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Analysis of Horizontal Directional Drilling Construction Risks using the Probability-Impact Model: A Contractor's Perspective.

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Abstract

All projects are subject to risks that have both a direct and indirect effect on the project cost and time. The risks vary from project to project because of the unique nature of each project. It is important for the project management team to include risk management as an integral part of their project planning and execution. Risk management strategies should be incorporated in every phase of an HDD project to ensure that the project meets the required quality and safety standards, and that the project delivery is within cost and schedule. This paper takes a look at Horizontal Directional Drilling (HDD) construction risks (the risks that occur during the construction phase) from the contractor's point of view. Through a literature survey and content analysis of previous works, various HDD construction risks were identified. An industry survey was administered and interviews with major HDD contractors in the state of Ohio were conducted and both the probability of occurrence and impact of these risks on project cost were determined. The paper employed the use of a probability-impact model to identify the critical construction risks and suggests risk management measures and strategies that can be utilized to effectively minimize the risks.

Keywords: Horizontal Directional Drilling, risk analysis, construction risks, and probability-impact.

Introduction

All projects are subject to risks that have a direct effect on the project cost and time. The risks vary from project to project because of the unique nature of each project. The risks also occur during the different construction phases. It is important for the project management team to include risk management as an integral part of their project planning and execution.

Generally risks that occur in a construction project can be classified into four different areas: (1) Financial: the risk that project will cost more than the budgeted amount, or it will cost more than the product itself is worth. (2) Time: the project will not be completed within the planned time. Worse, it will be completed so late that it has an adverse effect on other parts of the owner's work. (3) Design: the project will not perform the function for which it was intended or, more commonly, will perform the function in a degraded form. (4) Quality: the project will have poor-quality materials and/or workmanship, or the work will be incomplete in some way (Gould and Joyce 2003). Cost, social impact, environmental impact, and risk factors are key considerations that form the baseline for decision making when determining which construction method is the most feasible. According to Ariaratnam et al (1998), the risks involved when using trenchless methods can often times be similar to those in the traditional open-cut construction methods but the magnitude will vary.

With the population explosion experienced over the decades, there has been a concurrent growth of the underground infrastructure. The congested nature of this underground infrastructure, especially in the urban environments, has made it more difficult and also more costly for municipalities and utility companies to use the conventional open-cut construction method in installing, maintaining, rehabilitating, and replacing their product lines. The low environmental and social impact of directional drilling has made it extremely viable and desirable by municipalities where there is a high investment in surface infrastructure, congestion of existing buried utilities, and where the costs of restricting business or commuter traffic would make open cut alternatives inconvenient (Lueke and Ariaratnam 2005). The risks in a Horizontal Directional Drilling operation are wide ranging and can be: legal, financial, political, geotechnical, geographical, design related, commissioning, force majeure/act of God, safety related, environmental, social, construction related, etc. This paper focuses on construction risks and seeks the contractor's perspective on the probability of occurrence and impact of these risks on the cost of HDD operations. A risk management process would ideally involve: risk identification, risk analysis, risk response and review.

Horizontal Directional Drilling Overview

HDD is a steerable trenchless construction method that offers an alternative for installing underground pipes, conduits and cables. The method is used to install pipes, conduits, and cables along a prescribed bore path by using a surface launched drilling rig (North American Society for Trenchless Technology 2013). In urban settings with dense populations, businesses and local residents usually suffer from inconveniences caused by impacts to traffic flow, delays, and by the construction activities. Traffic detours, noise, impacts to business operations/access/parking, and air pollutants are

the most notable distresses on the public (Woodroffe and Ariaratnam 2008). HDD offers an alternative that gets the job done while at the same time minimizing these inconveniences.

HDD consists of a rig that makes a pilot bore by pushing a cutting or drilling head that is tracked from the surface as shown in Figure 1. The front end of the drilling head has an angled cutting bit that allows the steering via pushing and rotating the drill rods by the drill rig. Drilling fluid is pumped through nozzles in the drill head to cut and displace the soil. When the pilot bore is completed, a back reamer enlarges the hole. Progressively larger back-reamers are used until the hole is large enough to pull the product pipe (Atalah and Kariuki 2009). The pipe is laid out, fused or welded, and then pulled into place by the rig after connecting it to the backend of the backreamer.

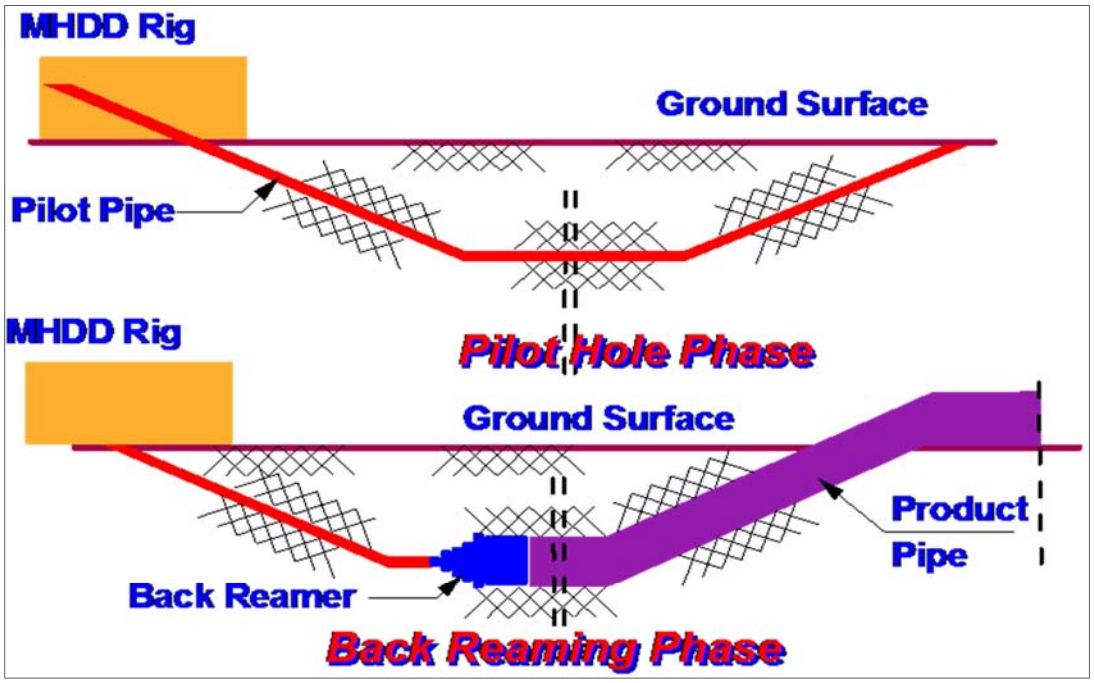

Figure 1. Traditional HDD process (Atalah and Ampadu 2006)

HDD can be used to install product pipes ranging in sizes between 2 inch and 63 inch. Installations exceeding 2600m (8500 ft.) have been completed successfully using HDD. Pipe materials commonly installed by HDD would include HDPE, PVC, ductile iron, and steel. Traditionally rigs were classified into three categories: small rigs, medium rigs, and large rigs; they are also called mini, midi, and maxi rigs respectively. The classification was based on a combination of thrust/pullback, torque, pumping fluid system capacity, and length and diameter of the product pipe (Bennett and Ariaratnam 2008). The advancement of technology, geological composition, and project specific considerations has led to a great degree of overlap among the categories. The large rig operations require considerably larger working footprint, longer time for both mobilization and demobilization, and considerably higher operational costs because of the larger scope of operations involved. By virtue

of the size of operation and the costs involved, large rig operations inherently bear larger risks.

Research Methodology

A survey questionnaire was created based on literature review and with input from HDD contractors and consultants. The questionnaire was made up of three sections: 1. HDD risks encountered, 2. Probability of risk occurrence, and 3. Impact of risk. The questionnaires were distributed to HDD contractors across the state of Ohio. Follow up calls were made to the survey subjects to increase the response rate and to clarify questions and solicit more explanation on their perception of occurrence and impacts of HDD risks. To enrich the information gathered through the questionnaires, personal interviews were also conducted with some experienced HDD contractors in the state of Ohio. This was valuable in creating the impact-probability model.

HDD Construction Risks

It is evident that a good number of the identified risks are interrelated. For instance, the loss of circulation could lead to hydrofracture. Hydrofracture could also lead to operational risks. Though closely related, these risks are usually distinctly recognized and defined separately and categorized accordingly when encountered. The response/mitigation actions for the interrelated risks were definitely expected to overlap. The various HDD construction risks were identified through the literature review and assigned identification numbers as shown in Table 1 below.

Table 1. HDD Construction Risks

No.	Risk
R1	Hydrofracture / Inadvertent returns–escape of the drilling fluid from the bore to the surface.
R2	Loss of circulation – escape of drilling fluid from formation without flowing to the entry and/or exit holes or to the surface.
R3	Hydrolock – creation of a hydraulic cylinder due to pressure buildup after loss of circulation (Bennett and Ariaratnam 2008).
R4	Loss of depth/Floating line.
R5	Mixed soil conditions – these create challenging conditions for HDD operations
R6	Heave/hump on surface.
R7	Surface subsidence.
R8	Hitting unknown existing utilities and structures – this includes cross-bores and utilities that are affected by the displacement of soil and other movement.
R9	Loss of formation/collapse of borehole – refers to collapse of borehole and is common in loose soil situations, especially random fill (Bennett and Ariaratnam 2008).

R10	Collapse of product pipe–this can result if the bore is not adequately prepared to receive the product pipe or if the pipe is not adequately designed.
R11	Drill pipe/ down-hole tooling failure – here, the tooling (bottom hole assembly - BHA) or pipe is damaged to a level beyond the normal anticipated and manageable wear and tear (Osbak, et al. 2012).
R12	Stuck pipe–This is a case where the product pipe is lodged in the bore hole and is immovable.
R13	Weather related risks –delays and other damages that may result from weather related issues including excessive rains or snow.
R14	Operational risks– this covers the time lost when operations are halted following unscheduled maintenance, delay of equipment, client request, need to make decisions, and other events leading to delays.
R15	Obstructions – these include cobbles, boulders and other obstructions that may be encountered during the drilling operation. These have the potential to deter bore completion (Bennett and Ariaratnam 2008).
R16	Inability to maintain line and grade.
R17	Safety – physical / Bodily harm to workers or/and general public.
R18	Environmental risks – contamination, drilling fluid disposal, drilling through contaminants, and potential risks when drilling in environmentally sensitive areas.
R19	Bypass related risks – risk involved when you have to bypass the flow to allow construction to take place, especially when rehabilitating or replacing a section of a pipeline.

Survey Results on Probability and Impact

A total of 28 questionnaires were sent out to HDD contractors in the State of Ohio and 19 were returned, making a 68% response rate. Five experienced HDD contractors and consultants were interviewed in addition to the questionnaires. Both the questionnaire and interview results were rated using the same scale. Figure 2 is a depiction of the probability of occurrence of the various risks in HDD construction projects. It is evident from the analysis that R5 (Mixed soil conditions) has a considerably high probability of occurrence while R4 (Loss of depth/Floating line) was reported to have the least probability of occurrence. All other risks had moderate to low probability of occurrence with R1 (Hydrofracture / Inadvertent returns) and R2 (Loss of circulation) recording reasonably high probability of occurrence.

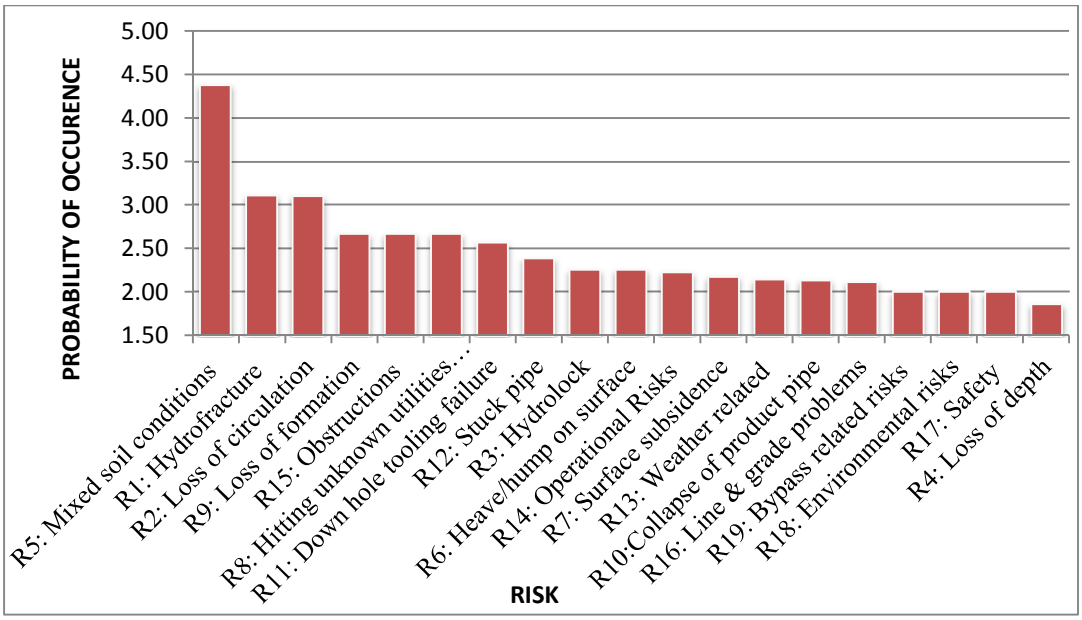

Figure 2. Probability of Occurrence of Construction Risks in HDD projects

Figure 3 indicates the magnitude of the impact of the various risk factors on the project. The impact scale ranges from 1 through 5 where 1 indicates no impact, 2 indicates low impact, 3 indicates moderate impact, 4 indicates high impact, and 5 indicates very high impact. According to the survey, R8 (Hitting unknown existing utilities and structures) was projected to have the greatest impact. R10 (Collapse of product pipe), R11 (Drill pipe/ down-hole tooling failure), and R12 (Stuck pipe) were also reported to have reasonably high impact on project cost. R19 (Bypass related risks) were reported to have minimal impact. All other risks were reported to have a moderate impact on the project cost.

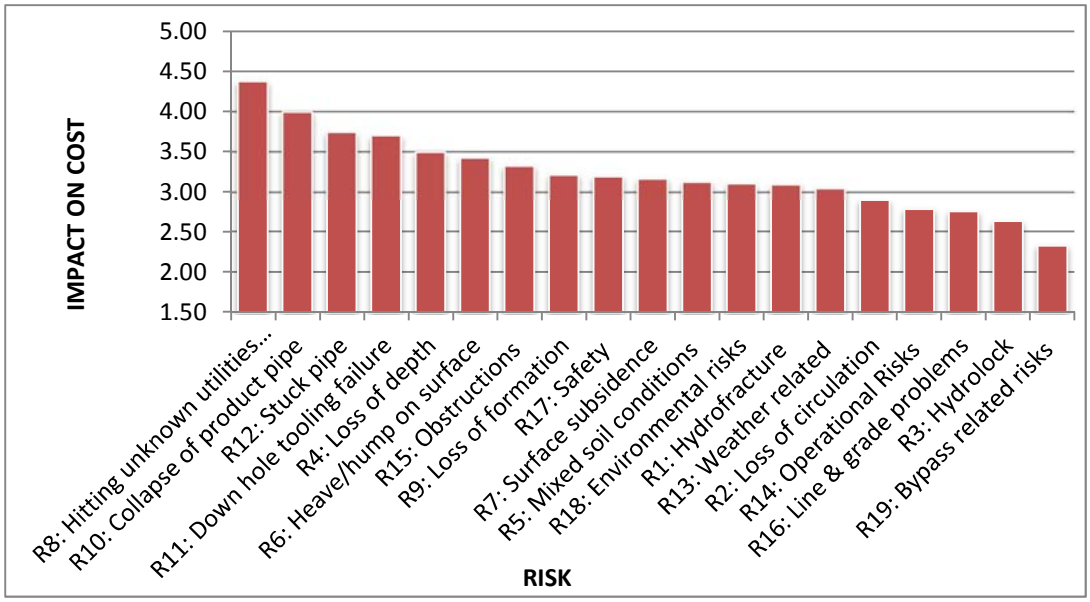

Figure 3. Impact of Construction Risks on HDD Project Cost

The Probability - Impact Model

The probability-impact model was selected to enable the identification of critical risks in the construction process and, from that standpoint, take the appropriate risk response. The model should position the contractor to manage the associated risks. Following the survey responses, the risks were classified into four groups based on their impact on project cost and their probability of occurrence: (1) high probability-low impact, (2) high probability-high impact, (3) low probability-low impact, and (4) low probability-high impact. The probability-impact values were derived from the survey results as shown in Figure 4.

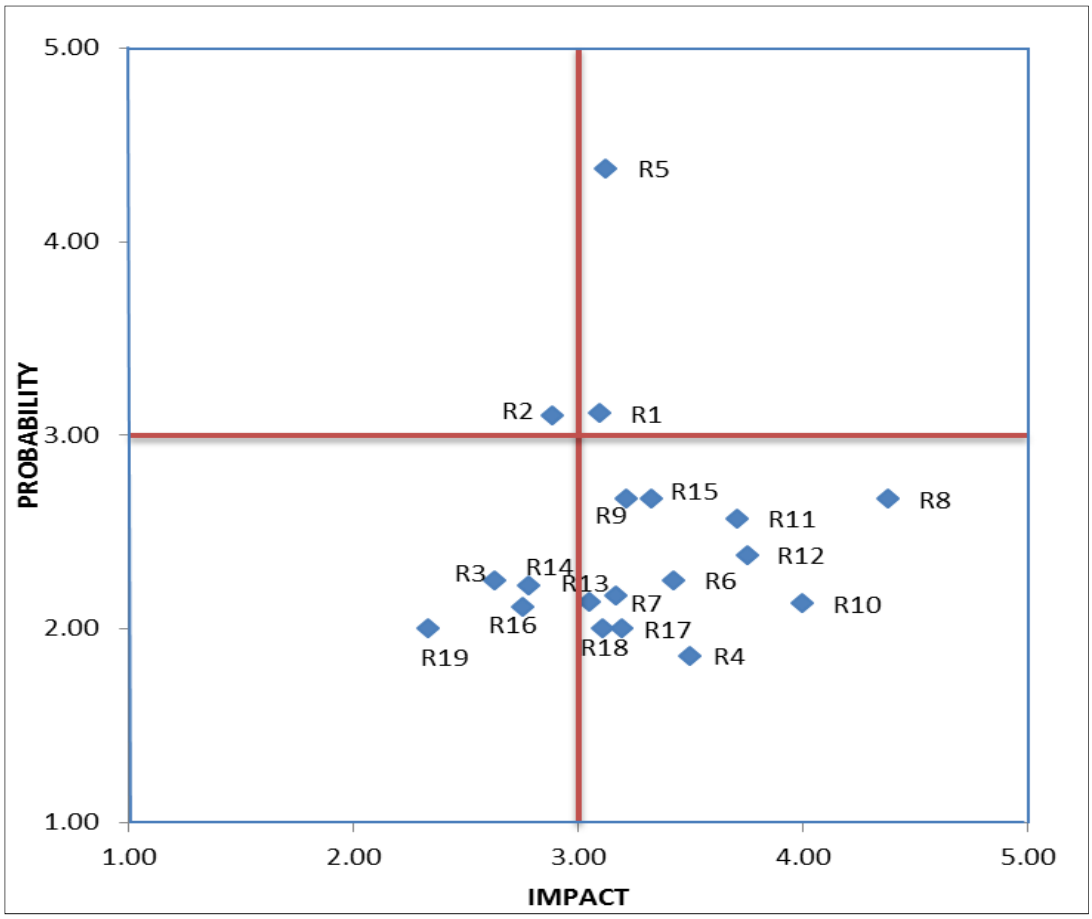

Figure 4. Probability-Impact Chart for HDD Construction Risks

<u>High Probability - Low Impact</u>

This is the top left quadrant and contains risks which have low impact on the project but high probability of occurrence. These risks are of moderate importance which means the contractor can cope with them if they do occur. However, mitigation actions can and should be taken to reduce the impact and probability of occurrence. R2: Loss of circulation falls within this quadrant.

High Probability - High Impact

This is the top right quadrant. Risks in this quadrant have high impact on the project and high probability of occurrence. These risks are very critical and the contractor must take the necessary measures to reduce both the probability of occurrence and the impact of these risks. R1: Hydrofracture / Inadvertent returns and R5: Mixed soil conditions fall within this quadrant. If these risks cannot be mitigated, every possible measure should be adopted to avoid them.

Low Probability - Low Impact

These risks are in the bottom left corner and have low impact on the total cost of the project and low probability of occurrence. Although categorized as acceptable, the contractor should take the necessary measures to reduce their probability of occurrence. These risks include: R3: Hydrolock, R14: Operational risks, R16: Inability to maintain line and grade and R19: Bypass related risks.

Low Probability - High Impact

This is the bottom right quadrant and contains risks with high impact on the cost of the project and low probability of occurrence. These are critical risks and they include: R4: Loss of depth/Floating line, R6: Heave/hump on surface, R7: Surface subsidence, R8: Hitting unknown existing utilities and structures, R9: Loss of formation/collapse of borehole, R10: Collapse of product pipe, R11: Drill pipe/ down-hole tooling failure, R12: Stuck pipe, R13: Weather related risks, R15: Obstructions, R17: Safety and R18: Environmental. Some of these risks can be transferred to the owner, manufacturer or insurance companies. It is expedient for the contractor to transfer those risks that can be transferred and also take the necessary measures to reduce their probability of occurrence and impact. R8: Hitting unknown existing utilities and structures, and R10: Collapse of product pipe are the two risks with extremely high impact on the project. The contractor will usually absorb most of the risks in this quadrant, and put in place the necessary measures to reduce both their probability of occurrence and their impact.

Discussion on Risk Responses

Identification and assessment of risks must be accompanied by well-structured and meaningful mitigation responses. Effective response to these risks ought to meet a certain criteria. The risk responses should be appropriate, affordable, actionable, achievable, assessable, agreeable, and allocable (Hillson 1999).

When the chance of risk occurrence and the impact associated with it are high, then risk avoidance is the proper response technique that should be followed. This means choosing not to do the activity or significantly reducing the potential of occurrence. For example changing the scope of work so that risky items are no longer undertaken is a risk response technique. When the impact is high even though the chance of occurrence of the risk source may be relatively low, risk transfer strategies are applied (Panthi et al. 2007). This can be achieved through insurance, which transfers the risk to insurance companies or through provision in the contracts that will transfer

the risk to a third party such as the owner or subcontractor. If the impact of the risk is high, risk reduction can be achieved by lessening the extent of the damage. If, on the other hand, the frequency of occurrence of the risk is high, the focus should be on the root cause (measures should be taken to eliminate the source). Whenever the risk probability and the impacts are high, the response strategy should be to reduce both (Hillson 1999). When the risks have a low impact and low probability of occurrence, risk acceptance is the appropriate response. Acceptance can be passive when the impact is minor for which no prior plans may be required. Acceptance can also be active when the impact is high and a contingency plan of action must be in place. Sufficient time and resources should be allocated to handle these events when they happen (Panthi et al. 2007).

The type of utility, above and below the ground conditions, the soil type and soil properties, are some of the factors that change from site to site. These are factors that directly affect both the rate of occurrence of these risks and their impact on the project. However, there are measures that can be taken to minimize the probability and impact of these construction risks

In an effort to minimize both the probability of occurrence and impact of the construction risks, it is important for HDD contractors to follow the good drilling practices in their projects. To ensure smooth operations, it is important for every HDD contractor to have a company policy that outlines safety procedures and helps in cultivating a culture of safety within the company. It is important to couple this with safety training of the workforce. As part of job site safety, the contractor should ensure that the construction area is delineated and proper traffic control maintained in the interest of public safety (Ariaratnam 2008).Safety procedures must be followed throughout the job to reduce the likelihood of incidents or accidents (Bennett and Ariaratnam 2008). The investment of time and money in training or hiring an experienced crew is minimal when compared to the cost of injuries or damaged utilities.

Lueke and Ariaratnam (2005) discuss some of the factors that contribute to surface heave. These include: mud flow (rate), backream rate, reamer type, and depth of cover. These factors must be carefully considered in order to minimize the risk of having heave and subsidence. Francis et al. (2003) recommend that contractors adopt the following practices to effectively minimize this risk:

- Take detailed drilling records and fluid records, and have a qualified person supervising the operation.
- Perform continuous surface heave monitoring and evaluate the influence of the operation on nearby utilities and structures.
- Measure and maintain drilling fluid pressures within the prescribed limits.
- Incorporate ground improvement or underpinning to protect critical structures at risk.

The importance of having a supervisor during the construction process cannot be overstated. The inspectorate should be well informed on the directional drilling process and have geotechnical knowhow. Monitoring the soil conditions in real time

and comparing them to the geotechnical data used in the design of the bore will enable the construction team to make real time and appropriate adjustments to minimize if not eradicate the potential risks that are due to the soil conditions. Donovan and Hanford (2012) note that the geologist on site can monitor the lithology of cuttings and the volume of sand and silt that is cleaned from the drilling mud to confirm that the exploratory boring data have been accurate in the anticipated volumes of each type of soil encountered.

Extensive subsurface investigation is critical in identifying potential obstacles. This should be coupled with detailed historical research that can reveal any obstructions that may have been buried. There are cases where there is no record of buried obstructions, but the residents may be aware of them. Historical research, that may involve inquiring from the residents, can unearth information that is vital to project success.

Down-hole pressure monitoring is a particularly beneficial risk management tool that directly monitors the build-up of pressure in the borehole which can warn of probable inadvertent returns. The threshold, or allowable maximum pressure, is normally determined by the design team. Providing this information to the construction contractor will allow field personnel to track the build-up of pressure and make adjustments once the rising down-hole pressure becomes a concern. (Donovan and Hanford 2012).

It is important to have an understanding of the potential hydrofracture risk before the commencement of the drilling operation and to have an appropriate response strategy in place. Having a plan in place to expeditiously contain any inadvertent returns and to clean up the drilling fluid that finds its way to the surface considerably reduces the negative impact that hydrofracture may have on both the project and the environment.

There are steps that can be taken during the planning or design phases as an effort to reduce the risks and ensure the success of the project. Pullen and Strater (2013) outline some of the areas which include: ensuring permitting requirements are met, ensuring that you capture both the surface and subsurface characterization, ensuring adequate depth of cover, ensuring you have sound pit support design (where needed), ensuring that the method selected (in this case HDD) is the right method for the job, and ensuring that the pipe is adequately designed to take the loads it will be subjected to.

Finally, it is important for the entire team to work collaboratively. When the owner, engineer and contractor work cooperatively, identification of potential problems is effective and practical solutions are easily generated.

Conclusions

The probability impact model is a good tool for identifying and categorizing the various risks that are encountered in the horizontal directional drilling process. This categorization helps in identifying risks priorities. In the construction field, to minimize most of these risks, it is advisable to follow the good drilling practices. These include ensuring that you: collect as much information as possible about the subsurface conditions, select the proper tooling for the soil conditions and the proper

drilling fluid mixture; maintain constant circulation of the fluid within the bore hole; maintain an appropriate pumping rate which should be coupled with a pressure monitoring program; ensure that the bore is ready to pullback the product pipe through necessary reaming and swabbing processes before pulling the pipe in place; and always ensure that workplace safety is a top priority.

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