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RISK MITIGATION IN TRENCHLESS DESIGN AND MANIFESTATION IN CONSTRUCTION

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1. ABSTRACT

Trenchless risk has become the focus of many trenchless designs. A successful design is much more than evaluating the capabilities and features of different trenchless methods for a site, it is accurately evaluating the trenchless risk on a project. This evaluation is then the focus of collaborative work with the Owner to ensure a clear understanding of the risks and the likelihood of manifestation given the approach taken in design. Owners often make significant investments in mitigating risk through the incorporation of design features and specification provisions meant to minimize or even eliminate these risks.

Although we see an increasing trend in Owners willing to invest in risk mitigation, we also see an equally disturbing trend in the relaxation of these important design features during construction. Often this is due to a point of departure in communication between the design team and the construction management team, where the reason for a specified feature may not be immediately recognizable. Another cause is a Contractor's refusal to follow a specification requirement seen as an "extra step" and the hesitation to enforce the specification due to the fear of controlling the Contractor's means and methods and "Owning" their construction performance or becoming responsible for additional costs, or ill will with the contractor. This paper will discuss risk management strategies included in design but not effectively implemented during construction and the resulting impacts. It will also share some lessons learned and strategies to avoid such issues.

2. INTRODUCTION

On any pipeline project, trenchless installation typically carries the highest construction risk of any pipeline installation method. As such, many Owners, Engineers, and Construction Managers are focusing effort and substantial investments on managing trenchless construction risks. To effectively implement risk reduction strategies, it is critical that all parties have a clear idea of the risk management approach that has been chosen for a project. If the Owner, Engineer, or Construction Manager tries to implement a risk reduction strategy in isolation, without consideration for the approach that has been or will be used on other phases of the project, the results can be disastrous and can even increase the project risk. Successful implementation of risk management strategies emerges only when Owners, Engineers, and Construction Managers work in concert to employ a project-wide risk management approach. Without clear understanding and acceptance of this approach, items included in the design and specification to manage risk may inadvertently introduce risk to a project. Alternatively, construction managers may be faced with enforcing specifications, that were meant to manage a risk, that do not decrease risk in practice and may actually introduce other risks to the project.

3. IDENTIFYING RISKS ON A PROJECT BASIS

The key to managing trenchless risk starts with identification and expectations. There are many stages in a trenchless project where risk is introduced. Identifying where those risks are introduced, the probability those risks will occur, the consequence of the risks should they occur, the mitigation measures necessary to minimize the risk or consequences once it occurs, and the cost of mitigation are the pieces of information needed to evaluate project risk. The project risk approach involves deciding which risks are going to be addressed in design – included within the design and paid by the Owner in the cost of the project during bidding, and the risks that are going to be paid during construction should they come to fruition – risks that the Owner decides to take.

There are many types of project risks that must be considered on a project. Primary risks impact the feasibility of using a trenchless method and are typically governed by geotechnical conditions or existing pipe conditions. These risks often impact the choice of trenchless technology that is used on the project, the risk mitigation strategies that are included in the specifications, and are considered when the Owner selects their approach for risk sharing with the Contractor.

Identification of primary risks is based on project experience and is often specific to a particular region because of the geotechnical conditions or existing pipe materials, dimensions geometry and repairs. Individual risks may have vastly different impacts on different trenchless techniques; therefore, it is important that the impacts of risks are well understood. During design, it is not uncommon to use the results of a risk analysis to choose the preferred trenchless method for a project. method. For example, if the geotechnical conditions in a region contain large amounts of cobbles, the risk to microtunneling is getting stuck because the machine may not be able to develop enough torque to crush the cobbles. However, the risk to pipe ramming may be loss of line and grade because pipe ramming generally does not have difficulty penetrating ground conditions containing cobbles. Depending on the type of project under consideration, the impact of having cobbles on the project to the two trenchless techniques are vastly different.

Every trenchless method has a different risk profile and depending on application will present a different risk to a project. Therefore, risk may drive the selection of one trenchless method over another depending on how risk averse an Owner is and how willing they are to negotiate change orders as compared to paying higher up-front costs for a construction project. Using the technical risks associated with a project are often used to choose the most appropriate trenchless technique on a project; however, beyond the choice of technology, there are secondary risks that must be considered such as political, financial, and schedule risks. Managing project risk is largely dependent on investigation of existing conditions, then adequately preparing the stakeholders for the types of risks that could occur on a project, and what changes and impacts might be should the risk occur, and receiving buy-in from the project team of the risk allocation moving forward.

4. MANAGEMENT OF RISK PRIOR TO BIDDING (DURING DESIGN)

Risk management on a trenchless project often begins during the design phase, with first the geotechnical investigation, and surveys of the existing pipe system, considering the range of trenchless and non-trenchless construction methods. During this time, it is critical that the project team has a high level of knowledge and understanding of risk management. The key decision makers must also be knowledgeable in trenchless methods and the impacts of the critical risks on a project. However, since trenchless technology is still evolving at a rapid pace, this often takes a tremendous amount of education for stakeholders to increase their base of risk knowledge.

In the first stages of design, risks analyses are often implemented when evaluating the trenchless technique that presents the lowest risk to the crossing under consideration. Although the risk analysis is early in the design process, a quantitative process can be used to reflect the relative level of risk between the different trenchless techniques. It is stressed that the risk costs developed in the early design are relative measures of risk and not absolute risk costs because the project is too early in the design process for the designers to know all the risks that may be associated with the project. In addition, at the time the risk analysis is performed, there is likely not enough accurate information on the risk issues to adequately evaluate the probability that a risk will come to fruition; therefore, all parties must understand that the principles of the analysis are sound and the real risk costs will be determined as the project design develops.

For the analysis, a key step is defining the definitions of probability and impact cost. These definitions are not critical to the outcome of the analysis. Their importance is that they are applied without bias across each risk factor and technology throughout the evaluation. Table 1 is one example of common definitions for risk probability and impact cost that have been used in trenchless method risk analysis.

Table 1 Definitions of Probability and Impact for Evaluation of Relative Risk Assessment

Probability of Occurrence			Impact Cost	
1	< 20%		1	< $100,000
2	20% < X< 40%		2	$100,000 < X < $250,000
3	40% < X < 60%		3	$250,000 < X < $500,000
4	60% < X < 80%		4	$500,000 < X < $1,000,000
5	80% < X < 100%		5	$1,000,000 < X < $5,000,000

Variations in Table 1 typically occur in the impact cost, depending on the size of the project and trenchless crossing under consideration. Clearly, as the size of the trenchless crossing increases, the magnitude of the impact costs likely increase. Although the early risk analysis is a relative measure of risk, the designer should understand that estimating realistic impact costs is important to the future of the project. Presenting exaggerated risk costs can steer an Owner or Stakeholder away from using trenchless simply because unrealistic risk costs present unnecessary fears of an unknown or new technology. Alternatively, if the impact costs are unrealistically low, an Owner or Stakeholder may favor a trenchless solution with an unrealistic notion of the level of risk the method presents when compared to an alternate construction method.

Figure 1 presents a risk analysis that was used to select a technology that would be specified to cross a fish bearing stream. For this crossing, features/risks for the crossing were identified, the probability of a feature/risk occurring was assigned a value, and the impact of a risk determined for a particular technology based on the experience of the design team and their knowledge of the local conditions and contractor's practices.

A weighted risk score was then determined by multiplying the probability factor by the impact factor and a risk cost was developed by multiplying the percent probability of risk occurrence by the estimated impact cost. From this table, it is clear that for this particular example, pipe ramming presented the lowest weighted risk profile for installing a casing beneath the fish bearing waterway. This tool was useful for the design team to select the trenchless method for the project; however, there are many risk assumptions included in the analysis that could dramatically change the outcome if not considered. In addition, the analysis does not speak to any of the assumptions (as written in the colored boxes) and their viability – such as the assumption that it is reasonable to dewater along the alignment for the Open Shield Pipe Jacking alternative. Therefore, it is critical that the analysis consider the timing of the design with full knowledge that the factors influencing the results are yet to be fully developed. It is also critical to realize that any of the assumptions on the success of a method assume that critical elements will be included in the design, such as the notation for microtunneling in gravel and cobbles which states "OK if MTBM head opening limits volume/size of material entering crushing chamber." The risk of encountering gravel and cobbles for microtunneling is only low if the Owner trusts the contractor to approach the geotechnical conditions with a machine configuration suited to the soils OR if the Owner is willing to specify such.

Documentation of the construction options considered, reasons for acceptance or rejection is critical. This document can then be used later when the construction contractor proposes alternate methods. The document can be used as a starting point for those discussions and risk allocation. Hopefully moving the project forward rather than rehashing old decisions.

TRENCHLESS CROSSING RISK ASSESSMENT - Installation Method Comparison						
30-inch Carrier Pipe within a casing - 150LF						
FEATURES/RISKS	**MICROTUNNELING - 42"**		**PIPE RAMMING - 48"**		**Open Shield Pipe Jacking - 48" +**	
	PROBABILITY	IMPACT	PROBABILITY	IMPACT	PROBABILITY	IMPACT
Encountering Soft Soils	4	5	4	2	4	5
	Very loose sands along alignment may not have sufficient bearing capacity and cause MTBM to sink.		Potential to impact line/grade. Use oversized casing. Possibly shallow/deepen alignment to avoid density differentials between contacts.		Very loose sands along alignment may not have sufficient bearing capacity and cause shield to sink.	
Loss of Face Stability	4	3	2	1	4	5
	Very loose sand may not provide adequate resistance to slurry pressures. Use additives in slurry, ground improve, deepen alignment.		Not a concern with method unless face access is required.		Limit face openings or use closeable doors/sand shelves to control. Must fully dewater entire alignment.	
Groundwater Causes Loss of Face	2	1	2	1	2	2
	Shallow groundwater head at crown. Not a concern with method.		Use soil plug to counterbalance water pressures.		Must fully dewater alignment.	
Encountering Gravel and Cobbles	2	1	2	1	2	3
	Very loose gravel possible. OK if MTBM head opening limit volume/size of material entering crushing chamber.		Not a concern with method.		Loose soils with gravels may run into face if cobbles must be removed by hand and difficulty increases with groundwater.	
Risk of Surface Settlement	4	3	1	3	4	3
	Shallow cover increases chance of settlement coupled with loose sands and gravels.		Unlikely with adequate soil plug and little groundwater pressure head.		Shallow depth with loose soils. Must dewater alignment.	
Risk of Pipe Becoming Stuck	1	2	1	1	1	2
	Jacking forces not a concern at this length. Mitigation - Pipe ram back to rescue machine.		Telescope ram smaller casing or pipe ram back from other direction.		Jacking forces not a concern at this length. Mitigation - Pipe ram back to rescue machine.	
Weighted Risk Score	**50**	**$ 2,130,000**	**18**	**$ 440,000**	**64**	**$ 3,150,000**

Figure 1. Weighted Relative Risk Table for Selection of Trenchless Method

Once a trenchless method is selected, it is then common to revisit a modified version of the risk assessment, evaluating each feature/issue in more detail for the specific crossing and the selected technology. This is typically done later in design when much more information has been gathered about the project and a more informed risk analysis can be developed. It is at this stage that the Owner can make decisions on how to allocate risks that exist on a project. In general, there are two ways to allocate known risk: designing for the risk by including risk mitigation in the specification (paying for the risk in the bid) or carrying the risk and assigning it to the contractor with the potential of paying for the risk in a change order should the risk come to fruition during construction of the project. This should be an informed choice that is based upon a detailed risk analysis that is very specific to each trenchless crossing. It is wise to expend the resources to investigate risks with high impacts during design to determine the value of paying for the risk in the bid as change orders can carry costs well beyond those associated with the technical risk cost.

If an Owner decides to "design around" risk, it typically involves including risk mitigation measures in the specifications. This is a relatively new concept as historically risk has been evaluated by Contractors when preparing a bid price. Theoretically the Contractor prices the project risk into the bid. However, in the low-bid environment, it is often the case that the contractor that accurately assesses trenchless risk and includes adequate risk pricing in the bid will not have the lowest bid and will not win the project. As a result, the Contractor that is awarded the project may not have adequate funding should a risk come to fruition and as a result the Owner is often faced with Change Orders that have a high chance of manifesting into claims (Staheli and Parnass, 2013).

It is not common for the construction industry to specify means and methods and many lean towards a pure performance specification. However, when Owners have a vast amount of experience in a construction method, are aware of significant construction risks, and have faced multiple claims due to this risk in the past, it may be wise to specify means and methods that mitigate the risk rather than remain silent on the issue. This is not to say that the

Owner should develop a purely prescriptive specification either. The Contractor needs the freedom to control the means and methods to use their expertise to construct the project successfully. The growing trend has been to produce a hybrid specification that leaves the vast majority of the means and methods to the Contractor while specifying some prescriptive items that the Owner chooses to adopt to mitigate known risks on the project. Specifying means and methods is one example of allocating risk to the owner to mitigate potential risks. Examples of that might be requiring micro-tunneling in high ground water areas, or specifying pneumatic pipe bursting for certain types of pipe or soil conditions.

Table 2 is a truncated final trenchless risk strategy matrix that documents the actions that are intended to be executed to address identified risks. The final risk implementation strategies reflect decisions made by the Owner on how they choose to address the risk during the construction of the project. It contains examples of prescriptive elements that will be included in the specification while allowing the Contractor to control the vast majority of the means and methods on the project. This partial table is an example for a large diameter HDD pipeline to be installed as a gravity sewer with an intersect and two HDD rigs.

Table 2 Final Risk Mitigation Strategies – Gravity HDD

Risk Identification	Risk Response	Final Design Mitigation
Materials and Equipment cause delays	**Transfer**	• Ensure long lead time in specifications for construction schedule • Provide adequate contract duration.
Settlement and Vibration from drilling rigs cause damage to homes	**Mitigate**	• Require pre- and post- construction surveys • Monitor during construction by Contractor and Owner • Set trigger levels in specification at which the Contractor must change methods
Deviations in Specified Alignment of HDD pipeline cause: *Need for Additional Easement* *Need for Additional Capacity* *Need for New Pipeline*	**Mitigate**	• Verify specified bend radii are achievable • Carefully crafted contract provisions for alignment tolerances that are achievable and understandable • Provisions in contract for notifying when reaching threshold values • Provisions in contract for re-drilling if outside specified tolerances • Careful monitoring during construction. • Requires full-time monitoring during construction of pilot bore by experienced staff that understand implications of out-of-tolerance pipe.
Encountering differing site conditions during drilling	**Accept**	• Clearly define DSC in contract • Rapid negotiation to allow continued construction and minimize delay time.

5. TRANSFER OF PROJECT FROM DESIGN TO CONSTRUCTION

There are ever-increasing challenges with transferring the projects that are designed around project risk strategies from the designer to the construction manager. Historically, it is atypical to have a contract that contains specified items that are part of the contract strictly to avoid a problem from occurring. Contractors and Construction Managers customarily only mitigate a risk when it is no longer a risk—it is a real problem that has occurred during construction that must be solved. There are few organizations that have systems in place that allow transfer of information from the designer to the construction management (CM) team that allow explanation of project risks for particular technologies, the risk sharing philosophies that were developed during the design, and the risk mitigation strategies that were incorporated into the contract documents to address the risks.

In addition, although the design team may have intended to include risk mitigation in the specifications, it can be difficult to communicate intent through standard specification language, let alone the method of mitigation since every risk may manifest in many ways and require a variety of mitigation measures. As a result, although the intention of the design team was to mitigate risk, it may not be possible to enforce (or even fully understand) the specification unless it is very clear on intent and communicated and adopted by the Construction Manager. Since standard specification language rarely states the intent of the specified item, the Engineer must break from drafting language in a way that is most common and focus on how the specification will be interpreted without any background information on how risk mitigation was developed for incorporation into the specification.

Structured communication to convey risk allocation and corresponding specifications can help at all phases of the project: design, bidding, and construction. During design this can take the form of meetings between the designer and construction manager where topics include risk issues and mitigation. The Construction Manager can lead project review of the design elements at 60% or 90% design and provide comments to the designer regarding schedule, means and methods, contract language, identified risks, key submittals and quality control elements, A main element of these discussions can focus on risk mitigation measures, and appropriate documentation that should be collected if the risks result in problems during construction.

During bidding structured communication should take the form of Bid Walks, Pre-bid meetings highlighting contract terms and conditions, and risk allocation. The response to any bid questions or clarification of the submittal should be agreed upon by the Design Engineer of Record, Construction Manager and Owner, then distributed to all bidders. During the construction phase the communication starts with the preconstruction meeting, pre-submittal meetings, pre-activity meetings, and regular site visits by the design team during critical pre-identified points in the project.

6. PITFALLS

There are several pitfalls of risk management that can result in a project risk approach that falls short of the original intent. Most of the issues can be solved with various communication techniques and a change in perspective on how risk is managed on a project from the beginning of design until the completion of construction. For comprehensive risk management to be successful, the design and construction management teams are going to have to work together to effectively manage risk.

6.1 Identifying High Risk Items and Realistic Mitigation Measures

A significant feature in trenchless risk management is the ability to identify risk issues and several risk mitigation measures that could be employed to remedy impacts during construction. It is absolutely critical to approach this task with qualified people who have the requisite experience to know the risks that can manifest, given the project conditions. Further, they must also know what a Contractor would be likely to do should the risk manifest. One pitfall of risk management is to include only upper level managers in risk discussions and exclude people who may have extensive field experience and knowledge regarding construction practices and what could be done to fix a problem arising from a particular issue/risk.

Since every trenchless technique has a different risk profile, a single risk issue (such as encountering cobbles, or encountering high groundwater) will manifest in a different way with each of the trenchless methods (as illustrated in Figure 1). Therefore, if the designer has experience with a limited number of trenchless methods, or has only designed trenchless projects in a limited geologic environment, impacts of risk may not be well understood or known how they differ between the different trenchless methods. In addition, the mitigation measures that would likely be employed during construction will vary by region and Contractor. Without a full understanding of the impacts and mitigation measures, Owners are unable to make well-informed decisions on whether it is wise to expend the funds to design around the risk and pay for the mitigations measures in the contract, or to take the risk and pay for the additional cost should the risk manifest during construction.

Design Engineers must realize that when they use project risk strategies, they don't always have the luxury of knowing if a risk comes to fruition during construction on a project they designed. That information is well known to the construction management staff but may not be transferred back to the trenchless designer. Thus, the designer will not know if the risk management process was effective and will not gain the critical knowledge on risk impacts and mitigation, especially as it relates to costs and claims. If design engineers and other design professionals who participated in risk identification and mitigation were to follow a project through construction, then the experience gained on risk management during construction could be transferred to future designs to continuously improve project risk strategy. Having book-end conversations at the end of each project is very important. This includes a conversation and transfer of information in regard to risk mitigation measures in the contract specifications and a lessons learned after construction with the design professionals and construction manager.

6.2 Communication between the Design and Construction Management Teams

Perhaps the largest pitfall in effective execution of project risk management is lack of effective communication. Historically the design team writes a set of contract documents that contain sufficient information (ideally) to fully build a project. What is clearly lacking from the contract documents is the *intent* of a specification requirement. Specified risk mitigation measures are typically "extra" things that are included in the specification that are not necessarily "normal" practice but were included in the specification to limit the Owner's exposure to a specific risk event. Without explanation, it is often very difficult to determine *why* the requirement is included unless one is privy to the history of the design or experience of a particular designer. Without documented protocols of how the information will be transferred, the specifications typically are not sufficient to provide the background information necessary to impart the criticality of the issue that would motivate the Owner or Engineer to specify something that is typically left to the Contractor to decide.

In addition, it is often very difficult to specify a mitigation measure when it is unclear how the risk will manifest and other project circumstances under which the risk occurs. It is analogous to submittal requirements in the trenchless specification that ask the Contractor to provide a contingency plan for a situation that is atypical and not yet occurred. Almost without fail, the first response from the Contractor is "well, it depends…", which is very true. Without knowing the other project circumstances at the time the risk manifests, it is very difficult to determine what the best mitigation strategy might be. For example, the design team may have knowledge of the soil conditions at the site and be aware that the soils tend to run even without the presence of groundwater. Therefore. the design team have considered the loss of face stability for an open shield pipe jacking project as a significant risk in those geotechnical conditions. The risk of concern would likely have been settlement of the ground surface (perhaps a major highway). However, the specification does not address surface settlement risk, the specification addresses loss of face stability at the face of the open shield.

To mitigate the risk of surface settlement, the Owner may have decided they were willing to specify a tunneling shield that would be capable of providing some support to the face of the excavation to prevent soil inflows at the face (such as closable doors, sand shelves, etc.). A purely performance specification would have been silent on the type of machine used to install the pipe. Here the Owner has chosen that a specification stating that the open shield should provide components to support the face still allows the Contractor a considerable amount of flexibility and choice of machine, along with the mean and methods of operation to use a hybrid specification, specifying some portions of the project while leaving the majority of the means and methods to the Contractor.

However, without communication between the design team and the construction management (CM) team, the will not know why the designer specified these features on the shield in the absence of groundwater. Further, they will be more likely to relax the Contract specification during construction because the information on the history of the contract risk mitigation was not explained. The specification may also include vague language regarding controlling all ground inflows at the face – attempting to alert the contractor that they are responsible for the costs associated with face stability; however, the mitigation measures may be unclear and the CM team does not know what is meant by the language or how to enforce the specification.

All mitigation measures that are included in the specification are costs to a project. Contractors attempt to build quality projects at the lowest possible cost. As such, relief of contract requirements that they deem "unnecessary" is a way for them to earn a higher margin on a project. A common practice is to include language from previous projects or keep adding risk mitigation measures to a boiler plate specification serving to dilute the requirements that are of particular importance for the specific project. If the construction management team is not properly informed of the intent of the specification requirements, it may be impossible for them to understand why a specification requirement is included and they may also deem the requirement unnecessary. As such, it is not uncommon to see these critical requirements waived in the field simply because the intent of the risk management strategy was not communicated to the construction management team. If the construction management team cannot see a reason to specify an item, especially if they perceive the item to slow production or add unnecessary cost, they are highly unlikely to enforce the specification.

7. CONCLUSIONS

On any pipeline project, the trenchless installation often carries the highest risk. Municipalities and pipeline owners have begun to use risk management strategies as part of the design process in hopes to increase the success rate of their trenchless projects, lower project costs, and minimize the number of claims. However, for overall project risk management to be successful there must be a joining of the design and construction management teams, especially in overall philosophy. If these two groups view themselves as separate, individual groups that work in spite of each other instead of with each other, successful project risk management will remain a difficult task.

One way to improve the transfer of knowledge and the implementation of the risk management strategy on a project is to include construction management staff in the design process and to include design engineers in the construction management process. Construction management staff would provide a tremendous value to a design at a 30 to 60 percent design stage where they could provide input on constructability, contractor means and methods, identification of project risks, and risk mitigation strategies that they have seen employed. The Construction Management staff would also have access to Contractors to gather information that might be needed by the design team to accurately reflect risk cost in the construction cost estimate and contingency budget. An additional benefit would be the Construction Management staff learning the critical elements of the project (not solely risk elements) to provide a better understanding of the critical elements of construction and an understanding of the engineering design process.

Likewise, having the Design Engineer of Record available during construction could assist in the interpretation of the specification, explaining the intent of risk mitigation measures, perform expedited submittal reviews, or quicker resolution of changed conditions. The Engineer could also provide background information on the risk management strategy that was adopted by the Owner and how the risk was intended to be mitigated at the time the project was designed. This would also provide a tremendous value to the Engineer to experience how a construction contract is executed, allowing the Engineer to better understand how risk mitigation specifications are executed in the field and how they are interpreted by both the Construction Management staff and the Contractor. It is important that an Engineer in this role understands that they are implementing a design and not changing the design as issues arise or risks come to fruition.

There is no doubt that there is a need for overall project risk management that extends from initial design of a trenchless project throughout construction. It is also clear that both the design and construction management teams must share a risk management philosophy to successfully implement the risk mitigation strategies that were developed during the design and chosen by the Owner for implementation through the Contract documents. Through focused efforts, formal communication, and a willingness to meld key members of the design and construction management teams, project risk management will improve as will the risk profile for a wide variety of trenchless techniques. For growth of this industry, moving along this path is not only desired, it is also necessary.

9. REFERENCES

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