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Tension of ground pressure on the foundations of railway catenary supports

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Abstract. This paper presents the results of calculations of the values of soil pressure stresses on the base of the contact network supports by the developed program NDGFOKS in the programming language - C#. Design and construction of the foundations of the contact network supports is provided in accordance with the requirements of regulatory documents and technological charts. When selecting the methods of fastening the overhead contact network supports in the ground of the earth bed, experience in construction of overhead contact network supports in various engineering and geological conditions was taken into account. The methods of calculation of load-carrying capacity of the contact network bases on the ground were analyzed. Methods of fastening the overhead contact network pylons, including those on the weak ground bases, were given. The NDGFOKS program has been developed in the C# programming language in order to calculate the stresses of soil pressure on the foundation faces. The program has been developed taking into account the variety of soils, the characteristics of foundations and the methods of their driving. A block diagram and a diagram of the stresses of soil pressure on the foundations of the contact network supports at different foundations are given.

1 Introduction

An electrified railroad can be considered as a transport natural-technical system (TNTS), which consists of homogeneous elements - engineering structures. Each element of such a system performs certain functions, being in dynamic equilibrium interacting with other elements. Maintaining the system, its subsystems and elements in a state of equilibrium is the main purpose of TNTS management in compliance with the normalized levels of environmental, economic and technical (functional) safety of the system as a whole [1]. Technical safety involves ensuring the structural reliability of the contact network supports [2].

The bases of contact network supports are designed and constructed according to the requirements of normative documents [3-6] and technological charts [7] on the types of construction and installation works.

The foundations of catenary supports ensure reliable operation of the catenary network during their service life. Three-beam steel foundations, as well as foundations of increased reliability and wedge-shaped anchors are mainly used to support the contact network of

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railroads. On unstable embankments in complicated engineering and geological conditions, pile and pile-rover foundations are provided for installation.

It is recommended to select the methods of anchoring the contact network supports in the ground of the earth bed on the basis of [3-6]:

– results of engineering-geological, hydrogeological, permafrost surveys and data on climatic conditions of the area of electrification or modernization and overhaul of the contact network;

– experience in constructing catenary supports in similar engineering and geological conditions of electrification implementation;

– data characterizing the overhead contact network to be constructed or upgraded, type of current, load on the overhead contact system and poles and operating conditions of the overhead contact system;

– local conditions for electrification and modernization of the overhead contact line network.

The loads from the overhead contact line supports are transferred to the ground. For normal operation of the overhead contact system, the ground stresses on the foundation should be such that they do not cause the tower to tilt. All devices that ensure the stability of the support are called ground anchors.

The catenary supports can be anchored using different foundations, which are buried in the ground by about 2 m or more. The part of the ground that absorbs the pressure of the foundation is called the foundation. The distance from the surface of the ground to the base of the foundation is called the depth of the foundation. The depth of the foundation is determined by calculation. For a single foundation, the horizontal plane that passes through the intersection point of the vertical axis of the foundation with the ground surface is taken as the design ground surface, or, if there is a loose packed layer (sand ballast, slag, etc.), with the bottom surface of this layer [3].

Before designing the anchorage of contact network supports in the ground, it is necessary to conduct geological and hydrogeological surveys, determining the physical and mechanical characteristics of soils.

Quality assurance of works on electrification of railroads with a variety of required conditions and factors, which are to be taken into account and regulated, provides for appropriate scientific methodological and technical-technological support [8].

2 Objects and methods of research

2.1 Analysis of the methodology for calculating the load-carrying capacity of contact network pylons foundations on the ground

In order to ensure the required bearing capacity of the foundations of contact network supports in different soil conditions, standard or individual design solutions are used.

If the load, the resultant force is located in one vertical plane of symmetry of the foundation, its stable attachment to the ground is considered to be secured if the values of design moment M^d and design vertical force N^d satisfy the conditions [3, 9, 10]:

$$M^d \leq M_f; \quad (1)$$

$$N^d \leq N_f, \quad (2)$$

where M_f is the design load-carrying capacity of the foundation on the ground for the action of the moment or the horizontal force, applied at the height H; N_f is the design load-carrying capacity of the foundation by the soil under the action of the vertical force.

The bearing capacity of the foundations of the contact network supports on the ground is determined in accordance with the method described in [3, 11], which is based on the experimental and theoretical studies conducted by E.P. Kryukov, K.S. Zavriev, and G.S. Shpiro [12]. The foundations of the contact network supports are calculated using the method of limiting states (Fig.1).

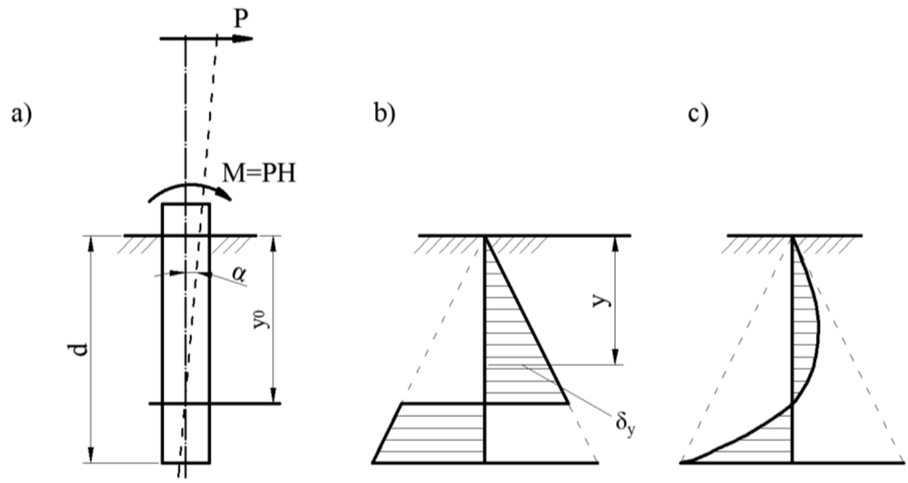

Fig. 1. Diagrams of the soil pressure on the side surface of the foundation of the contact network supports under the action of horizontal load:
(a) Scheme of the action of the load on the foundation,
b) soil pressure diagram in the limiting state,
c) the same in the elastic stage.

This calculation method is based on the epiure of soil pressure along the front and back faces of the foundation proposed by S.M. Kudrin (Fig. 1, b) [2]. This diagram reflects well the interaction of a foundation with the soil in the limiting condition corresponding to a full exhaustion of the soil resistance over the whole depth of the foundation when it is rotated [12]. To determine the internal forces in the cross-sections, the foundation's activity is considered in an elastic medium, and a parabolic epeure of soil resistance is used in the calculations (Fig. 1, c). Such an epiure is used, for example, in the German standards for the design of contact network support structures [13].

When vertical and horizontal forces act on the foundation without taking into account the ground friction on its lateral faces, tensions σ_y of ground pressure on the front face of the foundation (at the section from $y = 0$ to $y = 0$) and on the back face of the foundation (at the section from $y = y_0$ to $y = d$) arise in the ground, the size of which in each point of these faces is directly proportional to the depth y of location of this point from the design ground surface [3, 14-17]:

$$\sigma_y = \frac{R_g \cdot y}{b_f} \quad (3)$$

where R_g is the proportionality factor that represents the design resistance of soil at the depth $y=1$ under the conditions of the spatial problem (at the foundation width equal to b_f); b_f is the size of the foundation's cross-section in the direction perpendicular to the plane of the load;

The value of the proportionality factor R_g kN/m^2, characterizing the change in the pressure with depth at $b_f \geq 0.3$ m, is determined by the formula [3]:

$$R_g = k_g R_u (b_f + C_f) \tag{4}$$

where R_u is the proportionality factor (kN/m^3) representing the ultimate (normative) resistance of soil at the depth $y=1$ under the flat problem (with the foundation width equal to $b_f = 1$); C_f is a ground characteristic, m, that takes into account the spatial work of the foundation.

When designing, in order to determine the value of the carrying capacity of a given foundation, the conditional foundation is calculated, and then the obtained value is multiplied by the working conditions factors that take into account the actual factors that affect the carrying capacity of the given foundation in the soil [18-21]. A prismatic foundation of rectangular cross-section (Fig. 2), installed on a horizontal site in the absence of a railroad track in the immediate vicinity, is considered as a conditional foundation.

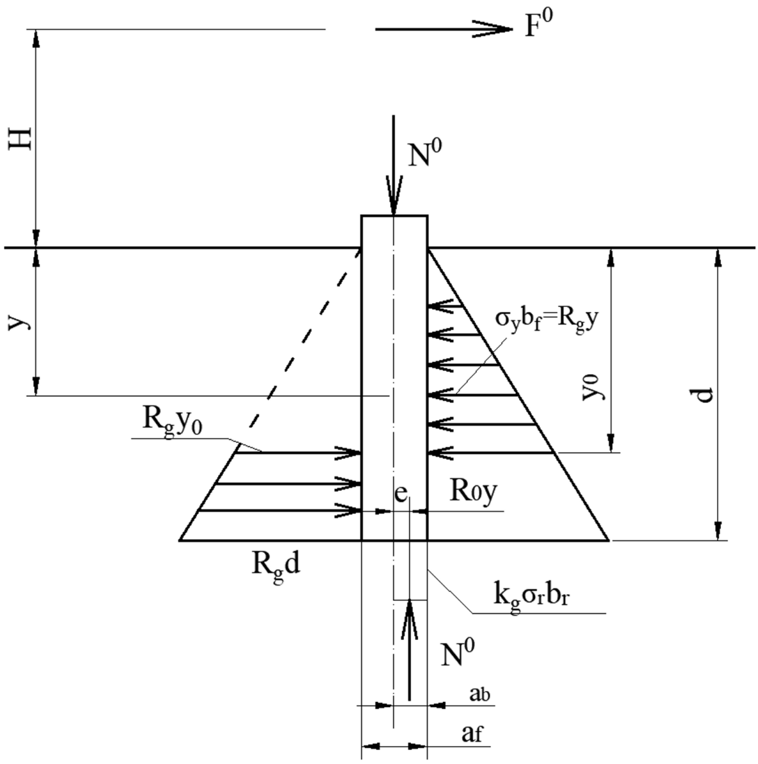

Fig. 2. Calculation diagram of a notional prismatic foundation.

2.2 Methods for securing the catenary supports

The supports can be fixed in the earth bed on sections of stable earth bed made of strong bulk soils and located on a solid base mainly with the use of shallow foundations. In this case, foundations can have a different design and be made of concrete, reinforced concrete, metal. The design of foundations is determined on the basis of technical and economic calculations and available experience in the construction of contact network supports [22, 23].

The depth of the foundations or the foundation part of the undivided supports shall be determined by calculation. In this case, the calculation must ensure that [24, 25]:

– from the action of design loads - sufficient bearing capacity of the foundation, not allowing the loss of stability of foundations and supports;

– from the action of operating loads - guaranteed deformation of the foundation, not exceeding the maximum allowable under operating conditions slopes of supports at the level of contact wire.

On the sections of the earth bed located on weak ground bases, it is recommended to fix the supports in one of two ways:

– by application of foundations located entirely in the strong soil of the embankment and located above the level of the layer of weak soils. It is advisable to design such foundations with an enlarged side edge in the direction of the load from the contact network and a base plate in the lower part of the foundations;

– by using pile foundations with a length of 6 to 10 m, resting on the dense soil located below the weak soil. To ensure the load-bearing capacity of the piles, depending on the loads involved, foundations can be made of both single piles and groups of piles.

Taking into account these recommendations given in the All-Russian Scientific Research Institute, the second method of fastening of catenary supports is considered, since due to the resistance of the side surface of the pile foundation, the bearing capacity of catenary supports can be ensured depending on the loads in force.

The first method of securing the catenary supports is not considered, since foundations with a widened side edge in the direction of the load from the catenary network and a baseplate in the lower part of the foundations are not possible to install completely in the strong soil of the embankments.

In especially unfavourable areas, it is recommended to secure the supports in the ground by means of deep foundations. For this purpose, reinforced concrete or metal piles with a length of 8-10 m should be used.

3 Results and their discussion

3.1 Calculation of soil pressure stress on the foundation face

To calculate the stress of soil pressure on the foundation face, the program NDGFOKS was developed in the programming language C#. Figure 3 shows a block diagram of calculating the ground pressure stress on the foundation face of the contact network supports. The program for calculating the stress of soil pressure on the foundation face was developed taking into account the following data and designations:

– types of soils - i (0 - sand of coarse and medium coarseness, clays, loam and sandy loam are hard; 1 - sand is fine, clay, loam and sandy loam are tight plastic; 2 - sand is dusty, clay, loam and sandy loam are soft plastic; 3 - sandy and clay with an admixture of plant residues; soddy, fused in the foundation of the earth bed);

– the shape of the foundation cross-section j (0 - rectangular; 1 - circular or circular; 2 - double-beam; 3 - triple-beam);

– foundation types and driving methods - k (0 - foundations installed in pits, manually excavated, drilled or otherwise (buried); 1 - pile foundations with continuous cross-sections and hollow foundations driven with the closed end; 2 - pile foundations with hollow, open end, double- and triple-beam foundations; 3 - clear foundations driven into the ground with a vibratory plunger);

– cross-sectional area of the foundations - s;

– the height of the embankment - d_1;

– depth (length) of the foundation - d (3.5; 4.0; 4.5 and 7.5 m);

– width of the earth bed - B_{zp}.

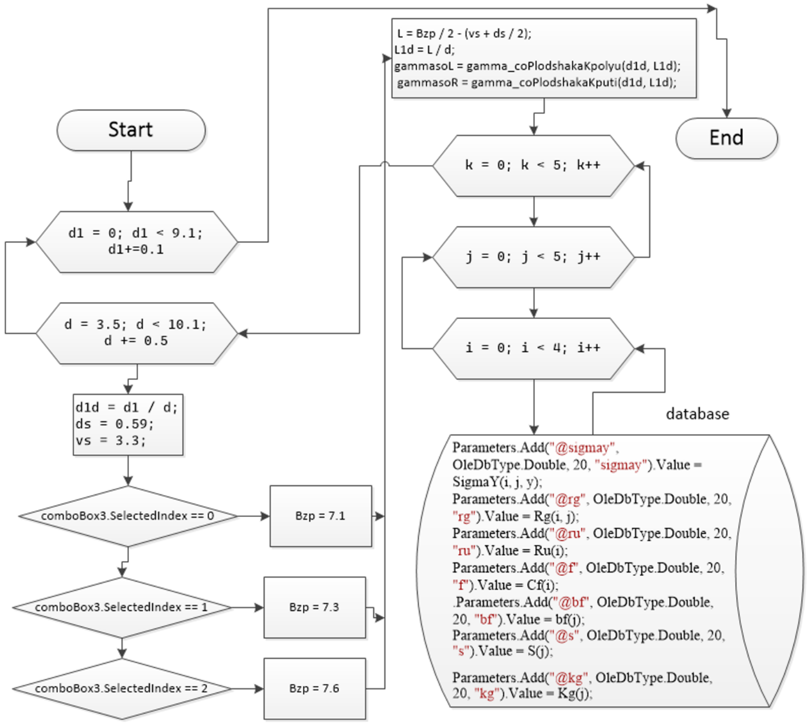

Fig. 3. Block diagram for calculating the stress of the soil on the faces of the foundations of the catenary supports

The results of calculating the soil pressure stress on the foundation faces using the NDGFOKS program are shown in Table 1. The stress diagram of the soil pressure on the foundations of the catenary supports for various foundations is shown in Figure 4.

Table 1. Tension of ground pressure on the foundations of the overhead system pylons

Form of foundation cross-section, depth of embedding, m	Soils, varieties	Tension of the soil pressure on the foundation, kN/m^2
Three-beam, d=4.5	Coarse and medium sands	671.37
	Fine sands	478.85
	Dusty sands	346.03
	Sandy	204.51
Three-beam, d=4.0	Coarse and medium sands	596.78
	Fine sands	425.64
	Dusty sands	307.58
	Sandy	181.79
Three-beam, d=3.5	Coarse and medium sands	522.18
	Fine sands	372.44
	Dusty sands	269.13
	Sandy	159.07
Rectangular, d=7.5	Coarse and medium sands	1118.96
	Fine sands	798.08
	Dusty sands	576.72
	Sandy	340.86

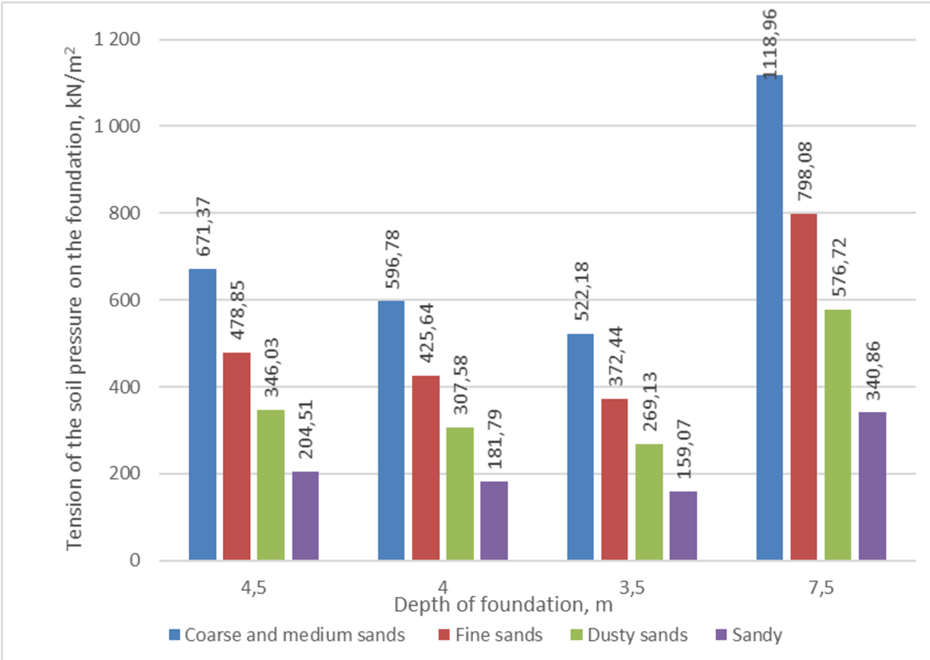

Fig. 4. Stress diagram of the soil pressure on the foundations of the catenary supports

4 Conclusions

For normal operation of the contact network, the ground pressure stresses on the foundation faces must guarantee its stable anchoring in the ground and ensure the bearing capacity of the foundations of the contact network supports of railroads.

The methodology for calculating the load-carrying capacity of the foundations of the contact network supports on the ground is based on the ground pressure diagram at the front and rear faces of the foundation. When vertical and horizontal forces act on the foundations without taking into account the friction of soil on their side faces, the soil stresses σ_u of soil pressure on the front face of the foundation and on the back face of the foundation occur in the soil.

When designing to determine the bearing capacity of a given foundation, a conditional foundation installed on a horizontal site in the absence of a railroad track in the immediate vicinity is calculated.

In order to ensure the bearing capacity of the supports depending on the existing loads, the method of fixing the contact network supports through the use of pile foundations of 6 to 10 m in length has been considered.

NDGFOKS program has been developed in C# programming language and a block diagram for calculating the soil pressure on the foundation faces of the contact network supports.

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