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# INCREASE OF DYNAMIC STABILITY OF A BASIS AT OPERATION OF THE COMPRESSOR EQUIPMENT OF THE ABAZIVKA UNIT OF COMPLEX GAS PREPARATION

*The object of research is the basis of the compressor equipment of the complex gas treatment plant at the Abazivka field and the strengthening of the base soils with soil-cement elements, which are proposed to be arranged with the use of drilling technology. The research area is located on the territory of the current Abazivka Integrated Gas Preparation, near the village of Bugaivka, Poltava region, Ukraine. Abazivka Integrated Gas Preparation receives products from wells in Abazivka and Sementsivske deposits. It is proposed to carry out the reconstruction of Integrated Gas Preparation, which includes strengthening the foundation of the compressor model C1004-JGT/2-1 manufactured by «Propak» (Alberta, Canada). The amplitudes of oscillations of the compressor foundation were determined at a speed of 1400 rpm at the appropriate site with geological conditions. The magnitudes of oscillations and subsidence of the compressor foundation of the Abazivka complex of complex gas treatment were investigated experimentally. When determining the amplitudes of oscillations of the compressor foundations, only the amplitudes of oscillations in the direction parallel to the sliding of the pistons were calculated, and the influence of the vertical component of the perturbing forces was not taken into account. It is established that the amplitude of horizontal-rotational oscillations of the upper face of the compressor foundation relative to the horizontal axis exceeds the maximum allowable. It is substantiated that soil cement is a sufficiently strong and waterproof material that can be used to strengthen the base during the construction of equipment foundations. The possibility of application of the technology of application of soil-cement piles, made by brown-mixing technology for strengthening the base under the foundation of the compressor, is described and investigated. It is proposed to reinforce the base with rows of soil-cement elements, which will increase the modulus of deformation of the base, which is represented by loam, light to 14.3 MPa. In the case of strengthening the base, the amplitude of horizontal-rotational oscillations of the upper face of the compressor foundation is much less than the maximum allowable 0.1 mm. The subsidence of the foundation at reinforcement of the base, which does not exceed the maximum allowable value, is determined. Soil-cement elements are proposed to be arranged according to the drilling technology.*

**Keywords:** *complex gas treatment plant, soil cement, vibration amplitude, compressor foundation, drilling technology, deformation module.*

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## 1. Introduction

The production of wells in the development of deposits requires comprehensive training. Industrial gas treatment at integrated gas treatment plants consists of the following stages, which include absorption or adsorption drying; low temperature separation or absorption; oil absorption. In gas fields, gas preparation consists in its drainage. All these processes require the installation of appropriate equipment. For example, adsorption dehumidification requires the installation of air cooling devices, compressors.

During reconstruction or repair, it is often found that the load-bearing capacity of the foundation is not able to withstand the load of machinery and equipment. The technical condition of the foundations may deteriorate over time due to the influence of groundwater and atmospheric water. Often there is the phenomenon of suffusion – washing away with water part of the soil under the foundation.

In these cases, it is recommended to strengthen the foundations of machines and the soil around them, which prevents excessive horizontal and vertical movement of the foundation. Also, reinforcement of the soil around the

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foundations may be necessary when laying the foundations next to the existing ones. In this case, the development of pits can cause deformation of the soil around the existing foundation. In recent years, with the development of technologies for the installation of compacted piles, a new method of construction of artificial foundations by reinforcing weak soils with vertical rigid elements has been introduced.

The authors of [1] proved the sufficient efficiency of the use of soil-cement elements in strengthening the foundations of buildings and structures erected by drilling technology. With the help of special equipment loosening the soil directly in the massif without removing it. At the same time, a cement slurry is pumped into the loosened soil and mixing and compaction of the soil-cement mixture is performed. After hardening of the mixture along the entire thickness of the weak layer, a strong soil-cement material is formed [2, 3]. Thus, *the object of the study* is the basis of compressor equipment of the complex gas treatment plant at Abazivka field (Ukraine) reinforcement of the base soils with soil-cement elements, which are proposed to be arranged using drilling technology. *The purpose of the work* is to consider the possibility and propose a technological solution to strengthen the basis of compressor equipment for the installation of integrated gas treatment at the Abazivka field.

## 2. Methods of research

The author of [4] argues that mixing and jet mixing technologies are more economical in terms of material consumption and do not require pulp disposal; research of material (soil cement) is required.

In [5] it is emphasized that a very important factor in favor of the use of drilling technology is that the soil-cement elements can be arranged below the groundwater level. There is experience in the application of such technology at the site of construction of technological tracts of crushing and concentrating plants at «Poltava Mining and Metallurgical Plant» (Horishni Plavni, Ukraine).

That is, soil cement is a sufficiently strong and waterproof material that can be used to strengthen the foundation during the construction of the foundations of the equipment of mining and processing plants [6–8]. The authors propose to describe and investigate the possibility of using the technology of application of soil-cement piles made by drilling technology to strengthen the basis of equipment in the oil and gas industry. Normative documents recommend in difficult engineering and geological conditions, which are represented by weak soils, to consider the option of foundations on the basis of which is fixed by reinforcing the soil with soil-cement elements. The research area is located on the territory of the current Abazivka Integrated Gas Preparation, 2 km north of the village. Bugaivka, Poltava region, Ukraine. The Abazivka Integrated Gas Preparation receives products from the wells of the Abazivsky and Sementsovsky deposits. Abazivka Integrated Gas Preparation works according to a typical scheme of low-temperature separation with cold production due to the operation of excess gas pressure of Abazivska and Sementsivka gas condensate fields in a monoblock turboexpander unit. Abazivka Integrated Gas Preparation consists of two technological lines. The first technological line is experimental. The technological mode of the test line depends on the parameters of the well under study. The second technological line is designed for gas field preparation. The gas condensate mixture from the wells of the Abazivka Integrated Gas Preparation and natural gas and condensate from the Sementsov Gas Pre-treatment Plant are supplied via individual loops to the inlet node.

It is proposed to carry out the reconstruction of Abazivka Integrated Gas Preparation, which includes the installation of the foundation of the compressor model C1004-JGT/2-1 manufactured by Propak (Alberta, Canada).

Compressor equipment belongs to a group that creates vibration loads on buildings and structures located nearby. Vibration and noise complicate technological processes and have a detrimental physiological effect on people, increasing employee fatigue. The main measure to combat vibration is a qualified justification and compliance with the technology of laying foundations for machines. To this end, let's analyze the geological conditions of the construction site. Geomorphologically, the territory of the Integrated Gas Preparation is located within the central part of the Poltava forest plateau, complicated by a developed beam system. The site is located in the upper, fairly flat, part of the wide and deep beam. Aeolian-deluvial loamy deposits of the Quaternary period, which lie on Neogene clays, which, in turn, lie on Neogene sands, take part in the geological structure of the site.

One pressureless aquifer was identified in the development area by drilling wells, the level of which for the research period was 10.1–10.5 m below the Earth's surface. Groundwater for concrete and reinforcement is non-aggressive.

Adverse physical and geological processes and phenomena within the site include:

– the presence of a significant thickness of subsidence soils. It is 7.0 m;

– the possibility of flooding.

According to DSTU B B.2.1-2-96 within the site are the following engineering and geological elements (IGE):

– *IGE-1* – soil-plant layer – light loam, dark gray, humus, hard. Layer thickness 0.3–0.5 m;

– *IGE-2* – loam, woody, light, greenish-gray, carbonated, refractory, sagging with a sharp specific odor due to the impact of production. The thickness of the layer is 1.8 m. $E$=5.5 MPa;

– *IGE-3* – loam, medium, brown-yellow semi-hard, carbonate, subsidence. Layer thickness 2.5–3.0 m. $E$=7.5 MPa;

– *IGE-4* – loam, semi-hard, light, pale yellow, semi-hard, subsidence. Layer thickness 3.0–3.1 m. $E$=6.5 MPa;

– *IGE-5* – heavy loam, brown, loess, refractory, carbonate. Layer thickness 1.4–1.5 m. $E$=14 MPa;

– *IGE-6* – brownish-brown, refractory clay. Layer thickness 3.2–3.3 m;

– *IGE-7* – loam light, pale yellow, homogeneous, soft-plastic to fluid. Layer thickness 2.6–2.7 m;

– *IGE-8* – variegated clay, red-yellow, refractory, passed to a depth of 15.1 m.

Compressor foundations are mainly subjected to horizontal loads. For normal operating conditions of machines, the amplitude of oscillations of the foundation must satisfy the condition:

$$a \le a_{ad}, \quad (1)$$

where $a$ – the largest amplitude of oscillations of the foundation, which is determined by calculation; $a_{ad}$ – the maximum allowable amplitude of oscillations of the foundation, taken according to SNiP 2.02.05-87. For machines $a_{ad}$=0.05 mm. In calculations according to regulatory documents, the base is assumed to be linearly deformed, perfectly elastic-viscous and devoid of mass (excluding inertia).

The viscosity of the substrate is due to the damping properties of the soil, i. e. the ability to absorb elastic waves. The properties of the base are determined by the coefficients of elastic uniform and non-uniform compression, elastic uniform and non-uniform shear. The machine-foundation system is considered to be an absolutely rigid body with a mass located in the center of gravity of the acting static loads.

## 3. Research results and discussion

The calculation of the compressor foundation was performed according to item 1.19. SNiP 2.02.05-87. The amplitudes of oscillations of the compressor base were determined at a speed of 1400 rpm at the appropriate site with the geological conditions described above.

When determining the amplitudes of oscillations of the compressor foundations, only the amplitudes of oscillations in the direction parallel to the sliding of the pistons were calculated, and the influence of the vertical component of the perturbing forces was not taken into account (Fig. 1). In this case, of the two harmonics of perturbing forces and moments, one component is less than 20 % of the other. The frequency of harmonics of perturbing forces differs by more than 25 % from the natural frequency of oscillations of the foundation. The amplitudes were calculated for each of the first two harmonics of the perturbing forces. The values of the perturbing forces of the first and second harmonics were $F_I$=347.14 kN and $F_{II}$=340.48 kN.

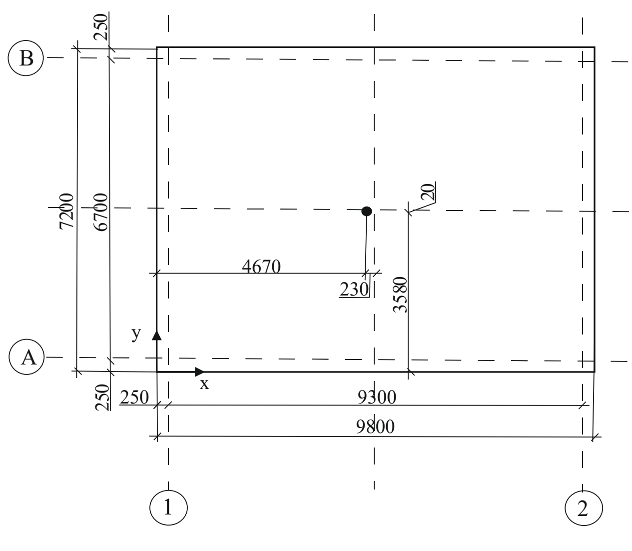


**Fig. 1.** Coordinates of the point of application of equivalent static and dynamic loads of the foundation of the modular compressor model C1004-JGT/2-1 manufactured by Propak

The difference between the forces of the first and second harmonics is 2 %, which is less than 20 %.

The angular frequency of the natural oscillations of the foundation was 15.7 s$^{-1}$.

The angular oscillation frequency of the foundation of the modular compressor model C1004-JGT/2-1 manufactured by Propak, respectively horizontal relative to the horizontal axis passing through the center of gravity of the foundation sole perpendicular to the oscillation plane, was calculated $\lambda_x$=13.14 s$^{-1}$. It is established that the frequency differs by 89 %, more than 25 % from the natural frequency of oscillations of the foundation. In this case, the calculation of the amplitudes was performed for the first of the two harmonics of perturbing forces and moments.

According to p.1.25 SNiP 2.02.05-87 the main elastic characteristic of the base (IGE-2) of the foundation of the machine – the coefficient of elastic uniform compression $C_z$ was 9085 kN/m$^3$.

The base area of the foundation was 70.56 m$^2$. The stiffness coefficients for natural bases, which are at elastic uniform compression $K_z$=641038 kN/m, are established. The angular frequency of oscillations of the foundation was ω=147 rpm. As a result of researches the value of eccentricity on the $X$ axis, which was $e$=1.04 % and on the $Y$ axis, equal to e=0.06 %, respectively, was determined. The eccentricity does not exceed 3 %, i. e. the compressor is placed correctly according to the foundation.

The weight of the equipment to be installed on the foundation took 56.7 tons.

The circular frequency of rotational oscillations of the foundation of the compressor manufactured by Propak was $\lambda_\varphi$=528 s$^{-1}$ [9].

The moment of inertia of the mass of the entire installation relative to the axis passing through the center of gravity of the base of the foundation perpendicular to the plane of oscillation, was $\theta_{\varphi o}$=9958.64 kN.

Coefficients for calculating the horizontal-rotational oscillations of the upper face of massive and wall foundations relative to the horizontal axis: $\Omega_1$=1776.9; $\Omega_2$=–2928.11; $S_1$=1652; x=0.062; $S_2$=36.94; $S_3$=6.69; $S_4$=1.062; $\psi_1$=1651,3; $\psi_2$=37.05; β=0.1.

The horizontal force acting on the upper part of the foundation is 347 kN. The amplitude of horizontal-rotational oscillations of the upper face of the foundation of the modular compressor manufactured by Propak relative to the horizontal axis was calculated by the formula:

$$a_{\mathrm{h},\phi}=\frac{F_h}{K_x}\sqrt{\frac{\psi_1^2+4\xi_x^2(\omega/\lambda_x)^2\psi_2^2}{\Omega_1^2+4\xi_x^2(\omega/\lambda_x)^2\Omega_2^2}}, \quad (2)$$

where $F_h$ – the calculated horizontal component of the perturbing forces of the machine, kN; $K_x$ – stiffness coefficient for the natural base with elastic uniform displacement, kN·m; $\lambda_x$ – the angular frequency of horizontal oscillations of the foundation, which passes through the center of gravity of the base of the foundation perpendicular to the plane of oscillations, s$^{-1}$; ω – the angular frequency of natural vertical oscillations of the foundation, rpm; $\Omega_1$, $\Omega_2$, $\Psi_1$, $\Psi_2$ – coefficients for calculating the horizontal-rotational oscillations of the upper face of massive and wall foundations relative to the horizontal axis; $\xi_x$ – the damping factor relative to the $x$-axis.

The amplitude of horizontal-rotational oscillations of the upper face of the foundation is calculated by formula (2) and is 0.11 mm, which is greater than the limit value of 0.1 mm That is, according to the calculation, the foundation design does not meet the requirements of modern standards, so the foundation under the foundation of the modular compressor must be reinforced with rows

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of soil-cement elements, which will increase the deformation modulus IGE-2 from 5.5 to 14.3 MPa. Soil-cement elements are proposed to be arranged according to the drilling technology.

It is proposed to arrange soil-cement elements using stirring technology. This method is that with the help of equipment the soil is loosened within the well without removing the soil. At the same time, a water-cement suspension is injected into this soil, the soil-cement mixture is mixed and compacted [10]. The location of reinforcement elements and their number is justified based on the required modulus of deformation of the soil layer, which is reinforced. In this case, the calculated modulus of deformation of the soil layer in the absence of field research data can be defined as a weighted average within the soil volume, which is amplified by the formula (D.1a) DBN B 2.1-10-2018:

$$\bar{E} = \frac{E_s \cdot V_s + E_{sc} \cdot V_{sc}}{V}, \quad (3)$$

where $E_s$ – the modulus of soil deformation, MPa; $E_{sc}$ – the modulus of deformation of soil cement (accepted 70 MPa); $V_s$ – soil volume, m$^3$; $V_{sc}$ – volume of soil cement, m$^3$ in total, $V$, m$^3$.

Depending on the distance in the plan between the elements of soil reinforcement and the strength of soil cement, the modulus of deformation of weak soil can be increased 2–6 or more times [9, 11].

This method of reinforcement should be carried out for the entire subsidence thickness. It is assumed that the calculated resistance of the base after improvement will be $R$=250 kPa. It is proposed to perform vertical reinforcement of the array with soil-cement elements with a diameter of Ø500 mm and a length of 6.5 m with a step of 1200x1200 mm.

The pitch of soil-cement elements (GCE) depends on the dimensions of the foundation sole and is assigned in such a way that all GCE are within the foundation spot (Fig. 1).

The modulus of deformation of soaked soils, calculated by formula (3) for IGE-2 will be 14.3 MPa; for IGE-3 – 16 MPa; for IGE-4 – 15.1 MPa; for IGE-5 – 21.6 MPa. The coefficients for calculating the horizontal-rotational oscillations of the upper face of massive and wall foundations relative to the horizontal axis when strengthening the base were: $\Omega_1$=1642; $\Omega_2$=–479.94; $S_1$=415.08; $x$=0.062; $S_2$=18.91; $S_3$=1.92; $S_4$=1.062; $\psi_1$=414.89; $\psi_2$=19; $\beta$=0.1.

There is a decrease in the values of the coefficients for calculating the amplitude of oscillations during the strengthening of the base. The horizontal force acting on the upper part of the foundation is 347 kN. Amplitude of horizontal-rotational oscillations of the upper face of massive foundations relative to the horizontal axis:

$$a_{h,\phi} = \frac{F_h}{K_x} \sqrt{\frac{\psi_1^2 + 4\xi_x^2 (\omega / \lambda_x)^2 \psi_2^2}{\Omega_1^2 + 4\xi_x^2 (\omega / \lambda_x)^2 \Omega_2^2}}. \quad (4)$$

The amplitude of horizontal-rotational oscillations of the upper face of the foundation is 0.074 mm (according to formula (4)), which is less than the maximum allowable 0.1 mm.

That is, the first condition for calculating the foundations for dynamic machines is met. The designed foundation slab is sufficient to withstand dynamic loads. When calculating the static and dynamic loads that occur during the operation of the compressor, the equivalent force $N$=567 kN is determined.

The coordinates of the point of application of the force – $(x;\ y)$=(4.67; 3.58), – are shown in Fig. 1. The average static pressure under the base of the foundation was 38.3 kPa, much less than the calculated resistance of the base soil to 250 kPa.

The foundation is calculated as centrally loaded. Calculation of the foundation under the compressor by the method of layer-by-layer summation according to the formula (D.1) DBN B 2.1-10-2018 is calculated. It was found that the depth of the compressible thickness should not be less than half the width of the foundation, ie not less than 3.6 m. In the case under consideration, the subsidence was $S$=3.82 mm. In order to increase the modulus of deformation of the base by 2–6 or more times, it is recommended to use reinforcement of subsidence soil layers with coverage of elements of subsidence thickness. Reinforcement is recommended to be performed with the use of brown mixing technology. The tip of the pile should be deepened into the soil of semi-solid, solid consistency.

Let's justify the location of reinforcement elements and their number, based on the required modulus of deformation of the soil layer, which is reinforced. It is proposed to reinforce the array with vertical soil-cement elements with a diameter of Ø500 mm and a length of 6.5 m with a step of 1200x1200 mm.

When designing foundations for compressors, it is necessary to determine the amplitudes of oscillations of the foundation parts and check the condition for exceeding the maximum allowable amplitude of oscillations and subsidence. Reinforcement of the soil with soil-cement elements in this case allowed to increase the deformation modulus of IGE-2 from 5.5 to 14.3 MPa 2.6 times. This method is used to improve the strength characteristics of subsidence loess soils. It is necessary to investigate the influence of reinforcing mesh on the physicochemical properties of soil layers.

## 4. Conclusions

During the study of the possibility of installing a suitable compressor foundation on the site of Abazivka Integrated Gas Preparation, it was found that the amplitude of horizontal-rotational oscillations of the upper face of the compressor foundation produced by Propak relative to the horizontal axis exceeds the maximum allowable.

Therefore, it is proposed to strengthen the base with rows of soil-cement elements, which will increase the deformation modulus of IGE-2 to 14.3 MPa. In the case of strengthening the base with soil-cement elements, the amplitude of horizontal-rotational oscillations of the upper face of the compressor foundation will be 0.074 mm, which is much less than the maximum allowable 0.1 mm.

The subsidence of the foundation during reinforcement of the foundation was determined, it was 3.82 mm, which does not exceed the maximum allowable value. It is proved that if the base is weak soils, then in order to improve their strength characteristics, it is recommended to use thickness reinforcement with soil-cement elements. When strengthening the soil with rows of soil-cement elements, the modulus of deformation of the base can be increased 2–6 times. Soil-cement elements are proposed to be arranged according to the drilling technology, which according to the authors is the most economical in this case.

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