ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

SETTLEMENT AND LOAD DISTRIBUTION ANALYSIS OF UNDERREAMED PILES

C. Y. Lee
Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional, Selangor, Malaysia
E-mail: cylee@uniten.edu.my

ABSTRACT

This paper presents the elastic behaviour of underreamed piles in homogeneous soils. The modified boundary element method is used to obtain parametric solutions of underreamed piles under axial loading. Consideration is given to the effect of pile slenderness ratio, pile-soil relative stiffness, underreamed diameter and bearing stratum on response of underreamed piles. The characteristic of load distribution along the pile length is also studied.

Keywords: pile, underreamed, homogeneous soil, elastic solution, settlement, load distribution.

INTRODUCTION

Bored piles may be straight shafted, underreamed, or multiunderreamed. Underreaming is usually done to increase the pile base size and hence provides additional load-carrying capacity. It is primarily used in stiff cohesive soils. During the construction process in unstable soils such as loose and water-saturated soils, there is a danger of collapse of the bell; the strength of the soil, the presence of soil layers, and the possible inflow of groundwater in pervious strata are important factors, which need to be considered. The load testing on instrumented underreamed piles performed by Martin and De Stephen (1983) suggest that such piles are viable cost effective foundation in very stiff overconsolidated clays.

Underreamed piles have been widely used in India, both as load-bearing and anchor piles in expansive clays. For anchor piles, a single underreamed bell is often used, while for load-bearing, multiunderreamed bells may be used. Mohan *et al.*, (1967 and 1969) suggest that the base and shaft resistance may be added to provide the ultimate load capacity. Patra and Deograthias (2004) performed experimental investigations on the behaviour of model underreamed piles, embedded in layered sand and homogeneous sand subjected to axial pulling and oblique pulling loads respectively. The experimental results indicate that the load-displacement response of the underreamed piles is nonlinear and the uplift capacity increases with increase in length and base enlargement. The effect of the underreamed base on the total and end-bearing capacities of a pile in ice-rich permafrost is evaluated along the principles used to evaluate the total capacity of uniform diameter and underreamed piles of the same length in ice-rich soils (Sego, Biggar and Wong 2003). It was found that the total load capacity can be substantially improved through the use of underreamed piles in ice-rich permafrost.

In this paper, a modified boundary element method is employed to analyse the behaviour of underreamed piles in elastic homogeneous soils under axial loading. Some of the important factors such as the pile slenderness ratio, pile-soil relative stiffness, underreamed diameter and bearing stratum, affecting the response of underreamed piles are presented and discussed. The characteristic of the load distribution along the pile length is also studied.

METHOD OF ANALYSIS

A modified form of the boundary element approach is employed here in which the pile is modeled as an elastic cylinder and the surrounding soil mass as an elastic continuum, as shown in Figure-1.

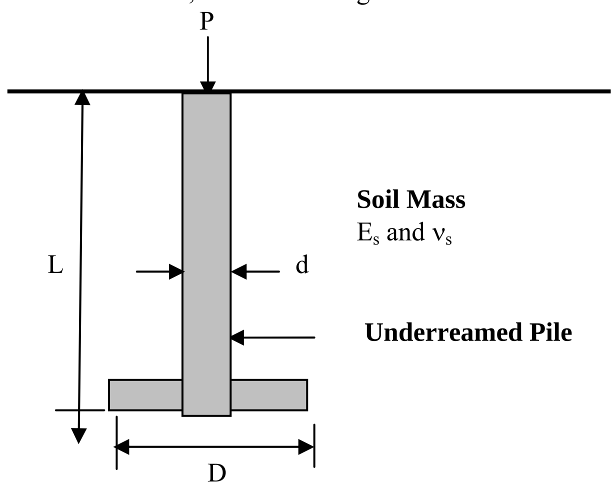

Figure-1. Underreamed pile analysis.

For a pile embedded in a homogeneous soil mass, the incremental displacements of the soils adjacent to each element can be expressed as:

$$\{\Delta S_s\} = \left[I / E_s \right] \{\Delta p\} \qquad (1)$$

Where $\{\Delta S_s\}$ = vector of incremental soil displacements;
$[I/E_s]$ = matrix of soil influence factors divided by soil modulus; and
$\{\Delta p\}$= vector of incremental pile-soil intersection stresses.

Considering the nodes on shaft and base of the pile, the incremental compression vector $\{\Delta S_c\}$ can be expressed as:

$$\{\Delta S_c\} = [FE]\{\Delta p\} \qquad (2)$$

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Where [FE] = pile compression matrix

The total pile incremental displacement vector $\{\Delta S_p\}$ is:

$$\{\Delta S_p\} = \Delta S_b \{1\} + [AD]\{\Delta S_c\} \quad (3)$$

Where ΔS_b = incremental displacement of pile base.
{1}= vector whose elements are unity.
[AD] = summation matrix.

By the consideration of compatibility of incremental pile and soil vertical displacements from Equations (2) and (3),

$$\{\Delta S_p\} = \Delta S_b \{1\} + [AD][FE]\{\Delta p\} \quad (4)$$

The vertical equilibrium condition requires that:

$$\sum_{i=1}^{n} A_i \Delta p_i = \Delta P \quad (5)$$

Where A_i = surface area of element i;
Δp_i = interaction stress increment on element i;
ΔP = increment of applied load on pile head; and
n = total number of elements.

The unknown interaction stress increments Δp and base incremental displacement ΔS_b may be computed by solving Equations (4) and (5). The evaluation of the elements of [I] is most conveniently carried out by integration of the Mindlin equations for the displacements due to a point load within a semi-infinite mass (Mindlin, 1936). Details of the analysis are described by Poulos and Davis (1980).

THEORETICAL RESULTS

For a pile with an underreamed base of 3d (where d = pile shaft diameter) having a typical relative compressibility K=1000 (where $K = E_p/E_s$, E_p = pile modulus and E_s = soil Young's modulus), in a deep homogeneous elastic soil mass, Figure-2 shows the normalized pile settlement ($S_D dE_s/P$ where S_D = underreamed pile settlement and P = applied load) as a function of the pile slenderness ratio (L/d). The soil Poisson's ratio (υ_s) is assumed to be 0.5. The normalized pile settlement decreases with increasing pile slenderness ratio indicating that long underreamed piles are able to sustain more loads than short underreamed piles. However, if a further reduction in settlement of a long underream pile is sought, there appears to be little to be gained by having a pile length greater than 50d.

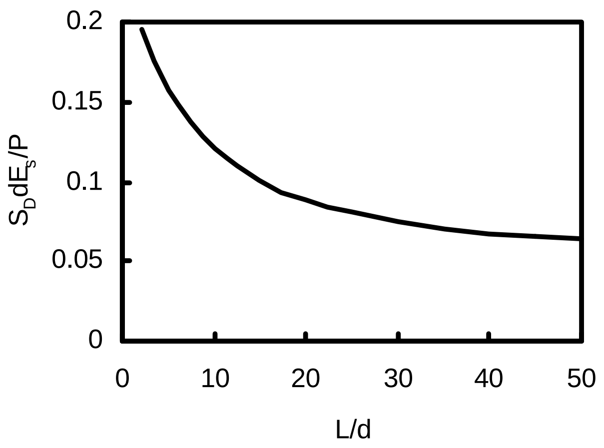

Figure-2. Effect of L/d on pile settlement (K=1000, D/d=3).

The effect of the size of underreamed bell on the pile response is illustrated in Figure-3. As would be expected, the normalised underreamed pile settlement (S_D/S_d where S_d = settlement of uniform diameter pile) decreases as the size of the underreamed bell increases. However it is interesting to learn that the underreamed piles behave similar to the response of uniform diameter piles, as the pile length approaching 50d and it appears to be relatively independent of the size of underreamed bell, as shown in Figure-4. It implies that the pile shaft supports most of the applied load and only minimum load is transferred to the underreamed base for long piles.

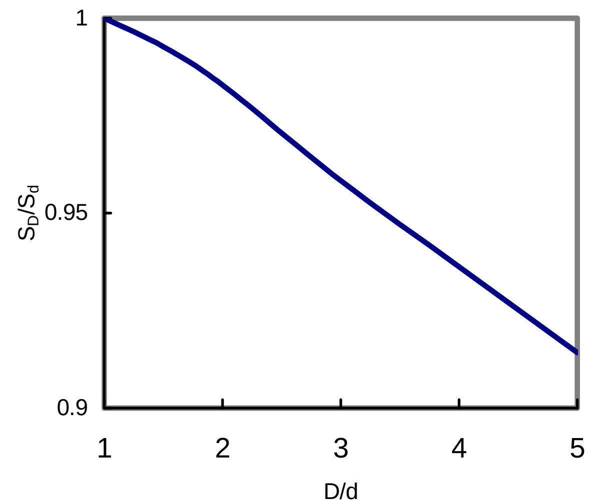

Figure-3. Effect of size of underreamed bell on pile settlement (L/d = 25, K = 400).

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

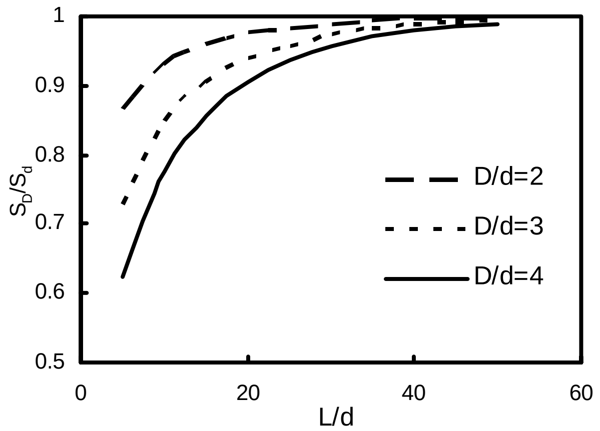

Figure-4. Effect of L/d on pile settlement (K = 400).

Figure-5 shows the comparisons between the load distribution curves for piles with different underreamed sizes (where P_z = pile load at depth z and P = total applied load). As would be expected, larger load is transferred to the pile base with larger underreamed size. The load distribution at upper half of the pile length is not affected much by the underreamed size.

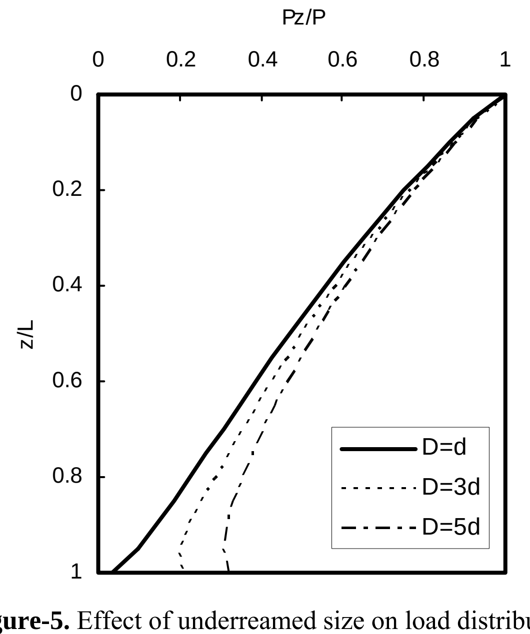

Figure-5. Effect of underreamed size on load distribution curves (L/d = 25, K = 400).

The stiffness of underlying soil layers may have significant effect on underreamed pile behaviour. Figure-6 shows an example of the effect of the relative stiffness of the underlying soil (E_b/E_s where E_b = bearing soil modulus) on the settlement of the underreamed piles. The presence of a softer bearing layer (E_b/E_s<1) may substantially increase the settlement, as compared with the case of a homogeneous soil mass (E_b/E_s = 1). Similarly, the present of a stiffer bearing layer (E_b/E_s>1) may significantly decrease the settlement.

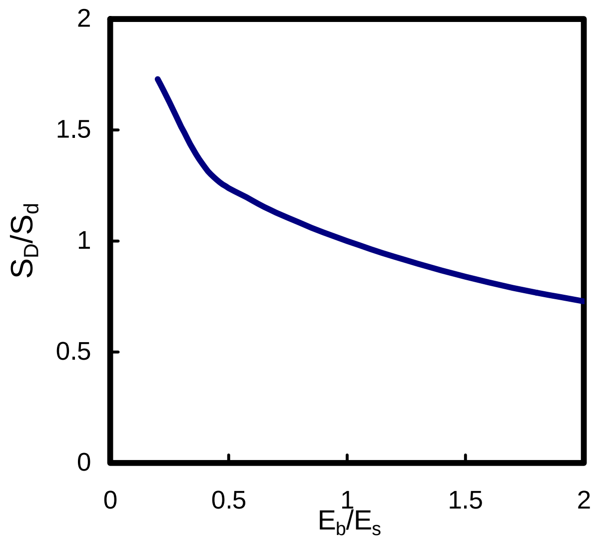

Figure-6. Effect of bearing stratum (L/d = 25, D/d = 3, K = 400).

Figure-7 demonstrates the effect of pile-soil relative stiffness ($K = E_p/E_s$) on the normalised pile settlement (S_DdE_s/P). The lower the value of K, the greater is the pile settlement indicating that compressible underreamed piles may settle more than rigid underreamed piles. When K is greater than 1000, the underreamed pile settlement is reduced substantially implying larger load is transferred to the pile base.

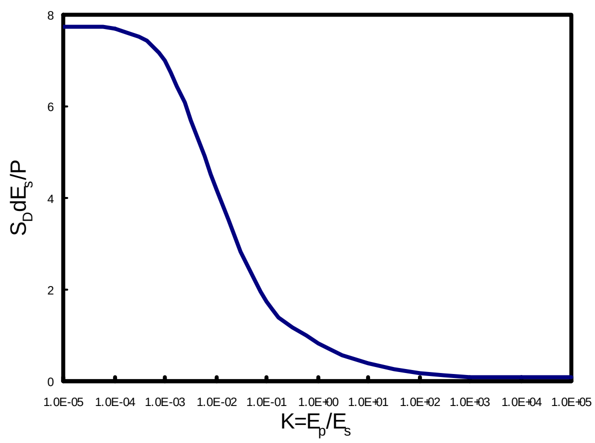

Figure-7. Effect of pile-soil stiffness K (L/d = 25, D/d = 3).

Figures-8 shows the effect of pile-soil relative stiffness K on the load distribution curves of underreamed piles. For very compressible piles (K≤10), most of the loads are supported by the upper half of the pile length and very little loads are transferred to the base. It appears that more loads are transferred to the pile base as the pile-soil relative stiffness K increases. It is therefore apparent that the enlarged base has the greatest influence when the pile is relatively rigid (K≥1000).

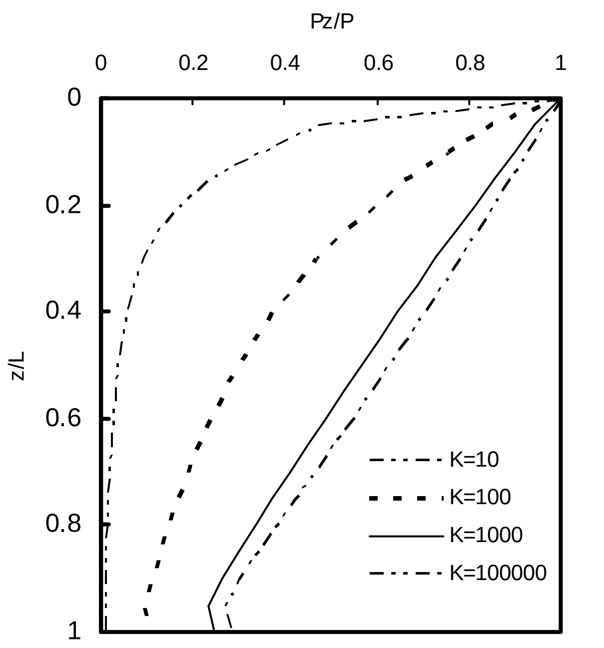

Figure-8. Effect of K on load distributions along piles (L/d = 25, D = 3d).

The location of the underreamed bell (L_D) along the pile length may have significant effect on the overall behaviour of the pile as shown in Figure-9. The pile settles more when the underreamed bell is located at the upper half of the pile ($L_D/L < 0.5$) than it is located at the lower half of the pile ($L_D/L > 0.5$). The effect is most significant when the underreamed bell is located at the pile base indicating that the pile tends to behave as an end-bearing pile in which larger load is transferred to the base and hence reducing the settlement.

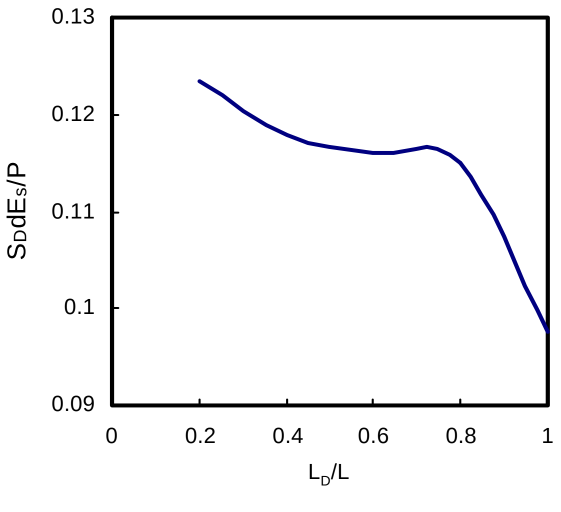

Figure-9. Effect of underreamed bell location (L/d = 25, D/d = 3, K = 400).

Figure-10 shows the load distribution curves for piles with underreamed bell located at different depth. For a uniform diameter pile (D = d), the load is transferred "smoothly" down to the pile base. It is found that there is an "abrupt" increase of load transfer at the location of the underreamed bell indicating that larger load is attracted to it.

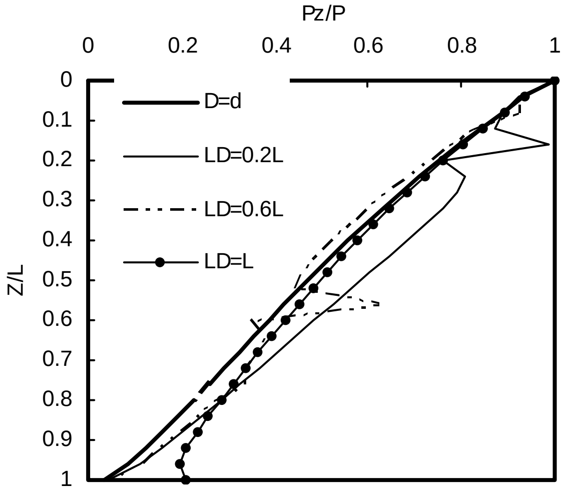

Figure-10. Load distributions along underreamed piles (L/d = 25, D/d = 3, K = 400).

CONCLUSIONS

A modified boundary element method has been employed to analyse the behaviour of underreamed piles in elastic homogeneous soils. Some of the important factors affecting the response of underreamed piles have been presented and discussed. Theoretical solutions suggest that short rigid underreamed piles would settle much less than long compressible underreamed piles. The characteristic of the load distributions along the underreamed piles may also be affected by the pile-soil stiffness and location of the underreamed bell. It was found that the most efficient means of reducing underreamed pile settlement occurs when the enlarged base is resting on stiffer soil stratum.

REFERENCES

Martin, R.E. and De Stephen, R.A. 1983. Large diameter double underreamed drilled shafts. J. of Geotechnical Engineering, ASCE. Vol. 109(8): 1082-1098.

Mindlin, R.D. 1936. Force at a point in the interior of a semi-infinite solid. Physics, Vol. 7, p. 195.

Mohan, D., Jain, G.S. and Sharma, D. 1967. Bearing capacity of multiple underreamed bored piles. Proc. 3rd Asian Conf. S.M. & F.E., Vol. 1, pp. 103-106.

Mohan, D., Murthy, V.N.S. and Jain, G.S. 1969. Design and construction of multi-underreamed piles. Proc. 7th Int. Conf. S.M. and F.E., Vol. 2, pp. 183-186.

Patra, N.R. and Deograthias, M. 2004. Pullout capacity of anchor piles. Electronic J. of Geotechnical Engineering.

Poulos, H.G. and Davis, E.H. 1980. Pile foundation analysis and design. New York, Wiley.

Sego, D.C., Biggar, K.W. and Wong, G. 2003. Enlarged base (Belled) piles for use in ice-rich permafrost. Journal of Cold Region Engineering. Vol. 17(2): 68-88.