The simplex piles bearing capacity

L M Borozenets¹, E A Ushakova²*
Tolyatti State University, 14, Beloruskaya st, Tolyatti, 445020, Russia

E-mail: tsp@tltsu.ru

Abstract. The results of innovative achievements in the pre-stressed tubular-filled single-drilled piles-foundations construction field are presented. The integrated solution relevance of the scientific and technical problem of developing geotechnical engineering for the considered piles designing efficient structures is shown. For the first time, the physically maximum possible resource carrying capacity of the piles bases under investigation is realized. Geotechnical design of single-hole Simplex piles effective structures allows determining their design dimensions from the bases bearing capacity values equal to the values of critical loads on the pile.

Introduction
Nowadays cast grout piles performed on site in boreholes are widely used. The advantage of bored piles is the possibility of their manufacture with diameters up to three meters in size, the possibility of increasing the bearing capacity of the foundations by stuffing the concrete mixtures using various technologies. The disadvantages of cast grout piles include the relatively small value of the specific bearing capacity of the pile base per cubic volume of concrete, ground removal from the well volume with the base remaining in its natural state, ground loss in the wells walls, the impossibility of improving the wells base grounds quality in the process of their drilling, geo-ecology violation on the site for the Simplex piles construction. In addition, the lack of scientific and technical support of the constructive-technological principle and scientific and theoretical substantiation of the possibility of realizing the physically maximum resource bearing capacity of the drilling and boring piles foundations significantly reduces their practical efficiency. The building these technical means problems solution is connected with the possibility of manufacturing, as a type, promising progressive innovative drilling-pressed pile foundations satisfying the design values of concentrated loads from the structures of the above-ground structures.

A Simplex pile is a rod-like tubular-filled structure in the ground, prepared in a well-drilling design, by means of reinforcement, the dry concrete mix free laying into the pile shell volume and inert drainage aggregate in the inner cavity of the tubular shell with their preliminary tension -the dry concrete mix for hardening project well and the subsequent water saturation volume ground-embossment mechanical extrusion.

The authors made an experimental Simplex pile with a diameter of \( d_1 = 220 \) mm, a length of 3.2 m in clay grounds, shown in Figure 1, by means of a mechanical primer-displacing extrusion from the diameter of the original drill hole to the diameter of the project drilling hole of the tubular string, illustrated in Figure 2.
Figure 1. Photo-view of the tip of an experienced Simplex pile: 1 - a reinforced concrete tubular trunk sheath; 2 - drainage filler

Figure 2. The working element of the composite tubular column, ground-displacing extrusion well of a design diameter

However, the design-technological solution developing scientific and technical problem comprehensive solution lack for ground-embossing by squeezing the original drilling wells foundations for Simplex piles design and geotechnics for designing their rational tubular-filled structures is a deterrent to using their efficiency and physical the greatest possible resource of the bases bearing ability. Therefore, the Simplex piles geotechnical design development for the physically maximum possible foundations bearing capacity is a very popular part of the problem in time. The purpose of this article is to create a drilling drilled single-bed piles effective structures manufacturing and geotechnical design-technological support based on the bases’ physically maximum possible resource bearing capacity values. The purpose of the study defines the following tasks:
- the design and technological support for the prestressed tubular-filled Simplex piles manufacture development;
- the preliminary ultimate stress of the ground around the squeezed pro-project well and material of the pile shaft justification;
- the Simplex piles effective tubular-filled structures geotechnical design creation at the base physically maximum possible resource carrying capacity.

The main content of the research is shown with the obtained scientific results justification. The main conclusions of the study are given. Experimental work with a view to showing the perfect reliability of experimental and theoretical research results is a promising direction of further scientific activity.

Constructive-technological decision of manufacturing a pre-stressed tubular-filled simplex pile

The Simplex pile foundation physically maximum possible bearing capacity initial implementation is achieved in the ground displacement extrusion process from the volume of the original borehole to the volume of the design well during its manufacture. The method of making the pile [1], illustrated in Figure 3 includes the formation of a drill hole 1 in the ground, the reinforcement cage placement in it,
the elementary tube composite element sections installation of the forming column 2 open at the ends, the diameter of which is less than the diameter of the drill hole \(d_b\) by the shell wall piles thickness. Dry concrete mix 3 is poured into the space between the borehole wall and the forming column tube, and subsequently drainage material 4 for the pile shaft entire height to the wellhead into the pipe cavity and conical socket 9 of the forming column 2. The formed column 2 is removed from the well to the design height \(h\), while the conical socket 9 compresses the dry concrete mix 4 and with it helps produce additional ground displacement of the project well \(5\) and ground compaction by pressing out the base to form the calculated five zones of the limiting equilibria state 1 ... 5 of the preliminarily maximizing ground stress keeping it with the compacted drainage material of the aggregate \(4\). The elementary section is disconnected 6 from the column pipe and from the hydraulic cylinder 7 section. Fill an additional portion of the drainage material into the free cavities of two elementary pipe sections 6. The hydraulic cylinder 7 section is connected with the pipe columns. Its rise to the calculated height \(h\) is carried out. Next, the making piles to the wellhead process is made by repeating the above-mentioned operations. The draining material and dry concrete mix are water saturated. After the pile shaft 5 tubular shell concrete hardening, the formwork of its cap 15 is formed, as shown in Figure 4.

Figure 3. Diagram of the forming column 2, the dry concrete mix 3 filling with the tubular shell of the pile shaft, filling the drainage material 4 with the tubular shell filler of the pile shaft, the design contour of the tubular shell of the pile shaft 5, limiting equilibrium state five zones of 1 ... 5 pre-stressed ground

Figure 4. Longitudinal section of a Simplex pile: 4 - drainage aggregate, 5 - the pile shaft tubular sheath, 14 - the compacted ground circular cone, 15 – the pile cap

Technological tool for the method implementation in the form of a forming extrusion column 2 includes a composite pipe with open ends, assembled from elementary sections 6, rigidly connected
using the quick-disconnect joints. The forming working body 8, provided in accordance with the calculated geometrical parameters, determined by the need for additional ground displacement of the project well and the ground compaction by pressing out the maximally stressed ground maximum equilibrium states five zones base, including the length of column pipe 2, fitted in the quick coupling upper end, the bell in the form of a truncated cone 9 and a segment of the forming cylinder 10. The hydraulic cylinder 11, coaxially placed in the separate section 7 cavity of the pipe and the hydraulic cylinder body 1 upper end, rigidly connected to the flange 12 closing the upper end of the section 7, containing a loop for hanging on the load-lifting crane, as well as the lower end of section 7 open for the hydraulic cylinder rod 13 exit, equipped with a quick disconnect joints. In the process of extracting the forming column 2 to a height equal to the length of one elementary section of the pipe h, the hydraulic cylinder 12 rod forces and seals the drainage material in the pipe to a depth equal to two lengths of the elementary sections h. Figure 4 shows a longitudinal section of a pre-stressed tubular-filled brown-extruded pile.

Justification of the preliminary stressed tubular filled simplex piles basis carrying physically maximally possible resource capability implementation

The prestressing of a tubularly-filled Simplex pile and its base is achieved by forming the limiting equilibria states five zones in the process of primary additional ground displacement by the mechanical extrusion for the radius dimensions difference value of the design and initial borehole equal from 50 mm to 70 mm depending on the ground type. By extrusion, preliminary principal maximum normal compressive stresses σ1 are generated, orthogonal to the pile shaft lateral surface, and the main minimum normal compressive stresses σ3, acting along the pile shaft, preserved in the ground by the pile shaft materials preliminary stress.

The base subsequent sedimentary mechanical priming by the vertically loading the prestressed Simplex pile, see Figure 4, the ground from under the circular cone 14 sticks up along the lateral surface of the pile shaft upwards, generating the minimum principal normal compressive stress σ3 orthogonal to the pile shaft lateral surface, which is added to the stress σ1 of the preliminary ground stress, and is generated along the pile shaft lateral surface, the maximum principal normal compressive stress σ1, which is added to the stress σ3 of the ground prestress. Thus, the limit equilibrium states five zones total stress expression is obtained:

$$\sigma = (\sigma_d + c)(\cos \varphi + \sin \varphi),$$

(1)

where $\sigma_d$ is the dry ground skeleton stress specific pressure; $c$ – is a specific grip.

Tangential stresses of resistance to the pile piling into the ground:

$$\tau_1 = \sigma g \theta \psi_1 = \sigma g \psi_1,$$

(2)

$$\tau_5 = \sigma g \theta \psi_5 = \sigma g \psi_5$$

(3)

where $\theta$ defines the angles of internal friction elastoplastic-viscosity; $\psi$, defines the internal friction elastic-plasticity viscosity angles.

The total values of the tangential stress in five zones are:

$$\tau_{0-1} = 0 + \tau_1,$$

(4)

$$\tau_{0-5} = \tau_{0-4} + \tau_5.$$
According to the stress obtained expressions, the Simplex pile base maximum resource of the physically bearing capacity is determined.

**The preliminary-stressed tubular-filled simplex piles designing effective structures geotechnology**

The single foundation piles effect structures geotechnical design under consideration is carried out according to the foundations bearing capacity determined values [2]. According to the calculated design load on a single pile foundation \( P_d \) and the corresponding load bearing capacity \( F_d \), the critical load value \( R_{cr} \) and the maximum bearing capacity \( F_{pr} \) are calculated according to the equals:

\[
P_{cr} = \gamma_z P_d, \quad (6)
\]
\[
F_{lim} = \gamma_z F_d, \quad (7)
\]

where \( \gamma_z = 1.2 \) - the safety factor of the carrying capacity.

The size of the diameter of the barrel of the project pile \( d_b \) is taken based on the particular structures of the above-mentioned ground structure.

The dispersed granular medium clays and loams elastic-plastic viscosity properties resistance limiting equilibria states zones internal friction angles values \( \alpha \) with an exponent \( n = 1.0 \) as a function of \( \tan^n \phi \):

\[
\phi_1 = \phi; \quad (8)
\]
\[
\phi_2 = 22.5^\circ + \phi/2; \quad (9)
\]
\[
\phi_3 = 45^\circ; \quad (10)
\]
\[
\phi_4 = 67.5^\circ - \phi/2; \quad (11)
\]
\[
\phi_5 = 90^\circ - \phi. \quad (12)
\]

The dispersed-discrete and discrete granular media silty and sandy grounds of other types elastic-plastic-hardening resistance properties with the degrees’ indicators \( n = 1.0 \ldots 2.0 \) in equalities:

\[
\tan^n \phi_n = \tan \psi_n, \quad (13)
\]

The pile shaft 14 lower end circular cone base limiting equilibrium state five zones bearing capacity is:

\[
F_{K,1} = A_K \tau_{0-1}, \quad (14)
\]
\[
.............
\]
\[
F_{K,5} = A_K \tau_{0-5}, \quad (15)
\]

where \( A_K \) is the circular cone lateral surface area.

Total critical load on a circular cone

\[
F_{K} = F_{K,1} + \ldots + F_{K,5}, \quad (16)
\]

The length 10 section bearing capacity at the hooded pile. The limiting equilibria states five zones boundaries radii:

\[
R_s = \sqrt{2A_c / \pi}, \quad (17)
\]
\[ R_4 = R_5 \tau_{0-5} / \tau_{0-4}, \] (18)
\[ R_1 = R_5 \tau_{0-5} / \tau_{0-1}. \] (19)

Each ground layer compressible strata thickness between the zone boundaries
\[ \Delta h_5 = R_5 - R_6, \] (20)
\[ \Delta h_4 = R_4 - R_5 \] (21)
\[ \Delta h_1 = R_1 - R_2 \] (22)

The five zones stress collapse sections length on the side to the pile top:
\[ l_2 = \Delta h_2 \] (23)
\[ \text{...........} \]
\[ l_5 = \Delta h_5 \] (24)

Ejection section length
\[ l_0 = l_2 + ... + l_5 \] (25)

The limiting bearing capacity on the section of the stress sprung length 10
\[ F_0 = 0.5 A_0 \sum \tau_{3i} \] (26)

where \( A_0 = ul_0 \) - is the pile shaft side surface area; amount of stress
\[ \sum \tau_{3i} = \tau_{3.2} + ... + \tau_{3.5} \] (27)

The limiting bearing capacity on the truncated conical section of the length of the pile shaft \( l_k = h \)
\[ F_c = A_c \tau_{0-5} \] (28)

where \( A_c \) is the lateral surface area of the truncated cone; \( \tau_{0-5} \) - total value of the tangential stress (11).

Maximum bearing capacity on the length of the pile cylinder in the borehole \( l_b \)
\[ F_6 = A_6 \tau_{0-5} \] (29)

where \( A_6 \) is the lateral surface area of the cylinder in the borehole.

The bearing capacity of the base, coming in the total length of the region \( l_0, l_k \) and \( l_b \) from the stress of the interaction of the concrete of the barrel with the ground \( \tau_b \) [3]
\[ F_{bi} = (ul_0 + u_k l_k + u_6 l_6) \tau_b \] (30)

where \( u_i \) defines the pile shaft sections perimeters.
The pile shaft $l_c$ cylindrical section base on the length maximum bearing capacity is:

$$F_c = u(l_c \tau_{0-5} + l_c \tau_b) \quad (31)$$

$$l_c = F_c / u(\tau_{0-5} + \tau_b) \quad (32)$$

The design pile length is:

$$l_c = l_0 + l_e + l_c + l_b \quad (33)$$

The base $F_i$ limiting bearing capacities are determined to be equal to the values of critical loads on the pile $P_i$ on the limiting equilibria $F_i = P_i$ states five zones. Calculated sedimentary mechanical immersion of vertically loaded extremely stressed tubular-filled single Simplex piles foundations in the ground-displaced bases along the limiting equilibrium $S_i$ states five zones. Based on the obtained values of $P_i$ and $S_i$, a theoretical-calculated non-linear-linear plot of the draft dependence on the load $S_i = f(P_i)$ is built [4, 5]. According to the pile $P_d$ design load, the corresponding stabilized draft sediment $S_d$ is graphically found.

**Summary**

The pre-stressed tubular-filled Simplex piles effective structures geotechnical design positions are based on the funders’ granular media foundations geomechanics innovative theory.

The piles under consideration effective structures design is based on the principle of determining their sizes from the values of the limiting load-bearing abilities on their own bases.

The maximum physically possible resource bearing capacity of the base of a pre-stressed tubular-filled single Simplex pile foundation is realized by means of a primary additional ground displacement of the project well to a radius 50...70 mm exceeding the radius of the initial borehole and subsequent sedimentation mechanical ground repair of the circular with a bottom cone of a vertically loaded single Simplex pile foundation.

The basics of the methodologies, methods and means of computational and theoretical studies of the explosive-high explosive Simplex piles foundations non-existent foundations ability are shown.

A method for determining the critical loads along the limiting equilibria state five zones boundaries is presented.

For the first time, the precipitation plot dependence calculating and theoretical construction possibility on the load according to the critical loads’ values and the corresponding sediment at the limiting equilibria states five zones boundaries is shown, which is absolutely appropriate in terms of experimental accuracy.

The possibility of graphical determination of the limiting stabilized sediment by the value of the design load on a single pile foundation is presented.

**References**

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