Communicating Geology – How do we portray Geotechnical Risk to Non-Geotechnical Professionals

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ABSTRACT
Working in a broad multi-disciplinary consulting firm comes with the distinct challenge of communicating important conclusions and data to co-workers (or clients) not versed in the technical aspects of your field. In particular, a project undergoing a risk review may draw upon expertise from several disciplines with the expectation that complex risk scenarios are identified and mitigated. Like a relay race, one must match the other to ensure a successful hand-off of pertinent information. In the Horizontal Directional Drilling (HDD) industry, this “baton pass” occurs frequently between the HDD design engineers and the geotechnical SMEs. Within this paper, several real scenarios are highlighted in which this crossroad of communication determined the success or failure of the HDD crossing.

RÉSUMÉ
Travailler dans une grande société de conseil multidisciplinaire s'accompagne du défi distinct de communiquer des conclusions et des données importantes à des collègues (ou clients) qui ne connaissent pas les aspects techniques de votre domaine. En particulier, un projet faisant l'objet d'un examen des risques peut s'appuyer sur l'expertise de plusieurs disciplines dans l'espoir que des scénarios de risques complexes sont identifiés et atténués. Comme une course de relais, l'un doit correspondre à l'autre pour assurer une transmission réussie des informations pertinentes. Dans l'industrie du forage directionnel horizontal (HDD), ce "passage de relais" se produit fréquemment entre les ingénieurs de conception HDD et les PME géotechniques. Dans cet article, plusieurs scénarios réels sont mis en évidence dans lesquels ce carrefour de communication a déterminé le succès ou l'échec de la traversée HDD.

1 INTRODUCTION

One of the most challenging aspects of being a geotechnical professional is communicating important conclusions and data to those who have a stake in a project outcome, whether co-worker or client. We write reports that distill information into what we perceive is a clear message, but often is lost or misinterpreted due to the lack of experience in the geotechnical field. This fact will never change, and depressing as that is, the endeavor to communicate geology and earthly data is one of the most important roles we as geotechnical professionals undertake.

Working in a multi-disciplinary consulting firm, we have seen our roles transform from data collection and analysis among geotechnical peers, to building analogies to best explain soil and rock mechanics to those who have no idea why Montmorillonite might be important to clay composition. Fortunately, discussions in risk review meetings offer a great environment to relay important conclusions in a less structured manner, that otherwise might have been lost in the rigid format of a report. The conversations held in these meetings sparked the notion that other geotechnical professionals must be experiencing the same challenges as we have. Some of the more common geotechnical risks that required advanced communication form the bulk of this paper.

Our lens of communicating geotechnical risk is through the Horizontal Directional Drilling (HDD) industry, a form of trenchless pipeline construction that relies heavily on the proper transference of geotechnical information to the design engineers and working in concert with their needs. Pertinent information regarding subsurface layers and variability among soil types, the presence and effect of water, behavior of bedrock, and the limitations of field investigations, are the common themes of discussion. This paper will outline some of the risks associated with above mentioned themes and how a proper understanding often decides the success or failure of a trenchless crossing.

2 HORIZONTAL DIRECTIONAL DRILLING (HDD)

To provide context, HDD is a trenchless method of installing pipe underground at variable angles using a guidable drill bit. The process itself involves setting up a level workspace on “entry” side of the obstacle and utilizing a horizontally positioned drilling rig to penetrate the ground at an entry angle between 8 and 20˚ from horizontal. Following a specific design radius, which is dependent on the product pipe specifications and operating conditions being utilized, the drill bit is progressed until exiting the ground on the other side of the obstacle. This process is shown on Figure 1, below. This drilling operation utilizes pressurized drilling fluid (or “mud”) to provide lubrication and cooling of the downhole equipment, to provide torque to the drill bit (if a mud-motor is required, in harder materials), and to carry the cuttings out of the borehole to the entry pit where they can be separated from the drilling fluid. The drilling fluid also provides support to the borehole wall with the intention of preventing sidewall collapse.

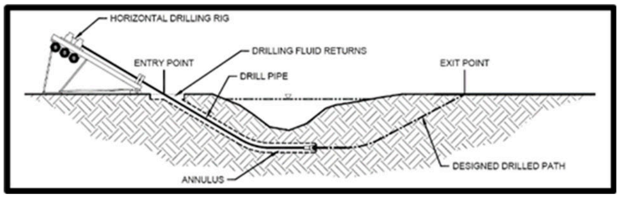

Figure 1. Pilot hole phase of an HDD (J.D. Hair, 2015)

Once the pilot hole is complete, it can be enlarged through the process of reaming by utilizing hole openers or reamers. This is accomplished by pulling or pushing the hole opener or reamer through the existing pilot hole to progressively enlarge the borehole until the borehole is a sufficient diameter to allow the product pipe to be installed. The reaming operations also utilize pressurized drilling fluid for lubrication, cooling, cuttings removal and borehole support. Once the hole is satisfactory for the product pipe installation, the product pipe is attached to a pullhead, swivel and reamer assembly on the exit side of the HDD and pulled back towards entry using the rig. This process is shown on Figure 2, below. Once the pipe is installed, the HDD operation is complete, and the equipment demobilizes from the location leaving the mainline contractor company to complete the pipeline tie-in.

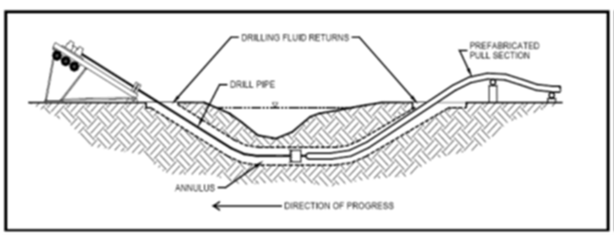

Figure 2. Pullback phase of an HDD (J.D. Hair, 2015)

3 RISK REVIEW

The main construction risks and challenges for any HDD crossing designed are identified and discussed in a risk review conducted by project participants of various experience and backgrounds. This is where the complex risk scenarios for each unique crossing are discussed and mitigated. The risk categories range from low to high based on the probability and consequence of each factor. Some of the risks for an HDD include:

- Casing requirements
- Fracture to waterbody
- Water ingress
- Unstable borehole

These are only 4 of the often 25 or more risks reviewed, however they highlight the reliance on geotechnical data to inform the proper risk determination. The feasibility of a casing installation, for example, is massively determined by the subsurface conditions at the project location.

One aspect in the risk review that can challenge young geotechnical professionals especially, is the delivery of "bad news". Often, the negative perception that the other participants in the risk review will "shoot the messenger" is enough that important geotechnical details may not be relayed as effectively. In our experience, overcoming this hurdle garnered us with the endearing nickname, "Black Cloud," however the moniker has since been embraced and we will happily tell a designer that their intended drill path is doomed if the geology suggests it will.

4 LAYERS AND SOIL VARIABILITY

HDDs of any size and scope are going to pass through some layer of soil at some point in the drill path. This fact applies to HDDs that are several KMs long to the shortest driveway crossing. Understanding soil properties and passing along layer geometries that are representative is often the first item geotechnical professionals are tasked.

4.1 Clay

Clay forms much of Alberta's surficial geology and is the backdrop for most crossing profiles in the province. Its defining mechanical property is its plasticity, and its behavior can be described in drained or undrained conditions, normally consolidated or over-consolidated, making a geotechnical professional's job arduous trying to explain the differences.

In one example, a project crossing location was investigated, and it was determined the subsurface generally comprised clay till soil conditions. The designer completing the required Annular Pressure (AP) analysis for a crossing and proceeded to design the drill path at a depth suggested to be safe from the risk of frac-out. The purpose of the AP analysis is to limit the likelihood the induced drilling pressures will overcome the in-situ soil strength creating a release of drilling fluid to an undesirable location outside of the borehole wall. Running the analysis requires reasonable soil parameters based on the project field investigation and location. The designer correctly assumed a drained analysis appropriate, based on soil stiffness from SPT "N values", but incorrectly used parameters such as undrained shear strength in the calculation. The resulting designs were too shallow and not enough confining pressure resulted in this type of formation.

4.2 Till

Till, especially clay till, continues to be a discussion at almost every risk review. Recited *ad nauseum,* "till comprises a heterogeneous mixture of all soil types including a random distribution of cobble and boulder sized materials. Therefore, the presence of cobble or boulders along any drill path through clay till should be expected." This phrase generates a collective eye roll at every meeting but it's importance cannot be overstated. Countless examples of seemly slam-dunk crossings through component clay material have been thwarted by a random boulder stopping a drill in its track and adding costly schedule delays. Fingers point to the geotechnical personnel for not providing adequate warning, and in that sense, it becomes clear how important it is to unpackage the word till to the non-geotechnical professionals.

4.3 Sand

Seemingly opposite from clay, sand often evokes a certain fear in an HDD designer. In our experience, most non-geotechnical professionals envision sand as the beach variety, medium grained, rounded, well sorted (poorly graded), monogranular, and prone to collapse, when in reality, sand comes in many variations and can provide some of the best drilling conditions under the right circumstances. Dense, poorly sorted (well graded) sand is a very competent material and has excellent resistance to hydraulic fracture under pressure or collapse (provided sufficient drilling pressures are applied to the borehole wall) deriving most of its strength from friction. Slapping a gradation curve in front of a mechanical engineer with no explanation is a pointless endeavor, and care should be taken to explain differences in material strength between different varieties of sand.

In the HDD industry, the trick to sand is maintaining drilling fluid support and the risk of borehole collapse becomes low. This is all predicated on the concept that drilling fluid circulation within the confines of the borehole can actually be maintained. In some instances, such as a drill profile in which the entry location is at a lower elevation than the exit location, i.e. drilling up a slope, a sand formation located above the entry elevation may be a massive cause for concern. Without the benefit of hydrostatic pressure from the drilling fluid, a borehole in a sand formation could easily collapse and prevent meaningful progression, or worse, entomb expensive tooling never to be recovered.

4.4 Silt

The worst material to try and explain to non-geotechnical professionals. Lumped in with “fine-grained” soils, it’s not quite clay, it’s not quite sand, and has particle sizes smaller than the naked eye can see, yet usually not small enough to experience ionic bonding and plasticity. Silt in general is not a good material for underground construction.

Although silt is not generally considered a massive deposit in Alberta, these formations could be encountered in some areas of the province. These sensitive soils can collapse when moisturized and increases in pore pressure due to drilling fluid exertion may induce hydraulic fracture. Communicating the mechanical properties of silt, and how this material changes with increasing moisture, to non-geological professionals can be a difficult but necessary exercise.

5 WATER

For a geotechnical professional, it’s obvious that the erosional forces of a river on the toe of a slope can initiate a landslide, and non-geotechnical personnel can be instructed to avoid working on the slope, but what is often overlooked is water with potential energy within the slope. Geotechnical practitioners will recommend drainage installations to de-water a slope so excavations can be completed safely but with an HDD, the drill path can become an unwanted drainage conduit and result in disaster.

5.1 Free Water

“Low to High HDDs” or “slope drills” are scenarios where the HDD entry elevation and associated rigging is lower than the exit elevation. They are often designed to mitigate a problematic slope with landslides or slopes that are not conducive to pipeline open-cut methodologies. They provide some major benefits including reduced annular pressure and lower pullback forces required to install the product pipe. Despite these benefits, designers and clients must be cognizant of the risk of encountering water within the slope above entry elevation. The hazard occurs when the drill intersects into a water-bearing formation and the drill path becomes a preferential conduit for the water to drain from the formation directly back to the entry rig location. This flushing can flood entire construction sites and produce water at unmanageable rate. Depending on the volume of water within the formation, it may be completely improbable from a resource and time perspective to wait for the formation to drain. In addition, if the water-bearing formation is a soil, such as sand, the flush and subsequent loss of hydrostatic pressure within the borehole can cause a collapse of the formation, potentially trapping “down hole” tooling or equipment. With this risk in mind, a geotechnical professional must outline the necessity for a detailed investigation prior to construction. The equipment required to mitigate water flushing back to the entry location may not be routine and must be planned for ahead of time.

5.2 Pore Water

Why does it seem that the designers and construction personnel we work with are always trying to break the soil we worked hard to define? Knowing a soil’s limits is important to the success of almost every geotechnical project, and as such, the interaction of water and soil shear strength is paramount. It gets tricky when water can both help and hinder shear strength and explaining this concept to a non-geotechnical professional is not easy. In the HDD industry, knowing when it is appropriate to use total stress, or an effective stress is not always apparent, and it is our role as geotechnical professionals to ensure the correct parameters are being used.

Recently, we have been involved in several shore approach HDD projects. These projects involve drilling under the shoreline of a large body of water. The HDD rig is typically set-up slightly further on land from the beach, and the exit some distance offshore. This typically results in a drill arrangement with a “High to Low” elevation profile and a significant height of water above the land topography.

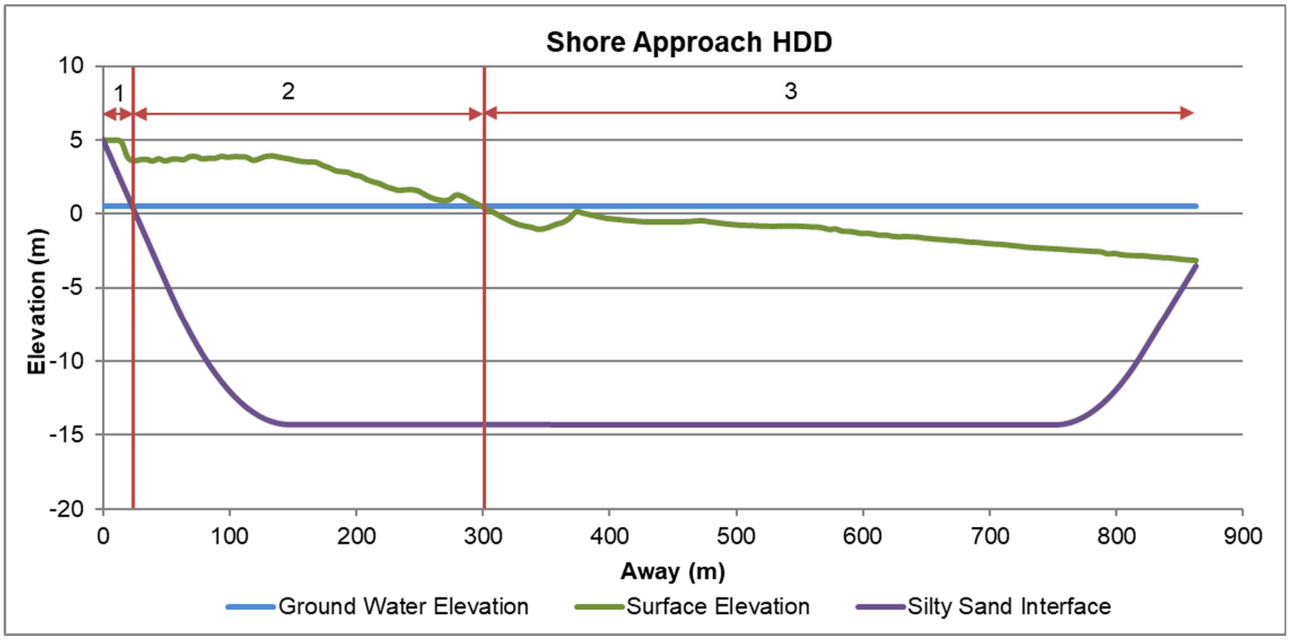

Figure 3. An example of a shore approach HDD profile (example by author)

Figure 3 demonstrates three distinct zones where the HDD designer is going to have to consider the water's interaction with the subsurface material. In Zone 1, on the far left, the HDD drill path is above the groundwater elevation and the designer will likely need to consider soil moisture content and shear strengths of partially saturated soil. In Zone 2, the ground water is below the surface topography and the drill path is below the ground water elevation. Here, the drill path is passing through fully saturated soils with a pore pressure component. In Zone 3, the HDD passes into the open water section of the drill and a designer must adjust the soil stress analysis accordingly.

Similar to what was mentioned in Section 4, the application of drained and undrained analysis is at the forefront of designs that need to consider the water component of the soil mechanics. Astute attention to the parameters selected for such analysis should be undertaken by the geotechnical professional and the reasoning why passed onto the non-geotechnical personnel.

6 BEDROCK

As a geotechnical professionals, it is entirely possible we may get a little too excited when it comes to discussing bedrock with colleagues. We like it for the fact that it *exists* and the joy we display describing slickensided features or thin bentonite seams, as seen in Figure 4, is often misinterpreted by our coworkers. They naturally get excited because we are excited, but the reality is, we are describing some serious evidence of potential landslide activity within their project footprint. There-in lies the problem with bedrock. Too often an assumption is made that bedrock will solve all the geotechnical woes in an HDD design and effort is made to ensure the drill path will pass through bedrock for the majority of its length. However, bedrock comes with its own unique hazards that need to be interpreted and relayed accordingly.


Figure 4. A slickenside feature found in the bottom core run (photo taken by author)

6.1 Fractures

Fractures in bedrock present a massive hazard for HDD design. Supportive drilling slurry providing important services for the success of the drill can continuously escape the annulus through pre-existing fractures, never to be seen again. Due to this risk, designers are always asking about the fracture state of bedrock. However, describing the extent is almost always a challenge due to limits of investigation, but an attempt is always made using concepts like Rock Quality Designation (RQD) and joint angles. In our experience, RQD and joint angles can mean a lot or very little, and this distinction is where the geotechnical professional provides the most support to the non-geotechnical professional. Again, a robust geotechnical investigation should be encouraged as clues can found in core photos if fractures are going to cause a problem for an HDD.

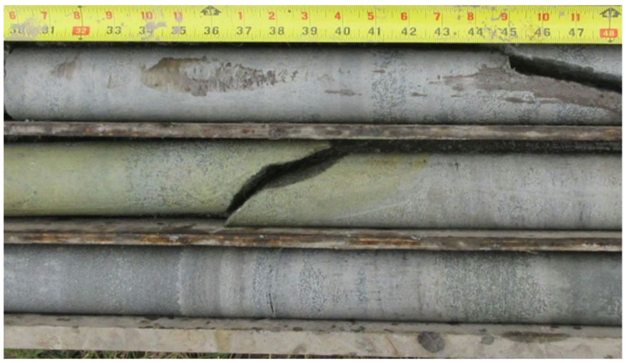

Figure 5: A fracture in discolored sandstone (photo taken by author)

In Figure 5, the RQD values for the core run are quite high, displaying infrequent fractures at spacings larger than 4 inches. A designer may look at the borehole log and only notice the 90% to 100% RQD value, leading to overconfidence and incorrect risk assessment. What should be noticed, however, is the sandstone formation displaying clear oxidization near the fracture. This oxidation can only occur with the presence of water and if water is has moved through the fracture in the past, then it is likely the drilling slurry would too. Picking up this kind of clues is where the geotechnical professional provides unique support in a multi-faceted consulting firm.

7 LIMITS OF INVESTIGATION

As geotechnical professionals, a constant struggle is to do so much with so little. The subsurface is complex, never homogenous, and always steeped with history. It takes a great deal of effort to even try to explain soil behavior over distances adequately. What's more, is sometimes all we have is a 6 inch wide hole in the ground, yet we are asked to make an interpretation for a location 1 km away. Investigations have limits and that needs to be understood by coworker and client alike.

7.1 Planning

At the planning stage of a geotechnical investigation, a focus should be on understanding your clients or coworkers risk tolerance. With a high risk tolerance, an investigation can be completed cheaply, relying on stretching interpretation over longer distances. For HDD geotechnical investigations, the completion of boreholes is typically the focus of the scope and effort is made to be clear on what kind of data will be acquired from the drilling methodology. Samples taken off an auger flight will not provide the same level of detail as core samples, but it will also not cost as much. Tailoring a program to the risk tolerance and ensuring the non-geotechnical professional is aware provides an excellent start to investigations.

7.2 Investigating

In our opinion, one of the easiest ways to add value to any geotechnical program is to just describe how the program went. All too often, reports are crammed with scientific analysis and fancy charts of expensive lab testing but lack a simple description of how the investigation progressed. It can be embarrassing to describe that the casing shoe sheared off while drilling a borehole, but this statement alone provides valuable insight into the subsurface behavior. Borehole logs should be filled with descriptions and comments of how the drill rig is behaving. In HDD geotechnical investigations, the borehole program is akin to a mini test run of the HDD and a lot of parallels can be drawn between the two. Insights into whether the HDD will require casing can be gleaned just by how the geotech rig is reacting to the subsurface. Loss of fluid while coring almost always translates to a loss of drilling fluid during the HDD. These plain language descriptions are excellent tools to relay risk to non-geotechnical people and an effort should be made to always include them.

8 CONCLUSION

Described in several different manners, communicating geotechnical risk is a very important part of the engineering process. Fortunately, we have had the opportunity throughout our careers to work alongside mechanical engineers, civil engineers of different disciplines, project managers, construction managers, as well as drillers or other contracting personnel. Communicating risk associated with underground infrastructure is a unique challenge because if the receiver of this information is not conveyed in a way that is understandable for them, the risk will be left unmitigated. With respect the discussion here-in, take a step back, look in the mirror if you have to, and ask, are you communicating geology effectively?

9 REFERENCES

J.D. Hair and Associates, 2015. Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide, *Pipeline Research Council International, Inc (PRCI),* Catalog No. PR-277-144507-E01