Assessment of the Operability of a Low-depth Concrete Anchor of Overhead Line of Type AM using Modeling

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Abstract: The article analyzes the design of a concrete low-depth anchor of overhead line of type AM. This design was recently developed by Tolmachevsky Plant of Reinforced Concrete and Metal Structures. It is fundamentally different from the design of widely used three-beam reinforced concrete anchors of the overhead line. To assess the operability of the structure, a finite element model of the anchor itself placed in the ground was created. This model is two-dimensional, taking into account plastic deformations of soil and concrete, as well as mechanical contact of these materials. As a soil, sand is considered as weakly bearing: the worst conditions during operation. According to the calculation results, the fields of equivalent mechanical stresses and pressures arising in the soil and concrete are determined. The analysis of the results confirms the operability of the AM anchor in the considered ground conditions with a force in the anchor cable of the overhead line up to 90 kN inclusive.

1 INTRODUCTION

LLC Tolmachevsky Plant of Reinforced Concrete and Metal Structures has recently developed a design of a concrete low-depth anchor of the overhead line of type AM. It is fundamentally different from the design of widely used three-beam reinforced concrete anchors of the overhead line. For example, reinforcement is completely absent, its weight and dimensions are significantly larger than the standard existing anchors of the overhead line. The manufacturer has applied for a patent for this design. For this reason, the manufacturer does not provide the results of calculation and physical tests of such a design for the operating organization Directorate for Energy Supply of JSC "Russian Railways". In this regard, the anchor's operability was checked in a calculated manner.

The calculation of such a structure by analytical methods set out in regulatory documents (Standards for the design of the overhead line STN CE 141-99, 2001; BSI Standards Publication, 2020) concerning calculations and standards for the design of an overhead line seems extremely complex and not fully adequate, since all formulas are focused on the main types of existing foundations with deep laying. In addition, the top layer of soil up to 0.3 – 0.5 m is usually considered non-bearing, i.e. conditionally not resisting. Thus, the AM anchor is located almost completely in a non-bearing layer.

Therefore, the calculation was performed using simulation in the COMSOL Multiphysics software package license number 9601577 in a two-dimensional formulation.

2 MAIN PART

2.1 Materials and Methods

The calculation was performed on a two-dimensional model. A concrete anchor with a steel eye for the anchor guy is buried in the ground at 0.5 m. The geometry of the computational domain with signed materials is shown in Fig. 1. Sand was chosen as the soil as a weak-bearing one, concrete was taken from the B30 grade, carbon steel was used for mounting with an eye.

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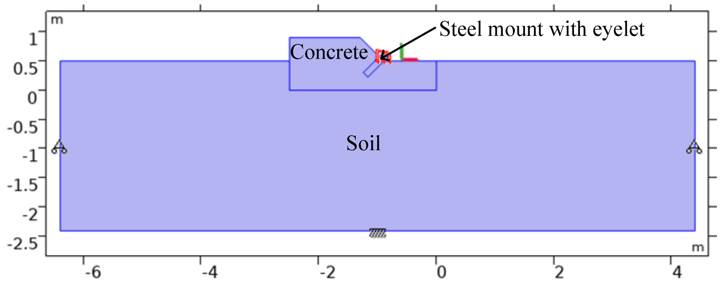

Figure 1: Geometry of the calculated area with signed materials.

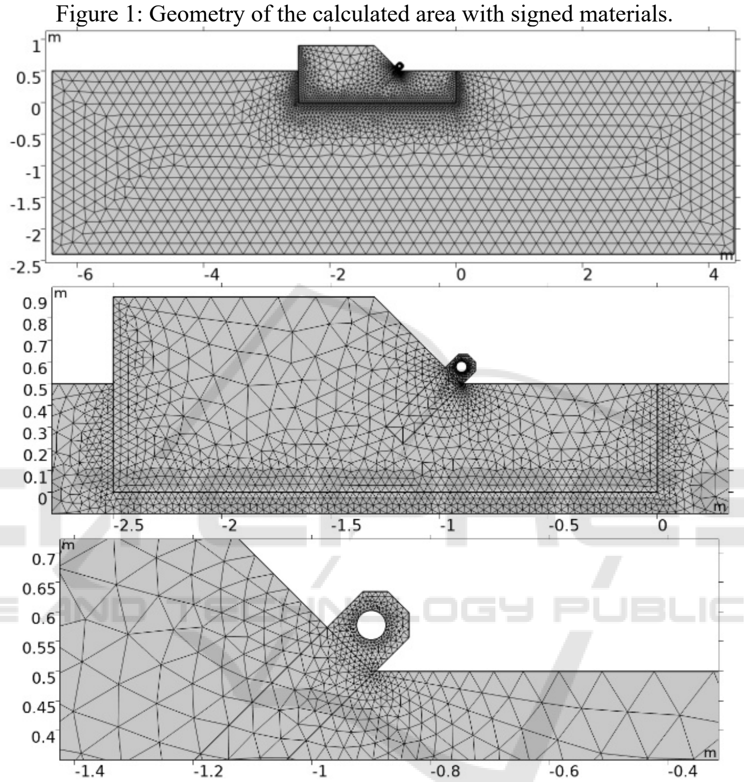

Figure 2: The finite element grid used in the calculation.

The COMSOL Multiphysics software package uses the principle of virtual operation to describe continuum mechanics. This principle states that the internal work performed by infinitesimal deformations under the influence of internal stresses is equal to the external work performed by the corresponding virtual displacements under the influence of external loads. For this purpose, Green-Lagrange deformations and second Piola-Kirchhoff stresses S (Pascon, 2013) are used. Such a formulation is commonly called a complete Lagrangian. The displacement field **u** is used as the calculated variable (u is the horizontal component, v is the vertical component). In the described two-dimensional model, the hypothesis of plane displacements is accepted.

A linear elastic model was chosen for steel, i.e. there are no plastic deformations. Plastic deformation models are set for concrete and soil. The model of plastic deformation for soil was adopted by Drucker — Prager (Wojciechowski, 2018; Liu, 2017) with the calculation of its coefficients based on the adhesion c and the angle φ of the internal friction of the soil (Jiang, 2012). Plastic deformation is specified for concrete according to the Ottosen model (Ottosen, 1996; Zhang, 2020).

Normal zero normal displacements are set on the lateral boundaries of the soil: $\mathbf{n} \cdot \mathbf{u} = 0$. The condition of immobility $\mathbf{u} = 0$ is set at the lower boundary of the soil.

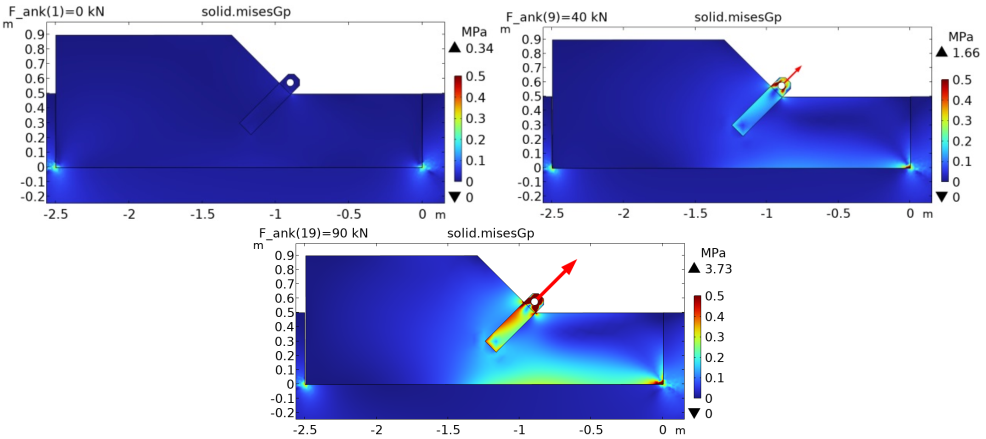

Figure 3: Plot of equivalent Mises stresses with a guyline force of 0, 40 and 90 kN (red arrow).

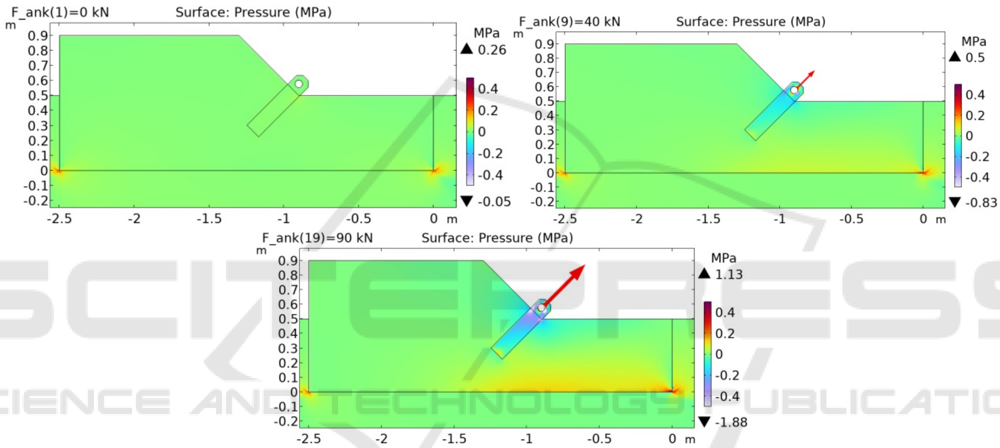

Figure 4: Plot of the pressure inside the material at a guyline force of 0, 40 and 90 kN (red arrow).

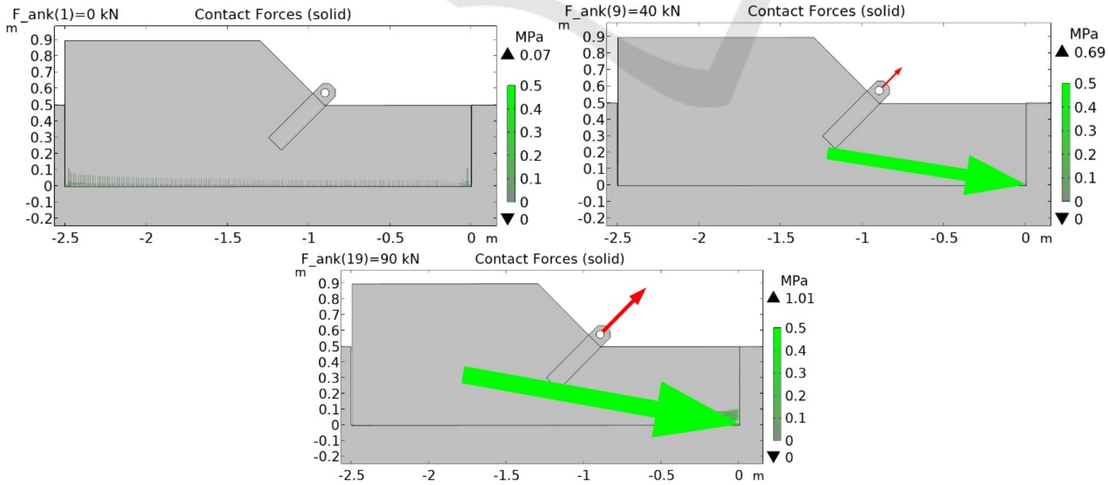

Figure 5: Plot of the pressure arrows on the contact surface (the color is the value of MPa, the size of the arrow is proportional to the pressure value in a logarithmic scale with a base of 10) with a guyline force of 0, 40 and 90 kN (red arrow).

A mechanical contact is used at the boundary of the soil and concrete junction. In this case, the contact pressure is calculated by the penalty method based on the field of concrete and soil movements. On the connection line of the steel fastening with the eye and the concrete foundation, the condition of continuity of the displacement field **u**. The upper boundary of the eyelet is given by the force F_{anc}. When calculating, it incrementally increases from 0 to 90 kN.

The distributed volumetric force from its own weight is set throughout the volume.

The finite element grid is shown in Fig. 2.

The type of finite element is quadratic serendipitous. Since mechanical contact is assumed, geometric nonlinearity is taken into account in the model. In other words, the equilibrium conditions are written taking into account the deformation.

The solution is in two stages by gradually increasing the nonlinearity.

Stage 1: the strength of the anchor guy $F_{ank} = 0$, under the action of its own weight, there is a gradual stabilization of the contact between the soil and concrete. To do this, the lower limit of the contact pressure gradually decreases from large values to zero and the soil adhesion gradually decreases from 0.1 to 0.03 MPa. Below 0.03 MPa, the solution is not stable. At the same time, the anchor sags slightly in the ground, the contact pressure is distributed mainly along the sole.

Stage 2. Starting from the final result of stage 1, the strength of the anchor guy begins to increase step by step from 0 to 90 kN. The anchor is shifted to the right and slightly upwards. The contact pressure is redistributed mainly to the lower right corner of the anchor. At $F_{ank} > 93$ kN, the solution is not found. There are too large plastic deformations.

2.2 Results and Discussion

The main results are presented in the plot of equivalent stresses according to Mises (Fig. 3), the pressure inside the material (Fig. 4) and the contact pressure (Fig. 5) at a force in the anchor tie F_{ank} of 0, 40 and 90 kN. The magnitude of the stresses is indicated by color, the color scale is on the right. The red arrow indicates the force in the anchor tie.

The figure shows a graph of the horizontal and vertical movement of the eyelet from the magnitude of the force in the anchor tie F_{ank}.

According to the results of the calculation on a finite element mathematical model, it follows that the specified anchor withstands the traction force in the anchor tie at least 90 kN when 0.5 m is sunk into the ground with characteristics close to sand. The density, the angle of internal friction and Young's modulus correspond to sand, and the adhesion of 30 kPa is closer to loam. For sand, the adhesion is up to 8 kPa. However, with a value less than 30 kPa, the calculation cannot be performed.

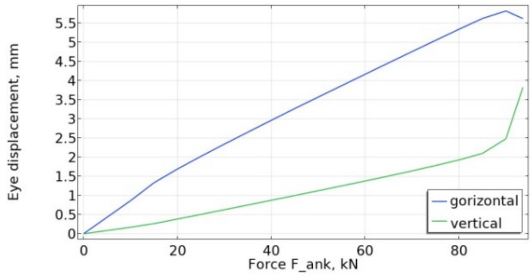

Figure 6: A graph of the horizontal and vertical movement of the eyelet from the magnitude of the force in the anchor tie F_{ank}

The anchor weight is approximately 6.2 tons, which is three times more than three-beam anchors. The work of the AM anchor is provided by contact pressure on the ground in the lower right part from the side of the anchor guy. It can be said that the anchor conditionally "cuts" the soil at this angle and thereby perceives the force in the anchor tie, due to the resistance of the soil.

The movement of the eyelet is no more than 7 mm with a guyline force of 90 kN. This is three orders of magnitude less than the length of the anchor guy and, accordingly, the shift of the anchor under load will not lead to a significant weakening of the guyline force.

It follows from the pressure diagram inside the concrete that the greatest compression (positive pressure) occurs in the lower right part of the anchor. Most of the left (protruding from the ground) side of the anchor experiences a slight compression pressure due to its own weight. The stretched area of concrete with negative pressure is located near the metal anchorage for the anchor guy. But there the modulo negative pressure is not great. It should be noted that the design of the steel fastening in the model is reproduced approximately. From the point of view of the strength of concrete, there are no large stretching zones in it, which explains the lack of reinforcement. The maximum compression stress occurs at the lower right corner, where the greatest contact pressure with the ground. It is not more than 0.5 MPa, which is significantly lower than the calculated permissible compression resistance of concrete B30 equal to 17 MPa.

3 CONCLUSIONS

Thus, it can be said that according to the simulation results, the design of the AM anchor is operable under the specified conditions of sinking even in a weakly bearing sand-type soil.

It is worth noting that there remains the question of the expediency of using such anchors and the conditions for their use. It is hardly possible to install them on embankments and recesses, only at zero levels and with reasonable necessity. They have relatively large dimensions, a larger amount of excavation work will be required during installation and a crane of the appropriate lifting capacity.

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