Comparison between the Behaviour of Coated and Uncoated Lightly Loaded Piles in Swelling Soils

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Abstract

In the last four decades significant effort has been devoted to designing piles in swelling soils. Nevertheless, only a scant effort has been devoted to the elimination of heave forces acting on the upper part of lightly loaded piles. For this purpose, an investigation site was established in Karmiel in Northern Israel. On this site sixteen 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 2.0 m and 7.0 m and were observed over a period of 27 months. Another nine unloaded cast-in-situ bored piles, both coated and uncoated, were installed at the end of summer 1998 for carrying out pullout tests. These piles were embedded two meters from the ground surface. 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. The scope of the work is, determining of the elimination degree of the heave forces due to the provision of the above sleeve.

Keywords: sleeves, swelling, figures, tables, references

1.0 Introduction

For many years, foundation engineers have tried to solve the problem of heave and downdrag forces on piles in shrinkable clay. It is well known that swelling forces on lightly loaded piles in clay subsoil demand anchoring of the piles deep in the ground because the vertical applied load issmaller than the heave force. In this research case the soil consists of 7.2 m clay overlying hard rock. If it is impossible to drill into the rock, the length and diameter of the pile may be too small to provide sufficient resistance to the applied vertical load from the building. In this case, the usual solution is to increase the pile diameter, but by this way the heave forces on the pile will increase because the increase of the contact area between the swelling soil and the pile shaft. On the other hand, if it is possible to drill into the rock, the pile might fail in tension. The ability of a pile to withstand vertical load is based, usually, on shaft friction which provides the majority of resistance to vertical applied loads. In order to maximize the pile load capability, it is desirable to have a high shaft friction and therefore beneficial to obtain as rough a surface as possible between the pile shaft and the clay. When either uplift or downdrag occurs via clay expansion or desiccation, respectively, it is again the shaft friction that transmits the heave or downdrag forces to the pile. Hence, to minimize heave and 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. Since tensile forces on piles are undesirable, it was proven in this research that by the provision of lubricated and unlubricated pile sleeve, these forces were significantly minimized.

2.0 Description of Test Site

Location and description of items in the test site are shown in Figure 1. The twenty five piles shown in Figure 1 were divided into two groups executed in two different periods. The first group shown in Table 1 includes piles No. 1 to 16 which where observed over a period of 27 months. The second group includes piles No. 17 to 25 which are shown in Table 2 and were pulled out together with piles No. 13,14,15 and 16 from the first group. Test site stratigraphy illustrated in Figure 2.

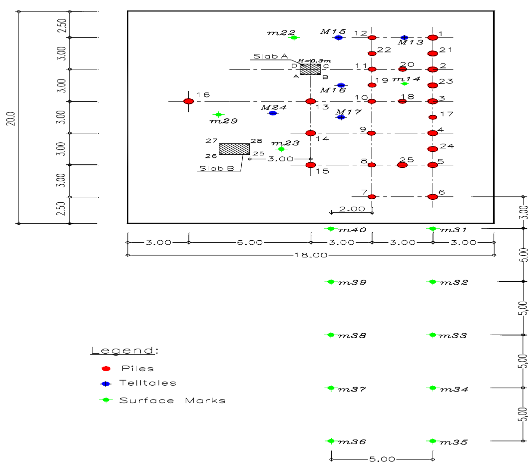

Fig. 1: Location and description of items in the test site

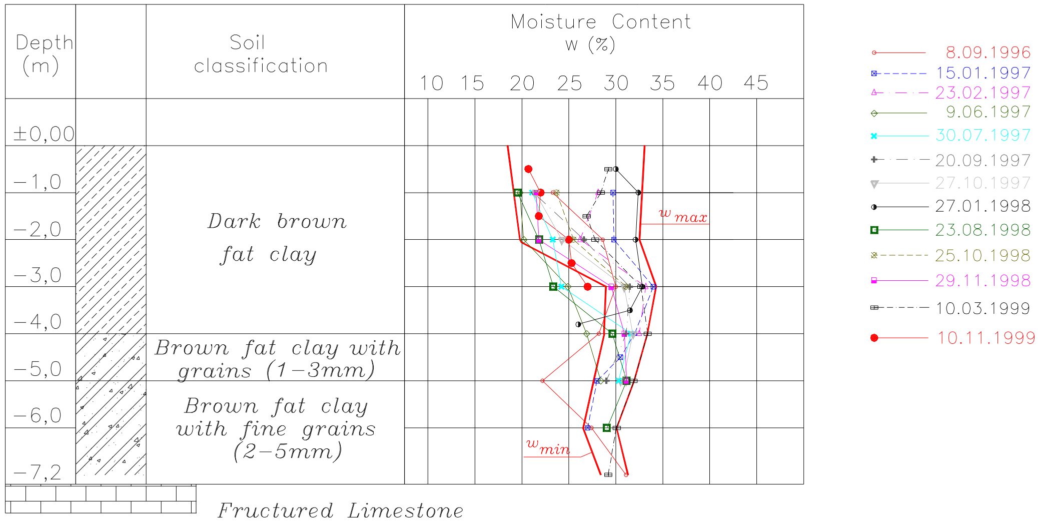

Fig. 2: Test site stratigraphy

Table 1: Specification of the Observed Piles

Pile No.	Diameter (cm)	Emb. Length (m)	Pile No.	Diameter	Emb. Length (m)
1	50	5.0**	9	50	6.5**
2	40	5.0**	10	50	7.0¯
3	40	6.0¯	11	50	7.0**
4	40	7.0¯	12	50	7.0***
5	40	6.5**	13	50	2.0¯
6	40	7.0***	14	50	2.0**
7	50	6.5**	15	50	4.0**
8	50	6.0¯	16	50	4.0¯

Legend: ***: Coated Pile, PS=3.0m **: Coated Pile, PS 2.0m : Uncoated Pile.

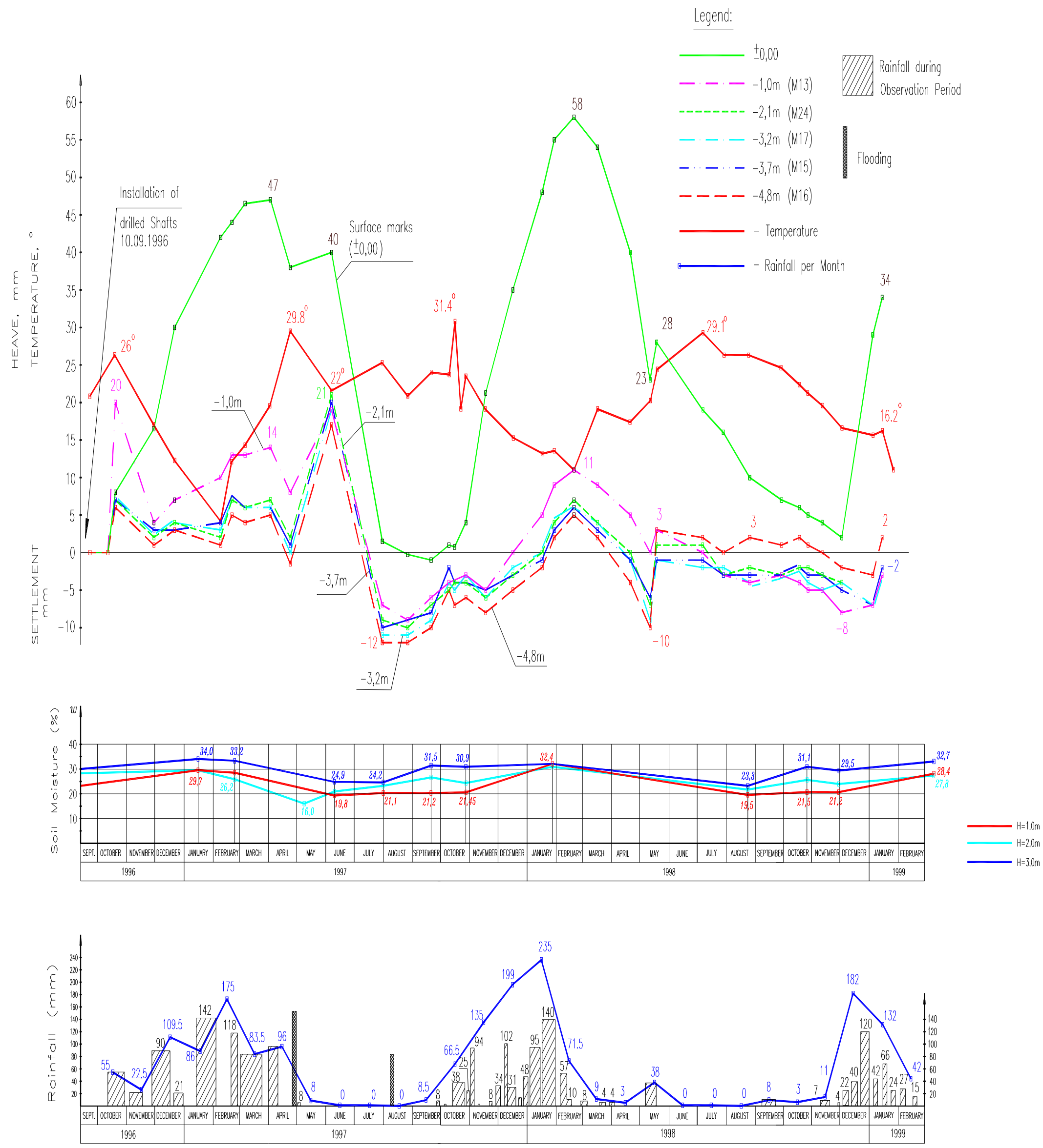

Fig. 3: **Vertical Movements in Clay Layers and Ground Surface**

Table 2: Specification of the Pulled Out Piles

Pile No.	Diameter (cm)	Emb. Length (m)
13	50	2.0$^-$
14	50	2.0**
15	50	4.0**
16	50	4.0$^-$
17	50	2.0$^-$
18	50	2.0**
19	50	2.0*
20	60	2.0$^-$
21	60	2.0**
22	60	2.0*
23	70	2.0$^-$
24	70	2.0**
25	70	2.0*

Legend: *: Coated and Lubricated Pile, PS = 2.0m **: Coated Pile, PS 2.0m

Figure 3: Vertical Movements in Clay Layers and Ground Surface

3.0 Field Measurements

3.1 *Vertical Movement of Ground Surface and Clay Subsoil*

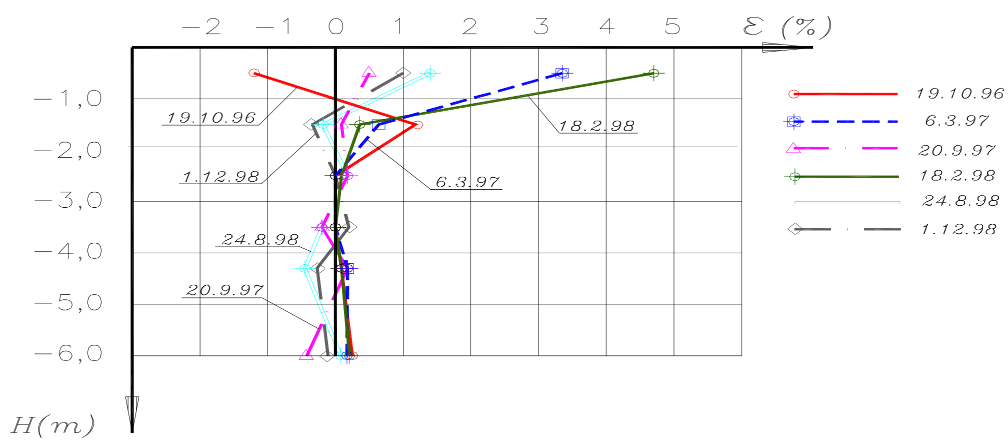

Figure 4: Seasonal Strain in the Clay Subsoil

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 (Figure 4).

3.2 Vertical Movements of Piles

The vertical movement of the piles as a function of rainfall is shown in Figure 5. The vertical movements of all observed piles showed a good accordance with the rainfall

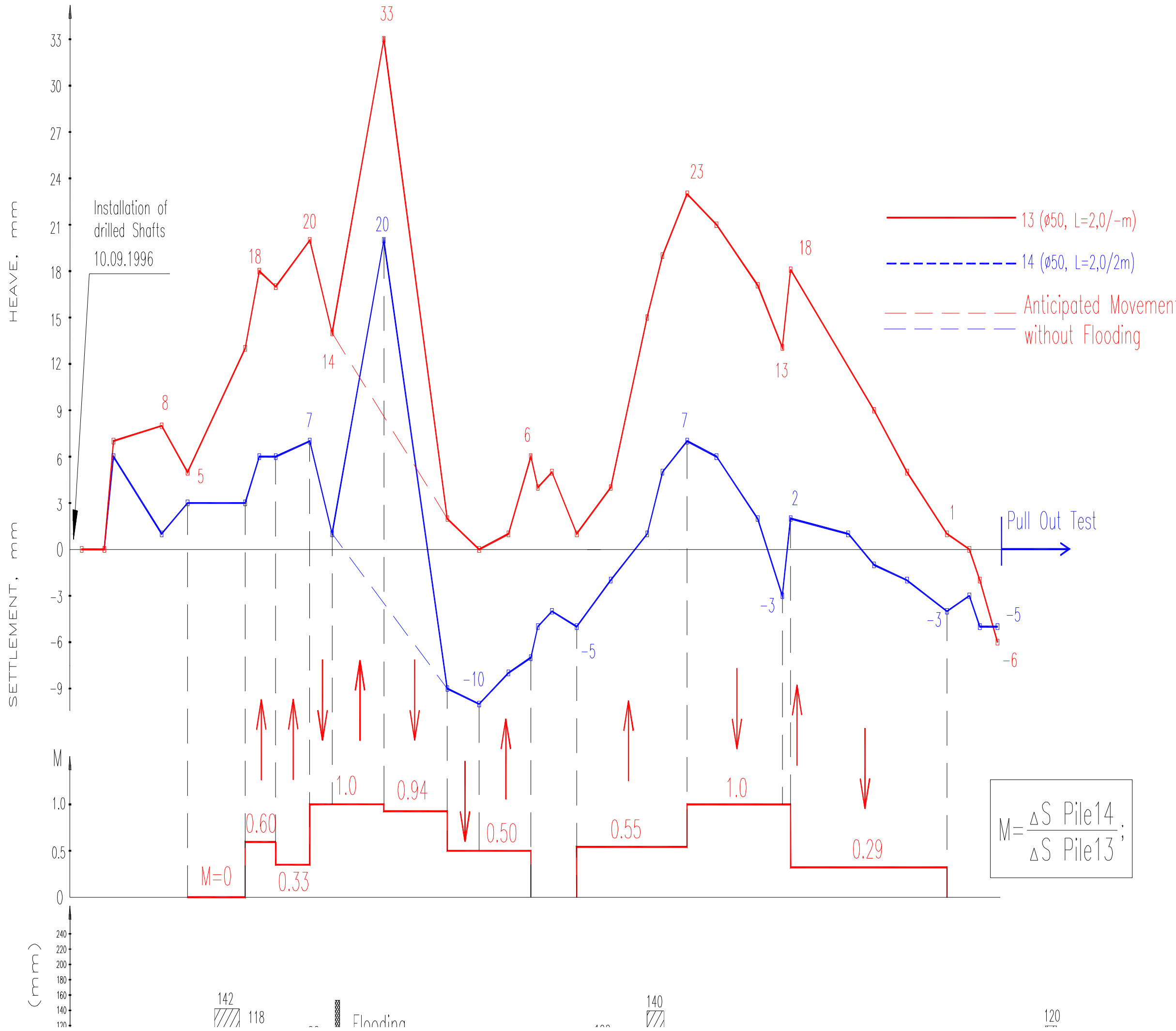

Fig. 5: The vertical movement of the piles as a function of rainfall

4.0 Determination of Earth Pressure Coefficient K_0

Norlund [8] 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 [2] 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 6, where P□□ is the ultimate compressive load, K□ is the earth pressure coefficient inclined by an angle (□),□ □ □□is the friction angle between the shaft and the soil, W_p is the weight of pile, □□ 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□ is the ultimate uplift resistance of pile (kN), p is the perimeter of pile and p.Δl is the shaft area in slice of Δl. For conventional piles where □<□^{0} and the pile shaft is rough (inclined resultant K□ P_l), Equation (1) will have the form:

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

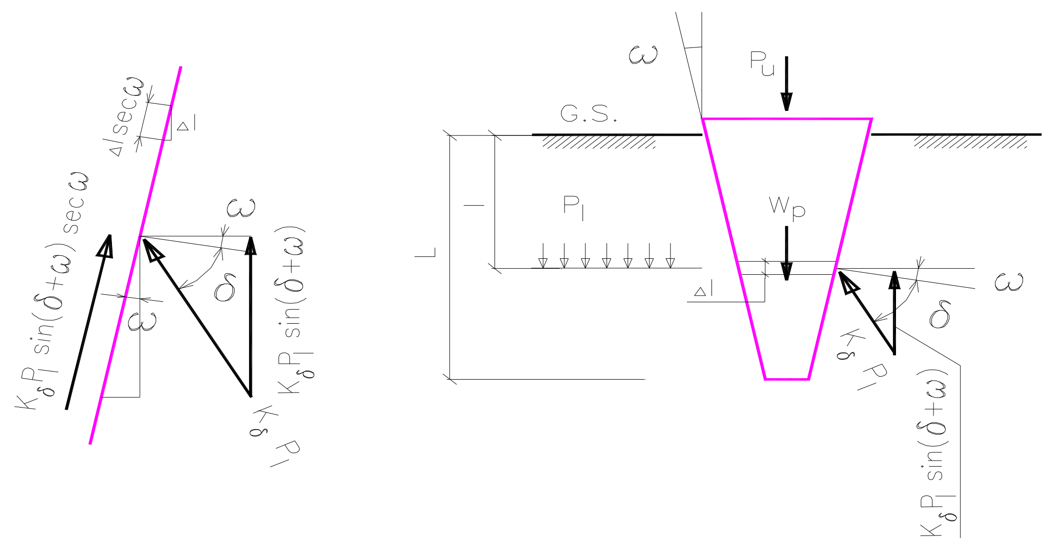

Fig. 6: Determination of Earth Pressure Coefficient K_0

frictional resistance terms will be as shown in Figure 7. Hereinafter, P□ will be defined as the ultimate pull out load which is equal to the ultimate uplift capacity (Q□) 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:

Vertical component: $$P_{uv} = K \cdot P_l \cdot \sin\delta \quad (3)$$

and

Horizontal component: $$P_{uh} = K \cdot P_l \cdot \cos\delta \quad (4)$$

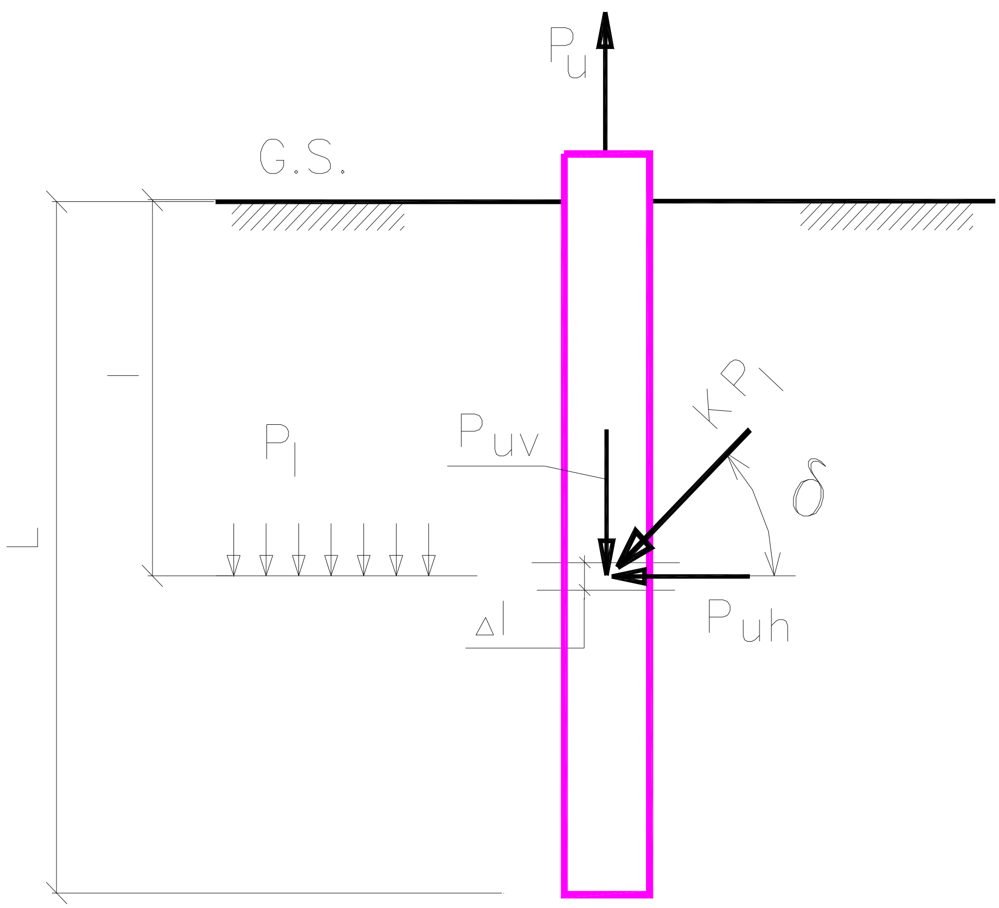

Fig. 7: Forces acting on a Rough Pile Shaft due to Uplift Load

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:

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

where □□$_f$ is the shearing resistance at failure between the soil and the pile shaft.
By substituting $\tau_f = \sigma_{□} \cdot \tan\delta + C_a$ and $\sigma_{□} = KP_l \cdot \cos\delta$, then Equation (5) will be:

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

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 (□ = 0) obtained in this work and the double direct shear test results (Ca=15 kN/m^2, □=45^0), the resultant ($K_{□} \cdot P_l$) will act theoretically on the concreted pile shaft at an interface friction angle of □ = 45^0 (Figure 6). 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 5 summarizes the various K- values of various types of unsleeved, sleeved and lubricated piles.

Table 5: Comparison between K- Values of Pulled Out Unsleeved, Sleeved and Lubricated Piles.

Pile o.	Dimensions		$K_{□}$	$K_{□t}$	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

From the above results it can be concluded that the earth pressure coefficient decreased by increasing the smoothness degree of the pile shaft. For example, $K_{□}$ 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. By taking the effect of the lubrication and the basal tension resistance into account the earth pressure coefficient will be greater by 32% and 55% 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). By considering the tension resistance at the pile toe the decrease in the earth pressure coefficient will be 88%. Furthermore, the tension resistance effect on the earth pressure coefficients for the unsleeved piles ($K_{□}$) can be neglected because it is a relatively small contribution (5% to 10%) in decreasing $K_{□}$□□. On the other hand, 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 [1], Sowa [9] and Kulhawy [6] [7]. 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 [6] [7] and it is not a function of smoothness/ roughness of the pile shaft only as mentioned by Burland [2] and by Norlund [8], 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.

9.0 Conclusions:

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 sleeves allow the use of 40cm and 50cm pile diameter despite the fact that the swelling forces could increase significantly. Without the provision of the sleeve, such piles might fail in tension. 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/drag down 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 was 10% only. 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.

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