Influence of energy characteristics of vibropercussion source on efficiency of soil plug removal from casing pipes

AS Kondratenko, AM Petreev, AYu Primychkin and AS Smolentsev

Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia

E-mail: *kondratenko@misd.ru

Abstract. This article describes the method of vibropercussion ramming of an open-ended steel pipe in soil. The study focuses on interaction between the pipe and internal soil plug by the law of dry friction. The test bench for the effect exerted by impact impulses on displacement of soil plug is presented. The reduction in the friction force under the simultaneous static influence on the soil plug and vibropercussion load on the pipe is evaluated. The influence of energy characteristics of vibropercussion source on the efficiency of soil plug removal from the pipe is determined.

1. Introduction
Trenchless laying of underground utility lines is actually an efficient alternative to shoveling and sometimes is the only way of achieving the goal. The method of vibropercussion driving of open-ended pipes finds increasingly wide application these days [1]. Efficiency of this method is connected with high rate and accuracy of penetration in soil cut by the front edge of the driven open-ended pipe [2]. Soil enters the pipe drive under dynamic impacts, gets compacted and eventually forms a plug. After that new batches of soil cannot enter the pipe and are pressed into walls of the hole, which increases radial deformation in surrounding soil body while the pipe penetrates at far smaller rate. Thus, removal of soil plug during pipe driving is an important factor governing efficiency of the technology [3].

2. Soil plug removal: laboratory test results
In this connection, the method of vibropercussion driving with soil plug removal by batches has demonstrated practical success [4]. Figure 1 shows schematic of the technology with pipe ramming by pneumatic hammer.

In this technology, to the tailpiece of the pipe 1, via a separate line component 2, a fluid 3 is fed. As soon as a soil plug 4 is formed, the fluid is fed under pressure into the pipe through a hole 4. The fluid cuts off a batch from the plug and displaces it toward the back end of the pipe 1 where the soil batch is ejected through a discharge opening to the pit 7. The pipe ramming process continues until the soil plug is formed again. The ramming and plug removal cycles are repeated until the pipe comes in to the inlet pit [5]. It has been found under production conditions that owing to soil plug removal by batches, it is possible to accelerate ramming, reduce energy consumption of the process, and improve degree of mechanization and accuracy of pipe installation.
Figure 1. Pipe ramming with soil plug removal by batches: 1—driven pipe; 2—separate line component; 3—ejecting fluid container; 4—soil plug; 5—feed hole for ejection fluid; 6—discharge opening; 7—working pit; 8—soil body; 9—compressor; 10—pneumatic rammer.

In vibropercussion ramming, additional factors to influence separation and displacement of soil plug are vibration of the pipe and adjacent soil as well as elastic deformation of the pipe walls under impacts [6, 7]. It is known that internal and external friction coefficients can be reduced under the action of alternating loads [8, 9]. However, these processes are studied insufficiently, and their favorable effect on removal of soil plug by batches needs to be analyzed additionally using physical analogs.

Figure 2. Test bench: general view.
Figure 3. Test bench schematic: 1—air hammer; 2—visual control channel; 3—sliding element; 4—measurement piston; 5—soil batch; 6—loading piston; 7—pipe; 8—rod; 9—force sensor; 10—cylinder; 11—frame; 12—hinged support; 13—pumping station; 14—computer; 15—limit stop with a faceplate; 16—clip; 17—compressor.

Figures 2 and 3 present the lab test bench designed to determine how the impact load influence efficiency of soil batch displacement. The thick metal frame of the test bench is made of I beams. The pipe with a diameter of 48 mm is pressed to the frame by clips with rubber inside to crate friction force variable depending on the pressing force. Inside the pipe, a cylinder rod is placed. The cylinder is hinged to the frame. The force sensor mounted on the rod records the drag of a soil batch relative to the pipe and sends the data to a computer. At the opposite end of the pipe, an air hammer is arranged (piston weight is 0.5 kg, impact frequency is 8–28 Hz, blow energy is 1.8–5 J). For convenience of observation over the soil batch motion, an axial channel is made in the pipe, with an output sliding element rigidly connected with the piston. The equipment set includes air compressor and pumping station to power the hammer and cylinder, respectively.

For the repeated experimentation, soil plug was man-made. In order that the test conforms with a real process, density and moisture of a soil plug formed in the same length pipe in ramming in natural soil were measured and then used to form artificial soil plugs (Table 1). In each test series, a soil plug was formed by compaction of filled soil under axial force of 4 kN. For all types of soil, the length of the plug was 150–155 mm.

Table 1. Testing results.

| Experiment | Clay | Loam | Sandy clay |
|------------|------|------|------------|
| Content of clay particles, % | 62 | 39 | 21 |
| Batch length, mm | 155 | 150 | 150 |
| Density, kg/m³ | 1960 | 1840 | 1860 |
| Moisture, % | 14 | 13 | 13 |
| Type of loading | Statics | Vibro | Statics | Vibro | Statics | Vibro |
| 1 | 3.0 | 1.8 | 2.76 | 1.53 | 2.5 | 0.38 |
| 2 | 2.8 | 2.0 | 2.35 | 1.4 | 2.8 | 0.44 |
| 3 | 2.8 | 2.0 | 3 | 1.26 | 2.6 | 0.32 |
| 4 | 2.4 | 1.7 | 2.6 | 1.29 | 2.6 | 0.36 |
| 5 | 2.7 | 1.9 | 2.5 | 1.47 | 2.7 | 0.34 |
| Average | 2.7 | 1.9 | 2.5 | 1.38 | 2.6 | 0.37 |
The tests on starting and displacement of plugs were carried out using three types of soil (clay, loam and sandy clay). Soil plugs of the same length, density and moisture were placed at the same distances to the pipe ends and ten were ejected under axial force applied by the rod; the moving-off resistance was determined. The experiments were repeated with ejection of soil plugs by compressed air fed in the pipe.

At the next stage the tests were carried out with the simultaneous application of vibropercussion loading applied to the pipe by the air hammer. The natural interaction of the pipe and soil was simulated by means of a limit stop with a rubber faceplate to simulate frontal drag, while the resistance due to pipe and soil friction is created by two clips. The test results are compiled in the table and in Figures 4 and 5.

Furthermore, the influence of energy characteristics of the vibropercussion rammer on efficiency of soil plug removal was assessed. The vibropercussion source was chosen to be Typhoon air hammer designed at the Institute of Mining, SB RAS.

The tests of the blow energy effect were carried out using loam type of soil. The blow energy was adjusted by variation of energy source pressure in the feed line, and using different cross-section air bleeds installed in the feed line of the back run chamber (Figure 6).

The tests show that the friction between the soil plug and pipe walls reduces with increasing blow energy. The curve of the friction force as function of the unit blow energy of air hammer is presented in Figure 7.
In the experiments with loam, the influence of blow frequency of the air hammer on the friction force was evaluated under constant energy of blows at 4.5 J, the blow frequency was varied from 8 to 28 Hz using air bleeds with different flow areas installed in the feed line of the back run chamber of the hammer.
After averaging results of 5 experimental series of each test, no evident dependence between the friction force and the impacts was found. All results were within the error of 10%.

The damping effect was studied using the same test bench. Absorption of blow energy was regulated by the force of tightening of the clips 16 (Figure 3), and the axial displacement of the pipe under blows was varied by means of different stiffness rubber ring set on the damping unit 15 (Figure 3). The tests revealed no influence of damping on the friction between the pipe and soil plug. However, it should be mentioned that velocity of the soil plug ejection increases with the higher amplitude of the pipe displacements under percussions.

3. Conclusions
Thus, the authors have found that:
1. In terms of the test type of soil, the vibropercussive lod reduces resistance to soil plug moving – off and this effect is higher in soil with less content of clay particles.
2. As the unit blow energy of the vibropercussion rammer is increased from 1.8 to 5 J, the moving-off resistance reduces 2 times.
3. The variation in the blow frequency and damping parameters has no considerable influence of the soil plug resistant to moving-off.

Acknowledgements
The study was supported by the Russian Science Foundation, Project No 17-77-20049.

References
[1] Kondratenko AS and Chervov VV 2006 Typhoon-70 air hammer and new method of soil plug removal from pipe Mekhanizats. Stroit. No 8 pp 8–12
[2] Gileta VP, Vanag YuV and Tishchenko IV 2016 Improvement of hole making efficiency by the vibration–percussion ramming method Vestnik KuzGTU No 6 (117) pp 82–89
[3] Kondratenko AS 2008 Features of soil removal from a casing pipe GIAB No 7 pp 327–331
[4] Danilov BB, Kondratenko AS, Smolyanitsky BN and Smolentsev AS 2017 Improvement of pipe pushing method Journal of Mining Science Vol 53 No 3 pp 478–483 DOI: 10.1134/S1062739117032391
[5] Kondratenko AS, Timonin VV, Abirov AA, Gosmanov MK, Esenov BU and Zharkenov EB 2014 Technology of safe trencless hrozintal and inclined hole making Vestnik KuzGTU No 1 pp 40–45
[6] Kondratenko AS, Smolentsev AS, Timonin VV and Primychkin AYu 2018 The perspective of batch-wise removal of soil plug from pipes during trenchless installation IOP Conf. Series: Earth and Environmental Science Vol 134 DOI :10.1088/1755-1315/134/1/012029
[7] Gromov I, Belonogov LB and Yankovskii LV 2010 Elastic loss of efficiency in instaillation of pipes–casings using pneumatic hammers Vestnik PGTU pp70–74
[8] Mametiev LE, Khoreshok AA, Nekhin AM and Borisov AYu 2018 Improving efficiency of degassing hole driling and broken coal haulage Vestnik KuzGTU No 1 (123) pp106–112
[9] Aleksandrova NI 2017 Influence of soil plug on pipe ramming process Journal of Mining Science Vol 53 No 6 pp 1073–1084 DOI: 10.1134/S1062739117063138