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Determining the angle of the frontal working surface of the soil-piercing head asymmetrical tip for static soil-piercing

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Annotation. Problem. *From the analysis of the technical literature, it was established that among the trenchless technologies for laying underground engineering communications and service pipelines, the technology with the possibility of forming a horizontally directed communication cavity in the soil using soil-piercing installations of static action is the most common.* ***Goal****. This method consists in forcefully pressing a soil-piercing working body, which has the form of a conical-cylindrical projectile, into the soil. At the same time, the well is formed by radial extrusion of the soil around the formed well. However, the use of such equipment does not provide high accuracy, which limits its practical application within 20 m. It is not sufficient for modern requirements of creating transitions during the laying of communications.* ***Methodology****. One of the ways to improve the efficiency of laying underground networks is to extend this method over a longer distance by correcting the trajectory of the working body. This is achieved by using a soil-piercing head with an asymmetric tip. Due to this, in addition to the axial resistance of the soil, a transverse component force appears, which deflects the head during its advancement in the soil. The question of determining the angle of displacement of such a tip is important in terms of the process control.* ***Results****. In the paper, a calculated dependence is proposed for determining the rational value of the angle of inclination of an asymmetric tip working surface, which is a flat plane cut at the angle of a cylinder. An analysis of the dependence of the angle of the working surface inclination on the physical and mechanical properties of the soil is also given.* ***Originality****. It was determined that the maximum angle of inclination of the frontal surface is determined by the conditions of soil descent from it. Its maximum value, for example when working in loam, should not exceed* 55^o*-*67^o *for a tip made of steel.* ***Practical value.*** *The obtained calculated dependence can be useful for determining the angle of inclination of the flat frontal surface of the tip of the soil piercing working tool for controlled static soil piercing at the stage of designing networks and choosing an effective method for drilling a well under roads or other obstacles.*

Key words: *engineering communications, soil development, trenchless technologies, borehole, static soil puncture, soil compaction, distribution pipeline networks.*

Introduction

When laying engineering communications, there is a need to build crossings under roads, tram and railway tracks. Excavating an open trench is the most expensive way of performing such works [1], which is associated with stopping traffic flows and increasing social problems. Today, it was replaced by modern technologies, which made it possible to practically push the open trench method out of the field of construction of underground communications and their repair, especially in compact urban networks.

These technologies refer to the so-called trenchless methods of laying underground communications. Among the large number of alternative methods proposed by modern practice is the goal of static puncture of the soil, which, according to the above calculations, is the most effective for laying distribution pipelines with relatively small diameters up to 300 mm [2].

This method consists in forcefully crushing the soil-piercing working body in the form of a conical-cylindrical projectile into the soil. At the same time, the well is formed by radial extrusion of the soil around the well. But the use of such equipment does not provide high accuracy, which limits its practical application within 20 m, which is not sufficient for modern requirements of creating transitions during the laying of communications. One of the ways to improve the efficiency of laying underground networks is to extend the use of this method over a longer distance. This is achieved by using a soil-piercing head with an asymmetric tip, when the resistance of the soil is additionally divided into a transverse component. The question of determining the angle of displacement of such a tip is important from the point of view of controlling the process of piercing the soil with installations of static and combined action.

Analysis of the status of the issue and determination of the relevance of the issue

From a review of the technical literature, it was established that there are a large number of modern trenchless technologies for laying underground engineering communications, which have their own scope of purpose and effective use [1]. One of these technical means is the method of static puncture of the soil [2]. But it has limitations, in practical use it is only for distribution pipelines of relatively small diameters up to 300 mm and a length of up to 20 m. This is due to the creation of great efforts to crush the conical-cylindrical working body, which in turn causes stress in the soil massif around the well after its radial compaction [3].

It was also determined that the use of a working body with such a traditional form is deprived of the opportunity to influence the trajectory of movement and may deviate for a number of reasons: heterogeneity of the soil along the horizon, stony inclusions, waterlogging of the soil, etc. [4].

For work in tight urban networks, small-sized soil-piercing installations using hydraulic jacks are widely used and belong to static action installations [5].

The destructive effect of static machines on nearby communications or on the road surface is considered in [6]. But if the conditions for drilling are chosen correctly, the well created by static drilling of the soil will have hard, stable walls that do not require additional reinforcement with expensive drilling fluid, as required, for example, by the drilling method [7]. This is another important positive indicator that adds to the advantage of the method under consideration.

The above-mentioned disadvantages of the construction of communications by the method of static soil puncture can be reduced due to the recommendations considered in the works [5, 9-11]. One of the ways to improve the efficiency of laying underground networks is to extend the use of this method over a longer distance. This is achieved by using a soil-piercing head with an asymmetric tip, when the resistance force of the soil is additionally distributed into a transverse component, which deflects the working body in the opposite direction and provides an opportunity to correct or control the trajectory of the equipment in the soil. The question of determining the angle of displacement of such a tip is important, taking into account various basic conditions and their physical and mechanical properties. As it was established [12], in practice, two types of tips can be used for controlled soil puncture. It can be a tip in the form of a cylinder cut at an angle by a flat plane, or a cone with an offset top.

From the theory of deep soil cutting, it is known that in the process of advancing the earthmoving working body into the soil in front of it, a core of compaction may appear, which affects the work process [13]. Features of different types of soils and their physical and mechanical properties are considered in the work [14].

Purpose and Tasks

The purpose of the research is to determine the maximum allowable slope of the frontal working surface of an asymmetric tip for controlled static puncture in various soil conditions.

Determination of the angle of inclination of the frontal working surface of the asymmetric tip of the piercing head for static piercing of the soil

In work [5], the power dependence of soil resistance on its physical and mechanical properties and the geometry of the tip head was established. These forces are determined both in the direction of the puncture and in the direction perpendicular to the axis and have the form:

- for the axial resistance of the soil:

$$P_y = 0,36\frac{(1+\omega)\rho_{\text{pd}}}{C_{comp}\rho_{\text{ns}}}\times \times\left[\left(1-f^2\right)+2f\cdot\text{ctg}\beta\right]D^2, \quad (1)$$

- and for the deflection force:

$$P_x = 0,36\frac{(1+\omega)\rho_{\text{pd}}}{C_{comp}\rho_{\text{ns}}}(\text{ctg}\beta - f)D^2, \quad (2)$$

where ω– soil moisture; f – coefficient of external soil friction; D– tip diameter, m; β – angle of inclination of the tip plane, degrees; ρ_{pd} – density of the solid phase of the soil (density of the soil under the condition that there are no pores in it); ρ_{ns} is the density of the soil in its natural state; C_{comp} – soil compression coefficient.

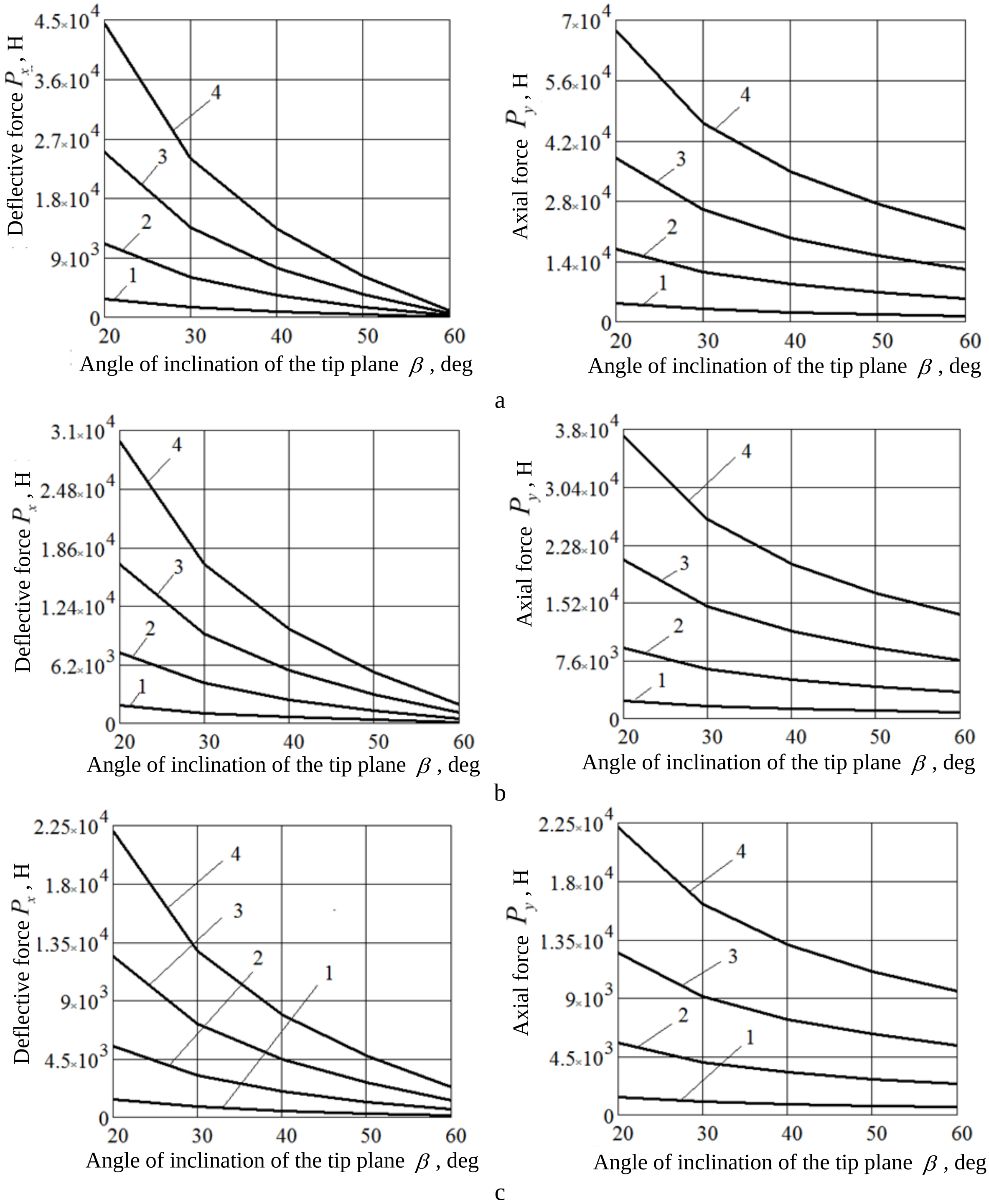

Fig. 1. Dependencies of the resistance forces on the angle of inclination for different soils at different values of the borehole diameters: a – sand; b – loam; c – clay; 1 – D = 0.05 m; 2 – D = 0.1 m; 3 – D = 0.15 m; 4 – D = 0.2 m

We will analyze the dependence of puncture resistance forces in different types of soil depending on the angle of inclination of the frontal working surface of the tip. To do this, we will present the components of soil resistance (1) and (2) in the form of graphs, which are shown in Figure 1.

It can be seen from the graphs that the forces of puncture resistance strongly depend on the type of soil being pierced and the angle of inclination of the frontal working surface of the tip.

It can be argued that determination of the components of soil resistance made it possible to establish that the axial and deflecting force will be smaller in plastic soils and reaches its greatest value in sandy loam and less in clay. The same principle applies to the effect on the resistance force and the angle of inclination of the working surface of the tip.

For a complete picture, consider the dependence of the deviation of the head on the length of the step of moving the rods on the angle of inclination of the frontal surface, which is revealed by the authors in the work [15] and presented as a graph in Fig. 2.

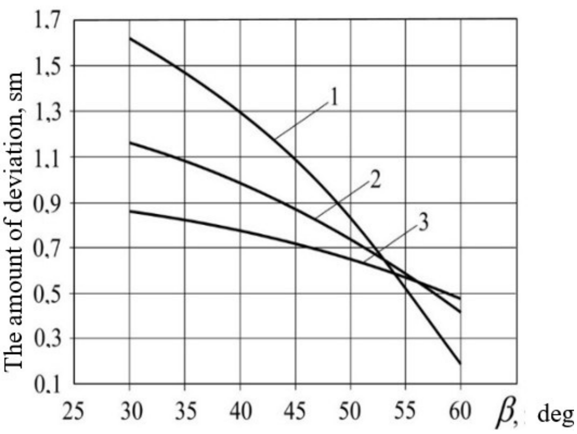

Fig. 2. Dependence of the deviation of the head on the length of the step of moving the rods from the angle of inclination of the cutting platform: 1 – hard sand; 2 – semi-solid loam; 3 - rigid clay

During the piercing process, as a result of the deviation of the tip head from the design axis, the orientation of the frontal cut plane of the tip relative to the puncture axis changes. It can be seen from Fig. 4 that in the process of deviation of the tip head from the design trajectory of the puncture, the axial and normal components of the puncture resistance change, and therefore the deflecting force changes. This should also be taken into account when piercing. According to the theory of soil cutting, a core of compaction can be created in front of the working body, which can come off or get stuck on the cutting edge of the earthmoving equipment. In the second case, the control process may not occur, because the permanent core that will be created on the tip will repeat the shape of a conical symmetric, as in the case of uncontrolled soil puncture.

To prevent this from happening, it is necessary to fulfill the condition of soil descent from the inclined frontal surface of the piercing working body. From the ratio of horizontal to vertical components of resistance reaction

$$\frac{P_y}{P_x} = \frac{\left(1 - f^2\right) + 2f\text{ctg}\beta}{\text{ctg}\beta - f} \tag{3}$$

we can get the inequality:

$$\left(1 - f^2 + 2f\text{ctg}\beta\right)\cos\beta \geq \frac{f}{\sin\beta}. \tag{4}$$

The condition of soil descent from the frontal surface will take the following final form:

$$\left(1 - f^2\right)\sin\beta\sqrt{1 - \sin^2\beta} + 2f\left(1 - \sin^2\beta\right) \geq f \tag{5}$$

Based on the obtained condition of soil ascent, the guaranteed control process will take place at the angle of inclination of the frontal surface of the asymmetric tip, which is calculated according to the dependence:

$$\beta < \arcsin\sqrt{\frac{1}{2} \pm \sqrt{\frac{1}{4} - \left(\frac{f}{1 + f^2}\right)^2}}. \tag{6}$$

The root must be preceded by a "+" sign. In this case P_y will take the minimum value.

The dependence of the maximum angle β_{max} on the friction coefficient is shown in Fig. 3. In the obtained calculations, the main indicator that affects the deviation process during controlled puncture is the soil friction coefficient on the working frontal surface of the working body for soil puncture with control of the movement trajectory. From the graph in Fig. 3, it can be seen that from the condition that the friction angle will be within 0.4 to 0.6, the rational angle of inclination can be taken from 67° to 55° depending on the steel and the condition of the frontal surface.

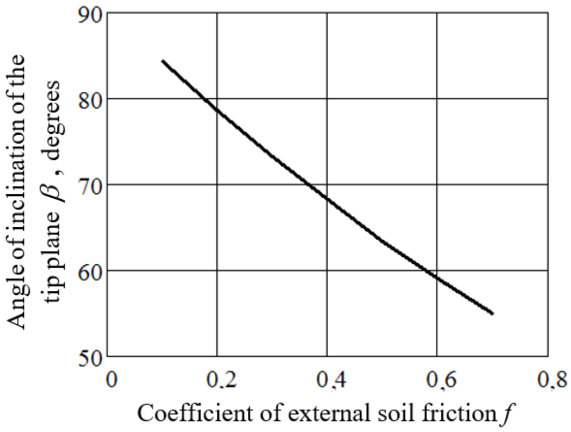

Fig. 3. Dependence of the maximum angle of inclination of the frontal plane of the tip on the coefficient of external friction of the soil from the condition of its movement on the plane

Analysis of the results of research on determining the angle of inclination of the working surface of the asymmetric tip of soil-piercing equipment

During the construction of engineering communications, one constantly has to face the need to cross obstacles in the form of roads, tram and railway tracks. In order not to stop traffic for the works, trenchless laying of underground communications technologies is used. Among them, the technology of forming wells using installations for creating horizontally directed wells in the soil by the method of its static piercing is the most effective. Expanding the scope of use of this method by increasing the distance of the spans became possible in connection with the introduction of modern devices for navigating the movement of piercing equipment in the soil.

The process of controlling the puncture trajectory is ensured by the creation of a deflecting force that occurs when using the working equipment of an asymmetric tip. One of the variants of such a tip is an inclined frontal working surface obtained by cutting at an angle of a cylindrical body. The component forces of the soil resistance and the deflection trajectory of the working equipment depend on this angle. Thus, changing the angle of inclination of the frontal surface of the working body from 30^o to 60^o in the conditions of a puncture in hard sand, the amount of deviation can change at a distance of 10 m from 0.2 cm to 1.6 cm. And in rigid plastic clay, the deviation will be within 0.6 cm to 0.9 cm.

Therefore, the goal of determining this angle, provided that it is possible to control the trajectory of the puncture and create a communication cavity in the soil, is of important scientific and practical importance.

The proposed method of determining the angle of inclination of the working surface of asymmetric soil piercing equipment is based on the concept of soil cutting by earthmoving equipment and the regularities of the process of controlled soil piercing. The obtained dependence of the maximum angle of inclination of the working surface depends on the coefficient of external friction of the soil, and will range from 55% to 85%.

This approach provided an opportunity to obtain objective results, which is evidenced by the received real practical recommendations for applying the results of the work.

Conclusion

Determination and analysis of the components of soil resistance made it possible to establish that the axial and deflecting force will be smaller in plastic soils and reaches its greatest value in sandy loam and less in clay. The same principle applies to the effect on the resistance force and the angle of inclination of the working surface of the tip.

The obtained dependence for determining the angle of inclination of the flat working surface of the asymmetric soil piercing equipment for creating a communication cavity in the soil, which is created by controlled static piercing. It was established that if the angle of friction of the frontal surface of the working body with the soil is within 0.4 to 0.6, then the rational angle of inclination can be taken from 67^o to 55^o depending on the steel and the condition of the frontal surface. The obtained results make it possible to determine the geometric parameters of the asymmetric tip for creating a well at the very beginning of the work to ensure the maximum efficiency of the process of trenchless laying of engineering communications, taking into account the type of soil, its physical and mechanical properties and the material from which the working equipment is made.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Визначення куту нахилу лобової робочої поверхні асиметричного наконечника грунтопроколюючої головки для статичного проколу ґрунту

Анотація. Проблема. *З аналізу технічної літератури встановлено, що серед безтраншейних технологій прокладання підземних інженерних комунікацій найбільш поширеною є технологія з можливістю утворювання горизонтально спрямованої комунікаційної порожнини в ґрунті з використанням ґрунтопроколюючих установок статичної дії.* ***Мета****. Цей метод полягає у силовому задавлюванні в ґрунт ґрунтопроколюючого робочого органу, який має вигляд конічно-циліндричного снаряду. При цьому свердловина формується шляхом радіального витиснення ґрунту навколо утворюваної свердловини. Але використання такого обладнання не дає високої точності, що обмежує його практичне застосування в межах 20 м, що є не достатнім для сучасних вимог створення переходів під час прокладання комунікацій.* ***Методологія****. Одним з напрямів підвищення ефективності прокладання підземних мереж є розширення цього методу на більшу дистанцію шляхом корекції траєкторії руху робочого органу. Досягається це шляхом використання ґрунтопроколюючої головки з асиметричним наконечником. Завдяки цього до осьового опору ґрунту додатково з'являється поперечну складову сила, яка відхилює головку при її просуванні в ґрунті . Питання визначення куту зміщення такого наконечника є важливим з точки зору керування процесом.* ***Результати****. В роботі запропоновано розрахункову залежність для визначення раціонального значення куту нахилу робочої поверхні асиметричного наконечника, який являє собою зрізану під кутом циліндру пласкою площиною. Також наводиться аналіз залежність куту нахилу робочої поверхні від фізико-механічних властивостей ґрунту.* ***Оригінальність****. Визначено, що максимальний кут нахилу лобової поверхні визначається умовами сходу ґрунту з неї. Його максимальне значення, наприклад при роботі в суглинку не повинен перевищувати 55º-67º для наконечника, який зроблено із сталі.* ***Практичне значення****. Отримана розрахункова залежність може бути корисна для визначення куту нахилу пласкої лобової поверхні наконечника ґрунтопроколюючого робочого інструменту для керованого статичного проколу ґрунту на етапі проектування мереж та вибору ефективного методу для проходки свердловини під дорогами або іншими перешкодами.*

Ключові слова: *інженерні комунікації, розробка ґрунтів, безтраншейні технології, свердловина, статичний прокол ґрунту, ущільнення ґрунту, розподільні трубопровідні мережі.*

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