , defined as

$$R_g = \frac{\text{Average group movement}}{\text{Movement of single pile at same total load as the group}} \quad [2]$$

Figure 3 shows the comparisons between empirical correlations of group settlement reduction factor versus group breadth to diameter ratio proposed by Skempton (1953), Fleming et al. (1985), the continuum elastic analysis and the pure shear interface model for various pile groups.

According to Fleming et al. (1985):

$$R_g = n^{-\alpha} \quad [3]$$

where n is the number of piles and for practical cases, the value of the exponent α lies in the range of 0.4 to 0.6. This simplified empirical relationship is recommended by the Hong Kong Department of Transportation (1994) for pile group design.

Figure 3 illustrates that for the typical case of a spacing to pile diameter ratio of $s/D=3$, with an exponent value α within the range of 0.6 to 0.7, the empirical correlations proposed by Fleming et al. (1985) yield R_g values which are consistent with those predicted by Skempton formula and the elastic solution.

Randolph and Wroth's (1979) pure shear interface model has been used by Bruce and Juran (1995) to evaluate the group effect yielding for axially loaded micropile systems:

$$R_g = \frac{R_s}{n} \quad \text{with} \quad R_s = n - \frac{\sum_{i=1}^{n-1} \ln(2r_i/D)}{\ln(2r/L/D)} \quad [4]$$

where n is the number of piles in the group, L/D pile length to diameter ratio, r_i the distance of each pile i from the pile under consideration and $r = 2.5 \rho(1-\nu)$ where ρ is the ratio between the soil shear modulus $G_{L/2}$ at depth $z=L/2$ and the soil shear modulus G_L at depth $z=L$, and ν is the poisson coefficient.

As illustrated in figure 3, Equation [4], yields slightly more conservative group settlement reduction R_g values as compared with the empirical correlations and the elastic solutions

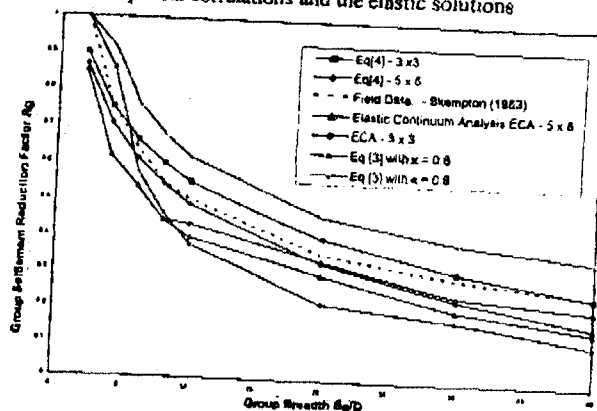


Figure 3. Comparisons Between Empirical Correlations of Group Settlement Reduction Factor Versus Group Breadth to Diameter Ratio Proposed by Skempton (1953), Fleming et al. (1985) [Eq 3], Pure Shear Interface Model Predictions [Eq 4] and Elastic Continuum Analysis Predictions.

4. NETWORK EFFECT

Plumelle (1984) investigated the inclination effect on the performance of hammered micropile group systems. The results illustrated on figure 4 show that the inclination of the micropile leads to a network effect that may significantly increase the ultimate axial loading capacity and decrease the movement of the micropile group. However, the comparison between the test results obtained for the micropile groups and networks with the load-movement curve obtained for the reference micropile group ($Q_g = 16 Q_s$) where Q_s is the load applied on the single micropile at the same movement than the reference micropile group, indicates that apparently a negative group effect develops due to the soil disturbance induced by the pile hammering into the soil. This apparent negative group effect results in a significant decrease of the loading capacity of the group and a significant increase of its movement as compared with that of a single pile under a load identical to the average load per pile in the group.

It is of particular interest to note that for the test results reported by Plumelle ($n=16$, $s/D=8$, $L/D=94$), and for the loading level of 50 percent of the ultimate loading capacity of the reference group, Equation [3], with an exponent value of 0.7 and equation [4] yield approximately the same calculated value of $R_g=7$ which agrees fairly well with the experimental results.

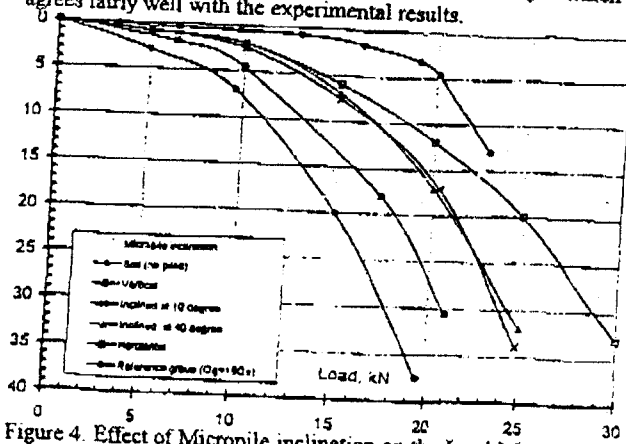


Figure 4. Effect of Micropile inclination on the Load-Movement Curves of Micropile Group Systems.

Figure 5 illustrates the comparison between the experimental interaction factor values α_i obtained for these tests and the numerical predictions obtained by Maleki and Frank (1994) with the GOUPEG hybrid model and the CESAR Finite Element method. The normalized interaction factor $\hat{\alpha}_i$ for a group of n micropiles ($n=16$ for Plumelle's test) is defined by

$$\hat{\alpha}_i = \frac{R_g - 1}{n - 1} \quad [5]$$

The experimental values of $\hat{\alpha}_i$ are obviously highly dependent upon the loading level. The $\hat{\alpha}_i$ values indicated in figure 5 are obtained for a loading level for $Q_{gu} = 16$ kN corresponding approximately to 50 percent of the ultimate loading capacity of the reference group. While any quantitative comparison between the experimental results obtained by Plumelle for a group of 16 inclined driven micropiles and the numerical predictions

obtained for a two-inclined micropile group system is highly approximate, both the experimental results and the numerical simulations consistently illustrate that the inclination of the micropiles in the group can significantly minimize the group effect and thereby, improve the movement response of the soil-micropile system.

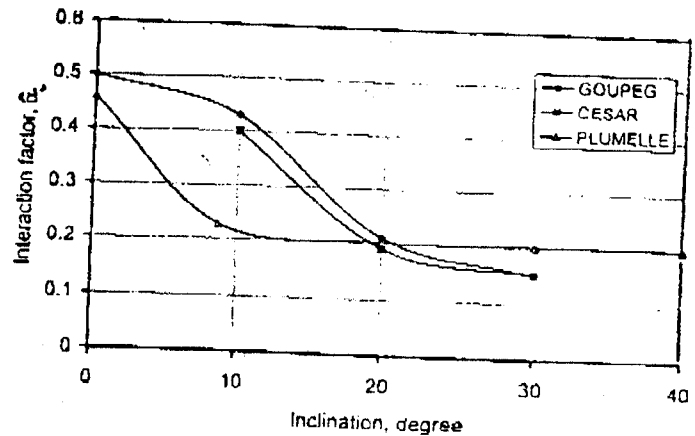


Figure 5. Comparison between the experimental interaction factor values α_i obtained for by Plumelle (1984) and the numerical predictions with the GOUPEG hybrid model and the CESAR Finite Element method.

5. CONCLUSION

The broad conclusion to be drawn from this study is that the group efficiency factor in micropile systems is highly dependent on a variety of factors and in particular the pile inclination and installation techniques. The group effect in gravity grouted micropile systems can significantly increase pile movement while pile inclination will significantly reduce the group effect on pile movement. The experimental results are consistent with empirical pile design correlations proposed by Fleming et al. (1985) and Skempton (1953), as well as the load transfer hybrid models. A pure shear interface model is proposed for evaluating the group effect in micropile design practice. Both the model test results reported by Lizzi (1978) and the full-scale test results reported by Plumelle (1984) demonstrated that the inclination of the micropile results in a network effect that increases the axial loading capacity and significantly decreases the movement of the soil-micropile group system. However, with the present state of practice, no specifications have yet been established to take into account this network effect in micropile design practice.

REFERENCES

- Bruce, D. A., and I. Juran 1995. Drilled and Grouted Micropiles; State-of-Practice Review. FHWA Contract No. DTFH61-93-00128.