

Challenges during Horizontal Directional Drilling (HDD) Wells Installation for Dewatering Opencast Mines

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Abstract

Dewatering is a prerequisite condition for accomplishing surface mining activities. To drain the huge volume of water, a conservative approach of using vertical well has been applied widely. However, some limitations does exist in this method such as low-efficiency, high-energy consuming and discontinuity. This leads to the appearance of an innovative way of dewatering opencast mines (Richard A. Eichler and Carsten Drebenstedt 2013). The method uses Horizontal Directional Drilling (HDD) technology to install horizontal wells in aquifers. Water will then be collected from aquifers and overlying materials and will be let to flow-out freely by its gravity. Nevertheless, lots of risks and difficulties have been faced during the HDD wells installation. Through theoretical analysis and based on gained experiences during the HDD wells installation in the MIBRAG lignite company, Germany, supported by German Federal Foundation for Environment (DBU-Deutsche Bundesstiftung Umwelt), the challenges in the HDD wells placement for open-pit mine dewatering will be detailed analyzed. The challenges analysis will then be used to discuss and propose solutions to minimize negative effects and look toward the successful, effective application the HDD tech for the purpose of drainage opencast mines.

Keywords: challenges, HDD well, open-pit mines, dewatering, drilling fluid, elevation, well structure.

1. Introduction

The usage of the HDD technology for purpose of dewatering opencast mines has lots of advantages over conventional method of using vertical wells (Holger Mansel, Carsten Drebenstedt and Others 2012). The HDD tech had been developed since the year of 1960s (North American Trenchless Technology 2012). This is a ‘steerable system’ (Youssef Hashash and Jamie Javier 2011) and is an extremely versatile trenchless technology used for installation utilities underground (Fig. 1). Typically, the HDD installation is divided into three steps. The first step is to drill a guided pilot hole along the bore path consisting of a shallow arc by mechanically cutting and mixing soil and/or rock formations with drilling fluids to form a flowable slurry. In the second or subsequent step(s), the bore is sufficiently enlarged with larger diameter back reamer(s) before the product pipe/conduit is pulled into the bore and installed in subsurface (Ariaratnam, S.T., Lueke, J.S. 2002). Despite its popularity and success, a number of risks relating to the HDD installation still remains. However, to apply this HDD tech for surface mining dewatering, more difficulties have been encountered. This paper focuses on reviewing challenges of conventional HDD installation, analyses difficulties of the HDD wells installation. The results of the risks and challenges analysis can be used to take a series of risk reducing measures and reduce the cost as well as time for the HDD wells placement.

2. Review challenges of conventional HDD installation

2.1 Conventional HDD technology

Generally, HDD technology (not HDD installation) can be divided into three phases: preparation (pre-installation), implementation (installation) and post-installation (Fig. 2). In which, HDD

installation phase normally includes three successive steps: pilot hole drilling, reaming(s) and pullback. According to Standard Guide for Use of Maxi Horizontal Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossing (ASTM F 1962-1999), before one of these steps can be done, it is needed to process following operations: preliminary site investigation, safety and environmental considerations, regulations and damage prevention, bore path layout and design (this is the preparation phase)



Figure 1: Horizontal Directional Drilling scheme (Tracto Technik 2010)

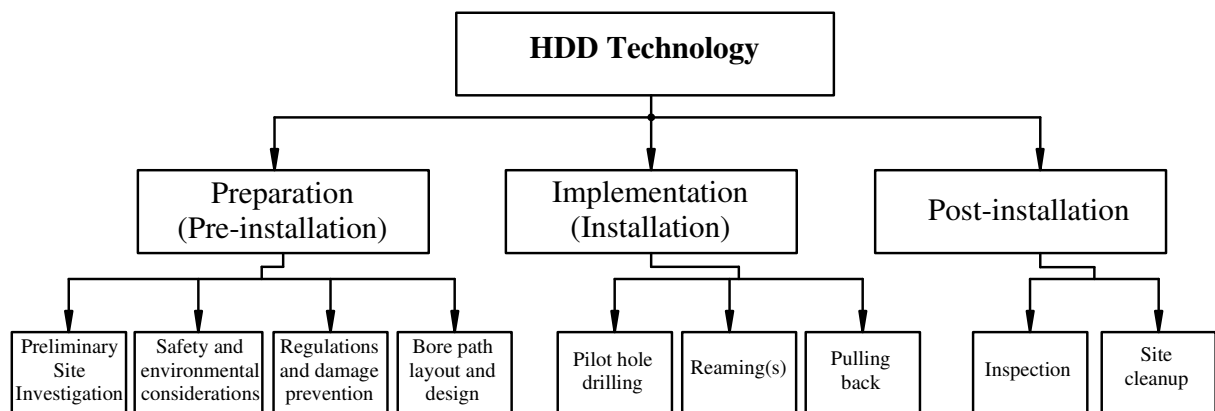


Figure 2: Different phases of HDD technology (Drawing bases on ASTM F1962)

In the pre-installation phase, the first and the most important work is preliminary site investigation. This work concludes surface investigation and sub-surface investigation. The surface investigation aims to survey topographic and hydrographic conditions. Base on these conditions, the locations of bore entry, bore exit, water supply sources, drilling fluid disposal means and drilling fluid recirculation can be determined. It should be noted that drilling fluid plays a very great role in HDD technology, its tasks include (Samuel T. Ariaratnam, Bruce C. Harbin and Richard L. Stauber 2007):

- suspending and removing cuttings,
- cleaning and lubricating the drill bit and pipe,
- cooling electronic locating equipment,
- increasing penetration rates,
- minimizing hole erosion (i.e stabilizing of the bore hole),
- creating buoyant force on the drill string and product pipe,
- and filling the annular space around product pipe.

Another important specification of the normal HDD tech is the elevation of the bore entry and bore exit, which should be as close as possible or avoid elevation in excess of 50feet (Plastic Pipe Institute 2014). The elevation of the entry point and exit point as well as the existence of the drilling

fluid are the big difference between the conventional HDD and the HDD wells. That will be analyzed more details in the later section.

The sub-surface investigation aims to determine properties of the soil formation through which the penetration will be accomplished. This information will be used to produce design drawings (including final bore route, pipe design, and bore design). The soil condition is a major factor affecting the feasibility and cost of using HDD in a given geographic area (ASTM F 1962 1999). Base on the understanding of the soil conditions and the surface condition, the contractor or designer can design the type of drilling fluid and estimate the reaction between the soil and the product pipe as well as the bore path design.

After finishing the preliminary site investigation and getting considerably sufficient information about the drilling site, it is necessary to access safety and environmental considerations as well as regulations and damage prevention (details can be found in ASTM F1962). These operation purpose to ensure safety for personnel and drilling equipments, prevent damages to other surface and sub-surface facilities, follows jurisdictions or other agencies, and above all look toward a smooth, safe and efficient working process.

Next steps for the HDD technology can be described as figure 3, in that estimation of thrust/pullback loads (for pipe pullback and reaming) and rotational torque probably constitute most important roles. Since the product pipe and the drilling equipments have been selected, the installation phase can be started.

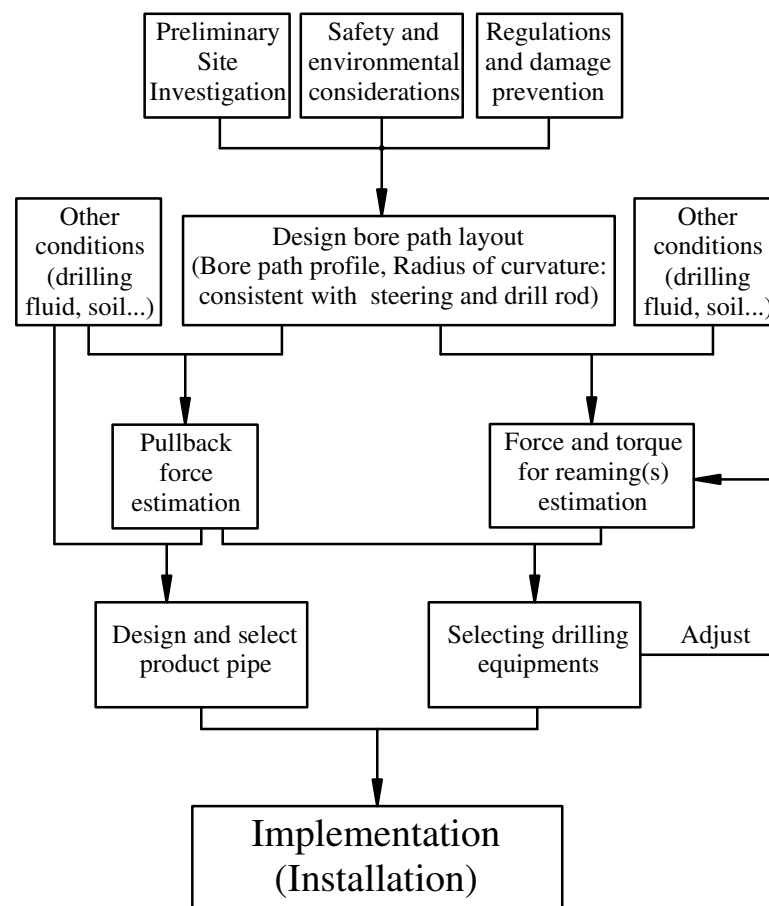


Figure 3: Later steps following preparation phase (Drawing bases on ASTM F1962)

The HDD installation starts with the pilot hole drilling step, following by the reaming step, and then the pulling back step. The size and capacity of drilling equipment must be compatible with thrust and torque required to perform different steps. In these steps, drilling fluid serves a critical role.

The usage of tracking and locating equipment swivel, breakaway link, and other facilities are necessary to ensure successfully implement the HDD installation.

The HDD technology finishes by post-installation phase. This phase evaluates the shrinkage and thermal equilibrium of pipes, and may test hydrostatic pressure or leakage of pipes. The as-built drawings shall be submitted to the owner's representative to indicate the pipe was placed at the proper location and depth, or within acceptable limits. In addition, records of pullbacks forces at the drill rig, breakaway link ratings, installation rate, etc., should be recorded and provided. After inspection and approval by the owner or representative, the surface area must be restored to its original condition. The site must be cleaned of equipment, tools, and spoils (ASTM F 1962 1999).

2.2 Challenges during HDD installation

Due to the various phases in the HDD technology, there are lots of difficulties revolving from the preparation phase to the post-installation phase. In that problems related to the pull back operation in the installation phase constitute a significant portion. The problems are various from high pulling forces to uncompleted pullback operations due to a jammed pipeline and from slight coating damages to deteriorated pipelines and deteriorated drilling pipes. The nature of the mentioned problems is related to the pipeline-soil interaction. The pipeline-soil interaction is produced due to the combined behavior of the pipeline and the surrounding soil in terms of stresses and deformations. During the pullback operation, the moving pipe contacts the wall of the borehole and pushes with a certain forces perpendicular to bore wall. These perpendicular forces (normal forces) determine the magnitude of the shear force in axial direction during the pullback operation and lead to a deformation of the soil. The pipeline-soil interaction is mainly determined by the following aspects (H.M.G. Kruse and H.J. Brink 2007):

- stiffness of the pipeline,
- stiffness and strength of the soil,
- occurrence of obstacles in the soil,
- shape of the borehole in axial and radial direction,
- effective weight of the pipe,
- and borehole stability.

The stiffness of the pipeline determines the reaction of pipeline on bending in the created borehole. A higher stiffness or smaller bending radius lead to a higher bending moment and hence leads to higher normal forces on the bore wall.

The bending moment and the resulting distribution of normal forces on the bore wall leads to a soil reaction pressure. The above soil reaction pressure is based on elastic soil behavior. Especially, at the head of the pipeline (location of connection between barrel reamer and drill pipe), soil deformation behavior can be plastic. The plastic soil behavior leads to non recoverable deformation, which in turn may lead to a displacement of the stiff pipeline beside the reamed borehole.

In order to reduce the normal forces on the bore wall, the pipeline is often ballasted during the pullback operation. In case of the HDD without significant bends, the distribution of normal forces on the bore wall is determined by the effective weight of the pipe (net weight). Effective weight depends on pipe's weight its self and the upward force of the pipe line (buoyancy). Buoyant force is determined by initial unit weight of the drilling fluid, type of soil, flow characteristics during reaming and pullback operation.

In case of the HDD located in the area in which obstacles such as blocks and boulders or man-made obstacles can be found, contact between these obstacles and pipeline during pullback step may lead to damage of pipe or to damage the coating of pipeline. The magnitude of the force between pipe and obstacles is also depends on roundness of the obstacle, dimensions of the obstacle, and deformability of the soil in which the obstacle is embedded.

Obviously, the shape of the reamed borehole in axial direction is one of the major causes in pipeline-soil interaction. The complex drilling process and the complicated soil condition result in deviations of the designed bore path during pilot step. These deviations are usually corrected, however it may lead to the so-called small distance irregularities in the drilling path. The existence of deviations after reaming operations leads to higher pulling force during pullback step.

The stability of the borehole is probably the most important factor for the success of the pullback operation. In case of bore wall instability, pipeline-soil interaction changes rigorously. In case of a collapsed borehole, a huge soil load exerts on the product pipe. Local borehole instability leads to greater pulling force, which can be overcome. Nevertheless, borehole instability over a long distance will certainly cause a jammed pipeline and thus incomplete installation. The borehole instability is caused by the reduction of the pressure of the drilling fluid (H.M.G. Kruse and H.J. Brink 2007). Besides the reduction of the drilling fluid pressure, borehole instability also can be caused by a relatively high hydraulic head in an aquifer, a borehole in loose packed sand or a borehole in a granular soil type.

3. Challenges analysis of HDD wells installation for surface mining dewatering

The usage of the HDD technology for purpose of dewatering open-pit mines have been developed and pilotly applied in MIBRAG lignite mine company, Germany. The main idea of this approach is to use a horizontal well to collect water from aquifer(s) and overlying materials, and then water is let to flow-out freely by its gravity to a basin at the mine's bottom (Fig. 4). From there, water is pumped out by a huge capacity pump or is treated before pumping-out if required.

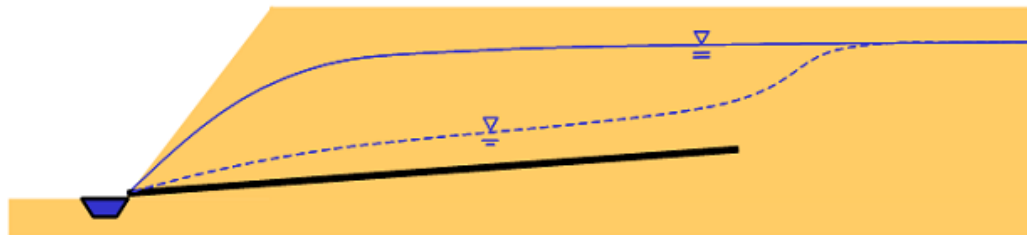


Figure 4: Dewatering of excavation face by horizontal well (Richard A. Eichler, 2013)

The application of the HDD technology has brought some advantages (e.g. continuity, lower-energy consuming and high-dewatering efficiency), however, some challenges have been encountered. These difficulties will be analyzed in the following sections.

3.1 Run-out of drilling fluid due to big difference in elevation between entry and exit bore point.

As mentioned before, the drilling fluid plays an important role in the HDD. In the classic HDD, due to the same (or very small) elevation of the entry and exit point, the drilling fluid is stored in the borehole (unless in some abnormal cases: voids, hydro frac-out) and then take out cutting spoil under pressure of fluid pump. However, to install the HDD wells for dewatering opencast mines, a huge gap in the elevation of the entry and exit borehole point has been faced (Fig. 5 - (Unpublished-report 2013)). This leads to the running-out of the drilling fluid. The drilling fluid running-out may lead to serious consequences:

- drying-out of the borehole,
- instability of the bore wall (i.e. collapse of the bore wall),
- increasing of the resistant force during the pullback operation,
- and in the worst cases, it can lead to the uncompleted installation.

Above all, the running-out of the drilling fluid leads to inaccurate estimation of the pipeline-soil interaction thus may cause the wrong choice of pipeline and the drilling machine to perform HDD wells installation.

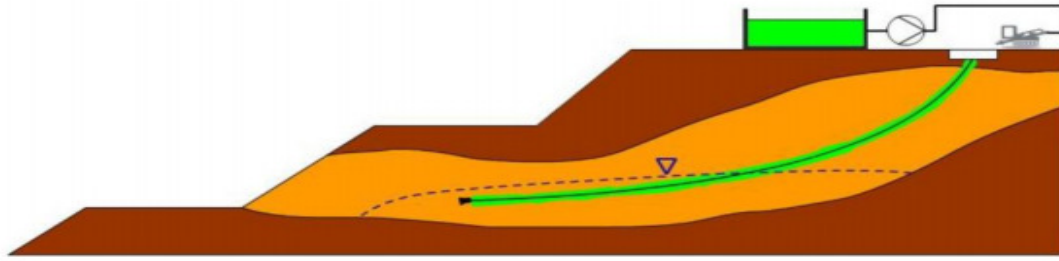


Figure 5: Big gap in elevation between the entry and exit borehole point (Unpublished-report 2013)

Due to the HDD tech for dewatering, the horizontal well is placed along the aquifers. This is a chance for the immersing of water into the drilling fluid, and may lead to the change in the drilling fluid properties such as the decrease of viscosity and unit weight. Hence, this change results in the difference of the pulling forces. Furthermore, the penetration of water can lead to the higher loss of drilling fluid and the higher risks for the HDD wells installation.

3.2 Significant increase of pulling back force due to wells structure.

In the classic HDD, the pipes or conduits are inserted by the pullback operation (Fig. 6). These pipes or conduits are usually made of the High Density Polyethylene (HDPE) or the Polyvinyl Chloride (PVC) or ductile steel. They are continuous pipes or discrete pipe (then need to be fused). These pipes should be strong enough to overcome the installation loads (i.e. the pullback force, the bending and combined force) and withstand post-installation loads (i.e. soil or water head load, thermal stress, and combined loads) (David P. Huey, John D. Hair and K. Brett McLeod 1996).



Figure 6: The pullback operation and types of pipe(s) (Source: internet)

For the purpose of dewatering opencast mines, the pipes using should have some spaces so that the water can flow into (filter pipes). With experiences through two finished projects in the MIBRAG, the type of used pipe was 'PVC wire wrapped screens' (PVC Wickeldrahtfilter). However, due to the existence of space for collecting water, this kind of pipe is not strong enough to overcome installation loads. This leads to the usage of a protective layer (a protection tube), the protective layer can be made of HDPE, PVC or steel (Fig. 7). The types of filter wells and their protection tubes are presented in Table 1 (Michael Struzina 2012; Unpublished-report 2013). The usage of an additional pipe layer leads to following effects:

- bigger diameter of the product pipe that needs to pull into reamed borehole,
- bigger diameter of final borehole,
- more working steps are required (i.e. take out the protection tube).



Figure 7: The filter pipe and protection tube

Table 1: The filter wells and their protection tube (Michael Struzina 2012; Unpublished-report 2013)

Project	Filter wells		Protection tube	
	Material	Nominal diameter	Material	Nominal diameter
1	PVC- Wickeldrahtfilter	DN 100	HDPE	DN 250
2	PVC- Wickeldrahtfilter	DN 150	Steel	DN 250

The bigger diameter of the product pipe and the borehole leads to higher resistant forces, and then bigger capacity of drilling rig is required. It should be noticed that with the classic HDD, the main challenges are caused by pipeline-soil interaction. However, in this case there is an additional interaction between the filter wells and the protective layer (Fig. 8). This leads to significant jump-up of the pulling force.

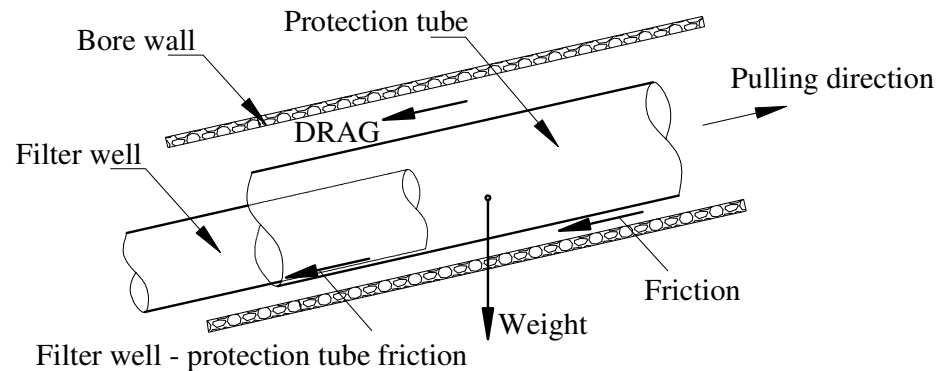


Figure 8: The pulling force in taking-out protection tube step

The interactions between the filter well and the protective layer are complicated, beside the foreseeable frictional force, bending force (in curved section), there might be friction due to buoyancy (in case of using fluid to reduce net weight during pulling whole pipes back). This issue has not been addressed yet and should need further investigation.

4. Challenges mitigation in the HDD wells installation

Based on the classic HDD tech challenges in combined with difficulties during the HDD wells installation, initial measures should be carried-out to minimize risks:

- detailed soil investigations with attention for occurrence of obstacles, history of man-made obstacles, occurrence of geological instability,
- design bore path with minimum unnecessary curves, and as big bending radii as possible,
- design appropriate drilling fluid for drilling stages and reaming operations,
- using a strong pipe to prevent damage due to contact with obstacles, and especially during pullback operations and post-installation time.

Besides reduced-risks measures for conventional challenges of the HDD, it is needed to propose measures to mitigate difficulties for the HDD wells installation.

4.1 Minimize the run-out of the drilling fluid

The leakage of the drilling fluid can be reduced by using following approaches:

- design an appropriate type of drilling fluid for soil condition in mining site (dewatering site),
- apply a special drilling technology in combined with other facilities.

The drilling fluid should be more vicious than usual to prevent leaking-down and be noticed about the immersing of water from aquifers and overlying materials. However, it is needed to ensure other properties of drilling fluid such as unit weight, filtrate rate, etc. The specific type of drilling fluid using for specific dewatering site and specific step should be decided by experienced designer (contractor) based on the soil conditions, shape of the borehole, diameter of the borehole, diameter of the product pipe.

Based on experiences during HDD wells installation in the MIBRAG and referring other material (Technical Proposal (Tim Riggall) 2014), a special drilling technology can be applied to reduce drilling fluid leakage in big-gap elevation of entry and exit point condition (Fig. 9).

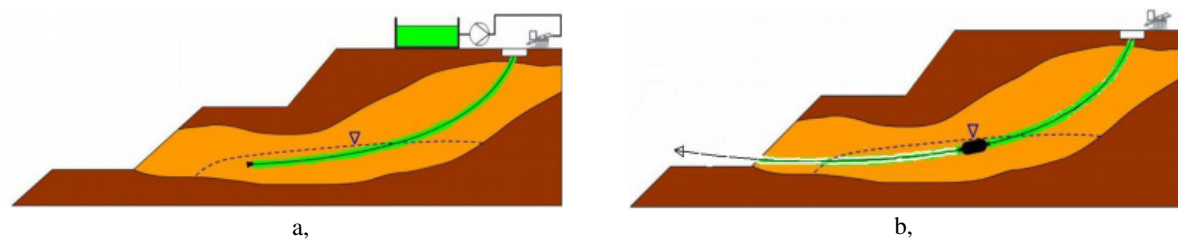


Figure 9: The drilling technology to minimize drilling fluid leakage (Unpublished-report 2013)

This drilling technology can be described: firstly, the bore path will be started at the high point. The pilot hole is stopped just before a safe point prior to exit is reached at the low point (Fig. 9.a). Secondly, the bore hole will be widened in the "forward direction" from the peak point downward low point with a forward reaming assembly. The reaming head will stop near the end of the pilot hole. Thirdly, the reaming head will be drawn back and then a punch-out assembly will be used to drill the last section of bore hole to the exit. The punch-out consists of the pilot hole bit, pre-reamer(s), and final reamer. Fourthly, after the expansion, the product pipes will be pulled back towards the high point from the low point (Fig.9.b). Finally, due to the dewatering purpose (collecting water), the protection tube will be taken-out in the direction from low point to high point. The advantages of this technology are high flushing discharge on top, high cuttings discharge, an empty borehole can be partially prevented, and thus better ensure the stability of the bore wall. The mentioned drilling technology should need further investigation to access efficiency both in terms of technical and economical aspects.

4.2 Optimize the structure of the filter-wells

Due to the special structure of the HDD wells, some negative effects have been encountered. These problems may limit the application of the HDD tech for open-pit mining dewatering. The negative implications may be reduced by following measures:

- detailed estimate the pipe-soil interaction (both in pullback and take-out steps),
- decrease the size, the weight of the protective pipe as much as possible,
- use (design) a new type of filter well that may not require the protective tube.

Based on the force estimation for pullback and take-out operation, in combined with other parameters (i.e. reaming forces and torque, the actual conditions), the contractor can decide the size and capacity of drilling rig and other facilities. The more accurate estimation, the more efficiency

drilling work will be gained. This estimation is also used for selecting the protective pipe. The considerable parameters of the protective pipe include type of material, diameter ratio (DR), and thickness. The reduce of the size and the weight of the protective pipe will lead to decrease resistant force (in both steps pullback and take-out), reduce working steps for the reaming, required smaller boring machine, and above all drop significantly drilling and installation expense.

The usage of 'PVC wire wrapped screens' (PVC Wickeldrahtfilter) type for collecting water has some advantages such as available in the market, has been used and tested with vertical wells. However, it can possibly be replaced by new types of filter pipe (not-marketed pipe), the structures of new types of the filter wells can be seen in Figure 10.

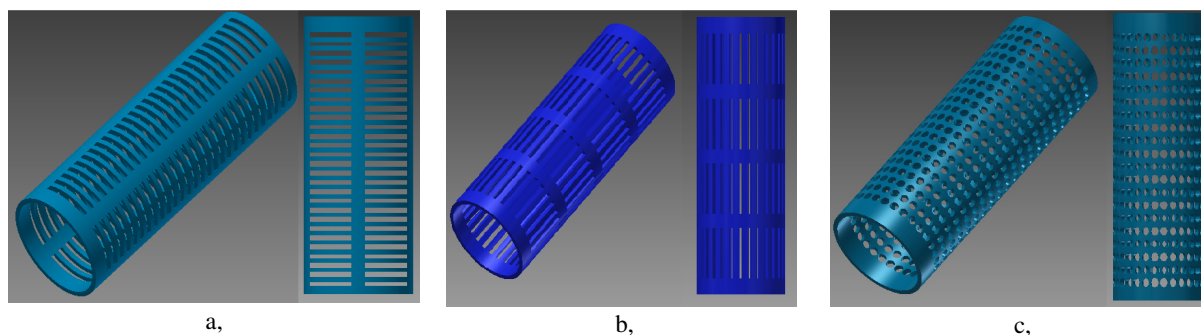


Figure 10: Idea for the new types of filter wells

The disadvantage of 'PVC wire wrapped screens' is its weakness in overcoming axial pulling load (Fig 10.a). This leads to the idea of using other structures of filter as in Figure 10.b and 10.c. These structures in combined with proper material can better withstand the axial load, thus some positive effects can be gained such as no-protective pipe requirement, decrease the final borehole diameter, decline the resistant forces, decrease the working steps. However, it is needed to accomplish more investigation to evaluate following aspects:

- hydraulic effects of these types of structures (i.e. pressure drop, permeability..),
- ability to suffer axial load, external loads in compare with 'PVC wired wrapped screen' in the same properties (i.e. material, permeability, diameter, thickness..),
- economic aspect.

The numerical method will be used to evaluate the hydraulic and mechanical effect of new structures. This method can also be used to verify proper material and suitable geometry for the new structures. The results will be presented in the coming time.

5. Conclusions

The success of the HDD wells installation for the purpose of dewatering opencast mines is largely dependent upon the pullback and take-out wells operations. In these steps, beyond the conventional difficulties, the challenges due to the huge-gap in elevation between entry-exit points as well as the complication of the HDD wells structure were analyzed. Based on theoretical analysis in combined with gained experiences, the special drilling technology was proposed to deal with the leakage of drilling fluid. The new structures for filter well were also referred. However, the above proposals are in the researching step and should need further evaluation.

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