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The Influence of Negative Skin Friction on Piles and Pile Groups & Settlement of existing Structures

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ABSTRACT: Negative skin friction occurs when concrete piles are situated in soft soils, consolidating soil-mass, etc., resulting in a downward force that increases loading on shaft piles and reduces the bearing capacity of the piles. A new concept based on the shifting rate of piles, and the settlement rate of the surrounding soils has been suggested far the study of negative skin friction. Negative skin friction occurs when the settlement rate of the surrounding soils is greater than that of the piles. Some relative equations have been established to define the negative friction zone of piles. Negative skin friction is dependent on the time factor and the degree of consolidation of the soil mass and can be negligible when the soil mass is nearly completely consolidated. The calculation of negative skin friction of some specific concrete piled foundations is also presented to be compared with other methods. The use of a concrete slab combined with beams and piles was employed to treat negative skin friction on concrete piles in soft subsoil.

Keywords: Negative skin friction, concrete pile, bearing capacity, consolidation, settlement rate, soft soils.

I. INTRODUCTION

A relative movement between a pile and a soil produces shear stress along the interface of the pile and the soil. Such movement can be induced by a push-load on the pile pressing it down into the soil, or by a pull-load moving it upward. A relative movement can also be induced when the soil settles in relation to the pile, or, in swelling soils, when the soil moves upward in relation to the pile. By definition, if the movement of the pile is downward, i.e. the shear stress induced in the pile is upward, the direction of the shear is positive. If the movement of the pile is upward, the shear stress direction is negative; accordingly, the induced shear stress is called positive or negative.

In older terminology, the induced shear along a pile was called 'skin friction'. In modern terminology, the term 'shaft resistance' is used and a distinction is made between on the one hand, positive and negative shaft resistance by which is meant shear induced by load on the pile in the form of push-load and pull-load, respectively, and, on the other hand, negative and positive skin friction, which is shear stress induced by setting of swelling soil, respectively.

When the consequence of the negative skin friction for design are included, these are discussed in terms of reduction of pile bearing capacity of allowable load. In contrast, this paper suggests that the problem of negative skin friction is one of settlement and not of bearing capacity, i.e., the magnitude of the drag load is of no direct relevance to the geotechnical capacity of the pile, nor to the allowable load of the pile. Consequently, as recommended below, in the design for a down drag condition, the calculation of the distribution of settlement is emphasized.

Objective: Study of Negative Skin Friction on Piles of a Existing Structure and suggesting measure to modification of pile Size and applying viscous coating to pile surface to neutralization of negative skin friction.

Geological Conditions and Material of pile & soil around pile. The soil deposit of the Yamato project belongs among the very soft soils in the region. The groundwater table is only from 0.6m to 1.00m below the ground. The soil properties are described as follows

Layer I: Embankment containing sandy soils. thickness from 1.5 to 2 m.

Layer 2: Organic muddy clay, high plasticity, average thickness h = 9 m, moisture content w = 85.92%, bulk density γ = 14.5 kN/m^3, submerged density γ_{sub} = 4.8 kN/m^3, specific gravity G_s = 26 kN/m^3, degree of saturation S = 95.72%, void ratio e = 2.334, plasticity index I_p= 34.08, coefficient of permeability k = 1.10^{-9} m/s. unconfined compression Q_u = 16 kPa, cohesion c = 8 kPa, internal friction angle φ = 4^o.

Layer 3: Sandy clay, medium plasticity, average thickness h = 8.5 m, w = 28, 08%, γ =19kN/m^3. γ_{sub} = 9.3 kN/m^3, G_s = 26.7 kN/m^3, S = 93.38%, e = 0.81, I_p = 11.71, k = 1.10^{-7}m/s. $Q_{u=}$ 75 kPa, c = 29 kPa, φ =13^0

Layer 4: Fine sand, medium density, average thickness h = I5m, w =22.12%, γ = 19.2kN/m^3, γ_{sub} = 9,82 kN/m^3, G_s=26.6 kN/m^3, S = 84.958%, e = 0.693, k = 1.10^{-4}m/s, c = 3 kPa, φ = 28^o.

Layer 5: Clay, medium to low plasticity, w = 22.95%, γ = 19.6 kN/m^3, γ_{sub} = 10 kN/m^3, Gs = 26.88 kN/m^3, S = 89.9%, e = 0.686, I_p = 26.47, k = 1.10^{-8} m/s, Qu = 182 kPa, c = 37 kPa, φ= 16^o

The load of the embankment's filling soil, which mainly causes the settlement of the subsoil, is q = 20 kN/m^2. The piled foundation design is: total normal load on the foundation cap P =750 kN, moment M = 200 kNm, foundation design of 4 reinforced concrete piles with a pile size of 0.25 × 0.25 × 24 m, the depth of the foundation cap D = 1.5 m. The point-pile is situated in the fine sand layer (layer 4), so this is the type of point-bearing pile.

Concrete in pile for bridge is M_{40} & Steel is M $_{415}$. Concrete in pile for building is M_{20} & Steel is M $_{415}$.

II. METHODS

Methodology: Design of piles considering Negative Skin Friction to avoid settlement of existing Structure by IS: Code-2911 Part-I(1979).

Neutral point: The point where the shear stress along the pile changes over from negative Skin Friction into positive shaft resistance is called the neutral point.

Neutral plane: The depth where the shear stress along the pile changes over from negative Skin Friction into positive shaft resistance is called the neutral plane.

Dragdrag: The downward movement on a deep foundation unit due to negative Skin Friction and expressed in term of settlement

Dragload: The load transferred to a deep foundation unit from negative Skin Friction

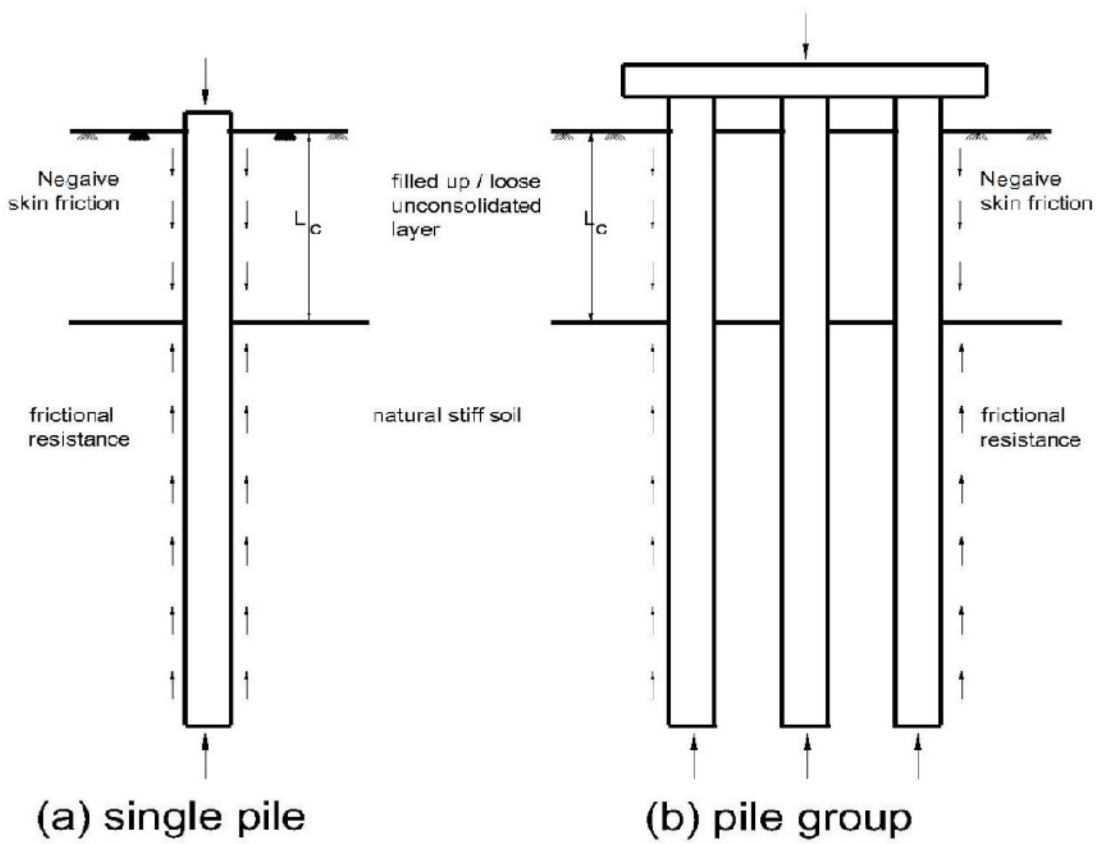

Fig.1. Negative skin friction.

Negative Skin Friction. Piles installed in freshly placed fills of soft compressible deposits are subjected to a downward drag, a consequence of the consolidation of the strata after the piles are installed. This downward drag on the pile surface, when the soil moves down relative to the pile, adds to the structural loads and is called negative skin friction.

This is in contrast to the usual shaft friction which is mobilised when the pile move down relative to the soil. Thus, negative skin friction has an effect of reducing the allowable load on the pile. Negative skin friction may also develop if the fill material is a loose sand deposit. It can also occur due to the lowering of the ground water table which increases the effective stress, thus causing consolidation of the soil with the resultant down-drag on piles.

A small relative movement between the soil and the pile, of the order of about 10 mm, may be sufficient for the full negative skin friction to materialise.

In bearing piles where the settlement of the pile is negligible, negative skin friction becomes a pile capacity problem. However, for piles in compressible soils where pile capacity is contributed by both point resistance and shaft adhesion, the problem of negative skin friction should be considered a settlement problem.

Negative skin friction in single piles. The magnitude of negative skin friction, F_n for a single pile in a filled up soil deposit may be estimated as below,

Cohesive Soils

$F_n = P\, L_c\, c_a$ … (1)

Where P = perimeter of pile

L_c = length of the pile in the Compressible Stratum (Fig 1(a))

c_a= Unit adhesion = αc_u

α = adhesion factor

c_u = Undrain Cohesion of the compressible layer

Cohesion less Soils

$F_n = 0.5\, P\, L_c^2 \gamma k \tan\delta$ …(2)

Where K = lateral earth pressure coefficient and

Δ = angle of friction between pile and soil, which may vary from 1/2Φ to 2/3 Φ.

Negative skin friction in pile groups. When a pile group passes through a soft, unconsolidated stratum (Fig. 1(b)), the magnitude of negative skin friction on the group, F_{ng} may be estimated from Equs. 3, 4. The higher of values obtained from these equations should be used in design

$F_{ng} = nF_n$ …(3)

$F_{ng} = c_u L_c P_g + \gamma L_c A_g$ …(4)

Where n= number of piles in the group

P_g = perimeter of the group

γ = unit weight of the soil within the pile group upto a depth L_c

A_g = area of pile group with in the perimeter P_g

Eq. 4 is worked out on the basis of block shear failure along the perimeter of the pile group which includes the volume of the soil $L_c A_g$ enclosed in the group.

The effect of negative skin friction on the factor of safety with respect to the ultimate load capacity of a pile or a pile group can be considered by defining the factor of safety thus

(working load + negative skin friction load)(Factor of safety)= ultimate load capacity of a pile or a group of pile

When a fill or load is place on compressible soil deposit, consolidation of the compressible material take place. When the piles are driven through compressible soils before consolidation is complete or the site has newly placed fill or will be placed in future, the compressible soil will downward relative to the pile. The downward movement of soil develops skin friction between the pile and surrounding soil and it is termed as negative skin friction. Negative skin friction can be developed from lowering on water level in compressible soils such as clay, peat, mud and soft soil and also due to increase in stress by some means (e.g. filling)

III. RESULTS

The authors' computer program is used to solve the problem of negative skin friction.

The first calculation is carried out to determine the bearing capacity and settlement of the piled foundation, excluding the effect of the negative skin friction (NSF) on the piles. The final summary results are given in Table 1. The second computation includes the negative skin friction on the piles. The depth of the negative skin friction ($z = l_{nf}$) is iteratively computed parallel to the time (t) until a maximum value l_{nf} has been found. The time of the ending of the negative skin friction can also be defined. The final results of settlement and settlement rates of soil layers as well as piles are briefly summarized in Table 2.

The affected length of the negative friction changes according to the time factor .Both the pile length affected by the negative skin friction and the time of the consolidation process can be determined. The maximum length of negative friction (also the maximum negative friction force P_{nf}^{max}) is approximate l_{nf} = H (H is the thickness of the soft soil layer). The calculation result of the maximum negative skin friction by the authors. Method and others are shown in Table 3. Q_a allowable bearing capacity of a pile Q maximum load acting on a pile R bearing pressure of soils under the plane of a point – pile.

Table 1: Result of the piled foundation calculations without NSF.

Q_a	Q	R	σ_{zm}	S
529.9 Kn	308 kN	977 kN/m^2	378 kN/m^2	5.1 cm

Table 2: Result of the settlements and without as *i* settlement rates of soils and piles.

Item	**Time (Year)**					
	0.2	0.5	1	2	5	α
Settlement of Soils (cm)	11.52	18.2	19.83	22.68	24.36	25.2
Settle rate of soils(cm/year)	-	1.92	1.78	0.46	0	0
Settlement of piles (cm)	4.88	4.98	5.04	5.1	5.1	5.1
Settlement of pile (cm/Year)	-	0.006	0	0	0	0

Table 3: Comparison sheet of the NSF calculation by different methods.

Methods	l_{nf}(m)	$P_{nf}^{max(kN)}$	Time of ending negative friction
Authors	L	91	2 Year
Bowles J.E	0.07L	75.7	Not mentioned
Frank R	-	74.9	Not mentioned
VNDSCE	0.71L	76	Not mentioned
CDSCR	0.8L	85.7	Not mentioned

Table 4: Result of the piled foundation calculations without NSF.

Q_a	Q	R	σ_{zm}	S
483.6 KN	399 kN	977 kN/m^2	487 kN/m^2	6.4 cm

σ_{zm} mean normal stress at the plane of a point pile S. Total settlement of pile foundation. l_{nf} the affected length of the negative friction P_{nf}^{max}. The maximum negative friction force(downward force) on pile, VNDSCE. Vietnamese Design Standard of Civil Engineering, CDCCE, Chinese Design Code of Civil Engineering.

The time of ending the negative skin fiction of piles is estimated at about 2 years and the degree of consolidation of the soft soils reaches 90% . These are very important value if the structure is constructed for more than 2 years. The negative friction might disappear after the end of the construction and we do not have to include the negative friction calculation in the design. The most significant approach of the study is that the time of ending the negative skin friction on the piles can be found. This is an advantage that other methods have not handled. Other methods do not mention either the time or the consolidation of the soft soil layers. However the authors' result seem to be higher than of other methods. The bearing capacity of piles decreases and the settlement of the equilibrium of a foundation increases when negative skin friction is taken into account. The results of the piles foundation calculation at the time of the maximum negative skin friction are shown in Table 4.

IV. DISCUSSION

A. Fundamentals

The design principle outlined in the following is essentially the same for all piles, whether single or in a group, whether installed in a soil that settles significantly under the influence of a surcharge, groundwater lowering, or other cause, or installed in a soil that does not experience appreciable settlement, and whether they are essentially toe bearing, shaft bearing, or both toe and shaft bearing.

To understand the design principle, it is important to realize that the live load and the drag load do not combine and that two separate loading cases must be considered dead load plus drag load, but no live load and dead load and live load, but no drag load. Furthermore, a rigid, high capacity pile will experience a large drag load, but small settlement, whereas a less rigid smaller capacity pile will experience a smaller drag load, but larger settlement. Moreover, the drag load is caused by settlement, or, rather, relative displacement, but the drag load does not generate settlement, and no pile will settle more than the ground surface nearest the pile, indeed no more than the soil settlement at the location of the neutral plane.

The design has to consider three aspects separately: The structural strength of the pile, the settlement, and the geotechnical capacity (the bearing capacity).

B. Neutral Plane

As a first step in the design, the neutral plane must be determined. The neutral plane is located where the negative skin friction changes over to positive shaft resistance (the point of equilibrium). Its location is determined by the requirement that the sum of the applied dead load plus the drag load is in equilibrium with the sum of the positive shaft resistance and the toe resistance of the pile. It can be found at the intersection of two load distribution curves construed as follows. First, as illustrated in Fig. 2, a load distribution curve (forcing load curve) is drawn from the pile head and down with the load value starting with the applied dead load and increasing with the load due to negative skin friction taken as acting along the entire length of pile. Second, a load distribution curve (resistance curve) is drawn from the pile toe up starting with the value of the ultimate toe resistance and increasing with the positive shaft resistance.

C. Structural Strength

The structural capacity is the structural strength of the pile material at the neutral plane for the combination of dead load plus drag load - live load is not be included. (At or below the pile cap, the structural strength of the embedded pile is determined as a short column subjected to dead load plus live load, but drag load is not included).

At the neutral plane, the pile is confined and it is suggested that the limiting value of maximum combined load be determined by applying a safety factor of 1.5 on the pile material strength (steel yield and/or concrete 28-day strength and long term crushing strength of wood).

It should be realized that if both the negative skin friction and the positive shaft resistance as well as the toe resistance values are determined assuming soil strength values "erring" on the strong side, the calculated maximum load in the pile will be on the conservative side (and the neutral plane located deep down in to the soil).

As illustrated in Figure, above, a reduction of the dead load on the pile will result in a lowering of the location of the neutral plane, but have proportionally smaller effect on the magnitude of the maximum load in the pile.

D. Special Considerations

All piles will be subjected to negative skin friction and experience drag load. However, unless the structural strength of the pile is exceeded, piles where the soil settlement is small will not constitute a problem. Where the settlement is large, the maximum drag load induced in a straight and vertical pile is not going to be significantly different to the drag load where the settlement are small. However, large settlement will cause an inclined pile to bend. For this reason, it is advisable to avoid inclined piles in the foundation, or, at least, to limit the inclination of the piles to values which can follow the settlement without excessive bending being induced in the piles. Piles which are bent, doglegged or damaged during the installation will have a reduced ability to support the service load in a down drag condition. Therefore, the design according to the above approach postulates that the pile installation is subjected to stringent quality control directed toward ensuring that the installation is sound and that bending, cracking, and local buckling does not occur.

E. Means for Reducing Negative Skin Friction

When the design calculations indicate that the pile settlement could be excessive, solutions such as increasing the pile length or decreasing the pile diameter, could improve the situation. When the calculations indicate that the pile structural capacity is insufficient, solutions such as increasing the pile section, or increasing the strength of the pile material could improve the situation. When such methods are not practical or economical, the negative skin friction can be reduced by the application of bituminous coating or other viscous coatings to the pile surfaces before the installation. For cast-in-place piles, floating sleeves have been used successfully.

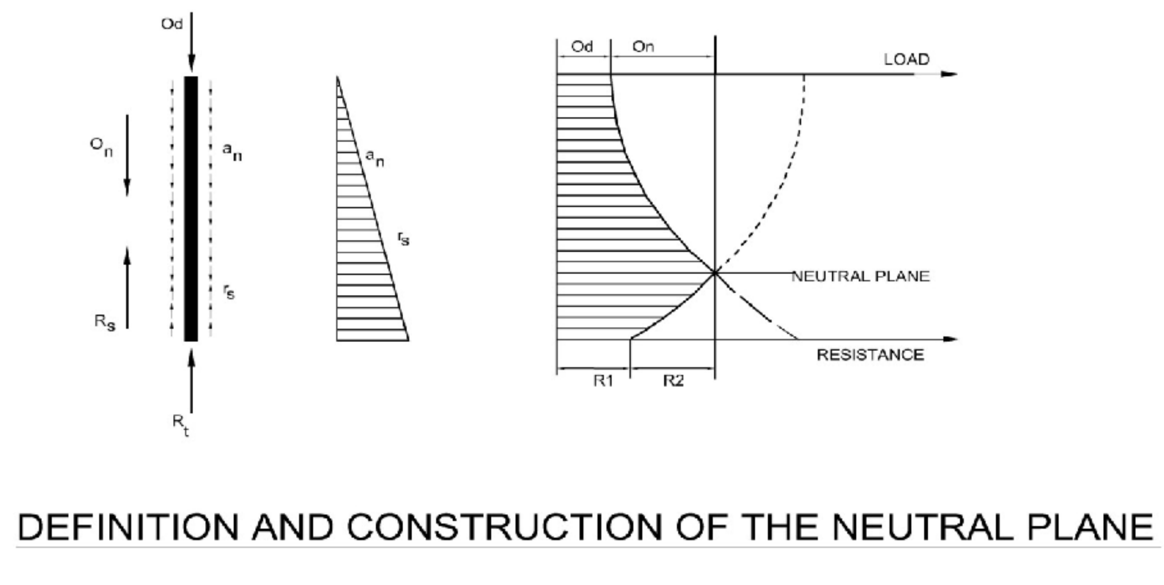

Fig. 2.

V. CONCLUSION

One of the common reasons for uneven settlement of existing structures, founded on pile foundations, is the negative skin friction (NF) developed along the piles.

1) Negative friction occurrence is controlled by the relative displacement between the pile and the ground. The neutral point, where skin friction changes from negative to positive, in a single-layer ground has the tendency to move upwards in proportion to the pile settlement.

2) Applied loadings at the pile head results in the upward movement of the neutral point. The pile axial stress is estimated to be the combined effect of applied load at the pile and NF. Negative skin friction is a downward shear drag acting on the pile surface due to relative downward movement of soil strata surrounding the pile the following are some of the causes of negative skin friction. Due to pile or pile segment passing through compressible soil stratum which consolidates. Due to placement of a fill on compressible soil layer causing the layer to consolidate. Lowering of ground water table causing the shrinkage of expansive soils. Under consolidated natural or compacted solids. If the pile tip is on a stiff or hard stratum, there will be a relative downward movement of upper compressible layer of soil w.r.t. pile, due to above causes, causing a downward drag force. Initial position of compressible deposit final position of compressible deposit Downward drag (negative skin friction) Vesic stated that downward movement as little as 0.6 inch may be sufficient to mobilize full negative skin friction. The down drag will not affect the geotechnical capacity of end-bearing piles but will increase stresses on the pile and pile cap. The negative skin friction of a single pile is given by Negative skin friction load = Unit frictional resistance (downward)* Length of the pile above bottom of the compressible layer* Perimeter of the pile cross section and total downward load = negative skin friction load + live load + dead load.

FUTURE WORK

At the time of design of pile shear drag (load) due negative skin friction should taken as design load in addition of other load for design. Design of piles considering Negative Skin Friction to avoid settlement of existing Structure by IS: Code 2911 Part-I(1979) By considering Negative Skin Friction, We can design of existing Structure to avoid settlement of existing Structure by IS: Code2911 Part-I By considering Negative Skin Friction, We can design concrete pile of different Structure like building bridges in Railway which situated in softy soil in future.

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