Interaction of a barrette with surrounding and underlying soil taking into account rheological property of soils

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Abstract. The article presents the formulation and solution to the problem: A barrette has interaction with the surrounding and underlying soils, taking into account their linear and rheological properties, under the influence of the force applied to the barrette head - which would be solved with the analytical method. As a computational geomechanical model, a soil column with limited dimensions of rectangular cross-section containing a barrette is considered. It was shown that the distribution of the force applied to the barrette is distributed between its side surfaces and its toe significantly not only depends on the ratio of the stiffness of the surrounding and underlying soils \( G_1/G_2 \); \( G_3/G_3 \), but also the geometric parameters of the barrette and the soil column. According to the value of the force applied to the barrette head, the stress-strain state of the "barrette-surrounding and underlying soils" system, including settlement and barrette's bearing capacity, is distributed between the side surfaces of the barrette and its toe. The papers result servers as a basic to calculate the barrette's bearing capacity and to prognose stress field and deformation of the ground surrounding the barrette and under its toe in time.

1. Introduction

For the design and construction on weak water-saturated soil at the present time, barrettes are increasingly used as a part of the barrette-slab foundation, which is able to bear significant loads from building sand structures with increased level of responsibility, including high-rise buildings.

When barrette interacts with the surrounding and underlying relatively dense soils, a complex and inhomogeneous stress-strain state (SSS) occurs not only in the surrounding and underlying soils, but also on the contact of barrette with soils, so that it can transform in space and time. Quantitative estimation of SSS in the surrounding and underlying soils, taking into account their interaction with barrette, is necessary for the prediction of settlement and barrette’s bearing capacity. In this paper, we present the formulation and solution to the problem of interaction of an absolutely rigid barrette with the surrounding and underlying soils, taking into account their linear property. It was shown that the distribution of the force applied to the barrette is distributed between its side surface and its toe. According to the results of calculation of the SSS system in linear formulation, settlement and barrette’s bearing capacity are determined and also the regularity of stress change on the side surfaces of the barrette and under its toe in time.

As a computational system for the quantitative assessment of SSS, a geomechanical model is used in the form of a rectangular soil column of finite size \((AxBxL)\), containing a barrette (Figure 1)
Figure 1. Calculation scheme of barrette interaction with surrounding and underlying soils. From the calculation scheme (Figure 1) we have an equilibrium condition:
\[ 2T_{a1} + 2T_{b1} + 2T_{a2} + 2T_{b2} + 4a\sigma r = N \] (1.1)
in which: \( a_1 = a + rtg\alpha \); \( b_1 = b + rtg\beta \); \( t\sigma = \alpha \); \( tg\beta = b / a \)

Shear stresses on the side surface of the barrette could be determined by the formula:
\[ \tau_{a1,2}(r) = \frac{T_{a1,2}}{2a_1(r)L_{a,2}} \] ; \[ \tau_{b1,2}(r) = \frac{T_{b1,2}}{2b_1(r)L_{b,2}} \] (1.2)

In this paper, to quantify the SSS of the surrounding and underlying soils interacting with the barrette, a shear mechanism is used when the shear deformation of the soil around the barrette is dominated by the mutual displacement of parts inside which is similar to telescope cylinder. At the same time, volumetric deformations of the surrounding soil can be neglected.

2. Program research

2.1. Interaction of a barrette with the surrounding and underlying soils in a linear statement.

Settlement and carrying capacity of a single barrette

Under the effect of a constant force (N) on the barrette’s head, it is distributed between the side surface of barrette (\( T = 2T_{a1} + 2T_{b1} + 2T_{a2} + 2T_{b2} \)) and its toe (R) depending on the ratio of the stiffness of the surrounding (\( G_1, G_2 \)) and the underlying (\( G_3 \)) soils (\( \frac{G_1}{G_3}, \frac{G_2}{G_3} \)) a also from the ratio \( L_{1,2}/a; \) \( L_{1,2}/b; \) \( L_{1,2}/A \) and \( L_{1,2}/B \). Considered the solution based on these parameters. Settlement of barrette and surrounding soil under the influence of force on the barrette head occurs due to shear deformation of soils within the active zone of influence around barrette, from \( 2a \times 2b \) to \( 2A \times 2B \) along the entire length of the barrette and on all four sides and along the length of the column. In this case, the settlement of the soil layer at depth \( z \) is determined from the condition of equal increment of vertical displacement \( S(r) \), depending on the angular deformation \( \gamma(r) \):
\[ dS(r) = -\gamma(r)dr \] (2.1)
in which:
\[ \gamma(r) = \frac{\tau(r)}{G} \] (2.2)

Settlement could be determined by integrating (2.1) with (2.2):
\[ S(r) = \gamma(r)dr = -\int \frac{\tau(r)dr}{G} + C \] (2.3)
in which: \( c \) – the constant of integration determined from the boundary conditions (defined below). Considering that \( \tau(r) \) has different values on the sides a and b (1.2) we obtain:
The settlement of the barrette’s toe is obtained from the known dependence of the deformation parameters of a rectangular rigid stamp taking into account the depth coefficient \( K_i < 1 \), so we have:

\[
S_R = \sigma_R \left( 1 - \nu_i \right) \frac{aK_i}{G_i}
\]

(2.6)

in which \( G_i \) and \( \nu_i \) - parameters of deformability of the underlying soil layer; \( \omega \) - coefficient, considering the shape of the stamp (square, rectangle).

From the condition of absolute rigidity of barrette, we have:

\[
S_R = S_{b_1} = S_{a_1} = S_{a_2} = S_{appum}
\]

(2.7)

So we have:

\[
\begin{align*}
T_{a_1} - H_1 &= T_{a_1} - H_1; & T_{a_2} - H_1 &= T_{a_2} - H_1; \\
&= \frac{T_{a_1}}{2L_1G_1}H_1; & \frac{T_{a_2}}{2L_2G_2}H_1 &= \frac{T_{a_1}}{2L_1G_1}H_1; \\
&= \frac{T_{a_1}}{2L_1G_1}H_1; & \frac{T_{a_1}}{2L_1G_1}H_1 &= \sigma_R K
\end{align*}
\]

(2.8)

in which:

\[
H_i = \frac{1}{\tan \alpha} \ln \left[ \frac{a + (B - b)\tan \alpha}{a} \right]; \quad H_i = \frac{1}{\tan \beta} \ln \left[ \frac{b + (A - a)\tan \beta}{b} \right]; \quad K = \frac{(1 - \nu_i) aK_i}{G_i}
\]

(2.9)

Combining (2.8) and (1.1), we obtain:

\[
2T_{a_1} + 2T_{a_1} + 2T_{a_2} + 4\sigma_R ab = N
\]

(2.10)

Solving the system of equation (2.10), we have:

\[
\begin{align*}
T_{a_1} &= \frac{G_i H_1 K L_1 N}{2 \left( K \left( G_i L_1 + G_i L_2 \right) \left( H_1 + H_2 \right) + H_1 H_2 \right)}; & T_{b_1} &= \frac{G_i H_1 K L_1 N}{2 \left( K \left( G_i L_1 + G_i L_2 \right) \left( H_1 + H_2 \right) + H_1 H_2 \right)}, \\
T_{a_2} &= \frac{G_i H_2 K L_2 N}{2 \left( K \left( G_i L_1 + G_i L_2 \right) \left( H_1 + H_2 \right) + H_1 H_2 \right)}; & T_{b_2} &= \frac{G_i H_2 K L_2 N}{2 \left( K \left( G_i L_1 + G_i L_2 \right) \left( H_1 + H_2 \right) + H_1 H_2 \right)}, \\
\sigma_R &= \frac{H_1 H_2 N}{4 \left( K \left( G_i L_1 + G_i L_2 \right) \left( H_1 + H_2 \right) + H_1 H_2 \right)}
\end{align*}
\]

(2.11)

The settlement of barrette is defined if the value \( \sigma_R \) put into (2.7), we get:

\[
S = \sigma_R K = \frac{H_1 H_2 N K}{4 \left( K \left( G_i L_1 + G_i L_2 \right) \left( H_1 + H_2 \right) + H_1 H_2 \right)}
\]

(2.12)

Thus, the problem is solved. The essential dependence of \( \sigma_R \) and \( T_{a_1}, T_{b_1}, T_{a_2}, T_{b_2} \) on deformation parameters of the surrounding and underlying soils; \( (G_i / G_j; G_i / G_j) \), and also the geometric parameters of barrette \( (a, b, L_1, L_2) \) and a rectangular column holding barrette \((AxBxL)\).
It is obvious that at a certain ratio of these parameters, the force at the barrette’s toe \( R \) can vary widely from zero to finite values \( R < \infty \) by \( G_1 > G_2; G_3 > G_2 \).

Determining the calculated value \( \sigma_R \) in the linear statement, the degree of its approximation to the limit state should be checked \( (\sigma_R < \sigma_L) \). This test can be carried out by the formula of L. Prandtl:

\[
\sigma_{Rl} = (\gamma d + c_s \cot \phi_3) \left( \frac{1 + \sin \phi_3}{1 - \sin \phi_3} \right) e^{\alpha \theta} \quad (2.13)
\]

in which: \( d \) - depth at the level of barrette's sole (m);
\( \gamma \) - specific gravity of soil from the ground surface to depth \( d \) (kH/m\(^3\));
\( c_s \) and \( \phi_3 \) - strength parameters of the underlying soil layer (kPa) and (radiance).

In the particular case of a perfectly cohesive soils \((c > 0, \phi \approx 0)\) in the conditions of the plane problem \( \sigma_R \) will be equal to:

\[
\sigma_{R_2} = \gamma d + (2 + \pi) c_s \quad (2.14)
\]

Considering example: \( N = 80000 \) kN; \( 2a = 1 \) m; \( 2b = 6 \) m; \( 2A = 5 \) m; \( 2B = 10 \) m; \( L_1 = 27 \) m; \( L_2 = 13 \) m; \( \alpha = \beta = 45^\circ; K_1 = 0.5; G_1 = 12000 \) kN; \( G_2 = 16000 \) kN; \( G_3 = 40000 \) kN; \( \omega = 1.22; \nu_0 = 0.3; \nu_1 = 0.3; \nu_2 = 0.25; \phi_1 = 12^\circ; \phi_2 = 10^\circ; \phi_3 = 19^\circ; \gamma_1 = 19 \) kN/m\(^3\); \( \gamma_2 = 21.3 \) kN/m\(^3\); \( \gamma_3 = 21.1 \) kN/m\(^3\); \( c_1 = 25 \) kPa; \( c_2 = 32 \) kPa; \( c_3 = 60 \) kPa.

Then we get: \( \sigma_R = 2407.4 \) kPa; \( \sigma_{R_1} = 5509 \) kPa; \( S = 0.04 \) m; \( T_{so} = 5543.1 \) kPa; \( T_{s2} = 3558.5 \) kPa; \( T_{b1} = 17464.4 \) kPa; \( T_{b2} = 11211.7 \) kPa; \( \sigma_{R_0} = 1114 \) kPa.

2.2. Interaction of a barrette with surrounding and underlying soils taking into account rheological property of surrounding soil

As a computational model for the surrounding soil, we take a modified visco-plastic Bingham model, complicated by taking into account the variable viscosity \( \eta(t) \) and structural strength of the soil \( \tau^* \) so we have:

\[
\gamma = \frac{\tau}{G} \quad \text{when } \tau < \tau^* \quad \dot{\gamma} = \frac{\tau - \tau^*}{\eta(t)} \quad \text{when } \tau \geq \tau^*
\]

in which:

\[
\tau^* = \sigma_m \tan \phi + c \quad \tau = \tau_r = \frac{T}{2L(a + rt \tan \alpha)}
\]

\( \sigma_m \) - medium pressure; \( \phi \) and \( c \) - strength parameters of the surrounding soil.

It follows from (2.1) that:

\[
dS(r) = -\dot{\gamma}(r)dr
\]

so we have:

\[
\dot{\gamma}(r) = -\frac{\tau_r(r) - \tau^*}{\eta(t)}
\]

The solution of this visco-plastic problem will be considered in the speed of gentle, at the initial moment the SSS corresponds to the linear solution.

Assuming, as a first approximation, that:

\[
\sigma_m = \frac{\sigma_0 + \sigma_1 + \sigma_2}{3} - \frac{\sigma_1 + 2\sigma_2 \xi}{3}
\]

(2.19)
in which: \( \sigma_1 = \sum_{i=1}^{n} \gamma_i \cdot h_i \) - the maximum main stress and \( \sigma_2 = \sigma_3 = \sigma_1 \xi \) - the minimum main stress, 
\( \xi = \frac{\nu}{1-\nu} \) - coefficient of lateral soil pressure.

We also assume that the rate of settlement of barrette in this case from the effect of the force \( 2T_{a1,2} \) and \( 2T_{b1,2} \) can be determined based on formulas (2.4) replacing the shear modules \( G_{1,2} \) on viscosity \( \eta_1 = const \) and \( \eta_2 = const \) , we get:

\[
\dot{S}_{a1,2} = \frac{T_{a1,2}}{2\eta_1 L_1 L_2 t g a} \ln \frac{a + (B - b) t g a}{a} - \frac{t_1,2}{\eta_2} (B - b); \dot{S}_{b1,2} = \frac{T_{b1,2}}{2\eta_2 L_1 L_2 t g \beta} \ln \frac{b + (A - a) t g \beta}{b} - \frac{t_1,2}{\eta_2} (A - a) \tag{2.20}
\]

The rate of settlement of the underlying soil under the sole of the barrette during the effect \( \dot{\sigma}_k \) can be determined based on the elastic solution (2.6), so we have:

\[
\dot{S}_k = \frac{\dot{\sigma}_k (1 - \nu) a K \omega}{G_i} \tag{2.21}
\]

From the condition of equality of settlement rates:

\[
\dot{S}_k = \dot{S}_{a1} = \dot{S}_{b1} = \dot{S}_{a2} = \dot{S}_{b2} \tag{2.22}
\]

Taking into account (2.11) we obtain:

\[
\frac{T_{a1}}{2\eta_1 L_1} H_1 - \frac{t_1}{\eta_1} (B - b) = \frac{T_{z2}}{2\eta_2 L_2} H_2 - \frac{t_2}{\eta_2} (A - a); \quad \frac{T_{a1}}{2\eta_1 L_1} H_1 - \frac{t_1}{\eta_1} (B - b) = \frac{T_{z2}}{2\eta_2 L_2} H_2 - \frac{t_2}{\eta_2} (A - a) \tag{2.23}
\]

The system of equation (2.23) can be rewritten as:

\[
\frac{T_{a1}}{2\eta_1 L_1} H_1 - \frac{t_1}{\eta_1} (B - b) = \dot{\sigma}_k K; \quad \frac{T_{a1}}{2\eta_1 L_1} H_1 - \frac{t_1}{\eta_1} (B - b) = \dot{\sigma}_k K \tag{2.24}
\]

Considering dependency \( T_{b1,2} = T_{a1,2} \frac{H_1}{H_2} \), obtained on the basis of (2.23) and (2.24), we get:

\[
2T_{a1} \left(1 + \frac{H_1}{H_2}\right) + 2T_{a2} \left(1 + \frac{H_1}{H_2}\right) + 4ab\dot{\sigma}_k = N \tag{2.25}
\]

Having \( T_{a1} = \dot{\sigma}_k \frac{2K\eta_1 L_1}{H_1} + \frac{2t_1 (B - b) L_1}{H_1} \) and \( T_{a2} = \dot{\sigma}_k \frac{2K\eta_2 L_2}{H_1} + \frac{2t_2 (B - b) L_2}{H_1} \) from (2.24), putting on (2.25) we have:

\[
4\dot{\sigma}_k K \left[\eta_1 L_1 + \eta_2 L_2\right] \frac{H_2}{H_1} + 4 (B - b) \left[\tau_1 L_1 + \tau_2 L_2\right] \frac{H_2}{H_1} + 4ab\dot{\sigma}_k = N \tag{2.26}
\]

After some transformations (2.26) can be represented as:

\[
\dot{\sigma}_k + \sigma_k P = Q \tag{2.27}
\]

in which:

\[
P = \frac{a b}{H_2 + H_1 K \left(\eta_1 L_1 + \eta_2 L_2\right)}; \quad Q = \frac{N}{4 \frac{H_2}{H_1} + \frac{H_1}{H_2} K \left(\eta_1 L_1 + \eta_2 L_2\right)} \tag{2.28}
\]

The solution of the differential equation (2.27) is known and has the form:

\[
\sigma_k (t) = e^{\int P dt} \left\{ Q e^{\int P dt} dt + C_0 \right\} \tag{2.29}
\]

When \( P = const \) and \( Q = const \), this equation takes the form:
\[ \sigma_R(t) = \frac{Q}{P} + C_0 e^{-\eta t} \]  

Taking into account the viscosity of the soil layers 1 and 2, at the initial moment \( t=0 \), applied load \( N \) is completely transferred to the lateral layers of the soil. Considering that when \( t=0 \), \( \sigma_R(t=0) = 0 \) we have \( C_0 = -\frac{Q}{P} \); when \( t \to \infty \), \( \sigma_R(t \to \infty) = \frac{Q}{P} \)

and finally

\[ \sigma_R(t) = \frac{Q}{P} - \frac{Q}{P} e^{-\eta t} \]  

Putting (2.31) into the system of equation (2.24), we obtain:

\[ T_{a_1}(t) = e^{-\eta t} \frac{2KQ \eta L_1}{H_1} + \frac{2\sigma_0'(B-b)L_1}{H_1} ; \quad T_{a_2}(t) = e^{-\eta t} \frac{2KQ \eta L_2}{H_1} + \frac{2\sigma_0'(B-b)L_2}{H_1} \]  

Taking into account the formula (2.6), the dependence of the settlement of a single barrette \( S_R(t) \) on time is written as:

\[ S_R(t) = \sigma_R(t)K = \frac{Q}{P}K - \frac{Q}{P}K e^{-\eta t} \]  

Considering an example using a PC Mathcad basic data:

\( N = 180000 \text{ kN}; \quad 2a=1 \text{ m}; \quad 2b=6 \text{ m}; \quad 2\mathbf{A}=5 \text{ m}; \quad 2\mathbf{B}=10 \text{ m}; \quad L_1=27 \text{ m}; \quad L_2=13 \text{ m}; \quad \alpha=\beta=45^\circ \text{; } K_L=0.5; \quad G_1=12000 \text{ kN}; \quad G_2=16000 \text{ kN}; \quad G_3=40000 \text{ kN}; \quad \omega=1.22; \quad \nu_1=0.3; \quad \nu_2=0.3; \quad \nu_3=0.25; \quad \varphi_0=12^\circ; \quad \varphi_2=10^\circ; \quad \varphi_3=19^\circ; \quad \gamma_1=19 \text{ kN/m}^3; \quad \gamma_2=21.3 \text{ kN/m}^3; \quad \gamma_3=21.1 \text{ kN/m}^3; \quad c_1=25 \text{ kPa}; \quad c_2=32 \text{ kPa}; \quad c_3=60 \text{ kPa}; \quad \eta_1=10^0 \text{ Pa.s}; \quad \eta_2=4.10^0 \text{ Pa.s}; \quad \eta_3=8.10^0 \text{ Pa.s} \); \( \eta_4=12.10^0 \text{ Pa.s} \). They are presented in figures 2-5 below.

**Figure 2.** Dependency curve friction force \( T_{a_1}(t) \) (kN) on the side surface on time \( t \) (days)

**Figure 3.** Dependency curve friction force \( T_{a_2}(t) \) (kN) on the side surface on time \( t \) (days)
Based on the Figures 2 – 5 shown that the shear stresses on the side surfaces of the barrette decrease with time and the stress under the toe of the barrette and its settlement, on the contrary, grows at a decaying rate and stabilizes to a certain value. Test on the Prandtl criteria shows that the stress under the toe of the barrette does not exceed the limit of the bearing capacity of the barrette. In addition, the stabilized settlement is under the permissible values.

In the case of variable viscosity over time \( \eta_1(t) = \eta_1(1 + \alpha_1 t) \) for the first soil layer and \( \eta_2(t) = \eta_2(1 + \alpha_2 t) \) for the second soil layer, equation (2.27) can be rewritten as:

\[
4\sigma_R K \left[ \eta_1 L_1 (1 + \alpha_1 t) + \eta_2 L_2 (1 + \alpha_2 t) \right] \frac{H_1 + H_2}{H_1 H_2} + 4(B - b) \left[ \tau^* L_1 + \tau^* L_2 \right] \frac{H_1 + H_2}{H_1 H_2} + 4\alpha b \sigma_R = N \tag{2.34}
\]

After some transformations, we obtain:

\[
\sigma_R + \sigma_R^a b \frac{I_3}{(I_1 \alpha_1 + I_2 \alpha_2) t + I_1 + I_2} = \frac{I_3}{(I_1 \alpha_1 + I_2 \alpha_2) t + I_1 + I_2} \tag{2.35}
\]

in which

\[
I_1 = \frac{(H_1 + H_2) K L_1 \eta_1}{H_1 H_2}; I_2 = \frac{(H_1 + H_2) K L_2 \eta_2}{H_1 H_2}; I_3 = \frac{N}{4} \frac{(B - b) (H_1 + H_2)}{H_1 H_2} \left( \tau^* L_1 + \tau^* L_2 \right) \tag{2.36}
\]

The solution of the differential equation (2.35) has the form:

\[
\sigma_{R,a} (t) = \frac{I_3}{ab (I_1 + I_2)} \frac{I_3}{I_1 \alpha_1 + I_2 \alpha_2} \left( I_1 \alpha_1 + I_2 \alpha_2 \right) t + I_1 + I_2 \right]^{-ab} \tag{2.37}
\]

Differentiating this equation, we obtain

\[
\sigma_{R,a} (t) = \frac{I_3}{ab (I_1 + I_2)} \frac{I_3}{I_1 \alpha_1 + I_2 \alpha_2} \left( I_1 \alpha_1 + I_2 \alpha_2 \right) t + I_1 + I_2 \right]^{-ab} \tag{2.38}
\]

Similarly substituting the obtained equation (2.38) in (2.25), we obtain:

\[
T_{a1,a} (t) = \sigma_{R,a} (t) \frac{2K \eta_1 (1 + \alpha_1 t) L_1}{H_1} + \frac{2 \tau^* (B - b) L_1}{H_1};
\]

\[
T_{a2,a} (t) = \sigma_{R,a} (t) \frac{2K \eta_2 (1 + \alpha_2 t) L_2}{H_1} + \frac{2 \tau^* (B - b) L_2}{H_1} \tag{2.39}
\]
Considering the results of the calculation $T_{a1-a}(t)$ and $T_{a2-a}(t)$ with $\eta_{i-1}(t) = \eta_i(1 + \alpha_{i-1} \cdot t)$ for the first soil layer; $\eta_{i-1}(t) = \eta_i(1 + \alpha_{i-1} \cdot t)$ for the second soil layer ($i=1,2,3,4$), and $\alpha_{i-1} = 0.005$; $\alpha_{1.2} = 0.02$; $\alpha_{1.3} = 0.08$; $\alpha_{1.4} = 0.25$; $\alpha_{2.1} = 0.0075$; $\alpha_{2.2} = 0.03$; $\alpha_{2.3} = 0.12$; $\alpha_{2.4} = 0.3$.

They are presented in figures 6-9.

**Figure 6.** Dependency curve friction force $T_{a1}(t)$ (kN) on the side surface on time $t$ (days)

**Figure 7.** Dependency curve friction force $T_{a2}(t)$ (kN) on the side surface on time $t$ (days)

**Figure 8.** Dependency curve of stress $\sigma_{R1}(t)$ (kPa) on time $t$ (days)

**Figure 9.** Dependency curve of settlement of barrette $S_{R}(t)$ (m) on time $t$ (days)

Data presented in the Figures 6 - 9 indicate that the shear stresses on the lateral surfaces of the barrette decrease with different rates depending on the viscosity, while the stresses under the toe of the barrette and the barrette settlement grow at a decaying rate.

### 3. Conclusions

- The problem of interaction of a single non-deformable barrette with the surrounding and underlying soils is set and solved by the analytical method, taking into account their linear and visco-plastic properties. Formulas for determination of settlement, stresses under barrette’s toe and shear stresses on its side surface and also estimation of barrette’s bearing capacity by Prandtl formula are obtained.
The problem of interaction of a single non-deformable barrette with the surrounding and
underlying soils taking into account their visco-plastic properties is set and solved on the basis
of the Bingham model. Closed-form solutions are obtained to determine the settlement and
stresses under the barrette's toe, and also the shear stresses on the barrette's surface side in time.

A significant dependence of the distribution of the force applied to the barrette head between
its side surface and its toe on the deformation, strength and rheological characteristics of the
surrounding and underlying soils as well as the geometric parameters of the barrette and the
surrounding soil column (transverse dimensions and length) is shown.

References

[1] Bartolomej A A, Omel'chak I M and Jushkov B S 1994 Forecast sediment pile foundation.
(Moscow, Strojizdat).
[2] Bezukhov N I 1968 Fundamentals of Elasticity, Plasticity, and Creep Theory Vysshaya
(Moscow, shkola Moscow).
[3] Booker and Poulos J 1976 Journal of the Geotechnical Engineering division. of the Proc.
A.S.C.E. 1.102 1-14.
[4] Goldshtein M N 1979 Mechanical Properties of Soils (Moscow, Strojizdat).
[5] Maslov N N 1982 Bases of the Engineering Theory and Soil Mechanics (Moscow, Vyshhaja
shkola).
[6] Nguen Z N 2006 Proceedings of the 4th International scientific conference of young scientists,
post-graduate and doctoral students «Building-forming living environment» 40-3.
[7] Seed H G and Reese LC 1957 Transactions ASCE 122 731-54.
[8] Telichenko V I, Ter-Martirosyan A Z and Sidorov V V 2016 Properties Procedia Engineering
165 1359-1366.
[9] Telichenko V I and Ter-Martirosyan Z G 2009 Vestnik MGSU 4 22-7.
[10] Ter-Martirosyan A Z and Ter-Martirosyan Z G 2015 Procedia Engineering 111 756-762.
[11] Ter-Martirosyan A Z Ter-Martirosyan Z G and Sidorov V V 2016 Soil Mechanics and
Foundation Engineering 3 10-5.
[12] Ter-Martirosyan Z G 2006 Vestnik MGSU 1 38-49.
[13] Ter-Martirosjan Z G and Nguen Z N 2007 Vestnik grazhdanskih inzhenerov SPbGASU 1(10)
52-55.
[14] Ter-Martirosyan Z G 2009 Soil Mechanics (Moscow, ASV Moscow).
[15] Ter-Martirosyan Z G Ter-Martirosyan A Z and Sidorov V V 2013 Proc of the 18th Int Conf on
soil mechanics and geotechnical engineering 2881-4.
[16] Ter-Martirosyan A Z, Ter-Martirosyan Z G and Sidorov V V Soil Mechanics and Foundation
Engineering, 53 166-173.
[17] Ter-Martirosjan Z G Ter-Martirosjan A Z and Sidorov V V 2014 Estestvennye i tehnicaskie
nauki 11-12 (78) 372-6.
[18] Rzhanicyn A 1968 The Theory of Creep (Moscow, Stroyizdat).
[19] Vjalov S S 1978 Rheological basics of soil mechanics (Moscow, Vyshhaja shkola).
[20] Ter-Martirosyan Z G 1993 Rheological Parameters of Soils and Design of Foundations
(Netherlands, A A Balkema Publishers).