The perspective of batch-wise removal of soil plug from pipes during trenchless installation

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Abstract. Modern approaches to construction of utility lines are reviewed. The hole-making technology of pipe driving can be improved by introduction of concurrent removal of soil plug by batches, which essentially enhances performance efficiency. The minimum air pressure required to separate batches from soil plug and to move it along a pipe is determined. The feasibility of cyclic destruction and removal of soil plug during pipe ramming is experimentally proved.

It is commonly known that the trenchless method of laying underground utility lines is the most advanced and ecology-friendly. This method enjoys wide application as development density is increased and different-purpose communications expand. Many trenchless passages are made under roads and railways. This lays higher standards on the hole-making technology such as elimination of subsidence or buckling of roadway surface both during construction and operation of underground passage [1].

In pipe installation under roads at shallow depth, one of the most widely applied approaches is one-ended pipe driving as it the best way of eliminating subsidence or buckling of roadways surface [2]. This method can be implemented either as pipe ramming by air-driven, hydraulic or electric hammer, or using static force of hydraulic jacks.

Percussion driving features high penetration rate and eliminates construction of a retaining wall in a working pit. In this method of pipe hammering, the disadvantages are increased noise, which is not permissible in urban conditions, and vibration that can result in over-compaction of engineering sand and gravel cushions made under roads and railways, and in failure of foundations of close-spaced buildings [3].

During both dynamic and static process of pipe ramming, soil enters the pipe, gradually compacts and makes a soil plug. This prevents continuous enter of soil in the pipe. Soil is pressed in the hole walls, which induces radial deformation in enclosing soil body, and the pipe penetrates considerably much slower as in case of closed-ended pipe. So, well-timed removal of soil plug is an important engineering factor of efficiency of the pipe driving technology [4]. The currently available technologies of intermediate soil plug removal (warms, barrels) require using auxiliary equipment and, moreover, need extra forces and time to assemble and disassemble cumbersome and heavy facilities [5].

It seems to be most reasoned to remove soil plug from pipes by batches without introduction of auxiliary equipment. The implementation layout of such approach in pneumatic hammering of pipe is depicted in the Figure 1 [6].
Figure 1. Layout of pipe driving with batch-wise soil plug removal: 1—driven pipe; 2—pipe line; 3—reservoir of pushing medium; 4—soil plug; 5—inlet for pushing medium; 6—outlet window; 7—working pit; 8—soil body; 9—compressed air source; 10—air-driven hammer.

In the proposed approach, a pushing fluid medium 3 is fed to the front end of the driven pipe 1 along the separate pipe line 2. When the soil plug 4 is formed, the pushing fluid medium is fed under pressure inside the pipe via the inlet 5. The pushing medium cuts off a batch of the soil plug and moves it towards the tail end of the pipe and pushes the soil batch through the outlet window to the working pit 7. After that, the pipe driving process continues until the next soil plug is formed. The driving and soil batch removal cycles are repeated until the pipe enters the receiving pit. It is also possible to remove soil batches without full break in the air hammer operation by providing lower pressure percussion.

The process of batch-wise soil removal can be divided into 3 stages: formation of the soil plug, separation of a soil batch and removal of the soil batch to the tail end of the pipe. At the stage of the soil plug formation, it is required that the soil batch in the zone of its cutting-off is dense and fills the whole cross section of the pipe. This is required to create and maintain the pushing medium pressure sufficient to displace and remove the cut-off soil batch. At the same time, it is clear that in the case of an over-compacted soil plug, it may be impossible to cut-off a batch, while in case of a low-coherent plug, a blue hole can appear, which results in the drop in the pressure of the pushing medium, and soil batch separation and removal becomes impossible. Thus, creation of suitable conditions for cutting-off and removal of soil batches is not a simple process and needs investigation.

For instance, according to the experimental data [7], soil plug is formed when pipe penetrates soil body by the value (6–10)D. If content of clay particles is high in soil, the soil plug is formed at the shorter length of the pipe penetration.

From the condition of equilibrium of elementary soil layer, the length of soil plug inside the pipe, $L_p$, is given by [8]:

$$L_p = \frac{D}{4f_c} \ln \left[ 1 + \frac{4f_c \sigma}{4e + \rho D} \right],$$

where $D$ is the driven pipe diameter; $f$ is the internal friction coefficient of soil; $e$ is the lateral earth-pressure coefficient; $c$ is the cohesion of soil; $\rho$ is the density of soil; $\sigma$ is the stress in the soil body.

Soil breakage by liquid or gas flow is used in practice of injection of soil foundations with different chemical compounds [9], in creation of anti-seepage screens in soil by hydraulic or pneumatic fracturing [10] and in pulsed gas ripping. The batch separation pressure can be found as [11]:

$$p = \rho gh + \frac{\nu}{1-\nu} (\sigma - \rho gh) + \sigma_{\text{max}},$$

where $h$ is the distance from the ground surface to the axis of the driven pipe; $\nu$ is Poisson’s ratio; $\sigma_{\text{max}}$ is the tension strength of soil.

In all mentioned practices, the rupture pressure for natural soil is not higher than 0.6 MPa.

The process of soil batch removal is a version of a tube transfer system. Such processes are implemented in drilling with coring [12], in transport of agricultural and construction materials [13].
When determining required pressure and flow rate of compressed air, it is necessary to take into account air leakage in the contact zone of soil and internal surface of the pipe, air loss connected with air seepage in soil and the limited cross section of the air feed pipe line. A sufficient condition for separated soil batch transfer is the relation [14]:

\[ p = \frac{1}{K} \cdot \gamma D \left( \exp \left( \frac{4 \gamma f}{D} l - 1 \right) \right) + p_0 , \]  

(3)

where \( K \) is the soil porosity; \( \gamma \) is the bulk weight of the soil plug; \( l \) is the soil batch length; \( p_0 \) is the atmospheric air pressure.

At this stage of batch-wise soil removal, it is important to preserve integrity of a soil batch, governed by the uniformity of the batch movement, density and moisture content of soil, roughness of the internal surface of the pipe and the change in the pipe cross-section. In case of vibro-hammering of a casing pipe, the other factors governing separation and removal of soil batches can be vibrations of the pipe and adjacent soil and elastic deformation of the pipe walls under impact. It is known that both internal and external friction coefficient can decrease under action of alternating load [15, 16]. On the other hand, this process remains yet to be studied better, and its positive effect on batch-wise removal of soil plug needs laboratory-scale investigation using physical models. Furthermore, vibration can affect integrity of a soil batch while removed.

In this manner, the proposed approach to trenchless pipe-casing driving with the batch-wise soil plug removal seems feasible but requires practical testing and multifactor laboratory experimentation and mathematical modeling.

The practicability of batch-wise soil removal by compressed air or air-and-liquid mixture was experimentally proved in conditions maximally close to real. The in situ tests were carried out on the testing ground of the Institute of Mining. It was required to make a hole with a diameter of 110 mm and 5 m long at a depth of 1.5 m from the ground surface, at an incline from 2 to 5 degrees. The static driving of pipe section used a hydraulic cylinder. The increment in length of the soil pipe was recorded while the pipe was driven in soil. The pressure of soil batch separation and removal was not higher than 0.6 MPa. Soil batch removal was carried out after the soil plug stopped growing in length by feeding compressed air or an air-and-liquid mixture along a separate pipe line. After the first batch was removed, the pipe driving process was re-started until the new plug was formed. The cycles were repeated down to the complete driving of the pipe in soil.

The tests proved efficiency of the proposed approach to pipe driving. The determined optimal length of a soil batch to be removed equals 3 diameters of a driven pipe.

**Conclusion**

The practical results obtained allow developing an efficient method of soil plug removal from pipes in the course of long trenchless pipe driving of high accuracy.

**References**

[1] Kondratenko AS 2008 Peculiarities of soil plug removal from casing pipes *GIAB* No 7 pp 326–331

[2] Kondratenko AS and Petreev AM 2008 Features of earth core removal from a pipe under combined vibro-impact and static action *J. Min. Sci.* Vol 44 No 6 pp 559–568

[3] Meskele T and Stuedlein AW 2013 Hammer–pipe energy transfer ratio for pipe ramming *Proc. No-Dig 2013* Liverpool NY

[4] Kondratenko AS, Timonin VV, Abirov AA, Gosmanov MK, Esenov BU and Zharkenov EB 2014 Safe trenchless horizontal and inclined hole-making technology *Vestn. KuzGTU* No 1 pp 40–45

[5] Gileta VP, Baris AV and Vanag YuV 2016 Evaluating layout and variables of air-powered drive of small-size pneumatic winch *J. Fundament. Appl. Min. Sci.* Vol 3 No 2 pp 25–30

[6] Kondratenko AS and Petreev AM 2010 RF Patent No 2399725 *Byull. Izobret.* No 26
[7] Gudavalli SR, Safaqah O and Seo H 2013 Effect of soil plugging on axial capacity of open-ended pipe piles in sands Soil Mechanics and Geotechnical Engineering pp 1487–1490
[8] Mitkina GV 1971 Influence of soil plug height on load-carrying capacity of soil piles Candidate of Engineering Sciences Dissertation Kuibyshev–Ufa (in Russian)
[9] Smagulova LK 2017 Chemical reinforcement of soil Simvol Nauki No 6 pp 28–31
[10] Fateev NT, Sergeev SV, Karyakin VF, Gapon SV and Shchetinin OV 2007 Directional hydraulic fracturing application to construction of enclosing structures in rock mass Proc. Miner’s Week-2007 pp 260–264 (in Russian)
[11] Winda AA 2011 Trenchless pipeline laying by the directional inclined drilling method. Hydraulic fracturing of sands and elimination of springs Sfera Neftegaz No 1 pp 104–105
[12] Ignatov AA 2012 Analytical Research of Core Velocity in Viscous Fluid Dnepropetrovsk: DonNTU (in Russian)
[13] Kril SI and Chaltsev MN 2010 Calculating procedures of basic parameters for pneumatic transport of granular materials in horizontal pipes Prikl. Gidromekh. Vol 12 No 4 pp 36–41
[14] Kershenbaum NYa 1968 Vibro-Method of Horizontal Drilling Moscow: nedra (in Russian)
[15] Aleksandrova NI and Sher EN 2010 Wave propagation in the ecodn periodical model of a block-structured media. Part I: Characteristics of waves under impulsive impact J. Min. Sci. Vol 46 No 6 pp 639–649
[16] Nikolaev SK and Korolev VA 1981 Role of temperature in thixotropic structurization of water-saturated clayey soil Inzhenern. Geolog. No 5 pp 37–47
Corrigendum: The perspective of batch-wise removal of soil plug from pipes during trenchless installation

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Description of corrigendum e.g.,

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