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Analysis of the Application of Horizontal Directional Drilling

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ABSTRACT

Construction works are often considered to be very intrusive for the environment. Project designers assume deep excavations, or a complete replacement of the ground within the investment, which sometimes changes the initial conditions drastically. The problem started to appear in places, where the terrain is complicated and the excavation is burdensome. Some of state authorities do not agree to carry out works by open excavation. Such as crossing the river, running a network under the street in the city center, or a necessity to cross the protected natural area. In a case of linear facilities, it is possible to minimize interference for the natural environment. An example is crossing through a river, where instead of running a network on the bottom, a controlled drilling can be used. Modern technology allows for streamlining of execution works in line with pro-ecological policy.

Keywords: pipelines, environmental engineering, controlled drilling

1. INTRODUCTION

Since the beginning of the 20th century, trenchless methods have been improved in order to speed up and facilitate work. The initiator of the appearance of the first pneumatic punches is the British engineer Thomas Thomson. Designed for war, the machine served as a prototype for later projects. In Poland in 1950s, punchers were patented for laying underground networks.

It was not until later that additional advantages of trenchless methods started to be noticed, such as reducing interference for the natural environment. Controlled drilling known as directional drilling with the possibility of control for placing in the ground of wires and pipes was promoted by the Electric Power Research Institute and the Gas Research Institute. Drilling machines are getting improved with various drilling muds, drills and control systems. Many designers do not know how to design networks using these methods, which is why they rarely undertake such a task. In contrast, in accordance with the construction law contractors must stick to the methods commissioned in the construction project. A shift in the method of implementation may be considered as a significant shift, which is associated with a longer formal procedure of construction. The following work examines the theory with practice and takes into account the ecological considerations of controlled drilling and open excavations at linear works, focusing on gas works and PE pipes.

2. MATERIALS AND METHODS

2. 1. Principle of operation

As mentioned above, many designers avoid designing controlled drilling, basing on the difficulty of the project, resulting from the ignorance of the principle of operation. The following is a brief summary of the basic knowledge about drillings controlled basing on the example of the VERMEER D40x55 machine owned by PIB SUCHOCKI company.

The core drilling machine consists of three basic elements (Figures 1-6):

- control pilot,
- pilot drill heads,
- drilling rig.



Figure 1. Pilot drill head



Figure 2. Reaming and flushing heads



Figure 3. Drilling rig side view.



Figure 4. Drilling rig side view.



Figure 5. Drilling rig front view.



Figure 6. The system for preparation of drilling fluid.



Figure 7. Execution of pilot drilling

Figure 7 shows the pilot transition. One of the operators passes the terrain with the control pilot, while the other drives the drilling machine. Mutual communication allows drilling to be made in accordance with the project.

The whole task of carrying out a pipeline under a terrain obstacle consists of three stages (Figure 8):

Stage I - pilot boring

Stage II - reaming the ground;

Stage III - pulling the pipeline.

The first stage, i.e. pilot drilling, involves drilling the drilling head under the obstacle while maintaining all required depths and route. Firstly the operator with the control pilot goes through the line which was designated by the surveyor. The signals sent bounce off many obstacles, which allows the operator to detect interference. Then, the drill head is put into operation into the ground in the entrance chamber. After the terrain surface, the operator with the remote control moves along with it and checks if the drill head is on the proper path. At the same time the second operator applies the right force and direction for the drill head. The thrust force depends on the strength of the machine and the type of soil. The operator is regularly informed about a possible obstacle located on the drilling route, through the monitoring of resistance when introducing further rods into the ground and the necessity to place a larger amount of bentonite into the ground.

The first stage ends with moving the drill head out of the ground in the exit point. The next stage is to expand the hole to the required diameter by pulling on the same route a different type of head, called reamer. In some cases it is necessary to carry out this step several times to obtain a sufficient hole diameter. The last stage is the readjustment, when the conduit is already inserted into the ground. It is mounted on the head using a swivel, that allows the tube to rotate around its own axis. The pipe is pulled from the output excavation towards the entrance excavation.

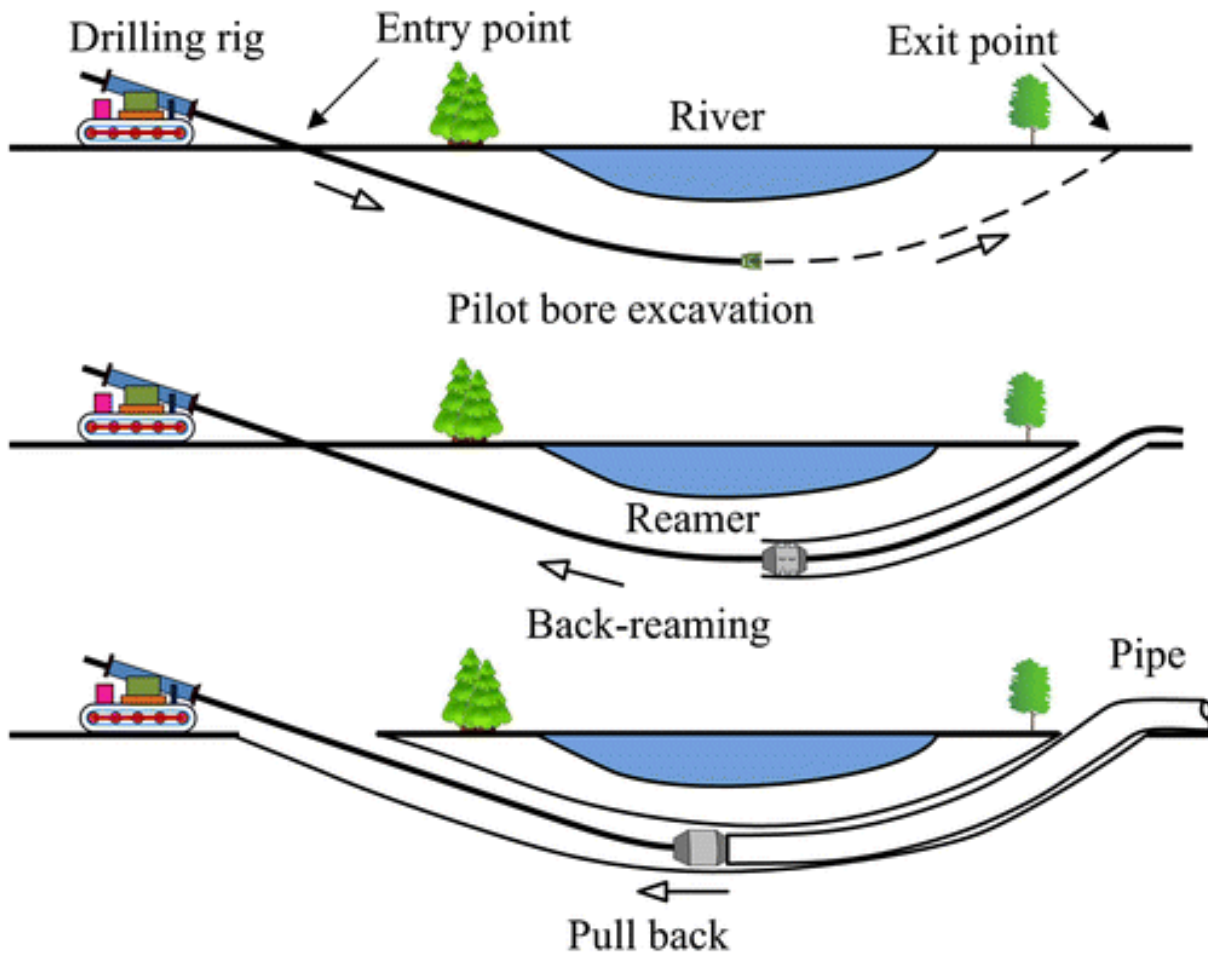


Figure 8. The principle of the drilling machine operation.

Above, a method of implementation is described which facilitates understanding of the design process. Before commencing the design of a controlled drilling, it is necessary to know the hydrogeological and morphological conditions and the existing utilities of the area. Knowing the basic parameters, you should determine the location of the entry point, adopt the appropriate type of drilling trajectory and calculate its geometrical parameters.

Three basic types of trajectory are shown (Figure 9): with a constant radius of curvature, with two curved sections separated by a straight line and with five sections alternating straight and curvilinear.

The first type is not recommended, because a constant control and control system is necessary along the entire length. In the case of designing straight sections, it does not require any control in this section.

The trajectory parameters of a controlled drilling include:

- distance from the entry point;
- depression of the drilling line axis from the reference level;
- tilt angle of the string relative to the horizontal.

Most often these parameters are determined at equal calculation intervals, because the control system expresses measurements in fixed measurement steps. The angle shift change can take place only in the second calculation step and should not exceed 4-5 °. The first rod is centrally attached to the bolts, so you can't change the set angle in the first calculation step. However, the bending radius of the drill string limits the possibility of radius of trajectory sections. It should be noted that depending on the diameter of the rod, its thickness and the type of connections with successive rods, the minimum bending radius of drill rods may vary. Depending on the manufacturer, the perches differ, which means that for the same rod diameters at different lengths, the minimum bending radii may vary. During the task, machine operators must make some adjustments depending on which machine they have.

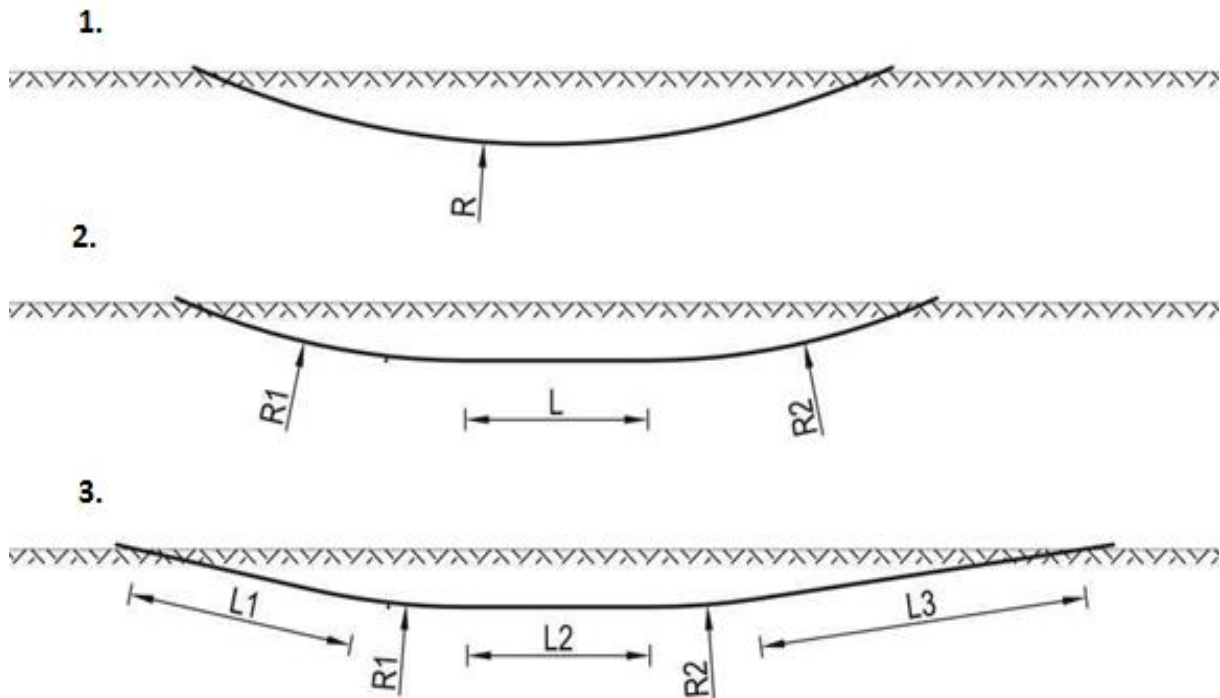


Figure 9. Basic types of trajectory of a controlled drilling

For tasks of different lengths, a corresponding increase in the diameter of the hole should be maintained in relation to the outside diameter of the pipe being placed. When drilling a length of up to 100 m, the diameter of the hole should be 20% greater than the diameter of the pipe. Every 100 m length results in approximately 10% increase of the hole diameter.

This involves the necessity to widen the hole and determine the number of these stages. Assuming that the same energy consumption is required for individual openings and the same hole length, then the energy consumption is directly proportional to the volume of soil being treated. From here it can be determined that for the first and second stages of hole widening we obtain a relation (2.1):

$$\frac{\pi d_1^2}{4} - \frac{\pi d_0^2}{4} = \frac{\pi d_2^2}{4} - \frac{\pi d_1^2}{4} \quad (2.1)$$

where:

- d_0 - diameter of the pilot hole,
- d_1 - diameter of the first extension,
- d_2 - diameter of the second extension.

The relation is based on the cross-sectional areas of openings in each stage of expansion. The series of mining and expanding tools on the market should be taken into account in the calculations. In addition to the hole diameter, it is also necessary to pay attention to the minimum depth of the pipeline positioning with note to its axis. For terrain obstacles, such as the riverbed or water reservoir, the appropriate coverage depth is defined as two and a half times the diameter of the reamed hole. Sometimes you should also pay attention while passing under the road, to not disturb the road foundation. The minimum coverage is determined only for the straight sections of the drilling trajectory. Then select a drilling rig and work tools like a drilling mud. The adoption of the control system and the magnitude of the forces acting on the drill string finish the static and strength calculations of the pipeline. The final stage is to determine the size of the machine and assembly area by the contractor.

2. 2. Bentonite

The bentonite fluid used for drilling consists of clay, volcanic clay called bentonite, ammonia soda and sometimes polymers. The mixture owes its specific properties from the construction from the crystalline structure of main mineral of bentonite i.e. montmorillonite mineral. After dissolution of bentonite in water, the structure tetrahedral octahedral layers is disintegrated due to water absorption. Figure 10 shows the package structure of montmorillonite.

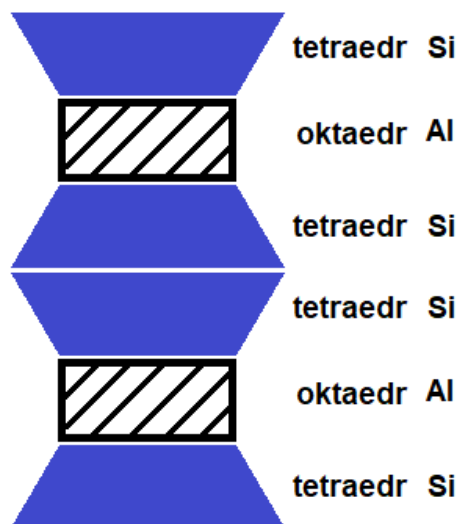


Figure 10. Package structure 2: 1 montmorillonite

The basic feature of bentonite is to increase its volume under the influence of water. According to research, it can absorb about 5 times more water than a sample of material weighs.

The result is that it can increase its volume up to 15 times. Its yield point is around 600%, which makes it resistant to breaking. Depending on the moisture level in the ground, pressed bentonite into the ground remains in the form of a gel, or it is dried out. Its variable properties are suitable for slowing down hole walls. Currently, research is being carried out to determine the effect of bentonites with an addition of polymers to the natural environment. [Raczkowski J., Pólchłópek T.: Chemical materials and chemicals for the preparation of drilling fluids. Works of the Institute of Oil and Gas, No. 95, Krakow, 1998.] Bentonite is also used in gardening, where people praise its ability to absorb water. The use of bentonite improves retention capacity in a low humidity environment. The bentonite clay absorbs toxins and harmful chemical compounds or heavy metals found in soil in addition to water. According to the Regulation of the European Parliament and Council (WE) No 1272/2008 of 16 December 2008, bentonite is not classified as a dangerous substance.

2. 3. Survey

The first survey that was carried out in order to verify the theory stating, that the controlled drilling are great methods of network construction, was a social questionnaire. The surveyed group consists of work managers, designers and machine operators. The questions concerned, among others, time of execution, the biggest advantages and disadvantages of open excavation and controlled drilling, possible difficulties and the price of execution. Every group consists of three people. The graph below presents the answers to the question about the reason for the design and execution of the controlled drilling.

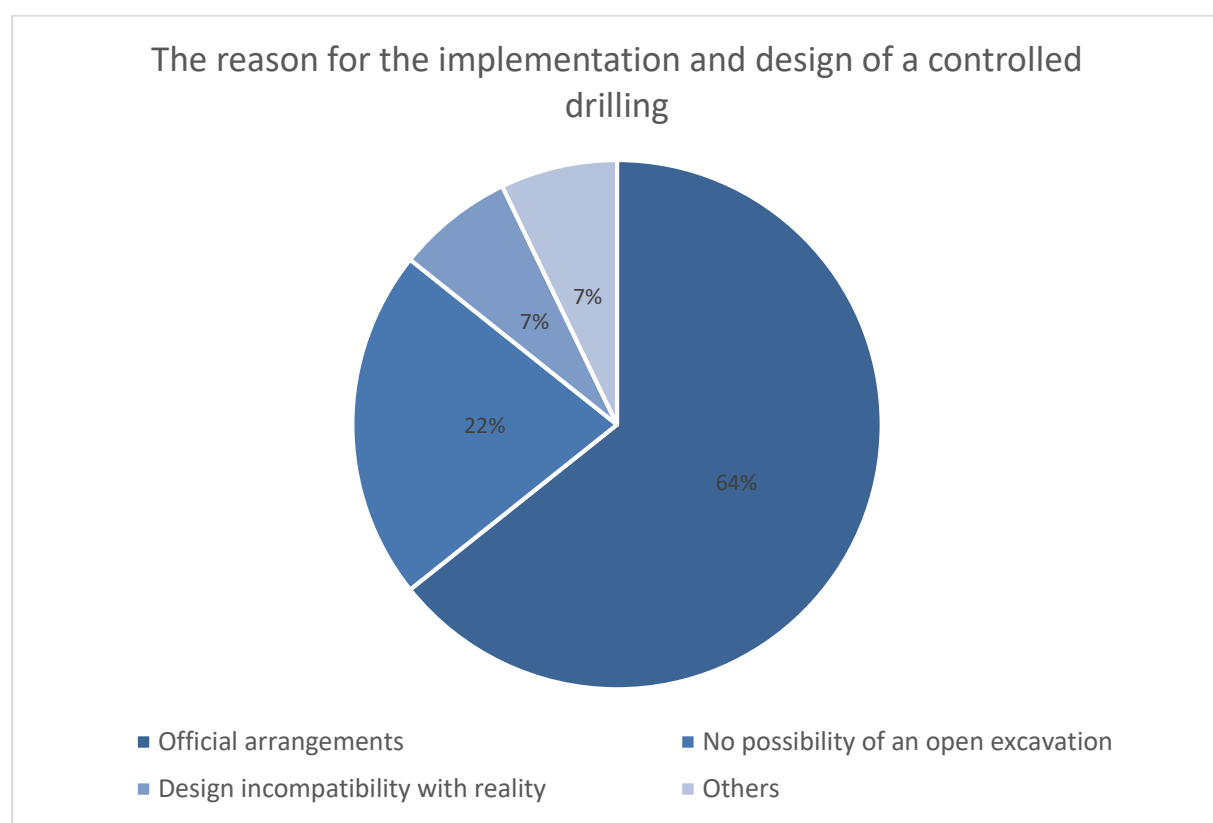


Figure 11. The results of the questionnaire

The basic reason for the design (figure 11), and then the implementation of the controlled drilling, are official arrangements. A decision on the infrastructure location in the local road may be an example of such a reconciliation. 30 official decisions regarding the location of the gas network infrastructure were analyzed and it was found out, that if the road has a category higher than G, the necessary requirement to cross this road is the implementation of the network with the trenchless method. Another arrangement that introduces the order to execute the network using the trenchless method, it is concluded with the manager of Wody Polskie (Polish Waters). Some of the arrangements have an additional record requiring the placement of line pipes in casing pipes. It happens that during the legislative process of a construction project, a shift will occur on the site. For example, in the project, the contractor gets information that the pipe should be made through a open pit at the side of a dirt road, while after a local inspection it turns out, that in the meantime a new pavement was made here. The contractor of this pavement has provided a guarantee for a given period of time, which will be annulled in the case of dismantling the pavement. This is one of the reasons for changing the technology of implementation on the very construction site. The respondents as the other arguments specified financial considerations or the time of the task. In the case of large diameters and long sections, the time of performing the task with the trenchless method becomes more and more favorable in comparison with the open excavation. Of course, financial considerations play an important role as well. The main part of financial differences stand out in work. The table below presents selected comparisons of the number of people on a construction site with the same task. Assuming the same time of execution of the gas network DN63 PE of the straight section of 400 m. Additionally, each person has only one function at the construction site. The task execution time is two working days, i.e. 16 hours of work. The maximum drilling length is 100 m (Table No. 1).

Table 1. Comparison of the number of people on a construction site

Function	The number of people		The cost of working hours * [PLN/h]
	Task using a controlled drilling	Task using an open excavation	
Contractor's supervision	1	1	30,00
Excavator operators	1	2	24,00
The operators of the drilling machine	2	0	27,00
Welder	1	1	29,00
Helpers	2	6	17,50
The total number of people	8	10	-
The average cost of team work hours at the task [PLN/h]	172,00	212,00	-

*Average prices determined by the average of available job offers for a given position.

Analyzed offers were from popular website with job offers. In the case of longer sections, the number of people employed in the construction executed by the controlled drilling method does not change. However, to do the same job, but using the second method should increase the number of people involved in the task. One of the tasks outsourced to the contractor was analyzed in more detail. The task was to cross the roadway in the city center. The problems that hindered the work included, among others, dense location of underground utilities and a sanitary sewer collector located under the road, or the presence of a latent network by the military. In addition, the road administrator did not allow work to be carried out by an open excavation due to the sensitive location of the road (city center, at the intersection of streets, Figure no. 12).



Figure 12. Localization: Poland, Gdynia, Waszyngtona Street

Data:

- dn160 PE 100 RC SDR 17 type 2 line pipe
- dn225 PE 100 RC type 2 protective tube
- length of carriageway in the transition route: 10.00 m
- sanitary sewer depth: 2.20 m below ground level

Decisions taken:

- resignation from the casing pipe while changing the type of the duct into type 3
- removal from the initial route by 2 m, due to the positioning of the drilling machine.

Type 3 PE pipes are characterized by an additional protective jacket, which increases the strength of the pipe. Differences between type 2 and type 3 PE pipes can be seen in the figure below (Figure no. 13).

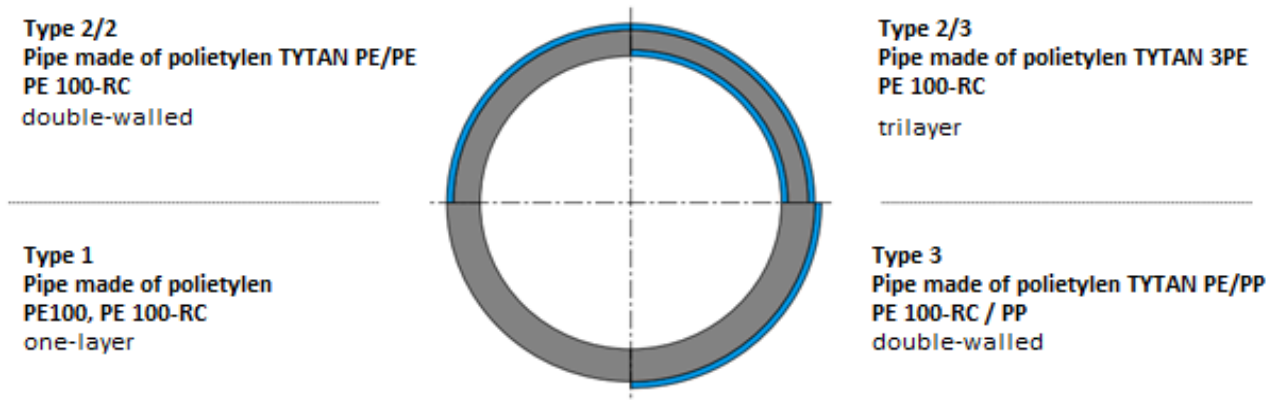


Figure 13. Types of pipes made of PE

The surveyor traced the route, and then two chambers were dug. One near the access chamber with telecommunication cables, and the other on the other side of the road to find two active waterworks. For the task VERMEER D9x13 S3 was used, which is smaller, and its perches are 1.83 m long. The pilot control operator passed the route 3 times to identify all disturbances from the environment. Then, the pilot head was slowly put into the ground at the adequate angle. At a distance of about 1.80 m, the location of the head was checked. The road was crossed the second time. The first withdrawal was necessary for the existing, unidentified resistance in the ground. During this time, the welders prepared the pipe to be pulled into the drilled hole. It took half the drilling time to drag the pipe through the hole (Figure 14). Then, the drawn pipe was connected to the remaining sections of the gas pipeline.



Figure 14. Leading the pipe in the entrance chamber

In order to check that nothing was damaged, the graphs generated by the control pilot and the machine were examined (Figure 15).

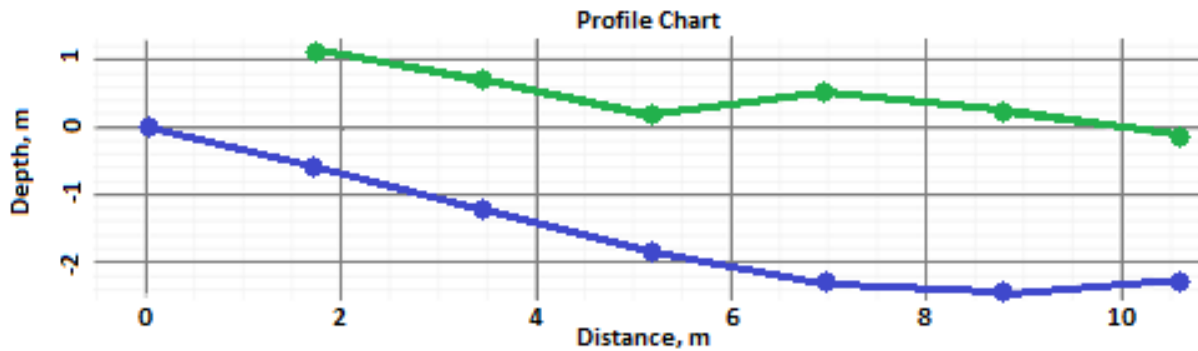


Figure 15. Graph generated by the drilling machine (green line – terrain, blue line – trajectory of the pilot)

The comparative level is marked from the moment the pilot's head is inserted into the ground, due to the introduction in the excavation, there is no reference to the area. At 7 m, it was crossed under the sanitary collector. The recess in this place is 2.80 m. The machine also provides information such as the pressure of the bentonite mixture, the type of drill pipe inserted, or the date of drilling. The data is saved after each inserted rod (Table 2).

Table 2. Data generated by the machine

Rod ID	Rod Len.	Bone Len.	X Det.	Pitch	Depth
0	0.00	0.00	0.00	-18.8	
1	1.83	1.83	1.73	-18.8	1.73
2	1.83	3.66	3.45	-20.8	1.92
3	1.83	5.49	5.17	-20.8	2.02
4	1.83	7.32	6.94	-8.0	2.80
5	1.83	9.15	8.76	-0.2	2.72
6	1.83	10.98	10.59	10.5	2.14

The diagrams created by the machine allow surveyors to find out at what depths the conducted pipes are located. On the other hand, current pressure information allows the operator to identify an obstacle along the route or change of ground conditions.

Monitoring was carried out through the sewage system in order to check for possible damage from the inside. The recording did not register any damage in the collector. The entire task lasted one working day drilling took half of the time. Preparation of the area for the drilling

is as important as the implementation of the drilling itself. It is necessary to get to know the area, utilities and ground as accurately as possible, because the level of complexity of a given task depends on them.

As-built cost valuation of this task was PLN 25,000.00. However, the estimated cost estimate for this task using the open excavation method was PLN 24,000.00. In this case the task was complicated, and it was a small length for drilling, hence the difference in price is not too high. In the case of tasks such as the construction of a gas pipeline along the forest line for a distance of 1 km, the difference in price is much bigger, and a well-developed drilling turns out to be a cheaper method of construction.

3. CONCLUSIONS

Summing up the above studies and analyzes, it can be concluded that controlled drilling technology is a useful and easy to use method. Dissemination of information about it would make it easier for designers to include it in a construction project. With the increasing degree of urbanization there will be more and more underground utilities, and thus, it is more difficult to introduce another technical infrastructure. Hence, the trenchless method meets expectations and allows you to conduct cables at greater depths, without the need for an open excavation. Despite its advantages, its shortcomings are and will continue to be improved by future engineers. However, the decision to use the trenchless method is individual for each task and you should know as many factors as possible to decide on its use.

References

- [1] Allouche, Lueke, Ariaratnam, Horizontal Directional Drilling: Profile of an Emerging Industry. *Journal of Construction Engineering and Management*, Vol. 126 (1), 2000, pp. 68-76
- [2] X. Wang, R.L. Sterling. Stability analysis of a borehole wall during horizontal directional drilling. *Tunnelling and Underground Space Technology*, Vol. 22, 2007, pp. 620-632
- [3] M. Polak, A. Lasheen. Mechanical modelling for pipes in horizontal directional drilling. *Tunnelling and Underground Space Technology*, Vol. 16, 2001, pp. 47-55
- [4] M. E. Baumert, E.N. Allouche. Installation Loads on Pipelines Installed Using HDD. CSCE Conference, London, Ontario, 2000, pp. 173-180
- [5] L. Cai, G. Xu, M. A. Polak, M. Knight. Horizontal directional drilling pulling forces prediction methods – A critical review. *Tunnelling and Underground Space Technology*, Vol. 69, 2017, pp. 85-93
- [6] X. Yan, S. T. Ariaratnam, S. Dong, C. Zeng, Horizontal directional drilling: State-of-the-art review of theory and applications. *Tunnelling and Underground Space Technology*, Vol. 72, 2018, pp. 162-173



- [7] A. G. Chehab, J. D. Moore. Parametric study examining the short and long term response of HDPE pipes when installed by horizontal directional drilling. *Tunnelling and Underground Space Technology*, Vol. 25, 2010, pp. 782-794
- [8] Ariaratnam, Stauber, Bell, Harbin, Canon. Predicting and controlling hydraulic fracturing during horizontal directional drilling. *Proceedings of the ASCE International Conference on Pipeline Engineering and Construction 2*, 2003, pp. 1334–1345
- [9] Ding P, Yan XZ, Yang XJ (2007) The mechanical parameter research of horizontal directional drilling crossing project. *J SWPU* 29: 152–155
- [10] Lueke, Ariaratnam. Surface heave mechanisms in horizontal directional drilling. *J Constr Eng Manag*, Vol. 135, 2005, pp. 540–547
- [11] T. Zayed, M. Mahmoud. Data acquisition and factors impacting productivity of Horizontal Directional Drilling (HDD). *Tunnelling and Underground Space Technology*, Vol. 33, 2013, pp. 63-72
- [12] A. P. Jaganathan, J. N. Shah, E. N. Allouche, M. Kieba, C. J. Ziolkowski, Modeling of an obstacle detection sensor for horizontal directional drilling (HDD) operations. *Tunnelling and Underground Space Technology*, Vol. 20, 2011, pp. 1079-1086
- [13] B. Shu, B. Ma. The return of drilling fluid in large diameter horizontal directional drilling boreholes. *Tunnelling and Underground Space Technology*, Vol. 52, 2016, pp. 1-11
- [14] S. Cherkashin. Installation of the Pipelines Made of Ductile Iron (DI) with the Usage of Horizontal-directional Drilling Technique (HDD) for Water Supply Treatment Service and Sewerage Pipelines Construction and Reconstruction. *Procedia Engineering*, Vol. 165, 2016, pp. 717-725
- [15] X. Yan, B. Ma, C. Zeng, Y. Liu. Analysis of formation fracturing for the Maxi-HDD Qin River crossing project in China. *Tunnelling and Underground Space Technology*, Vol. 53, 2016, pp. 1-12
- [16] L. Cai, M. A. Polak. A theoretical solution to predict pulling forces in horizontal directional drilling installations. *Tunnelling and Underground Space Technology*, Vol. 83, 2019, pp. 313-323
- [17] W. Yiquan, L. Guining, X. Laingkuai, Z. Panjun, M. Naibing. Technical difficulties and innovation in the Jiangyin Yangtze River crossing project of 3300 m HDD. *Natural Gas Industry*, Vol. 1, 2014, pp. 119-124
- [18] E. N. Allouche. Implementing quality control in HDD projects - a North American prospective. *Tunnelling and Underground Space Technology*, Vol. 16, 2001, pp. 3-12
- [19] X. Zhu, L. Dong, H. Tong. Failure analysis and solution studies on drill pipe thread gluing at the exit side of horizontal directional drilling. *Engineering Failure Analysis*, Vol. 33, 2013, pp. 251-264
- [20] X. Zhu, Q. Yi, „Research and application of reaming subsidence control in horizontal directional drilling. *Tunnelling and Underground Space Technology*, Vol. 75, 2018, pp. 1-10

- [21] J. A. Cholewa, R. W. I. Brachman, I. D. Moore. Stress–strain measurements for HDPE pipe during and after simulated installation by horizontal directional drilling. *Tunnelling and Underground Space Technology*, Vol. 25, 2010, pp. 773-781
- [22] M. Rabiei, Y. Yi, A. Bayat, R. Cheng. Simple methods for fluidic drag estimation during pipe installation via HDD. *Tunnelling and Underground Space Technology*, Vol. 76, 2018, pp. 172-176
- [23] H. Akbarzadeh, A. Bayat. Investigating ASTM F 1962 arching factor for Polyethylene pipes installed by Horizontal Directional Drilling. *Tunnelling and Underground Space Technology*, Vol. 39, 2014, pp. 50-57
- [24] H. Baik, D. M. Abraham, S. Gokhale. A decision support system for horizontal directional drilling. *Tunnelling and Underground Space Technology*, Vol. 18, 2003, pp. 99-109