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NEGATIVE SKIN FRICTION ON CONCRETE PILES IN SOFT SUBSOIL ON THE BASIS OF THE SHIFTING RATE OF PILES AND THE SETTLEMENT RATE OF SURROUNDING SOILS

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 for 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, using the authors' computer program, 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.

KEY WORDS

- negative skin friction,
- concrete pile,
- bearing capacity,
- consolidation,
- settlement rate,
- soft soils.

1. INTRODUCTION

In Southern Vietnam, concrete piled foundations are commonly used in soft soil deposits of soft clay, muddy clay, organic clay, etc., with a fairly deep thickness [8]. A number of industrial zones in the region have been built using concrete piles in the soft subsoils that are required for embankments from 1m to 2m of the filling soil because of the low ground level and high groundwater table. Most of the soft soils are early alluvial and sedimentation of very weak clay in the process of becoming saturated and consolidated and have very high deformations. The load of the embankment or external surcharge and soft soils are mainly among those factors which create a negative skin friction on the concrete piles [7].

Negative skin friction has been studied and considered as a well-known problem in the world. Some results of the affected zones of negative friction have been obtained, based on the assumption that the affected length of the negative friction is defined by the equilibrium of the forces acting on the pile (applied load on the pile, positive skin resistance, and negative skin friction) and point-pile bearing resistance. Therefore, the affected length of the negative friction is given approximately from 0.7L to 0.8L (L is the length of a pile situated in soft soil) by some researchers [1], [3], [6]. In the

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Vietnamese Design Standard of Civil Engineering, the affected length of the negative friction on a concrete pile is determined to be 0.71 L [5], while it is 0.8 L according to the Chinese Design Code of Civil Engineering. These conclusions are not satisfactory because they do not mention either the time factor nor the consolidation of the soil mass, and negative friction force would disappear after a certain period of time or after the completion of the construction in some cases.

The new concept suggested in this study is that negative skin friction occurs when the settlement rate of the surrounding soils is greater than that of the piles. This new idea is more suitable because it takes account of the time and consolidation process of the soft soil layers that are the main factors impacting on negative skin friction. The study of negative skin friction on concrete piles in soft soils is therefore really necessary to solve the problems in the region. The authors hope to contribute some of the approach's results to the Vietnamese Design Standard of Civil Engineering.

2. THEORETICAL APPROACH

2.1. SETTLEMENT RATE OF A SOIL MASS

Consolidation type 0: In cases where the soft soil layer (thickness H) is subjected to an infinite uniform load (q) and lying on an impervious layer.

The formula of pore pressure at the depth (z) and time (t) is defined as [2]:

$$u(z,t) = \frac{4}{\pi} q \sum_{i=1,3,5}^{n=\infty} \frac{1}{i} e^{-i^2 N_1} \sin\left(\frac{i\pi z}{2H}\right)$$
$$= \frac{4}{\pi} q \sin\left(\frac{\pi z}{2H}\right)\left[e^{-N_1} - \frac{1}{3} e^{-9N_1} + \frac{1}{5} e^{-25N_1} \dots\right] \qquad (1)$$

where $N_1 = \frac{\pi^2 c_{v1} t}{H^2}$ is the time factor; c_{v1} is the coefficient of consolidation of the soft soils; H is the thickness of the soft soil layer; q is the load of the embankment or external charge on the soft soils.

The settlement of the soft soil layer at the time t is then determined:

$$S_s(t) = a_{01} \int_0^H [q - u(z,t)] dz \qquad (2)$$

The total settlement of the soft soil layer at the time t = ∞ is:

$$S_s(\infty) = a_{01} \int_0^H q dz \qquad (3)$$

where $a_{01} = \frac{a_1}{1 + e_{11}}$ is the relative coefficient of the compressibility of the soft soil.

From Eqs. (2) and (3), we have the degree of consolidation of the soft soil layer at the time (t):

$$U_t = \frac{S_s(t)}{S_s(\infty)} = 1 - \frac{\int_0^H u(z,t) dz}{\int_0^H q dz} = 1 - \frac{8}{\pi^2} \sum_{i=1,3,5}^{i=\infty} \frac{1}{i^2} e^{-i^2 N_1} \qquad (4)$$

$$\text{or } U_t = 1 - \frac{8}{\pi^2}\left(e^{-N_1} + \frac{1}{9} e^{-9N_1} + \frac{1}{25} e^{-25N_1} + \dots\right) \qquad (5)$$

The settlement of the soft soil layer at the time (t) is finally given:

$$S_s(t) = a_{01} H q \left[1 - \frac{8}{\pi^2} \sum_{i=1,3,5,\dots}^{i=\infty} \frac{1}{i^2} e^{-i^2 N_1}\right] \qquad (6)$$

$$\text{or } S_s(t) = a_{01} H q \left[1 - \frac{8}{\pi^2}\left(e^{-N_1} + \frac{1}{9} e^{-9N_1} + \frac{1}{25} e^{-25N_1} + \dots\right)\right] \qquad (7)$$

After differentiating Eq. (7) and eliminating the high terms, we finally have the settlement rate of the soft soil layer at the time (t):

$$V_s = \frac{dS_{0s}(t)}{dt} = 2 a_{01} q (H - z) \frac{c_{v1}}{H^2} e^{-N_1} \qquad (8)$$

Consolidation type 2: In cases where the soft soil layer (thickness H) is subjected to a finite uniform load (q) and the vertical normal stress is linear.

The pore pressure u(z,t) is defined according to the formula:

$$u(z,t) = \frac{4}{\pi} q \sum_{i=1,3,5,\dots}^{i=\infty} \frac{1}{i}\left[4 - \frac{2}{i\pi} \sin\left(\frac{i\pi}{2}\right)\right] \sin\left(\frac{i\pi}{2H} z\right) e^{-i^2 N_1} \qquad (9)$$

The degree of consolidation of the soft soil layer at the time (t) is expressed as:

$$U_t = 1 - \frac{16}{\pi^3} \sum_{i=1,3,5,\dots}^{i=\infty} \frac{1}{i^2}\left(1 - \frac{2\sin\left(\frac{i\pi}{2}\right)}{i\pi}\right) e^{-i^2 N_1} \qquad (10)$$

The settlement of the soft soil layer at the time (t) is determined as:

$$S_t = \frac{1}{2} a_{01} H q \left\{1 - \frac{16}{\pi^2}\left[\left(1 - \frac{2}{\pi}\right) e^{-N_1} + \frac{1}{9}\left(1 + \frac{2}{3\pi}\right) e^{-9N_1} + \dots\right]\right\} \qquad (11)$$

After differentiating Eq. (11) and rejecting the high terms, the settlement rate of the soft soil layer at the time (t) is finally obtained:

$$V_s = \frac{dS_s(t)}{dt} = 2 a_{01} q \frac{c_{v1}}{H}\left(1 - \frac{2}{\pi}\right) e^{-N_1} \qquad (12)$$

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2.2 SETTLEMENT RATE OF PILES

2.2.1 Stress at the plane of the point-pile of a single pile

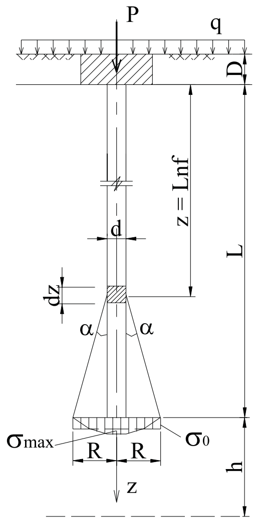

Fig. 1 *Stress distribution on a single pile*

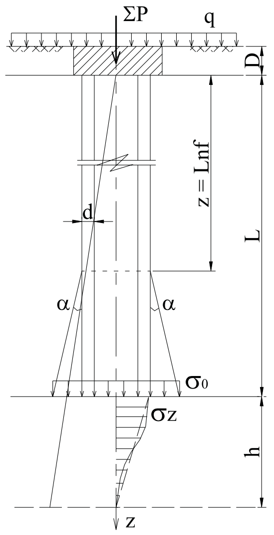

Fig. 2 *Stress distribution on a group of piles*

Considering the time t, at the depth z (≅L_{nf}) – the pile length affected by negative friction, stress at the plane of point-pile is assumed as a parabolic form. Regarding the portion of *dz* and all the terms shown in Figure 1, we have the equation:

$$\frac{P}{L}dz = \frac{1}{2}\pi R^2 d\sigma_{max} \tag{13}$$

where *L* is the length of the pile; *R* is the radius of the transfer stress zone;
σ_{max} is the maximum stress at the plane of the point-pile.

Substituting $R = \frac{1}{2}d + (L - z)\,tg\alpha$ into the equation (13), we have:

$$d\sigma_{max} = \frac{2P}{\pi L}\frac{dz}{\left[\frac{d}{2} + (L - z)\,tg\alpha\right]^2} \tag{14}$$

where *P* is the total force acting on the pile;
d – the diameter of the pile;
α – the angle of the transfer stress, $\alpha = \varphi/4$; φ is the internal friction angle of the soft soils.

The equation (14) can be integrated in the domain of (z, L) as expressed:

$$\sigma_{max} = \int_z^L \frac{2P}{\pi L}\frac{dz}{\left[\frac{d}{2} + (L - z)\,tg\alpha\right]^2}$$

$$= \frac{2P}{\pi L}\int_z^L \left[-tg\alpha.z + \left(\frac{d}{2} + L\,tg\alpha\right)\right]^{-2} dz \tag{15}$$

Considering a = tgα; b = d/2 + L tgα and using the formula

$\int (ax+b)^{-2}dx = \frac{1}{a}\frac{(ax+b)^{-2+1}}{-2+1} + C$ to integrate the equation (15), we have the result:

$$\sigma_{max} = \frac{2P}{\pi L}\left|\frac{1}{tg\alpha\left[\frac{d}{2} + (L - z)\,tg\alpha\right]} + C\right|_z^L \tag{16}$$

where *C* is an integral constant.

The maximum stress (σ_{max}) at the plane of the point-pile is finally achieved:

$$\sigma_{max} = \frac{4P}{\pi L}\frac{(L - z)}{d\left[\frac{d}{2} + (L - z)\,tg\alpha\right]} \tag{17}$$

If the stress at the plane of the point-pile is assumed to have a constant distribution, it can be simply written:

$$\sigma_{max} = \sigma_0 = \frac{P}{\pi\left[\frac{d}{2} + (L - z)\,tg\alpha\right]^2} \tag{18}$$

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2.2.2 Settlement rate of a single pile

The settlement of a single pile is assumed to be the settlement of the soil mass under the plane of the point-pile subjected to the maximum stress $\sigma_{max} = \sigma_0$ (Fig. 1). Using the result from the consolidation problem of type 2 (the case of a finite uniform load (q) and the vertical normal stress considered as linear) as discussed in section 2.1, we have the settlement of a single pile at the time (t) (also the settlement of the soil mass under the plane of the point-pile):

$$S_{p.s}(t) = \frac{1}{2} a_{02} h \sigma_z \left[1 - \frac{16}{\pi^2} \sum_{i=1,3,5}^{i=\infty} \frac{1}{i^2} \left(1 - \frac{2\sin\left(\frac{i\pi}{2}\right)}{i\pi} \right) e^{-i^2 N_2} \right]$$

$$= \frac{1}{2} a_{02} h \sigma_z \left\{ 1 - \frac{16}{\pi^2} \left[\left(1 - \frac{2}{\pi} \right) e^{-N_2} + \frac{1}{9} \left(1 + \frac{2}{3\pi} \right) e^{-9N_2} + \ldots \right] \right\} \quad (19)$$

The equation (19) is converged, so the high terms can be eliminated to be equivalent:

$$S_{p.s}(t) = \frac{1}{2} a_{02} h \sigma_z \left\{ 1 - \frac{16}{\pi^2} \left[\left(1 - \frac{3}{\pi} \right) e^{-N_2} \right] \right\} \quad (20)$$

Where $\sigma_z = \sigma_o + (\gamma_{s.c} - \gamma')L = \dfrac{P}{\pi \left[\dfrac{d}{2} + (L - L_{nf}) tg\alpha \right]^2} + (\gamma_{s.c} - \gamma')L$ (21)

is the stress causing settlement;
σ_0 is the stress at the plane of the point-pile;
L_{nf} is the pile length of the negative friction;
$\gamma_{s.c}$ is the mean unit weight of soft soil and concrete pile;
γ' is the mean unit weight of the soil;

$a_{02} = \dfrac{a_2}{1 + e_{12}}$ is the relative coefficient of compressibility of the soil under the point-pile;

$N_2 = \dfrac{\pi^2 c_{v2} t}{h^2}$ is the time factor;

c_{v2} is the coefficient of consolidation of the soil under point-pile;
h is the thickness of the compressive soil layer under the point-pile, approximately 10d.

The settlement rate of a single pile can be determined:

$$V_{p.s} = \frac{dS_{p.s}(t)}{dt} = 2a_{02} \sigma_z \frac{c_{v2}}{h} \sum_{i=1,3,5}^{i=\infty} \left(1 - \frac{2\sin\left(\frac{i\pi}{2}\right)}{i\pi} \right) e^{-i^2 N_2} \quad (22)$$

It can be approximated after eliminating the high terms:

$$V_{p.s} = \frac{dS_{p.s}(t)}{dt} = 2a_{02} \sigma_z \frac{c_{v2}}{h} \left(1 - \frac{2}{\pi} \right) e^{-N_2} \quad (23)$$

2.2.3 Settlement rate of a group of piles

Using the result from the consolidation problem of type 2 and assuming the vertical normal stress (σ_z) as linear (Fig. 2), the settlement of a group of piles at the time (t) is determined from the settlement of the soil mass under the plane of the point-pile:

$$S_{p.g}(t) = \frac{1}{2} a_{02} h \sigma_z \left[1 - \frac{16}{\pi^2} \sum_{i=1,3,5}^{i=\infty} \frac{1}{i^2} \left(1 - \frac{2\sin\left(\frac{i\pi}{2}\right)}{i\pi} \right) e^{-i^2 N_2} \right] \quad (24)$$

where $\sigma_z = \sigma_0 + (\gamma_{s.c} - \gamma')L = \dfrac{\Sigma P}{[a + 2(L - L_{nf}) tg\alpha][b + 2(L - L_{nf}) tg\alpha]} + (\gamma_{s.c} - \gamma')L$ (25)

is the stress causing settlement;
σ_0 – the stress at the plane of the point-pile (Fig. 2);
ΣP – the total force acting on the grouped piles;
a and b – the distances of the outer edge between the two marginal piles in the direction of the width and length, respectively.

The settlement rate of the group of files pile can be defined:

$$V_{p.g} = \frac{dS_{p.g}(t)}{dt} = 2a_{02} \sigma_z \frac{c_{v2}}{h} \sum_{i=1,3,5}^{i=\infty} \left(1 - \frac{2\sin\left(\frac{i\pi}{2}\right)}{i\pi} \right) e^{-i^2 N_2} \quad (26)$$

It can be approximated after eliminating the high terms:

$$V_{p.g} = \frac{dS_{p.g}(t)}{dt} = 2a_{02} \sigma_z \frac{c_{v2}}{h} \left(1 - \frac{2}{\pi} \right) e^{-N_2} \quad (27)$$

2.3 DETERMINATION OF THE AFFECTED LENGTH OF THE NEGATIVE SKIN FRICTION (L_{nf})

As suggested previously, negative skin friction occurs at the depth (z) of the pile and at the time (t) of the consolidation of the soil mass when the consolidation rate of the surrounding soils is greater than the settlement rate of the pile. That is:

$$V_s \geq V_p \quad or \quad \frac{dS_s(t)}{dt} \geq \frac{dS_p(t)}{dt} \quad (28)$$

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The settlement rate of the soft soils is applied from the result of the consolidation problem of type 0 that the load of the filling soils is infinitely uniform. The settlement rate of the pile is considered as the consolidation problem of type 2 for the soils under the plane of the point-pile so that the stress distribution at the plane of the point-pile is finitely uniform, and the vertical normal stress (σ_z) is assumed as linear.

2.3.1 A single pile

From Eqs. (8), (23) and (28), the maximum length of the negative friction (L_{nf}) on a single pile (substituting z by L_{nf} for the settlement rate of the soil layer) at the time (t) can be determined by the relation:

$$2a_{01} q \frac{c_{v1}}{H^2}\left(H-L_{nf}\right)e^{-N_1} = 2a_{02}\,\sigma_z \frac{c_{v2}}{h}\left(1-\frac{2}{\pi}\right)e^{-N_2} \qquad (29)$$

or $$\frac{1}{\sigma_z}\left(H-L_{nf}\right) = \frac{a_{02}}{a_{01}}\frac{c_{v2}}{c_{v1}}\frac{H^2}{h}\frac{1}{q}\left(1-\frac{2}{\pi}\right)e^{-N_2+N_1} \qquad (30)$$

We finally have a function which is dependent on the affected length of the negative friction (L_{nf}) and the time (t):

$$\left[\frac{1}{\dfrac{P}{\pi\left(\dfrac{d}{2}+(L-L_{nf})tg\alpha\right)^2}+(\gamma_{s.c}-\gamma')L}\right]\left(H-L_{nf}\right)= \\ = \frac{a_{02}}{a_{01}}\frac{c_{v2}}{c_{v1}}\frac{H^2}{h}\frac{1}{q}\left(1-\frac{2}{\pi}\right)e^{-N_2+N_1} \qquad (31)$$

2.3.1 A group of piles

From Eqs. (8), (27), and (28), the maximum length of the negative friction on a group of piles (L_{nf}) at the time (t) can be obtained:

$$2a_{01} q \frac{c_{v1}}{H^2}\left(H-L_{nf}\right)e^{-N_1} = 2a_{02}\sigma_z \frac{c_{v2}}{h}\left(1-\frac{2}{\pi}\right)e^{-N_2} \qquad (32)$$

The final function to determine the (L_{nf}) and (t) can be expressed as:

$$\left\{\frac{\left[a+2(L-L_{nf})tg\alpha\right].\left[b+2(L-L_{nf})tg\alpha\right]}{\sum P+(\gamma_{s.c}-\gamma')L\left[a+2(L-L_{nf})tg\alpha\right].\left[b+2(L-L_{nf})tg\alpha\right]}\right\}\left(H-L_{nf}\right)= \\ = \frac{1}{q}\frac{a_{02}}{a_{01}}\frac{H^2}{h}\frac{c_{v2}}{c_{v1}}\left(1-\frac{2}{\pi}\right)e^{-N_2+N_1} \qquad (33)$$

Eqs. (31) and (33) can be solved by the authors' computer program.

2.4 EFFECT OF TIME ON NEGATIVE SKIN FRICTION

Negative skin friction usually develops during the construction process or just after the completion of the construction. It depends on the executing time of the structures. That means the negative skin friction depends on the time of construction and the consolidation of the soft soils. Negative friction forces may increase to a maximum value during the construction and gradually decrease afterwards. Negative friction might disappear or not affect the piles after a certain time (t). The time factor is thus essentially important to be determined so that we can decide during design when and whether negative skin friction affects the piles or not.

The time condition of the effect of negative skin friction can be assumed:

$$S_{s.r}(t) = S_\infty - S_s(t) = S_{s.l} - S_p(t) \qquad (34)$$

Where $S_{s.r}(t)$ is the remaining settlement of the soils;
$S_s(t)$ – the settlement of soils at the time t;
$S_{s.l}$ – the limit of the settlement of the subsoil foundation;
$S_p(t)$ – the settlement of the piles at the time t.

For the piled foundations of industrial structures, it can be assumed that $S_{s.l} - S_p(t) = 0.5S_{s.l}$. So at the time t, if the remaining settlement of soils at a certain plane is less than $0.5S_{s.l}$, it can be considered that the portion of the piles under that plane is not affected by negative friction. We finally have the conditions to determine negative skin friction on concrete piles:

$$\begin{cases} \dfrac{dS_s(t)}{dt} \ge \dfrac{dS_p(t)}{dt} \\ S_{s.r}(t) \ge 0.5S_{s.l} \end{cases} \qquad (35)$$

In cases where the settlement of soils under the plane of a pile-point is less than $0.5S_{s.l}$, the settlement of the soft soil layer can be considered not to cause a negative friction force on the piles. If the settlement of soils under the plane of the pile-point at the time of completing the construction is less than $0.5S_{s.l}$, we can ignore the negative skin friction in the design of the piled foundations.

2.5 COMPUTER PROGRAMMING

The program is established on Delphi Langue and runs on Microsoft Windows. Figure 3 shows the flow chart to constitute the computer programming.

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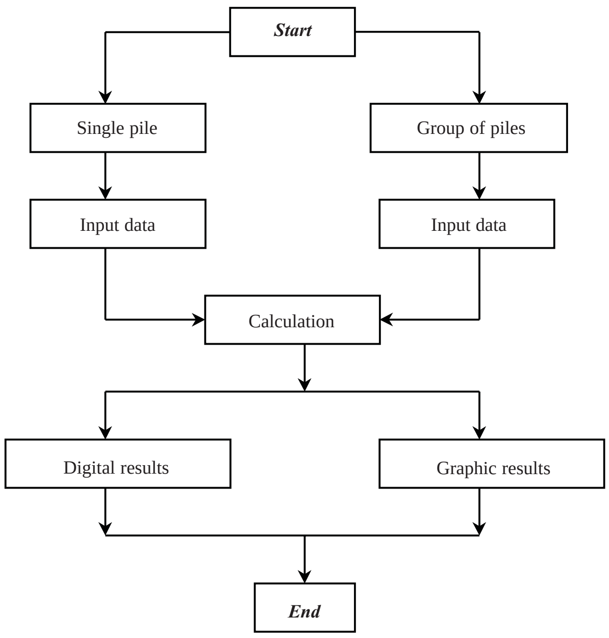

Fig. 3 Flow chart for the computer programming

3 APPLICATION OF THE APPROACH'S RESULTS TO CALCULATE THE NEGATIVE SKIN FRICTION

The piled foundation project of Yamato located in the Tan Thuan Industrial Zone in Ho Chi Minh City is used to investigate and compute the negative skin friction.

3.1 GEOLOGICAL CONDITIONS AND THE PILED FOUNDATION DESIGN

The soil deposit of the Yamato project belongs among the very soft soils in the region. The groundwater table is only from 0.6 m to 1 m below the ground. The soil properties are described as follows [4]:

Layer 1: 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 $\varphi = 4^0$.

Layer 3: Sandy clay, medium plasticity, average thickness h = 8.5 m, w = 28.08%, γ = 19 kN/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, $\varphi = 13^0$.

Layer 4: Fine sand, medium density, average thickness h = 15 m, w = 22.12%, γ = 19.2 kN/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, $\varphi = 28^0$.

Layer 5: Clay, medium to low plasticity, w = 22.95%, γ = 19.6 kN/m^3, γ_{sub} = 10 kN/m^3, G_s = 26.88 kN/m^3, S = 89.9%, e = 0.686, I_p = 26.47, k = 1.10^{-8} m/s, Q_u = 182 kPa, c = 37 kPa, $\varphi = 16^0$.

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 x 0.25 x 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.

3.2 RESULTS OF CALCULATIONS

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 ($z \cong L_{nf}$) 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 settlements and settlement rates of soil layers as well as piles are briefly summarised 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 results 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. *Results 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

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Table 2. *Results of the settlements and settlement rates of soils and piles*

Items	Time (year)					
	0.2	**0.5**	**1**	**2**	**5**	**∞**
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 pile (cm)	4.88	4.98	5.04	5.1	5.1	5.1
Settle. rate of pile (cm/year)	–	0.006	0	0	0	0

Table 3. *Comparison sheet of the NSF calculations by different methods*

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

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

Table 4. *Results of the piled foundation calculations with NSF*

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

The time of ending the negative skin friction on piles is estimated at about 2 years, and the degree of consolidation of the soft soils reaches 90%. These are very important values 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' results seem to be higher than that 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 piled foundation calculations at the time of the maximum negative skin friction are shown in Table 4.

4 CONCLUSIONS

Negative skin friction causes a downward force that increases the load on shaft piles and reduces the bearing capacity of piles in soft soils. The research approach takes into account the working condition of grouped concrete piles in weak soils. The negative skin friction occurs on a plane where the settlement rate of surrounding soils is greater than that of the piles. The results studied are satisfactory in that the influence of the time factor and consolidation of the soil mass is taken into account. The advantage of the studied approach over other methods is that the time of ending the negative skin friction on piles can be determined. Negative friction is not the same all the time; it develops during construction and gradually decreases afterwards. The negative friction force might disappear after a certain period of time or maybe after the completion of the construction in some cases. It is possible to determine the time when negative skin friction can be negligible or does not affect the piles. In some projects, if the executing time is adequate enough to dissipate the negative skin friction, it can be ignored in the design calculations. The executing time of the construction is a very important factor that should be analysed during the first step of a design.
Besides the load of embankment filling, the external surcharge on the ground also creates negative skin friction on the piles, so the utilisation of a concrete slab combined with beams and piles was applied to cure the negative skin friction on the concrete piled foundation of the Yamato Project.

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