Determination of the main technical reasons for the fall of pile driving machine near the slope of the foundation pit

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Abstract. The study was conducted to determine the main technical reasons for the fall of the pile-driving machine that occurred when driving-in of piles in the immediate vicinity of the slope.

As a result, slope stability of the soil in the process of driving-in of reinforced concrete piles near the slope crest of the underlying pit was determined. The calculations were performed using the following four well-known methods: methods of Fellenius, Krey, Terzaghi, Chugayev. The loss of stability of the soil was caused by the imbalance of external and internal forces (the presence of construction equipment and stored materials near the slope and its dead load). The calculations were performed for six loadcases of the earth wall. The article presents in detail the case in which the slope collapsed.

The importance of the results for the construction industry lies in the need for a comprehensive study of safety issues at all stages of the life cycle of construction projects, starting with the preparation of a design assignment, surveys, design, construction, operation, repair, reconstruction, etc.

Keywords: injuries, an accident, the stability of a slope, slope crest, wedge of failure, pile driving machine.

1 Introduction

Construction is one of the most dangerous industries. A significant number of production factors that constantly or potentially accompany the construction process explains this fact. It can also be noted that the existing level of industrial injuries in construction, including fatal ones, remains comparable to the level of injuries in other hazardous industries (for example, transport, agriculture, etc.). Despite the fact that the quantitative decline in injuries in the country is decreasing, work-related injuries, occupational diseases and fatalities lead to human and material losses. [1-6]. However, such a decrease is not associated with a significant improvement in production conditions of work and with the motivation to work without violating safety requirements. For now, it is impossible to create such conditions in the field of labor safety generally in the industry of construction in particular, when the level of safe work must be guaranteed. An example of ensuring the organization of safe work is technical research and solutions to strengthen the deep excavation during the construction of a residential building with multi-level parking in constrained conditions in Kazan [7].

Federal Law of December 30, 2009 № 384-FZ “Technical Regulation on the Safety of Buildings and Structures” requires ensuring safety at all stages of the life cycle of an object (building, construction), starting from the development of design assignments, engineering and geological research, design, construction, supervision during construction, operation, etc. It follows that for high-quality and safe construction work during the construction process itself [8], during major repairs, reconstruction and demolition work, it is necessary to take into account the experience of high-quality
design of construction projects and carry out their technical expertise [9], inspect the condition of existing buildings and their structures [10-12], use new effective building materials [13-15], new and modern building machines and mechanisms [16-21], accompany construction work [22]. Also, systematic monitoring of the engineering status of buildings should be carried out during the operation of construction sites [23].

The construction industry faces daunting tasks in building new, repairing, reconstructing and restoring existing capital facilities, and current economic conditions of the industry do not meet these requirements. Nowadays the construction industry in the country lacks qualified workers, line managers at construction sites (masters, foremen).

This article is written as a result of studying the causes of violations of the law during the construction of an industrial facility, as a result of which soil masses of the slope of the pit collapsed and overturning of the pile driving machine happened, which was driving-in reinforced concrete piles near this slope.

The task discussed in the article on assessing the conditions of slope collapse allowed to link together and establish causal relations with other technical and organizational events.

2 Materials and methods

During the expert study, materials from a survey of eyewitnesses and officials, project materials on the capital construction project, photographs of the scene of the accident, and pile driving machine were examined. Regulatory and technical documents and legislative acts were also studied. Photos of the pile driving machine SP-49 are shown in figure 1.

When performing the study, terminology was used in accordance with Industry Construction Standard 04-71 (VSN 04-71)"Guidelines for calculating the stability of earth walls." Key terms are presented in figure 2, and explanations of the terms are given in the comments to this figure.

Figure 1. Photos of the SP-49 pile driver: a, b, c – in transport position; d – in operational position.
Figure 2. Earth wall: Earth wall – a ground surface with an angle of inclination to the horizon of more than 10° (BC line). Slope ridge – a ground surface (line AB) with an inclination angle to the horizon of less than 10°. Slope base surface is an earthen surface (CD line) with an inclination angle to the horizon of less than 10°. Slope crest – a slope intersection line with its ridge, projected on to point B. Base of slope – the line of intersection of the earth wall with the surface of its base (see point C).

Research showed the following:

- the upper soil layers of the entire construction territory have been formed over decades and are of man-made origin, have incoherent structure with the presence of various organic impurities in it. An asphalt concrete plant was previously located on this territory;
- soil layers of this type of soil can be from a dozen centimeters to 7-9 meters, so pile foundations were chosen for all parts of the facility;
- the foundation pit for the main unit was excavated with sheet piling in accordance with the project on one side, and on the other, where adjacent and associated structures were located nearby -with a batter and slopes. The width of the horizontal part of the batter as per the design was supposed to be up to 15 m (in reality, the width of the batter did not exceed 10-12 m). The depth of the pit, the parameters of the slopes are given below;
- the piles were driven-in by tractor-mounted SP-49 pile driving machine based on the TB-100 tractor, when moving them, their destructive effect on structural bonds in the soil should be taken into account [15-17];
- the overturning of the pile driving machine occurred in preparation for driving-in of pile № 62, which was located in the pile cluster “61-62-63-64”, on a batter at a distance of 3,1 m horizontally from the edge of the slope of the underlying foundation pit;
- the overturning of the pile driving machine was accompanied by the collapse of the earth wall.

Thus, in order to determine the causes of the accident, a calculated justification for the possibility of collapse of the soil near the place of work on mechanized submersion of piles using the pile driving machine SP-49 should be made.

Thus, in order to determine the causes of the accident, it is necessary to make an analysis of the possibility of soil collapse near the site of mechanized driving-in of piles with the use of pile driver SP-49.

2.1 Basic design parameters
By the term “slope stability” we mean the stability of its prism or part of the slope to slide due to the imbalance of external and internal forces, which consist of the ground's dead load and additional loads in the presence of equipment and stored materials near the slope. The value of the safety factor is determined on the basis of the condition of static equilibrium:

\[ \Sigma (M) = 0, \]

where \( M \) is the moments acting on the slope blocks.
For greater reliability calculations of the slope stability were carried out by several methods (V. Fellenius, G. Kray, K. Terzaghi, and R.R. Chugayev) using designer reference books from the Soviet period:

- Designer reference guide. Hydraulic facilities / Ed. V.P. Nedrigi. - M.: Stroyizdat, 1983;
- Research and design of roads: Reference guide of a road engineer / Ed. O.V. Andreeva. - M: Transport, 1989.

Based on the calculations, the values of the safety factors ($K_s$) and possible slip lines were obtained. The criterion for the stability of the slope was the fulfillment of the conditions of the VSN 04-71:

$$K_s \geq [K_s],$$

where $[K_s]$ is the admissible safety factor, which was adopted on the basis of table 2 VSN 04-71 equal to 1,15 for building class I with a combination of factors corresponding to the construction period.

The calculated design section of slope was taken in the zone of the axis 9 (figure 3).

**Figure 3.** A fragment of the scheme of the pile field.

### 2.2 Load cases

Consideration of design materials and taking into account the chronology of the work on driving-in of piles made it possible to determine six load cases with building structures and the used constructional mechanisms:

- **case 1** – no external loads;
- **case 2** – surcharging the upper edge of the slope from the weight of the pile C12-35, prepared for driving-in the 62nd pile (placing the pile perpendicular to the pit edge);
- **case 3** – surcharging the upper edge of the slope from the weight of two piles C12-35, prepared for driving-in the 62nd and 64th piles, (placing piles perpendicular to the pit edge);
- **case 4** – surcharging the upper edge of the slope from the weight of the pile C12-35 prepared for driving-in the 64th pile (placing the pile along the pit edge);
- **case 5** – surcharging the upper edge of the slope from the weight of the SP-49 pile driver and pile C12-35 (the location of the pile driver and pile is perpendicular to the pit edge);
- **case 6** – surcharging the upper edge of the slope from the weight of the SP-49 pile driver and C12-35 pile (the location of the pile driver and pile is parallel to the pit edge).

In order to assess the most adverse conditions of the soil mass behavior, the above six load cases were considered, the most dangerous of which are case 5 and case 6, moreover, case 5 in which a pile driver was overturned corresponds to a real situation (figures 4-5).
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Figure 4. Scheme of the gage section in the plan with the load on the upper edge of the slope from the weight of the pile driver SP-49 and pile C12-35 (the location of the pile driver and pile is perpendicular to the pit edge for driving-in the 62nd pile) (case 5).

Figure 5. The vertical diagram of the gage section with the load on the upper edge of the slope from the weight of the pile driver SP-49 and pile C12-35 (the location of the pile driver and pile is perpendicular to the pit edge for driving-in the 62nd pile).

2.3 Design Methods

V. Fellenius's method. The method of V. Fellenius is based on a static stability analysis of individual vertical elements of the soil mass, which are limited from above by the surface of the soil, and from below - by a circular sliding arc. The method is called calculation on circular cylindrical sliding surfaces. To determine the coefficient \( K_u \) of stability, the sliding part of the mass is divided by vertical sections into a number of compartments (fig. 8). Retention and shear forces act on each compartment.

The ratio of the moment of forces holding the slope from the shift \( M_{ud} \) to the moment of forces tending to shift the slope \( M_{sdv} \) is taken as the slope stability coefficient \( K_u \):

\[
K_u = \frac{M_{ud}}{M_{sdv}} = \frac{\sum P \cos \alpha_i \tan \varphi_i + c_i l_i + P_i}{\sum P_i \sin \alpha_i}
\]

In this case, the stability of the strip, 1 m wide, perpendicular to the slope crest, is considered.
To determine the coordinates of the center O of the most dangerous circular cylindrical sliding surface, for which the factor of safety Ku is minimal, the Yanbu diagram is often used (figure 6).

**Figure 6.** Design model for the stability calculation according to the Fellenius method.

**G. Krey’s method.** The method of G. Krey (or the method of horizontal interacting forces) is quite accurate, and is recommended for calculating the slope stability of heterogeneous soils.

The determination of the safety factor \( K_z \) is made by trial and error, since \( K_z \) is expressed implicitly in the formula. The selection of \( K_z \) is carried out with such a degree of precision that the difference in neighboring definitions of \( K_z \) does not exceed 0.1%. The formula for the calculation is as follows:

\[
k_z = \frac{1}{\sum G_i \cdot \sin \alpha_i + \frac{f \cdot F}{R}} \sum \left( \frac{G_i \cdot \cos \alpha_i \cdot \tan \varphi_i + c \cdot b_i}{\cos \alpha_i \left( 1 + \tan \alpha_i \cdot \tan \varphi_i \right)} \right).
\]

(4)

**K. Terzaghi’s method.** The method of K. Terzaghi (or the method of inclined interacting forces parallel to the bottom of the compartment) has found wide application in practice due to its simplicity, however, when calculating gentle slopes with a laying of more than 2.5m, it leads to a downgrading of the value of \( K_z \), in other words it gives the value "in reserve". Formula for calculation has the following form:

\[
k_z = \frac{\sum (G_i - P_s \cdot \cos \alpha_i) \cdot \cos \alpha_i \cdot \tan \varphi_i + c \cdot b_i}{\sum G_i \cdot \sin \alpha_i + \frac{f \cdot F}{R}}.
\]

(5)

**R.R. Chugayev's method.** The method proposed by R.R. Chugayev, based on the formal coincidence of the results of the calculation on it with the results obtained by the Taylor method for homogeneous soils with the laying of slopes more than 2.5 m. The formula for the calculation is as follows:

\[
k_z = \frac{\sum (G_i - P_s \cdot \cos \alpha_i) \cdot \tan \varphi_i + c \cdot b_i}{\sum G_i \cdot \sin \alpha_i + \frac{f \cdot F}{R}}.
\]

(6)

Designations used in the above formulas:

- \( G_i \) (or \( P_i \)) – weight of soil and water within the compartment, taking into account the load on the surface of the earth;
- \( F_i \) – horizontal component of the external load on the compartment (surface and volume forces, excluding filtration);
\( \varphi_i \) – angle of internal friction of the soil on the sliding surface;
\( c_i \) – specific soil grip compartment;
\( b_i \) – compartment width;
\( R \) – radius of a circular cylindrical slip arc;
\( \alpha_i \) – tilt of the sliding surface to the horizon;
\( l_i \) – sliding surface length.

2.4 Loads

1. Pile C12-35.
   - pile weight: 3,73 t;
   - reduced uniform loading from the weight of one pile:
     - per 1 m wide strip: 0.31 t/m^2;
     - per 0.35 m wide strip: 0.8857 t/m^2;
     - per 0.4 m wide strip: 0.78 t/m^2;
   - uniform loading from the weight of two piles per 1 m wide strip - 0.62 t/m^2;

2. Pile driving machine SP-49.
   - the total mass of the mechanism with the equipment: 31,06 t;
   - maximum ground pressure: 5,351 t/m^2
   - reduced pressure on a strip of 1 m width: 4,8159 t/m^2.

The dimensions of the supporting surfaces of the pile driver are shown in figure 7.

![Figure 7. Plan view of the supporting surfaces of the pile driving machine SP-49 (caterpillar tread marks).](image)

Construction site soil. The design characteristics of soils located within the construction site are taken on the basis of geotechnical surveys given in table 1-3.

| № | Engineering and geological element | Soil constitution |
|---|-----------------------------------|-------------------|
| 1 | EGE № HC                          | Made-up ground is heterogeneous sand, sandy-loam, less often loamy with the inclusion of construction waste up to 20-75%, broken red brick, pebbles up to 45%, crushed stone 5-35%, sand and gravel, in separate slag wells up to 30-70%, glass, lime, in individual wells with the smell of petroleum products and hydrogen sulfide, with concrete residues, sprinkled in a dry manner, caked, uncoiled and unevenly caked |
Made-up ground is loamy, rarely sandy, with ash, soot, coal dust, semi-decomposed wood, sections with inclusions of construction waste up to 25-40%, with residues of wood, tar, lime, with the smell of oil products, peaty in some areas, sprinkled dry, caked, non-caked and unevenly caked.

Fine water-saturated sand of medium density, mica, iron, slightly loamy, with veins of loam and sandy loam.

Shallow water-saturated sand, dense, with streaks of loam and sandy loam, ironized, with wood inclusions.

Table 2. Soil characteristics.

| Characteristics of soil          | EGE № HC | EGE № HC1 | EGE № 6 | EGE № 6a |
|---------------------------------|----------|----------|---------|----------|
| Soil density $\rho$, g/cm$^3$   | 1,37-2,13| 1,23-2,0 | 2,0     | 2,05     |
| Soil density $\rho_{sat}$ at $W_{sat}$, g/cm$^3$ | - | - | 2,0 | 2,05 |
| Internal friction angle $\varphi$, degree | 6-34 | 8-21 | 32 | 34 |
| Internal friction angle $\varphi$ at $W_{sat}$, degree | 6-25 | 8-21 | 32 | 34 |
| Specific clutch $C$, kPa         | 16-58    | 17-64    | 1,9     | 2,8     |
| Specific clutch $C$ at $W_{sat}$, kPa | 12-46    | 12-27    | 1,9     | 2,8     |
| Elastic modulus $E$, MPa         | 2,8-40   | 0,8-29   | 26      | 36      |
| Elastic modulus $E$ at $W_{sat}$, MPa | 2,8-40   | 0,8-29   | 26      | 36      |

Table 3. The characteristics of the soils laid down in the calculation.

| Layer thickness, m | $\rho$, t/m$^3$ | $\rho_{sat}$, t/m$^3$ | $\varphi$, deg | $C$, kPa | $E$, MPa |
|--------------------|-----------------|----------------------|---------------|----------|----------|
| EGE № HC          | 0,7-3,0         | 2,13                 | 2,13          | 6        | 12       | 2,8      |
| EGE № HC1         | 6,8             | 2,0                  | 2,0           | 8        | 12       | 0,8      |
| EGE № 6a          | 2,1             | 2,0                  | 2,0           | 32       | 1,9      | 26       |
| EGE № 6a’         | 3,3             | 2,05                 | 2,05          | 34       | 2,8      | 36       |

Remarks
1. The most unfavorable of the presented soil characteristics are taken into account.
2. Under real conditions, the stress-related characteristics of soils can have lower values due to the likely softening of the soil caused by dynamic effects from driving previously driven-in piles and mechanisms moving along the construction site.

The hydro geological conditions of the construction site are characterized by the development of groundwater of the “top-water” type and groundwater of the main water-bearing layer. Water-bearing soils within the considered area are soils of engineering-geological elements EGE № HC, HC1, 6, 6a.

3 Results
The calculation results will be presented for the 5th case of load application and the location of the pile driving machine perpendicular to the pit edge in preparation for driving pile № 62, located at a distance of 3,1 m from pit edge of the underlying foundation pit.

It should be noted that piles № 61 and № 63 were already driven-in from the pile cluster “61-62-63-64”, and the pile № 64, located at the distance of 1 m from the edge of the slope of the foundation pit, was supposed to be driven after driving-in of pile № 62, having previously cut pile tops № 61, 62 and 63, and having the pile driver parallel to the edge of the slope crest.
The design model of the soil mass is shown in figure 7. Soil characteristics, initial data for calculations according to the methods of G. Krey, K. Terzsaghi, R.R. Chugayev and the calculations themselves are presented in tables 4-11.

We will present the results of the calculations for the 5th case of load application and the arrangement of the pile driving machine perpendicular to the pit edge in preparation for driving-in of pile No. 62, located at a distance of 3,1 m from the pit edge of the underlying foundation pit of the main building.

It should be noted that piles No. 61 and No. 63 from the pile cluster “61-62-63-64” were already driven-in and the pile № 64, located at the distance of 1 m from the edge of the slope of the foundation pit, was supposed to be driven after driving in of pile № 62, having previously cut pile tops № 61, 62 and 63, and having the pile driver parallel to the edge of the slope crest.

The design model of the soil mass is shown in figure 8. Soil characteristics, initial data for calculations by the methods of G. Krey, K. Terzsaghi, R.R. Chugayev and the calculations themselves are presented in tables 4-11.

![Figure 8. Design model of the soil mass.](image)

**Table 4.** Soil characteristics.

| №  | \(G_{\text{dry}}, \text{t/m}^3\) | \(G_{\text{satur}}, \text{t/m}^3\) | \(\text{tgV}, \text{degree}\) | \(C, \text{t/m}^3\) |
|----|-------------------------------|-------------------------------|-------------------|------------------|
| 1  | 2,13                          | 2,13                          | 6,00              | 1,20             |
| 2  | 2,00                          | 2,00                          | 8,00              | 1,20             |
| 3  | 2,00                          | 2,00                          | 32,00             | 0,19             |
| 4  | 2,05                          | 2,05                          | 34,00             | 0,28             |

**Table 5.** Coordinates of typical points on the slope.

| №  | X, [m] | Y, [m] | №  | X, [m] | Y, [m] |
|----|--------|--------|----|--------|--------|
| 1  | 0,00   | 12,00  | 3  | 18.07  | 9,70   |
| 2  | 15.77  | 12.00  | 4  | 30.00  | 9.70   |
Table 6. Coordinates of the points of the drawdown curve.

| №  | X, [m] | Y, [m] | №  | X, [m] | Y, [m] |
|----|--------|--------|----|--------|--------|
| 1  | 0.00   | 9.70   | 3  | 18.07  | 9.70   |
| 2  | 15.77  | 9.70   | 4  | 30.00  | 9.70   |

Table 7. Coordinates of soil boundary points 1 and 2.

| №  | X, [m] | Y, [m] | №  | X, [m] | Y, [m] |
|----|--------|--------|----|--------|--------|
| 1  | 0.00   | 9.70   | 3  | 18.07  | 9.70   |
| 2  | 15.77  | 9.70   | 4  | 30.00  | 9.70   |

Table 8. Coordinates of soil boundary points 2 and 3.

| №  | X, [m] | Y, [m] | №  | X, [m] | Y, [m] |
|----|--------|--------|----|--------|--------|
| 1  | 0.00   | 2.20   | 3  | 18.07  | 2.20   |
| 2  | 15.77  | 2.20   | 4  | 30.00  | 2.20   |

Table 9. Coordinates of soil boundary points 3 and 4.

| №  | X, [m] | Y, [m] | №  | X, [m] | Y, [m] |
|----|--------|--------|----|--------|--------|
| 1  | 0.00   | 0.10   | 3  | 18.07  | 0.10   |
| 2  | 15.77  | 0.10   | 4  | 30.00  | 0.10   |

Relative compartment width R/b = 100

External shear load:
- Load value [t/m²], q = 5.35;
- Original coordinate [m], X₀=10.95;
- Final coordinate [m], Xₖ=14.17.

Table 10. Area of centers and radii of sliding surfaces.

| Name          | X, [m] | Y, [m] | R, [m] |
|---------------|--------|--------|--------|
| Minimum values| 16.00  | 12.00  | 3.00   |
| Maximum values| 19.00  | 13.00  | 4.00   |
| Quantity of points | 5      | 5      | 10     |

Calculations by the methods of G. Krey, K. Terzsaghi, "equilibrium pressure" are presented in table 11.

Fellenius calculation. The design model according to the Fellenius method for case № 5 is shown in figure 9.

Factor of safety:

$$K_y = \frac{M_{ad}}{M_{adv}} = \left( \sum_{j=1}^{n} P_i \cos \alpha_j \tan \varphi_j + c_i f_i + P_i^* \right) \sum_{j=1}^{n} P_j \sin \alpha_j = 0.78$$  \hspace{1cm} (7)
Table 11. Calculations by the methods of G. Krey, K. Terzaghi, "equilibrium pressure".

| №   | K_{min} value by method | G. Krey | K. Terzaghi | "equilibrium pressure" | R_{min} [m] | X_{min} [m] | Y_{min} [m] |
|-----|-------------------------|---------|-------------|-------------------------|-------------|-------------|-------------|
| 1   | 1.0064667               | 0.9350662 | 0.9847378   | 3.00                    | 16.00       | 12.75       |
| 2   | 0.9939433               | 0.9290567 | 0.9761909   | 3.11                    | 16.00       | 13.00       |
| 3   | 0.9582398               | 0.8943524 | 0.9418034   | 3.22                    | 16.00       | 13.00       |
| 4   | 0.9741007               | 0.9082166 | 0.9555005   | 3.33                    | 16.00       | 13.00       |
| 5   | 0.9867023               | 0.9187356 | 0.9661336   | 3.44                    | 16.00       | 13.00       |
| 6   | 0.9871081               | 0.9176995 | 0.9652927   | 3.56                    | 16.00       | 13.00       |
| 7   | 0.9741159               | 0.9044958 | 0.9527369   | 3.67                    | 16.00       | 13.00       |
| 8   | 0.9676948               | 0.8973157 | 0.9456558   | 3.78                    | 16.00       | 13.00       |
| 9   | 0.9634240               | 0.8919587 | 0.9407392   | 3.89                    | 16.00       | 13.00       |
| 10  | 0.9689656               | 0.8952304 | 0.9445436   | 4.00                    | 16.00       | 13.00       |

At least by a method

| G. Krey | 0.9582398 | 3.22 | 16.00 | 13.00 |
|---------|-----------|------|------|------|
| K. Terzaghi | 0.8919587 | 3.89 | 16.00 | 13.00 |

"equilibrium pressure"

0.9407392 3.89 16.00 13.00

Table 12. Factor of safety calculations for case 5 by the method Fellenius (radius of the sliding arc R = 3.3 m).

| № of block | Average height of the block, m | Width of the block, m | Volume of the block, m³ | Weight of the block, t | Loading on a surface, t |
|------------|-------------------------------|-----------------------|-------------------------|------------------------|------------------------|
| 1          | 1                             | 0.7145                | 0.9                      | 0.64305                | 1.369697               | 5.351                  |
| 2          | 2                             | 1.5875                | 0.4                      | 0.635                  | 1.35255               | 0.78                   |
| 3          | 3                             | 1.881                 | 0.5                      | 0.9405                 | 2.003265             | 0                      |
| 4          | 4                             | 2.111                 | 0.5                      | 1.055                  | 2.248215             | 0                      |
| 5          | 5                             | 1.95                  | 0.6                      | 1.17                   | 2.4921               | 0                      |
| 6          | 6                             | 1.394                 | 0.6                      | 0.8364                 | 1.781532             | 0                      |
| 7          | 7                             | 0.726                 | 0.6                      | 0.4356                 | 0.927828             | 0                      |
| 8          | 8                             | 0.182                 | 0.5                      | 0.091                  | 0.19383              | 0                      |

Continuation of table 12

| № of block | α_i, degree | Cos α_i | Sin α_i | φ_i, degree | l_i, m |
|------------|-------------|---------|---------|-------------|-------|
| 1          | 8           | 9       | 10      | 11          | 12    |
| 1          | 58          | 0.529919 | 0.848048 | 6           | 1.721593 |
| 2          | 38          | 0.788011 | 0.615661 | 6           | 0.573864 |
| 3          | 29          | 0.87462  | 0.48481  | 6           | 0.573864 |
| 4          | 19          | 0.945519 | 0.325568 | 6           | 0.573864 |
| 5          | 9           | 0.987688 | 0.156434 | 6           | 0.631251 |
| 6          | 1           | 0.999848 | 0.017452 | 6           | 0.573864 |
| 7          | 12          | 0.978148 | 0.207912 | 6           | 0.631251 |
| 8          | 19          | 0.945519 | 0.325568 | 6           | 0.344319 |
End of table 12

| № of block | C_i t/m^2 | C_i t/m | P_i cos α_i tg φ_i, t | P_i sin α_i, t | P_i sin α_i, t |
|------------|------------|----------|------------------------|----------------|----------------|
| 1          | 13         | 14       | 15                     | 16             | 17             |
| 1          | 1.2        | 2.065911 | 0.374321               | 5.699474       | 0              |
| 2          | 1.2        | 0.688637 | 0.176625               | 1.312929       | 0              |
| 3          | 1.2        | 0.688637 | 0.184153               | 0.971202       | 0              |
| 4          | 1.2        | 0.688637 | 0.223423               | 0.731947       | 0              |
| 5          | 1.2        | 0.757501 | 0.258705               | 0.38985        | 0              |
| 6          | 1.2        | 0.688637 | 0.187218               | 0              | 0.031092       |
| 7          | 1.2        | 0.757501 | 0.095388               | 0              | 0.192906       |
| 8          | 1.2        | 0.413182 | 0.019262               | 0              | 0.063105       |
| Σ          | 6.748644   | 1.519095 | 9.105402               | 0.287103       |

Figure 9. Design model of the slope for case № 5.

The results of the calculations by various methods are summarized in table 13.

Table 13. Results of the calculations by various methods.

| Calculation method | K_{min} | R, [m] | X_{0}, [m] | Y_{0}, [m] |
|--------------------|---------|--------|------------|------------|
| G. Krey            | 0,958240| 3,22   | 16,00      | 13,00      |
| K. Terzaghi        | 0,891959| 3,89   | 16,00      | 13,00      |
| "Equilibrium Pressure" | 0,940739| 3,89   | 16,00      | 13,00      |
| V. Fellenius       | 0,78    | 3,30   |            |            |

4 Discussion
All calculations by various methods for case 5 identified the slope as unstable. The calculation data for all load cases are given in table 14.
Table 14. A summary table of the results of the stability analysis of the slope.

| Case number | Description                                                                 | Minimum Factor of Safety | Output               |
|-------------|-----------------------------------------------------------------------------|--------------------------|----------------------|
| Case 1      | No external loads                                                           | 1,695                    | Slope is steady      |
| Case 2      | On the upper edge of the slope, the load from the weight of the pile acts   | 1,455                    | Slope is steady      |
|             | (placing the pile perpendicular to the pit edge)                           |                          |                      |
| Case 3      | On the upper edge of the slope there is a load                            | 1,242                    | Slope is steady      |
|             | from the weight of two piles (placing the piles                           |                          |                      |
|             | perpendicular to the pit edge)                                            |                          |                      |
| Case 4      | On the upper edge of the slope, the load from the weight of one pile acts   | 1,64                     | Slope is steady      |
|             | (placing the pile along the pit edge)                                      |                          |                      |
| Case 5      | On the upper edge of the slope, loads from the weight of the pile and piles | 0,78                     | Slope is not stable  |
|             | act (the location of the pile and piles perpendicular to the pit edge)     |                          |                      |
| Case 6      | On the upper edge of the slope, loads are applied from the weight of the    | 0,939                    | Slope is not stable  |
|             | pile and pile driver (the location of the pile and pile driver parallel    |                          |                      |
|             | to the pit edge)                                                           |                          |                      |

5 Conclusions
The study of the conditions at the construction site, based on ground conditions, as well as six possible load cases, allowed us to establish the following:

1. Geotechnical survey revealed that the two upper engineering and geological elements (EGE) are represented by made-up grounds HC and HC1. The soils of these layers are not only extremely uneven in thickness (power), but also unstable in composition and inclusions, origin and particle size, have a significant variation in the technical properties that characterize these soils.

   Soil of the upper EGE № CH is a loose soil, heterogeneous sand, sandy, less often loamy with the inclusion of construction waste up to 20-75%, broken red brick, pebbles up to 45%, gravel 5-35%, sand and gravel, in a separate slag wells up to 30-70%, glass, lime, in individual wells with the smell of petroleum products and hydrogen sulfide, with concrete residues, sprinkled in a dry way, caked, uncoated and unevenly caked.

   In accordance with Note 2 to table 1 of SNiP 12-04-2002, the soil of EGE №. HC could be considered caked, given its formation period, estimated in decades, because untreated bulk include soils with a duration of filling up to two years for sand; up to five years - for dusty clay soils.

   However, due to its origin and formation conditions, the upper element №. HC should not be classified as caked.

   Therefore, changes in internal connections in the mass of such a heterogeneous and varying composition of the soil when exposed to external loads (different in magnitude, dynamics and static, etc.) under construction conditions at this construction site can be attributed to unpredictable, and the soil upper layers (HC and HC1) can also be considered non-predictable and called force majeure.

2. Analysis of the calculation results showed that under the conditions of manifestation of the worst soil characteristics of a construction site in the absence of external loads on the upper edge of the slope, as well as under the action of minor loads of 1-2 piles, the slope is stable.
3. Under the influence of loads from the weight of the SP-49 pile driver when it is placed perpendicular to the edge of the foundation pit for driving-in the 62nd pile located at a distance of 3.1 m from the edge of the slope, the stability of the slope is not ensured.

4. Under the influence of loads from the weight of the SP-49 pile driver when it is placed parallel to the pit edge of the foundation pit for driving-in the 64th pile located at a distance of 1.0 m from the pit edge, the stability of the slope is not ensured.

5. Possible shear planes of the soil mass are in the zone of the upper soil layer (EGE-№ HC).

6. A comprehensive study of security issues at all stages of the life cycle of construction projects should begin when preparing a design assignment, during surveys, design, construction, operation, repair, reconstruction, etc.

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