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Soil thrust boring plant of static action with ring spacers of horizontal wells

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Abstract. The combined method of horizontal wells development by a soil thrust boring plant of static action with cutting rings has been proposed.

The ratio between the diameters of the cutting ring and horizontal well has been determined. The regression equation was received to determine a minimum depth of a horizontal well laying depending on the diameter of the bore hole and soil porosity. The dependencies for determining emerging forces while developing a horizontal well with a cutting ring and its cleaning with a disk with account of geometric parameters of the working equipment and soil condition have been established.

The general view of the soil thrust boring plant and its working equipment for developing horizontal wells has been presented.

Key words: trenchless technologies; communication; horizontal well; thrust boring method; jacking; combined method; soil

Introduction

The constrained conditions of cities require small and easily mounted equipment for effective laying and repairing underground communications. These requirements are met by the plants for thrust boring and pipe jacking of horizontal wells with their subsequent expansion to the desired diameter by means of soil radial compaction to the wellbore wall or removing it to the surface from the hole of the developed well.

Thus, the increase in the efficiency of formation of horizontal wells is a topical issue. It has become particularly important in connection with the intensive development of underground communications and the urgent problem of the existing infrastructure reconstruction.

Analysis of publications

Fundamentals of the thrust boring and pipe jacking theory are thoroughly studied in [1–7]. The results of the application of these methods in combination with each other or with other methods, e.g. auger boring are given in papers [8–11]. Possibilities of working processes intensification due to hydraulic, pneumatic and vibrodynamic impact on operating equipment and developed environment have been explored.

Objective of work

On the basis of existing theoretical fundamentals concerning horizontal wells development with the help of thrust boring and analysis of research on improving its operating processes it is intended to substantiate the possible efficiency increase when using the method of static thrust boring by its combination with the method of jacking.

The objective of this work is to establish regularities of the process of thrust boring in combination with the method of jacking by a ring operating device.

Methods and Results

Today, trenchless laying of engineering services under various conditions is carried out with the help of various technologies and technical devices for their implementation [12–15].

The process of traditional boring of horizontal wells by compact thrust boring plants of static action comprises the interrelated steps: for the thrust boring method it is the initial thrust boring of the pilot hole and its expansion to the desired diameter with the help of conic expanders.

A significant limitation for the application of this method is the probability of damaging the road base and its pavement, as well as adjacent communications due to elastoplastic deformation of soil around the developed well [16, 17]. On the basis of experimental studies a regression equation was received which takes into account soil porosity and the diameter of the horizontal well for determining the minimum depth of its laying H_{min} which eliminates soil swelling [17]:

$$H_{min} = \left(4.4 + \frac{1}{(0.01 \cdot n_0)^{2.25}}\right) \cdot d \ , \qquad (1)$$

where n_0 is soil porosity, %; d is well diameter, m.

Dependencies of the minimum depth of the well laying on its diameter and soil porosity are shown in Fig. 1.

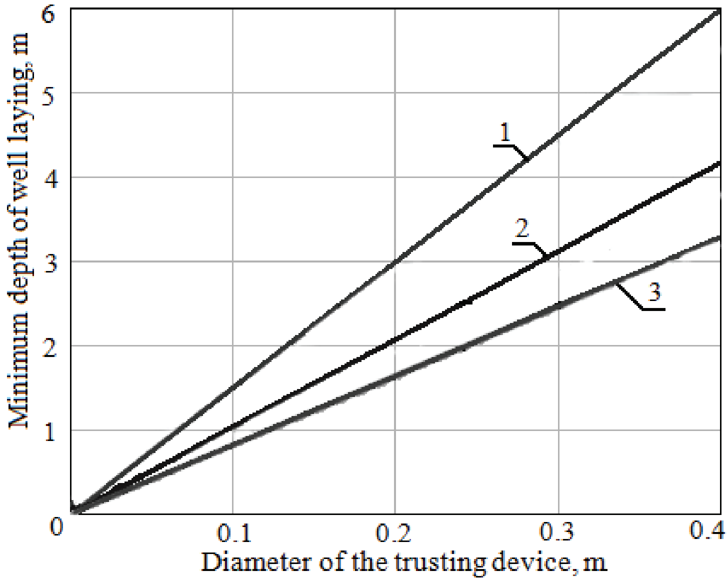

Figure 1. Dependency of the minimum depth of the well laying on the diameter of the thrust head and soil porosity: 1 – for solid clay with n_0 = 38 %; 2 – for loam with n_0 = 45 %; 3 – for loamy sand with n_0 = 53 %

There is no disadvantage like this when forming the well by the method of pipe jacking. However, significant sizes of the plant and a big volume of excavation connected with digging pits of appropriate dimensions, removing soil from the sunk pipe, also impose restrictions on the application of the method.

To receive greater efficiency in development of horizontal wells, the authors [19, 20] proposed a combined method which has advantages of each of the analyzed technologies, namely: the development of big diameter wells using a small size plant.

The possibility of developing big diameter wells is provided by the use of cutting rings, which excludes the further development of deformation around the well.

The combined method is implemented by the combination of the following equipment: a thrust head, a cone expander and cutting rings. Fig. 2 shows the implementation of the proposed method.

In Fig. 2a и 2b the well is developed with the help of thrust boring. The well depth should not exceed the allowable value of H_{min} that eliminates the destruction of the road base and the damage of adjacent communications from compacted soil which is calculated according to Equation 1.

The well can be further expanded by the method of jacking. The method of jacking (Fig. 2c) is realized by sequential drawing of special cutting rings when the diameter of the following cutting ring is bigger than that of the previous one. After cleaning the well with, e.g., a scraper working body (Fig. 2d), a protective case is drawn in its cavity (Fig. 2e).

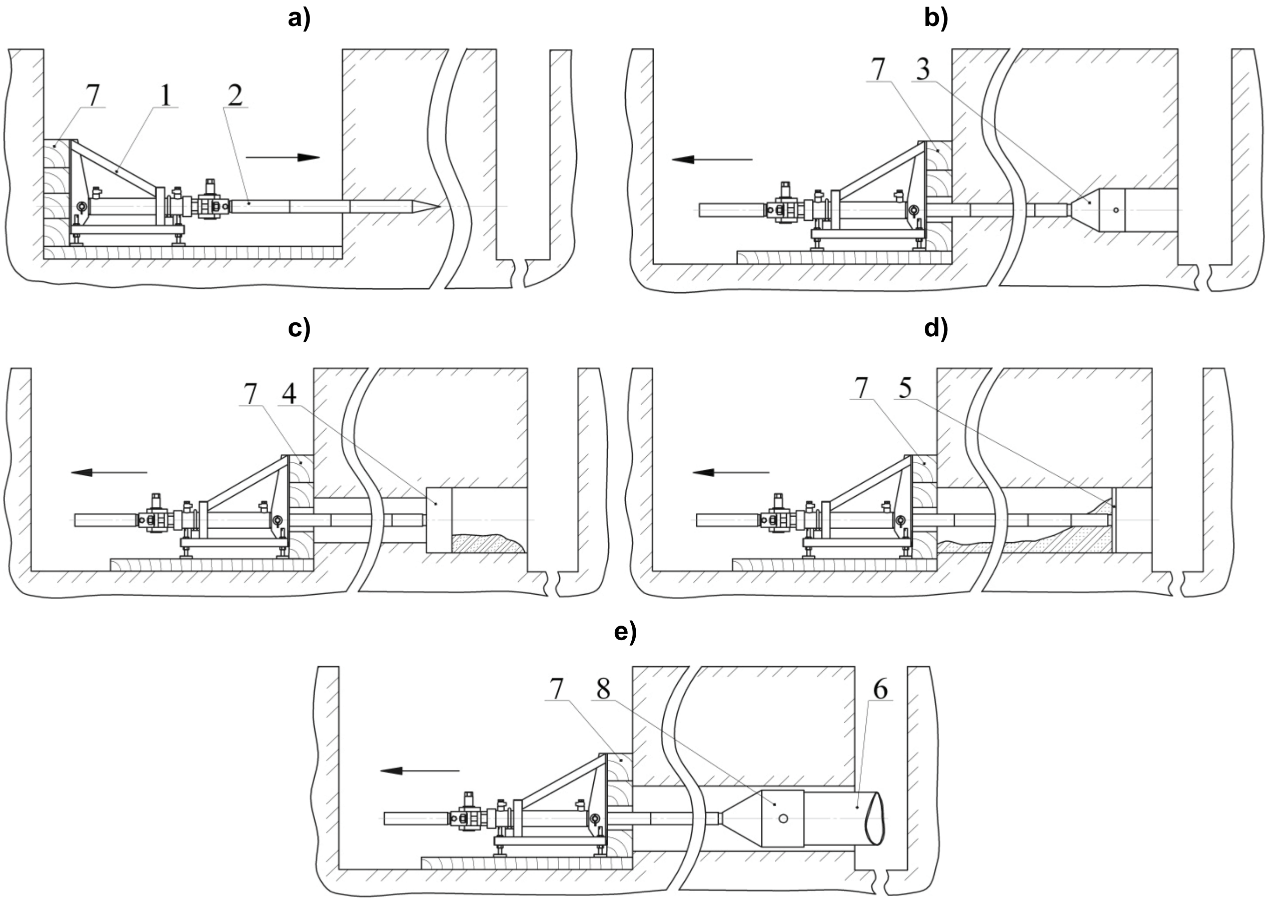

Figure 2. The well development by the combined method: a – pilot thrust boring; b – well expansion with the expander; c – well expansion with the cutting ring; d – well cleaning; e – drawing the protective case in the well; 1 – thrust boring plant; 2 – rod; 3 – conic expander; 4 – cutting ring; 5 – cleaning disk; 6 – protective case; 7 – resistant bars; 8 – pipe holder

Calculations showed that between the diameters of the cutting ring d and d_1 a certain ratio must be kept because of the necessity of the cut soil free passing through the cutting ring:

$$\frac{d_1}{d} \approx 1.25...1.35. \qquad (2)$$

The scheme of interaction of the cutting ring with soil in the well is given in Fig. 3.

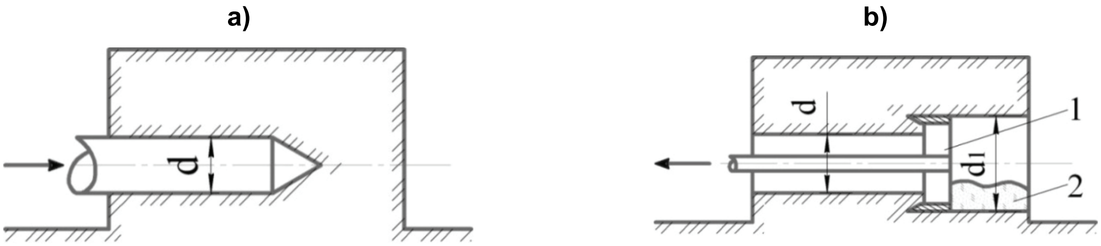

Figure 3. Scheme of the well expansion with a cutting ring: a – pilot thrust boring; b – well expansion with a cutting ring
1 – cutting ring; 2 – cut soil

The prism of the cut soil is formed in front of the cutting ring when it moves. Its pressure facilitates the passage of the cut soil through the holes in the ring. Force P_1 (Fig. 4) causes the thrust force P_r, which creates additional loading on the soil element cut by the ring. When moving the cutting ring the following forces should be overcome: force P_1, friction between the cutting ring and the well T_1, head resistance of soil to the edges of the ring P' and resistance to cutting soil with the cutting ring P_G.

a) b)

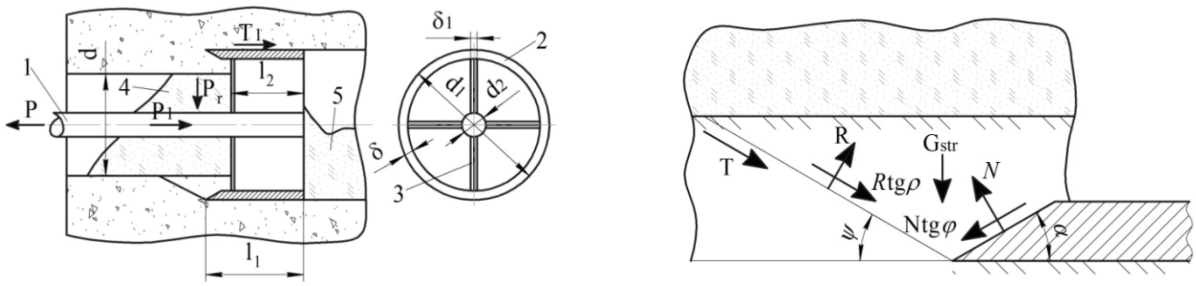

Figure 4. Scheme of interaction between the cutting ring and the well soil:
a – construction scheme; b – calculation scheme;
1 – rod; 2 – cutting ring; 3 – edge; 4 – prism of soil; 5 – soil passed through the ring holes;
α – wedge angle of the ring; ρ – angle of soil internal friction; φ – angle of soil external friction;
T– resistance of shear of the cut element to soil; N – normal pressure of the head facet of sharp edge of the ring on the soil; ψ – angle of soil displacement; G_{str} – weight of the soil cut element

The dependency for determining resistance of the cutting ring movement during the well expansion can be calculated like this:

$$P = 2\xi\,\mathrm{tg}\varphi\,\frac{l_2^2}{\alpha_1}E_p\,\frac{\lfloor(d_1-2\delta-d_2)(0.5n\pi+\pi^2)-2\delta\rfloor}{\pi(d_1-2\delta-d_2)}+p\pi d_1 l_1\mathrm{tg}\varphi+\frac{n}{\alpha_1}\delta_1 l_2 E_p+$$
$$+\frac{\sin(\alpha+\varphi)}{\sin(\alpha+\varphi+\psi+\rho)}\Bigg[\Bigg[\Bigg\{2\xi^2\frac{l_2^2}{\alpha_1}E_p\,\frac{\lfloor(d_1-2\delta-d_2)(0.5n\pi+\pi^2)-2\delta\rfloor}{\pi(d_1-2\delta-d_2)}+$$
$$+\delta\frac{\pi}{8}d_1(d_1-d)^2(\mathrm{ctg}\alpha+\mathrm{ctg}\psi)\Bigg\}\sin(\rho+\psi)+c\frac{\pi}{4}\frac{\sqrt{\mathrm{ctg}^2\psi-1}}{\mathrm{ctg}\psi}(d_1^2-d^2)\cos\rho\Bigg]\Bigg], \quad (3)$$

where α_1 – correction factor;
E_p – module of loose soil deformation;
ξ –coefficient of soil lateral pressure;
p – soil resistance to crumpling;
n –number of ring edges;
c – soil adhesion in the well wall;
γ – volume weight of soil.

Graphs of dependencies of forces applied to the cutting ring in relation to the diameter of the ring and the soil category are given in Fig. 5.

There is some cut loose soil inside the well along its entire length after expanding it with the cutting ring. This soil can be removed by pushing it out with a cleaning disc. Let us consider the concurrent processes (Fig. 6).

At the first stage, as the disk moves, some soil is accumulated in front of it until the prism of dragging is formed. Upon further movement of the disc the whole section of the well is filled with soil, and the soil begins to thicken.

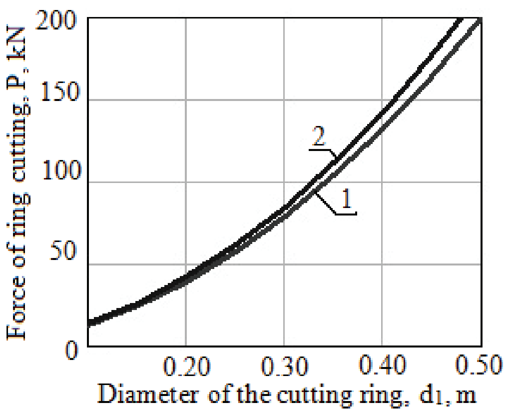

Figure 5. Dependency of the force of well expanding with the cutting ring: 1 – loam; 2 – clay

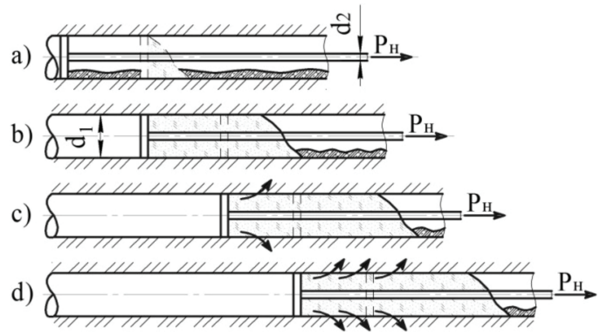

Figure 6. Well cleaning from the cut soil: a – formation of the prism of dragging in front of the disk; b – soil deformation with the disk; c – soil compaction with its partial displacement in the well walls; d – soil compaction with its complete displacement in the well walls

Let us select the element of soil at the distance x from the disk which will be acted upon from its both sides by normal pressure, respectively σ and σ + dσ; normal pressure σ_n will act on the perimeter of the selected element, and shear stress τ will act with the displacement of the selected element on its perimeter (Fig. 7).

The equilibrium equation for the selected element of soil (soil weight G_{gr} is neglected) can be given like this:

$$\frac{\pi}{4}d_1^2\sigma = \frac{\pi}{4}d_1^2(\sigma + d\sigma) + \xi\, tg\rho\, \pi d_1 \sigma dx + \xi\, tg\varphi\, \pi d_2 \sigma dx. \quad (4)$$

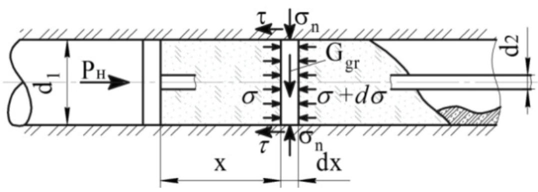

Figure 7. Diagram for determining the value of pressure of the cleaning disc on the pressed out soil

At the third and forth stages of the disk movement (Fig. 6) the part of soil starts getting pressed in the walls of the well, so for its cleaning some force should be applied to the disk:

$$P_H = \frac{\pi P_d}{4\xi}(d_1^2 - d_2^2), \quad (5)$$

where P_d is the resistance of soil to pressing.

When choosing value P_d, it should be taken into account that pressing occurs in the compacted soil, the strength of which can be increased 1.5–2 times.

The dependency of the force of cleaning the well with the cleaning disk on the diameter and the type of soil is given in Fig. 8.

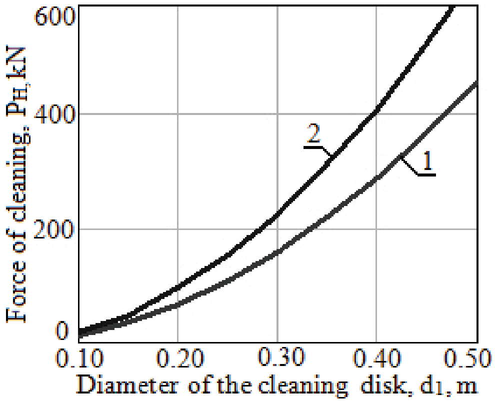

Figure 8. Dependency of the force of cleaning the well with the cleaning disk on the diameter and the type of soil: 1 – loam; 2 – clay

From the graphs shown in Fig. 5 and 8, it can be seen that the decisive parameter for choosing the plant is the force P_H, needed for cleaning the well.

Calculations based on these dependencies show that the application of the cutting rings allows us to obtain wells with the diameter up to 0.400 m and more, depending on the category of soil with thrust boring plants that are available.

The obtained results of the research have been confirmed by field trials on the basis of the plant for static soil thrust boring MP–250, produced by NPP "Gaztehnika". Under the conditions of scientific and research testing ground of Kharkiv National Automobile and Highway University the efficiency of the suggested combined method for the development of horizontal wells was proved (Fig. 9).

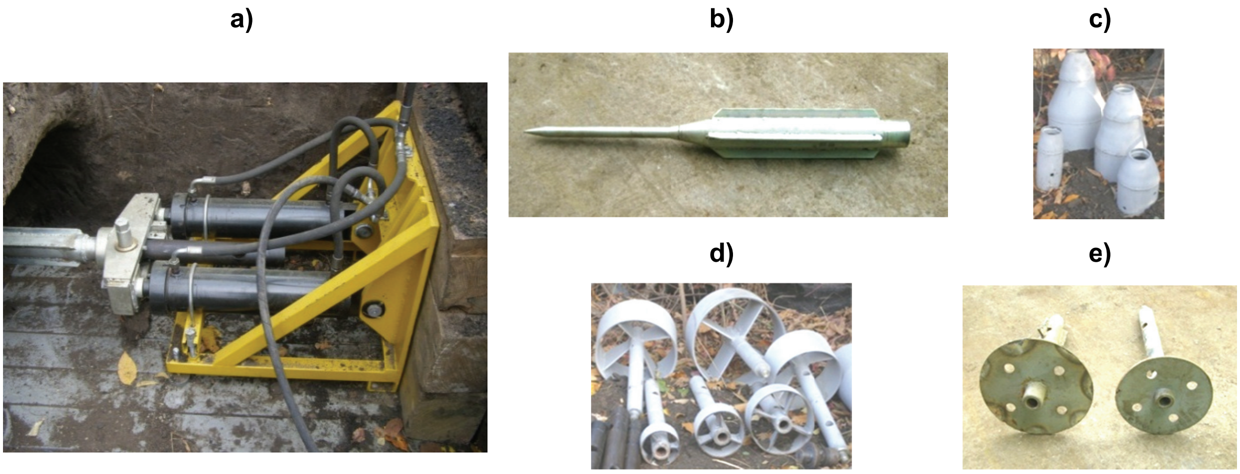

Figure 9. General view of the soil thrust boring plant and its working equipment: a – general view of a soil thrust boring plant; b – thrust boring head; c – conic expanders; d – cutting rings; e – cleaning discs

The hypothesis of the processes of digging soil with cutting rings and removing it from wells using the cleaning disc was confirmed. Convergence of theoretical calculations and actual values of resistance forces of wells development was in the range of 10–15 % that can be considered quite sufficient. By the results of the research a flow chart for developing a horizontal well with a soil thrust boring plant by the combined method was worked out. The effectiveness of the method was supported by its practical application at the objects of trenchless laying of protective cases with a diameter up to 0.325 m inclusively, for water and gas pipelines under roads (with a length of sections up to 10 m) at a depth of 1.5 m from the surface. In all cases, first the well was developed by the method of thrust boring up to a diameter of 0.159 m, and then it was brought to the project diameter with the help of cutting rings.

Conclusions

1. The dependency for determining the minimum depth of horizontal wells laying with account of the diameter of the communication and soil porosity has been studied.

2. The combined method of forming horizontal wells with the use of cutting rings has been developed.

3. The regularities for developing wells with cutting rings in various types of soil and cleaning the bottom hole from the cut soil have been established.

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Грунтопрокалывающая установка статического действия с кольцевыми расширителями горизонтальных скважин

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Ключевые слова

бестраншейные технологии; коммуникации; горизонтальная скважина; метод прокола; метод продавливания; комбинированный метод; грунт

Аннотация

Предложен комбинированный метод разработки горизонтальных скважин грунтопрокалывающей установкой с использованием кольцевых ножей.

Определено рациональное соотношение между диаметрами кольцевого ножа и существующей горизонтальной скважиной. Получено уравнение регрессии для определения минимальной глубины заложения горизонтальной скважины в зависимости от диаметра коммуникации и пористости грунта. Установлены зависимости для определения возникающих усилий при разработке горизонтальной скважины кольцевым ножом и ее очистки диском с учетом геометрических параметров рабочих органов и физико-механических свойств разрабатываемого грунта.

Представлен общий вид грунтопрокалывающей установки и ее необходимого рабочего оборудования для разработки горизонтальных скважин комбинированным методом.

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