The force on the drill tool in puncture and ramming in soil

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Abstract. The authors compare the technological capabilities of puncture, ramming and their combination in horizontal hole-making in soil. The test data on the hole-making tool–soil interaction are presented for the three methods. It is efficient to combine these methods to enhance performance of hole-making.

1. Introduction

Trenchless methods of utility pipeline laying are widely used in underground construction. It is necessary to improve these methods and equipment for accelerated construction.

The main methods of horizontal hole-making in shallow soil are puncture, ramming and drilling. The technological capabilities of these methods define the ranges of their application.

A puncture penetrates through soil, forms a cavity with displacement of some soil to the periphery of the hole. As a result of such transformation, the density of soil grows in the walls of the hole and in adjacent soil. The deformation zone reaches three and sometimes four diameters of the hole being made [1, 2], which increases the energy intensity of the process. For this reason, the maximum limit for the diameter of punctured holes is 300–350 mm.

Regarding the mechanism of the force impact, there are static, vibration and vibropercussion punctures. The most effective method of vibropercussion puncture enjoyed an advance when the Institute of Mining, SB RAS designed reliable air-hammer drilling machines [3]. The studies into the processes of soil compaction show that in vibropercussion, displacement of soil around a hole is reduced 1.3–1.6 times as compared with the method of static puncture [4]. As a consequence, the soil density increases directly in the hole walls, which enhances stability of the hole. This phenomenon is explained by the soil sluggishness property under high rate of soil deformation.

Ramming is the method of pipe installation with casing. In ramming, destruction of soil occurs along the hole perimeter, and soil resistance is therefore essentially smaller than in puncture. Accordingly, the energy intensity of ramming is less than in puncture. The feature of ramming is the so-called ‘pile-shape effect’. This means that movement of soil core inside a pipe decelerates due to friction on the inner surface of the pipe. This obstrucs the soil core advance, soil compaction increases, friction grows, and a soil plug forms in the pipe. Further ramming is only possible after removal of the soil plug from the pipe.

2. Laboratory testing results

The Institute of Mining, SB RAS has developed a framework for a combination technology of drilling using the advantages of puncture and ramming [5]. In this technology, soil in not removed from the hole but is pressed into the hole wall (Figure 1). The hole becomes more stable, which allows making holes
without casing and without drill mid. The deformation zone around the hole is small, and the energy intensity of the process is low.

Figure 1. Hole making with ring drill tool: 1—soil; 2—ring drill tool; 3—compact walls of the hole; F—active force; H—thickness of the ring; D—diameter of the hole.

For the analysis of forces generated in interaction of the tool and soil during hole-making be different methods, the tests were carried out of a special lab-scale installation named “soil channel”. The hole-making tool was simulated by a steel pipe with a diameter of 0.09 m and length of 1.5 m. At the frontal end of the pipe, the nozzles were installed by turn, to implement the combination technology with partial compaction of soil and puncture. The experimental installation (Figure 2a) is composed of pendulum hammer 4 mounted on the body of the “soil channel” 1 using runners 3. The front end of the soil channel is covered by cap 2 fixated using four steel angle bends. There are three openings made in the cap. The guide path was immovably fixed to steel sheet 6 using steel leg 7 and to cap 2 by bar 8. At the end of the model drill tool, to end 9 is welded to facilitate the transfer of the impact energy from the hammer.

Figure 2. Laboratory testing installation (a) and nozzles for hole-making tool (b).

Each of three experimental series consisted of three tests with penetration of the hole-making tool in the soil channel. In the first series, the tool penetrates soil with open front end. In the second series, the tool has the cone-shaped nozzle on its front end to implement the method of puncture (Figure 2b). In the third series, another nozzle is set to ensure hole-making by the combination technology with pressing of soil in the hole walls.

In each series, the model tool with different nozzles was driven in soil through three openings made in the wooden cap. The openings were equally spaced from each other at four diameters of the model drill tool and from the soil channel walls at three diameters of the drill tool. These spacings were selected to exclude the influence of soil deformation on the process of hole-making [3].

The friction forces between the tool and soil was determined by indirect measurement. We measured the value of the moment necessary to rotate the model tool in oil relative to the longitudinal axis of the tool and hole. At the same diameter, the value of the moment conforms with the tool–soil friction force.
The force required to rotate the tool in soil was determined using a dynamometer at the momentum arm of 0.55 m. After each series, soil was removed from the soil channel through special hatches and was re-compacted by layers 0.1 m thick. The density of each layer was measured using DORNII Institute’s densometer and was $C = 3–4$ units/\(\text{unit}^3\).

At first, the tests showed that the moment required to rotate the model tool in soil and, consequently, the friction force jumped high at the tool penetration depth of 0.7 m irrespective of the penetration mechanism. In order to avoid the influence of the tool length, the tool was redesigned so that after the tool penetrated in soil to a depth of 0.7 m, the area of the soil–side surface of the tool was unchanged. The testing data are depicted in Figure 3.

![Figure 3](image-url)

**Figure 3.** Rotative moment versus penetration depth of model drill tool in soil in adjusted testing.

It is seen in Figure 3 that the curves flatten at the tool length of 0.7 m, which defines the effective length of the tool gage surface. The lowest tool–soil friction is in the tool penetration by puncture, the highest friction is in ramming. The friction force in the combination of the two methods is moderate. It is highly likely that elastic response of soil decreases as the density of soil in the hole walls grows.

3. **Conclusions**

The combination method, a compromise at its bottom, in distinction from puncture, imposes no constraint on the hole drilling diameter. Moreover, the hole walls become compact, which, in distinction from ramming, allows casing installation after the formation of the hole void, or go without casing at all. The combination technology is a promising way of hole drilling improvement.

**References**

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