Forecast of Settlements of Aluminium Raw Material Elevator Foundation

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Abstract: This paper is devoted to the calculation of the settlements of the aluminium raw material elevator foundation in the sea port of the city of Murmansk, Russia. A bedplate is more than 4 m high and is arranged below the layout surface, the technological rooms of the elevator are situated inside it. Besides, the foundation has the special friction piles which can be involved into the operation, if necessary. The necessity of the involvement of the piles is determined according to the values of the settlements of the foundation. The settlements are calculated according to three-dimensional model with the help of the boundary element method. Various physical and mechanical characteristics of the foundation soils according to the layers, porous overpressure in the soils and stress-strain state (SSS) changes which take place when the friction piles are involved into the operation of the foundation are taken into consideration when the calculations take place. Due to the calculation results the values of the settlements of the elevator foundations with time have been determined as well as an optimal operation mode of the construction (the rate and the order of loading).

Key Words: boundary element method, elevator, friction piles, stress-strain state.

Introduction

A calculation of the settlements of the foundation of the elevators is considered to be rather a difficult dimensional task which is complicated by the fact that the loads on the foundation vary within the large range and during a short period of time. The rate of loading and unloading depends only on the capacity of the mechanisms and the rate of the arrival of the transport means. A diagram of loading also plays an important role for such constructions as the elevators. Thus, for example, if an elevator consists of two silos which rest on one common rigid foundation, the distribution of the raw material mass from one silo into another (unloading of one silo with the simultaneous loading of another) can lead to such a change of the SSS of the foundation when it loses stability. SSS is influenced greatly by porous water pressure. This pressure leads to a reduction of normal component of the stresses when the tangential stress values remain the same. As a result, the soil shifts can take place along some slip surfaces and due to it the constructions being loaded not in their centres can overturn. Such cases are known (for example, Transkon elevator, Canada, 1913).

Elevator Design

Design solutions of the foundations, the main tanks for aluminium raw material and production equipment which provides loading and unloading of the elevator's silos are
worked out by St.-Petersburg institute “LenmorNIIproject”. The total capacity of the elevator’s silos comprises 20000 tons (200 MN). A rigid hollow plate made of monolithic reinforced concrete with the dimensions 40×22 m in the plan is suggested as the foundations. Thickness of the plate which has box section is equal to 4 m (Fig. 1).

Fig. 1 Aluminium raw material elevator construction in the sea port of Murmansk

Production equipment is arranged in the hollows of the foundation plate. In addition, the box plate has the cast-in-place friction piles arranged along the short side of the foundation. The piles are connected with the plate in such a way that the piles being to take part in the operation only in case of a sharp increase of the settlements or the turns of the elevator. Such solution has allowed to control the value and velocity of the settlements and the tilts have provided the normal operation of the technological equipment.

Soil Basement Structure

The soils in the basement of the elevator being designed are presented mainly by sedimentary rock. According to the data of the engineering and geological surveying, till the mark of -2.5-3.4 m in the lithological section the plastic loams are met with an angle of internal friction of φ=15° and adhesion c=0.002 MPa. Till the mark of -8.2-9.6 m the dust-like sands are met with an angle of internal friction of φ=22° and adhesion c=0.006 MPa. Till the mark of -15.5-16.7 m the plastic sand loams are bedded (φ=16°, c=0.01 MPa), till the mark of -19.3-20.6 m the clay silts are bedded with the interlayers (up to 10%) of dust-like, water saturated sand with an angle of internal friction of φ=8°, c=0.005 MPa. Then till the surveyed depth of -60 m grey dense semi-solid clay is bedded with φ=19°, c=0.03 MPa. The surveying being carried out as well
as the laboratory investigations of the basement soils have allowed to find in soil thickness a number of engineering and geological elements (EGE) some data of which are specified in Table 1.

Physical and mechanical data of the basement soils

<table>
<thead>
<tr>
<th>No. of EGE</th>
<th>Layer toe mark, m</th>
<th>Lithological description of soil</th>
<th>Young’s modulus, MPa</th>
<th>Coefficient of permeability, m/day</th>
<th>Angle of internal friction, °, degrees</th>
<th>Adhesion c, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-3.0</td>
<td>Plastic loam</td>
<td>13.0</td>
<td>0.0015</td>
<td>15</td>
<td>0.02</td>
</tr>
<tr>
<td>2</td>
<td>-9.0</td>
<td>Dust-like, water saturated sand</td>
<td>21.0</td>
<td>0.3</td>
<td>22</td>
<td>0.006</td>
</tr>
<tr>
<td>3</td>
<td>-16.0</td>
<td>Plastic sand loam</td>
<td>14.5</td>
<td>0.02</td>
<td>16</td>
<td>0.01</td>
</tr>
<tr>
<td>4</td>
<td>-20.0</td>
<td>Silt with interlayers of water saturated sand</td>
<td>3.0</td>
<td>0.005</td>
<td>8</td>
<td>0.005</td>
</tr>
<tr>
<td>5</td>
<td>-60.0</td>
<td>Semi-solid clay</td>
<td>20.0</td>
<td>0.00001</td>
<td>19</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Poisson’s ratio is within the limits of 0.28-0.35 for the soil represented in Table 1 and can be assumed equal to 0.3. Underground water is found on the depth of 2-2.5 m from the earth surface.

Acting Loads and their Alteration Mode with Time

When the basement and the foundations of the elevator have been designed, the following loads have been taken into account:

- the own weight of the constructions of the elevator and the foundation plate;
- wind load;
- snow load;
- load from railway and automobile transport when unloading work takes place;
- engineering load from the weight of aluminium raw material being loaded into the elevator’s silos.

The development of the settlements and tilts of the constructions has been investigated for different combinations of the acting loads the calculation diagram of which is given in Fig. 2.
Taking into account of the consolidation processes plays a significant role for the calculations of water saturated soil basements. That’s why it is necessary to take into consideration not only the value of the loads, but their change with time. The most unfavourable combinations of loads (from the point of view of the soil basement behaviour) as well as the alteration mode of the engineering loads with time are shown in Fig. 3.
As it is seen from Fig. 3, the elevator operation mode is considered to be the most unfavourable one when after the long-time (2 months) loading of one silo its complete unloading takes place during the short time (2 days), and at once the second silo is loaded. In this case, under the unloaded part of the plate, the negative pore water pressure appears which facilitates a loss of the general stability of the basement soils.

**Calculation of Soil Foundation of Elevator**

The stress-strain state of the soil foundation has been calculated with the boundary element method with the help of the model of the volumetric forces. The elastic isotropic halfspace is accepted as the main calculation model, and Mindlin's solution [1] for the concentrated force arranged inside halfspace is considered to be a fundamental solution. The theoretical principles of the calculation are discussed by the author in the paper [2]. The numerical realization has been carried out with the help of the personal computer by means of working out of the computer program "ELEVATOR". The most characteristic diagrams of stresses and pore pressures on different stages of loading are represented in Figs 4 – 8.

Fig. 4. Pore pressure (a) and $\sigma_1$ stress (b) in soil skeleton, Kpa in the plane $y = 0$ at $t = 362$ days (12 months)

Fig. 5. Pore pressure (a) and $\sigma_1$ stress (b) in soil skeleton, Kpa in the plane $y = 0$ at $t = 420$ days
Fig. 6. Pore pressure (a) and $\sigma_2$ stress (b) in soil skeleton, Kpa in the plane $y = 0$ at $t = 422$ days

Fig. 7. Pore pressure (a) and $\sigma_2$ stress (b) in soil skeleton, Kpa in the plane $y = 0$ at $t = 424$ days (14 months)

Fig. 8. Pore pressure (a) and $\sigma_2$ stress (b) in soil skeleton, Kpa in the plane $y = 0$ at $t = 540$ days (18 months)
The alteration of the settlements and rotation round axes \( x \), \( y \) with time are shown in the diagram of Fig. 9.

Fig. 9. Settlements of elevator foundation in point \((0, 0, 0)\) and rotation round axes \( x \), \( y \)

The computations carried out with the help of the program "ELEVATOR" have helped to forecast the value and velocity of settlements in point \((0, 0, 0)\) and the rotation round axes \( x \), \( y \) of the fundamental plate of the elevator. The computation results have been used in order to provide a safety operation of the construction and the production equipment as well as stability of the soil basement. They have helped to select an optimal production mode of loading and unloading of the elevator's silos which excludes the possibility of the alarm (critical) stresses in "construction – soil foundation" system.

Conclusions

1. The results of the computations carried out with the help of the computer program "ELEVATOR" show that from the point of view of the behaviour of water saturated soil basement such mode of loading and unloading of the elevator’s tanks is considered to be the most unfavourable one when after the long-time loading of one silo (during 1-2 months) its comparatively quick unloading (during 1-2 days) takes place with the subsequent loading of another silo.

2. As the computations have shown, the elevator foundation design worked out by the institute "LesniiNIiproject" which includes the special friction piles provides soil basement stability and permissible values of the stresses of the construction under any most unfavourable production modes of operation.
References

