Behaviour of coated and uncoated lightly loaded piles in swelling soils
Comportement de pieux enduits et non enduits chargés légèrement dans des sols gonflants

B. Sh. Hazzan

ABSTRACT
In the last four decades significant effort has been devoted to designing piles in swelling soils. For this purpose, an investigation site was established in Be'ne in Western Galilee- Northern Israel. On this site twenty five unloaded cast-in-situ piles, both uncoated and coated, were installed in a moderately expansive clay soil in the end of summer 1996. The piles were executed to different depths ranging between 2.0m and 7.0m and were observed over a period of 27 months. Results obtained from observations and from full-scale static pull out tests showed that separating the piles from the surrounding clay in the active zone by a twin walled plastic sleeve eliminated the heave forces significantly.

RÉSUMÉ
Durant les 4 dernières décennies des efforts significatifs ont été dédiés au dimensionnement de pieux dans les sols gonflants. A cet égard, un site expérimental a été construit à Be'ne dans la Galilée de l'Ouest au Nord d'Israël. Sur ce site, vingt cinq pieux moulés en place, non chargés, enduits et non enduits, ont été mis en place dans une argile modérément expansive, à la fin de l'été 1996. Ces pieux ont été exécutés avec différentes fiches, de 2,0 à 7,0 m. Ils ont été observés pendant une période de 27 mois. Les résultats obtenus à partir d'observations et d'essais de traction statiques en vraie grandeur ont montré que séparer les pieux de l'argile environnante dans la zone active par un manchon plastique à double paroi éliminait les forces de soulèvement d'une manière significative.

Key words : pile design, load test, skin friction, end bearing, failure load of piles
Mots-clés : manchons, gonflant, figures, tableaux, références

INTRODUCTION

For many years, foundation engineers have tried to solve the problem of heave forces on piles in shrinkable clay. In one hand, big pile diameter is needed to increase the pile capacity, but on the other hand the heave forces on the pile will increase because the increase of the contact area between the swelling soil and the pile shaft. Hence, to minimize heave/downdrag forces on a pile it is desirable to have low shaft friction and therefore beneficial to provide as smooth a surface as possible between the pile and surrounding soil along the active zone. It was proven in this research that by coating the pile with a telescopic sleeve, the heave forces were significantly minimized.

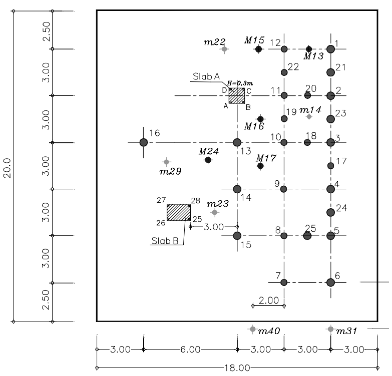

Figure 1: Description of items in the test site

1 DESCRIPTION OF TEST SITE

Location and description of items in the test site are shown in Figure 1. Test site stratigraphy illustrated in Figure 2.

2 FIELD MEASUREMENTS

2.1 *Vertical movement of ground surface and clay subsoil*

The ground surface showed a maximum heave of about 58-mm and a maximum settlement of 12 mm, amounting altogether to an amplitude of about 70 mm (Figure 3). Results obtained from calculation of the strain in the clay subsoil showed that the depth of the desiccated / expansible zone ranged between 2.0 m and 2.50 m

2.2 *Vertical movements of piles*

The vertical movements of all observed piles showed a good accordance with the rainfall (Figure 4).

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-1136

2.3 *Pullout tests*

The average ultimate uplift capacity of the pulled out piles obtained from the static pull out tests was determined according to eight different methods.

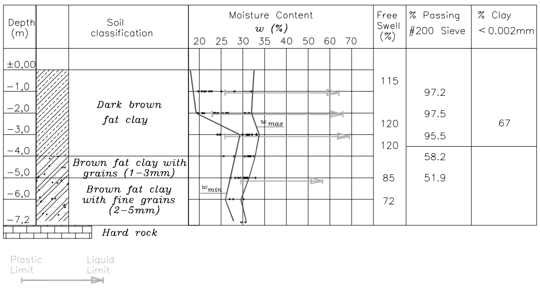

Figure 2: Test site stratigraphy

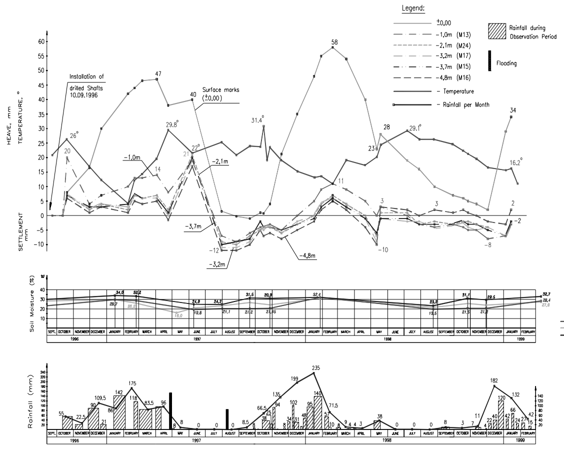

Figure 3: Vertical movements in clay subsoil and ground surface

3. DETERMINATION OF EARTH PRESSURE COEFFICIENT K_0

Norlund (1963) summarized the factors affecting the frictional resistance developed between the pile shaft and the surrounding soil as a function of: soil type and its density, degree of roughness of the pile shaft (Burland, 1973) and manner of casting. For a simplifying assumption it can be argued that by pushing the pile into the clay, an inclined resultant of soil resistance can be derived as shown in Figure 4, where, P_u is the ultimate compressive load, K_δ is the earth pressure coefficient inclined by an angle (δ), δ is the friction angle between the shaft and the soil, W_p is the weight of pile, ω is the shaft inclination angle, L is the embedded length of pile and P_l is the vertical total earth pressure at depth l below ground surface. Therefore, the general formula for calculating the frictional resistance will be:

$$P_u = \sum_{l=0}^{L} K_\delta \cdot P_l \cdot \sin(\omega+\delta) p \cdot \Delta l \cdot \sec\omega = Q_u - W_p \qquad (1)$$

Where Q_υ is the ultimate uplift resistance of pile (kN), p is the perimeter of pile and $p.\Delta l$ is the shaft area in slice of Δl. For conventional piles where $\omega < 1^0$ and the pile shaft is rough (inclined resultant K_δ P_l), Equation (1) will have the form:

$$P_u = \sum_{l=0}^{L} K_\delta \cdot P_l \cdot \sin\delta \cdot p \cdot \Delta l \qquad (2)$$

Hereinafter, P_u will be defined as the ultimate pull out load which is equal to the ultimate uplift capacity (Q_υ) minus the weight of the pile (W_p) and the uplift capacity at the pile toe (Q_{tu}). The resultant of the earth pressure during uplift force (K_p) has two components according to the following analysis:

$$P_{uv} = K \cdot P_l \cdot \sin\delta \qquad (3)$$

and

$$P_{uh} = K \cdot P_l \cdot \cos\delta \qquad (4)$$

Equation (2) could be derived in an approach according to the classical definition of shearing resistance. From the simple condition of vertical equalization of the forces acting along the pile shaft:

$$P_u = \sum_{l=0}^{L} \tau_f \cdot p \cdot \Delta l \qquad (5)$$

Where τ_f is the shearing resistance at failure between the soil and the pile shaft. By substituting :

$\tau_f = \sigma_v \cdot \tan\delta + C_a$ and $\sigma_v = KP_l \cdot \cos\delta$, then Equation (5) will be:

$$P_u = \sum_{l=0}^{L} p \cdot \Delta l (k \cdot p_l \cdot \sin\delta + C_a) \qquad (6)$$

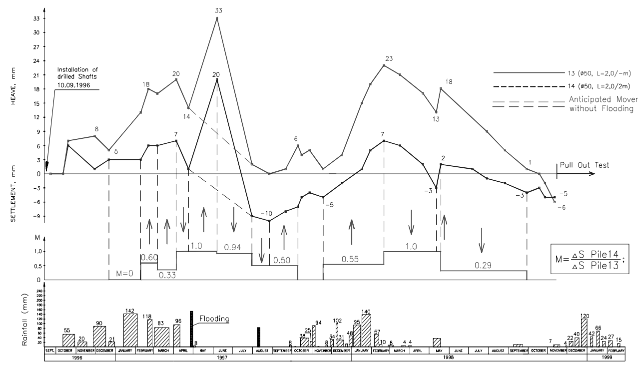

Figure 4: Vertical movements of pile 13 (uncoated) and pile 14 (coated) as a function of rainfall

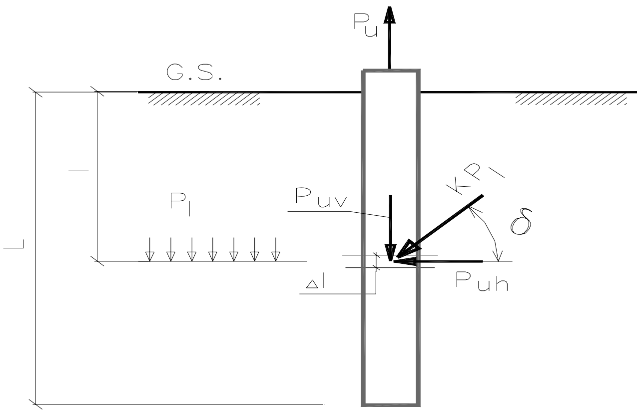

Figure 5: Forces on a rough shaft due to uplift load

Table 1: Comparison between K- Values of pulled out unsleeved, sleeved and lubricated piles.

Pile No.	Dimensions		K_υ	$K_{\upsilon t}$	K_s	K_{st}	K_l	K_{lt}
	L (m)	D (m)						
17,18,19	2.0	0.50	1.92	1.86	1.54	1.31	1.46	1.24
20,21,22	2.0	0.60	1.09	1.02	0.70	0.43	0.88	0.63
23,24,25	2.0	0.70	1.76	1.68	0.28	-	0.50	0.20

Hence, Equation (2) is a special case of C_a=0. Equation (6) shows an approach for estimating the earth pressure coefficient (K) by taking the adhesion into account. By considering a fully rough vertical pile shaft (ω = 0) obtained in this work and the double direct shear test results (Ca=15 kN/m^2, δ=45^0), the resultant ($K_\delta \cdot P_l$) will act theoretically on the concreted pile shaft at an interface friction angle of δ = 45^0 (Figure 4). The shear parameters obtained from two simple direct shear tests and one double direct shear test give an internal friction angle of 38^0 and an adhesion of 15 kN/m^2. Therefore, It could be assumed that the earth pressure resultant KP_L will act at an interface friction angle of 38^0. Hereinafter, the calculations of the K-values for the unsleeved, sleeved and lubricated piles will be derived from the pull out tests. The tension resistance at the pile toe will be taken into account in order to check its affect on the K-values. Table 1 summarizes the various K- values of various types of unsleeved, sleeved and lubricated piles. From the above results it can be concluded that the earth pressure coefficient decreased by increasing the smoothness degree of the pile shaft.

This approach does not take into account the adhesion (C_a) between the pile and the surrounding clay. By exerting a pullout load instead of a compressive load, the frictional resistance terms will be as shown in Figure 5.

For example, K_u for the unsleeved pile 17 is greater by 25% and 32% from that of the sleeved pile 18 (k_s) and the lubricated pile 19 (kl) respectively. The critical quoted decrease in the earth pressure coefficient is obtained by increasing the pile diameter. For example, the earth pressure coefficient for the lubricated pile 25 (D=0.70m) is smaller by 72% than the same unsleeved pile (pile 23). The decrease in the K_s and K_l -values by considering the tension resistance at the pile toe which reaches 89%, cannot be neglected because their great contribution in decreasing frictional uplift forces such as swelling forces which are the crux and the aim of this work. The same conclusion was obtained by Amir (1976), Sowa (1970) and Kulhawy (1985). The earth pressure coefficient K is not only a function of the original in-situ earth pressure coefficient at rest (K_0), the stress changes caused by construction, loading and time as mentioned by Kulhawy (1991) and it is not a function of smoothness / roughness of the pile shaft only as mentioned by Burland (1973) and by Norlund (1963), but it is also a function of the pile diameter. This finding must be connected to the fact that all piles are installed in swelling/shrinking clay.

4 CONCLUSION

From this study it was possible to conclude the following: Provision of sleeves minimizes the amount of reinforcement in the pile due to the strong reduction of the heave forces. The sleeve acts as a protection against the concrete entering cracks in the soil, which minimize the contact between the pile and the soil and hence minimize the heave/dragdown forces. Results have shown that the displacement necessary to mobilize the maximum shaft resistance of the uncoated piles ranges between 0.7% and 0.8% of the shaft diameter. By the coated and lubricated piles the displacement to mobilize the maximum side resistance decreased by 90%. It ranges between 0.07 and 0.08% of the shaft diameter. Results from the pull tests have shown that the displacement between the sleeves occurred at friction/side resistance of only 10KN/m^2. The frictional resistance of a bored concrete pile in medium to hard clays is about half the average undisturbed shear strength of the clay along the pile shaft. The butt displacement to mobilize the maximum tip resistance was found to be in the range of 2-3% of the shaft diameter. Criteria for establishing the ultimate pull out load has to be the load which causes a heave of 0.5-1.0% of the pile diameter.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to the supervisor of this doctoral research professor R. W. Sarsby from Wolverhampton University – U.K., for his support.

REFERENCES

Amir, J. July, (1976), "Finit Element Analysis of Piles in Expansive Media", Journal of the Soil Mechanics and Foundation Devision, ASCE, GT7.

Burland .J, (1973), "Shaft Friction of Piles in Clay" Ground Engineering, 6.

Komornik. A and David. D (1980). Stable Embedment Depth of Piles in Swelling Clays. Proc., 4th International Conference on Expansive