Uplift – Pulling behaviour of pile

Comportement de pieux sous l'effet de la pression et de la traction

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SYNOPSIS **This Paper deals with an approach to the calculate the uplift of a single pile, subjected to uplift forces (tension pile). In the theoretical part, pile - Soil interaction was considered for the case in which the pulling force was increased gradually from zero to the ultimate friction then the derived equations were adjusted with results obtained experimentally from pile tests results. Consequently a method for analysis of uplifted pile is established .A satisfactory agreement was achieved between the predictions and observation of uplift instrumented piles .**

INTRODUCTION

A great deal of research was undertaken into the behaviour of pile under compression loads.But little information is available on behaviour of pile under tension force.This paper deals with the determination of uplift when the pile is subjected to increasing pulling force with assumption that failure doesn't occur in the soil mass surrounding the pile. When applied pulling force on pile head, increases,for small displacement adhesion between the pile shaft and soil remains intact and prevents any disconnection between pile shaft and soil. When pulling force reachs to the ultimate value, friction of pile shaft is mobilized, under this condition pile shaft will move relative to the soil surrounding soil and slipping occurs. This paper investigates the pile - soil behavior when slipping has not occurs.

RELEVANT SOIL DEFORMATION AND UPLIFT OF PILE

Considering soil-pile system,when pile subjected to a pulling force,due to adhesion,soil will be displaced upward with pile. Assuming shear modulus of soil to be independent of "r" according to Cooke(1978),the vertical component of shear stress τ'_r at a distance, r,from pile axis;

$$\tau'_r = \frac{D}{2r}\tau_s$$

The gradient of the deformation line according to Fig.1,will be:

$$\frac{ds}{dr} = \frac{\tau'_r}{G} = \frac{D}{2rG}\tau_s$$

Hence the uplift of pile "S" is,

$$S = \int_{r=\frac{D}{2}}^{r=R_o} ds = \tau_s \frac{D}{2G} \times \frac{dr}{r}$$

$$S = D\frac{\tau_s}{2G}\ln 2\frac{R_o}{D} = \frac{D(1+\mu)}{E}\tau_s \ln 2\frac{R_o}{D} \qquad (1)$$

Where ;

S : Uplift of Pile

τ_s: Transfer stress from an element of soil within a cylindrical pile shaft of diameter (D)

τ'_r : Shear stress at radius "r"

G : Shear Modulus of soil

R_o: The distance from the pile axis at which soil displacements are negligibly small

P : Pulling force on the pile head

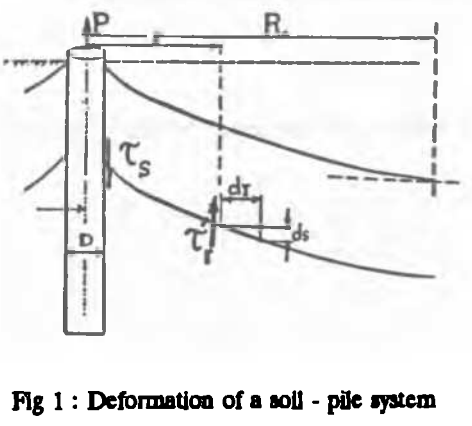

Fig 1 : Deformation of a soil - pile system

Generally R_o is determined experimentaly using sensetive instruments. Since R_o defines the radius of displaced zone around the pile therefore it is related to the intensity of shear stress "τ'_r". This also means that R_o depends on the pulling force "p" applied on the pile head.

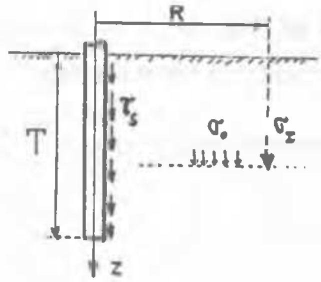

Fig. 2: Stress in the soil due to shaft resistance

The linear theory of elastic media was used in order to establish the relationship between R_o and "p". When the pulling force increases from zero to the ultimate friction, the ratio of normal stress occured at level z, to the overburden pressure σ_o at the same point were calculated by taking state of stress occured in cylindrical coordinate. Fig 3 shows the variation of this ratio with relative distance from pile axis.

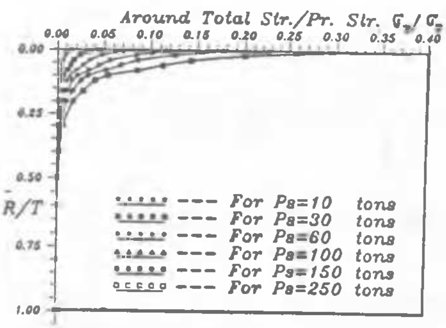

Fig. 3: Diagram of influence radius "R".

Figure 4 shows the correlation between "R_o" and "p" assuming "R_o" to be distance from the pile axis where the σ_z/σ_o becomes less than %5. Correlated curve follows a logarithmic trend,from which it can be deduced the following relationship, Amini Hosseini, K. [1]

$$\frac{R_o}{T} = b \ln p + a \tag{2}$$

Means values of the coefficients "a" and "b" are respectively 0.15 and 0.07 when level "z"varying from head to tip of pile It can be seen from Fig. 4 that "a" and "b" become unreal when R_o=0, this can be remeded by the shift of the R/T coordinate in Fig 4, and in this case Eq.2 takes the following form:

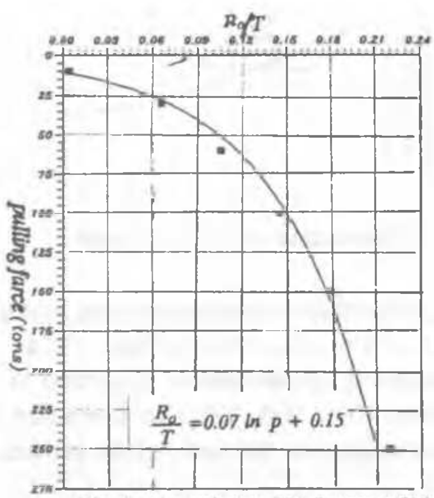

Fig 4 : Correlation "R_o" versus "p"

$$R_o = 0.07\ T \ln(p) \tag{3}$$

Now combining Eqs (1) and (3)

$$S = A\,\tau_s \ln\left[\frac{2T}{D} 0.07 \ln(p)\right] \tag{4}$$

Where :
D : pile diameter
T : pile length
A = D/2G

DEVELOPMENT OF STRESS ALONG THE PILE SHAFT

Transfer of stress from soil to the pile shaft, depends on pile-soil interaction, which varies when pulling force increase gradually. Measurement of stress in instrumented tension pile have shown that evolution of "τ_s" along the shaft has almost the two following distinct stages.

Stage (1) corresponds to the small values of "p" followed by stage (2) .

Indeed instrumented tension pile test results [2] showed that the uplift of pile tip starts almost when "p" is 20% of the ultimate resistance .This will be here accepted as a basis to define the extend of stage (1). However for long pile there would be some gap between the end of stage (1) and beginning of stage (2),as shown in fig-5c, or overlapping

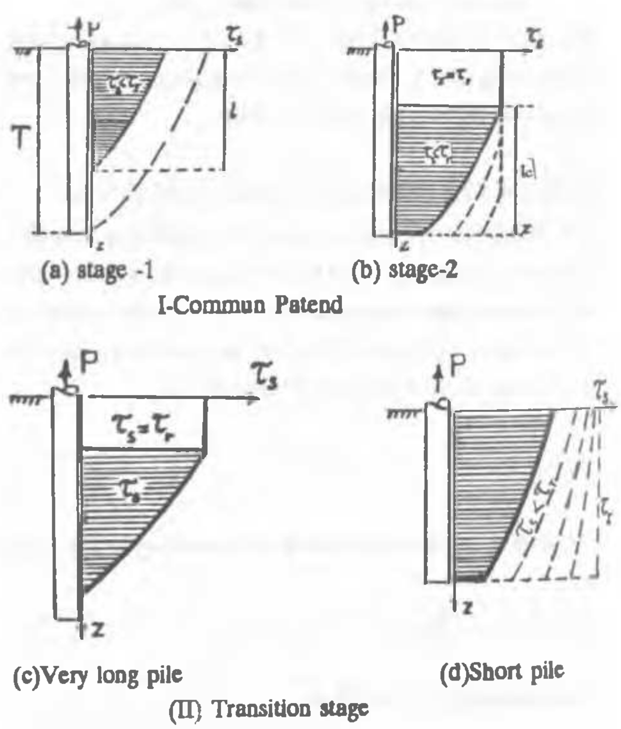

Fig.5 : Distribution of stress transfer along the pile shaft

when pile is short Fig 5-d. We call this transition stage which may also occure for nonhomgenous soil. However the transition stage has a short extend in comparison with stage 1 and stage 2, Figs 5-a,5-b.

In stage (1) , "l" expands with increasing "p" exponentially,

$$l = a_1\, p^{1/\beta}$$

When

$$\begin{cases} P = (20\%)Pr \\ l = T \end{cases}$$

Hence

$$a_1 = \frac{T}{(0.2\, p_r)^{1/\beta}}$$

$$l_\beta = T\left(\frac{p}{0.2\, p_r}\right)^{1/\beta} \tag{5}$$

$$p_r = \pi\, DT\, \tau_r$$

Where ;

p_r :Ultimate pulling force which mobilize friction along the pile shaft.

τ_r : Friction stress along pile shaft

D : pile diameter

T : Pile length

Hence equation (4) becomes:

$$S_1 = \frac{D \times P}{2G\pi Dl} \ln \frac{2l}{D}\,(0.07 \ln P)$$

Or

$$S_1 = \frac{0.136}{G}\sqrt[3]{D\tau_r\left(\frac{P}{T}\right)^2} \ln\left[0.163 \ln(p)\sqrt[3]{\frac{T^2}{D^4\tau_r}}\,P\right] \tag{6}$$

In stage (2), assuming that pulling force "p" doesn't produce any elongation within the pile, the uplift of pile head is controlled by movement of lower part of pile, because the interaction between pile shaft and soil is still due to adhesion. Indeed the upper part of pile where resistance has reached its ultimate, the adhesion has already been released and the increment of "p" is balanced by the adhesion of lower part of pile along "l_C" .

In this stage the expression for "l_C",with regard to Fig-5b is.

$$l_C = a_2 \ln \frac{Pr}{p} \tag{7}$$

Beginning of stage (2) corresponds to

$$\begin{cases} l_C = T \\ P = 0.2\, P_r \end{cases}$$

$$T = a_2 \ln \frac{Pr}{0.2Pr}$$

$$a_2 = 0.62T$$

$$l_c = 0.62T \ln \frac{Pr}{P} \tag{8}$$

When friction along the shaft is fully mobilized l_c and "p" values will be,

$$\begin{cases} l_C = 0 \\ P = Pr \end{cases}$$

Equation (8)responds well to the boundry conditions of stage -2 , combining equatins (8) and (4) it follows that:

$$\begin{cases} S_2 = P\dfrac{\ln\left[\dfrac{0.078}{D}\, T \ln\left(\dfrac{Pr}{p}\right) \ln(p)\right]}{3.9GT \ln\left(\dfrac{Pr}{P}\right)} \\ P_r = \pi\, D\, T\, \tau_r \end{cases} \tag{9}$$

Definition of symbole are as given for equations (5) and (6).

Considering a 12m. reinforced cylindrical concret bored pile placed in a homogenous clay soil with the following characteristics.

E = 1000 t/m2

μ = 0.3

Cu = 14 t/m2 or τ_r = 10 t/m2

T = 12m

D = 0.5m

With above data , Eqs (6) and (9) become ;

$$S_1 = 1.15 \times 10^{-4} (p^2)^{1/\beta} \ln\{p^{1/\beta} \ln(p)\} \tag{6 bis}$$

$$S_2 = \frac{\ln\{2.09 \ln(188.4/p) \ln(p)\}}{17971.2 \ln(188.4/p)} \tag{9 bis}$$

The above uplift are plotted on figure 6.In this case the ultimate resistance of pulling is P_r =188.4 ton. As shown in Fig.6 the uplift in stage "1",with linear trent,corresponds to the pulling force between zero and 20% of "p_r". The intersection point "a" indicates the change from stage 1 to the stage 2.

It should be noted that equation (9) is not well defined when "p" is close to the ultimate resistance"P_r".This is due to intervention of friction mobilization along the most part

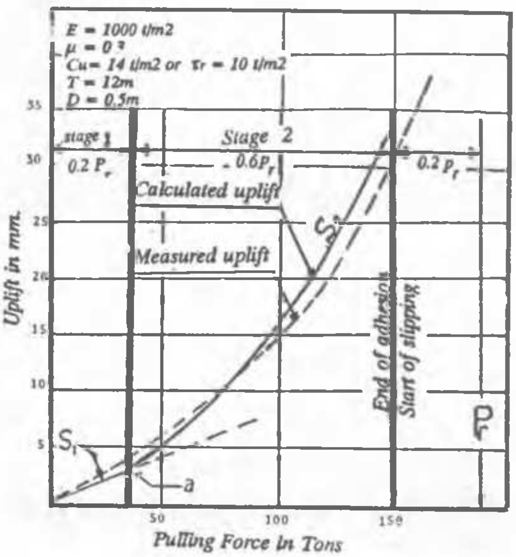

Fig.6 :Developement of uplift with pulling force in a homogenous clayey soil .

of pile shaft ,which doesn't fit with the basic assumptions for establishing of Eq.9 . For this reason equation (9) is valid when pulling farce is almost less than 80% of the ultimate resistance .

COMPARISON OF PREDICTED UPLIFT WITH PILE TEST

Average uplifts were measured for two reaction piles erected for a pile loading test and the results are plotted in fig. 6.The soil characteristic and pile geometric are those given above and theoretical uplift calculated from equation 6 and 9 are also plotted in Fig 6. Comparison of predicted and measured uplifts shown that both curves have the same shape which is the main purpose of the present research.

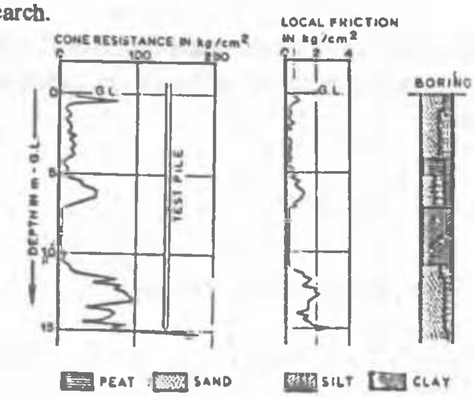

Fig.7:Soil profile and cone penetraton test near model test piles

predicted uplifts by using Eqs (6) and (9) depends mostly on the correct value of "G" modulus and means value of ultimate friction τr.

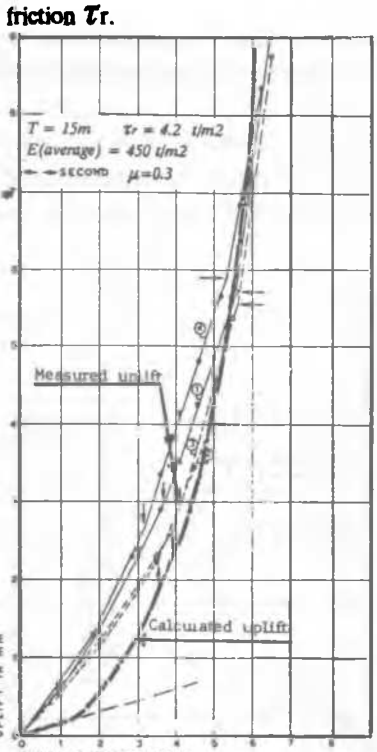

Fig.8 :Comparsion of measured and predicted uplift in layered soil.

As a second exemple it will be used the measured results obtained by Begmann (1969) on four model tension piles. Figure 7 shows the results of a penetration test with the adhesion Jacket cone, with the corresponding soil profile near four model steel piles. The means soil charcteristic with pile size are ;

$T = 15m \qquad \tau r = 4.2\ t/m2$
E(average) = 450 t/m2
$\mu = 0.3 \qquad D = 3.6\ cm$

Calculated uplift using equations (6) and (9) are plotted on Fit.8. Difference that appears between calculated one and measured one, for small pulling force, is due to the present of very soft layer in upper part of pile (See Fig. 7), which comes into action in the first stage. It is worth pointing out that for calculation of the uplift an average soil characteristic is taken into account.

CONCLUSIONS

The uplift behaviour of a single pile subjected to an axial tesion force, depends on the intensity of pulling force. Up to approximately 20% of the ultimate resistance of pile, the uplift is predictable by equation (6). For higher tension force the uplift would be estimated by equation (9). However the validity of equation (9) is limited to almost 80% of the ultimate shaft resistance, beyound this, gradually, slipping of soil along the pile shaft begins and friction replaces the adhesion.

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[4] Geddes (1966) Stresses in Foundation Soils Due to Vertical Subsurface Loading. Geotechnique XVI PP.231