DETERMINING THE OPTIMUM LEVEL OF INVESTIGATION FOR A TRENCHLESS INSTALLATION PROJECT – "HOW MUCH IS JUST ENOUGH?"

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ABSTRACT

With the increasing demand for, and application of, Trenchless installation methods for pipeline replacement and rehabilitation projects, it is prudent to consider what and how much investigation needs to be carried prior to construction for a trenchless project. This paper will consider and discuss the answer to this question, from a risk management basis, whilst also looking at what different investigations need to be undertaken for a trenchless installation project as opposed to the more traditional open trench replacement.

The paper will consider a range of typical trenchless installation methods from small bore HDD to large bore Maxi Rigs and similarly for small and large bore pipeline rehabilitation in a variety of different situations and locations. It will then look at the risks to the Client, in terms of cost, time, exposure and customer perception, by not completing adequate investigation. The paper will also discuss potential mitigation and management options for these risks.

There is no one simple answer, due to the differing nature's of the various types of trenchless installation projects. However matrices can be developed that give Client's an understanding of their risk exposure and strategies to manage these risks.

KEYWORDS

Risk, trenchless technology, cost, time, liability, public image, HDD, micro tunnelling, rehabilitation, pipe bursting

1 INTRODUCTION

Today's modern trenchless technology and its associated techniques provide utility networks owners with a number of tools to undertake their utility upgrade or renewal works with a minimum of disruption and disturbance to their customers and the general public. However, without sufficient planning, these advantages can quickly disappear and the very disruptions that the trenchless methods sought to eliminate or minimize become very real. Part of the project planning includes pre-construction investigation undertaken by the Client during the design phase. This paper will summarise the optimum level of investigation for various types of trenchless installation projects, from a cost of risk minimization perspective. The main key project risks which will be considered are time, cost, liability and image perception.

There are a vast number of items that need to be considered and investigated within the design phase of any project, however, not every issue impacts on ALL four of the key risks. This paper will focus on those items that do impact on all four key risks and therefore must be investigated as a minimum. For each issue, the consequence and mitigation strategy for each trenchless technique from new installations to pipe rehabilitation, will be reviewed. These include medium and maxi HDD, micro tunneling, pipe bursting and pipe lining.

2 CRITICAL ISSUES THAT REQUIRE INVESTIGATION

2.1 GROUND CONDITIONS

Encountering unexpected ground conditions may result in the contractor using the wrong equipment and not being successful in completing the installation within budget or having to complete open trench excavation to install the service. Examples of unexpected ground conditions that can significantly affect a trenchless installation range from encountering hard rock or uncontrolled fill to running cohesionless sand to very sticky bentonitic clays. If any of these situations, or similar, are encountered, without the correct forward planning, the likelihood that the installation won't be able to proceed, is very high.

In the case that these ground conditions are unexpected/unforeseen, then the Client may be liable for any additional costs incurred by the contractor, in completing the installation, as well as any time extension appropriate for the additional installation works. Furthermore the Client's liability to 3rd party costs and/or damages also increases. The public perception of poorly planned works negatively impacts on the client's public image, which can impact on future sales etc.

Geotechnical borehole sampling at approximately 200m intervals will assist in minimizing the likelihood of unforeseen ground conditions being encountered and assist in ensuring the contractor has the correct equipment to complete the works, with reduced risks, thus maximizing the trenchless technology benefits of less disruption and less impact on the environment. Boreholes should be taken at 10m offset from the proposed route, so as to avoid pressurization during the actual installation. Bore depths should extend another 30% deeper than the proposed design depth, to confirm material consistency and/or to allow for variations in the final drill alignment. Should the results from the bore holes show consistent ground geology then samples at 200m will be satisfactory. If, however, the bore samples show varying ground conditions then more sampling may be required. The borehole data should also show the level of the groundwater table, as again, different controls need to be implemented dependant on whether or not the works are above or below the water table.

There have been many specific papers written and presented on geotechnical investigations for a trenchless installation project. To generally summarise, the typical type of data and information that should be gathered from the geotechnical bore sample, will include:

- Atterberg limits, clay swelling limits
- Direct or triaxial shear,
- Unconfined compressive strength testing / Rock Mohs strength
- Standard Penetration Testing (SPT) / Cone Penetration Test (CPT)
- Grain size distribution and grain shape angularity
- Groundwater table depth

This information is also invaluable at the planning/design phase as it inputs into the option analysis and risk assessment that the client/designer will be carrying out to determine the optimum solution.

2.1.1 IMPACT OF UNFORSEEN GROUND CONDITIONS

2.1.1.1 Horizontal Directional Drilling Installation

These are the most common of trenchless techniques for new utility infrastructure installation projects currently being completed in New Zealand. Some typical examples of this type of project would be the replacement of existing local and/or trunk reticulation water, waste and storm pipes, up to 1200mm in diameter. In some cases, although the product pipe to be installed is of a smaller size, the scope of the project may encompass many kilometres of installation or it may be a single installation greater than one kilometre.

Unexpected ground conditions being encountered will result in the contractor using the wrong equipment i.e. drill heads, reamers and incorrect drill fluids/"muds". This will result in the contractor not being successful in completing the drill shot and having to complete open trench excavation to install the pipe.

Cobbles and boulders are the curse of the HDD contractor. These are the most difficult and demanding ground conditions to work in and, in some instances, even with the best strategies in place, can prevent the pipe installation from being successfully completed. Hence it is vitally important that the presence of cobbles and/or boulders is clearly identified.

2.1.1.2 Micro Tunnelling

The risk of encountering unexpected ground conditions, or cobbles/boulders, is that once the actual micro tunneling process starts it is neither possible to retract the tunnel boring machine (TBM) nor access the cutter head, without excavating down onto it. Therefore, if the correct cutter plates are not installed on the TBM, for the ground conditions that it encounters, the machine will not be able to proceed. The only option, at this time, is to excavate to the machine and carryout any necessary changes. The nature of having to complete this excavation works negates the value and benefits of a trenchless installation, as well as giving rise to claims against the client for cost, time, liability and a damaged public image.

2.1.1.3 Pipe Bursting

Although there are technically three different methods of bursting, for the purpose of investigations required, they can all be considered under the one common category.

Pipe bursting, whether for the same size or upsizing, relies on displacing the fragments of the existing pipeline into the surrounding ground. Therefore, confirmation that the surrounding soil is displaceable is fundamental to ensuring the project is successful. Encasement of the existing pipeline, typically by concrete, also needs to be determined as part of the investigation, as this will also affect the ability of the pipe fragments to be displaced into the soil.

Furthermore, determination of the nature of the surrounding soil will also provide valuable information to help manage a common risk of pipe bursting, that of ground heave. Ground heave is as a result of the bursting forces being exerted into the ground, causing the softer/weaker soil or where there is less restraining pressures, to be pushed.

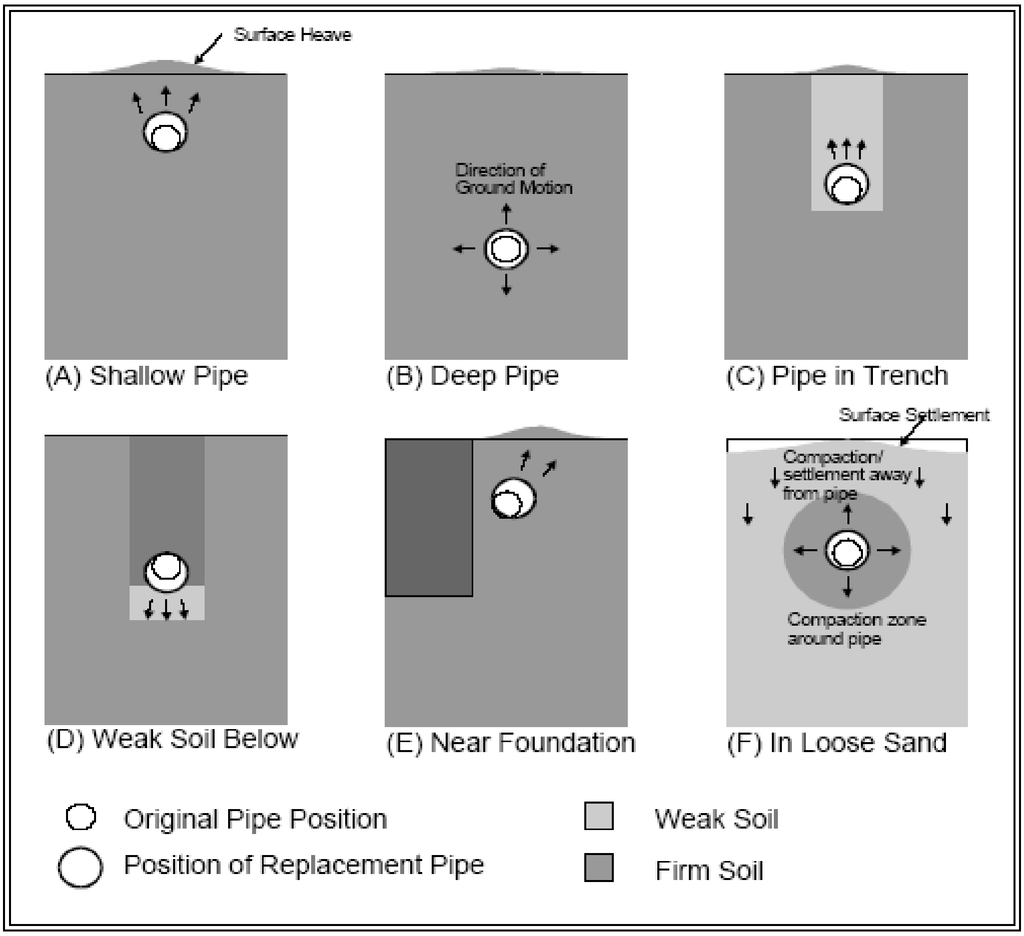

Figure 1: Ground heave scenario's associated with Pipe Bursting

If the soil conditions are known, then contingency planning to manage, mitigate and minimize this issue can be undertaken.

The depth of the groundwater table level also needs to be confirmed, as this will have an impact on the methodology to manage the water in the launch, receiving and connection pits.

2.2 UNDERGROUND SERVICE LOCATIONS

The location of the existing underground service and their impact on the new utility being able to installed in the designed position, is similar to the ground condition issue, in that inaccurate position determination may prevent the installation from being completed without some disruption and will impact on all the four key risk areas. Within this issue there are two components, one that relates to the nature of the service and the consequences of damage to it and the second issue is that of available corridor space.

In both cases the first step to be undertaken is a desktop review of the underground service plans from all of the utility providers. This will identify any high consequence/risk services in the construction window and give some indication, when plotted, as to the level of underground congestion.

In terms of high consequence/risk services, these could typically be; high pressure gas pipes, trunk sewers including rising mains, bulk watermains, high voltage power cables, fibre optic and international telecommunication cables and the like. Clear position determination and separation from these services must be ensured. Although there is a requirement on the contractor to carry out location and protection measures of these services, when they are installing the new utility, if the design does not ensure and allow for this to be reasonably achieved, by the contractor, then the combination of the high consequence and likelihood of a strike creates an unacceptable risk, that the client can not ignore and must mitigate. On-site potholing to confirm the correct position of these high risk services is therefore required to manage and mitigate the risk, for both the client and contractor. On site location determination, as well as managing the client's liability and image risks, also will protect against any potential variation cost and time claims.

The second aspect regarding underground service locations is from the point of view of congestion ie having sufficient room and clearance space to install the new utility product. Again the first step in identifying if this is a real risk is the desktop review of the underground service plans from the various Utilities. These should be plotted onto the base topographic plan and then checked, where possible, from a site inspection looking for obvious surface boxes to confirm the accuracy of the drawing. If, at this stage, a lack of space or clear working room is identified, it should then be confirmed by on-site potholing or a strip trench. The paper plans from the utility owners provide general information but cannot be relied upon for accurate positioning, either horizontally or vertically. Minimum separation distances from the existing service to the back reamed dimension of the new product also need to be checked. As a general "rule of thumb" the separation distances should be 500mm, however these should be increased in cases where the drilling is adjacent to either a high risk pipeline or a structurally deteriorated asset.

As above with Item 2.1 the underground service location information is invaluable at the planning phase to ensure that a rigorous option analysis and risk assessment will identify the best methodology and design to proceed with.

Please note that if neither the high risk service nor the congestion scenario is present then this issue will not impact on the four key critical area's and therefore can be managed within the contract procedure.

2.2.1 IMPACT OF LOCATION OF UNDERGROUND SERVICES

2.2.1.1 Horizontal Directional Drilling / Micro Tunnelling Installation

The consequence of inaccurate underground utility location is that the HDD / Micro installation will not be able to be installed on the design alignment. A change in alignment, in some cases, may not be acceptable or achievable eg replacement of a drainage gravity pipe between two fixed points within the reticulation. This will lead to design and/or methodology changes that will impact on cost, time, liability and image. In other situations, the new asset maybe able to be installed, however the final location will be less suitable than the original design eg having to install the asset in the carriageway rather than the grass berm due to insufficient clearance space. This again will impact on costs, time, liability and image.

2.2.1.2 Pipe Bursting

As well as ground heave, the process of pipe bursting, imparts/exerts pressures onto the surrounding ground that can be transmitted to the surrounding services. As per Section 2.2 the nature of the service needs to be considered and the risk consequence of ground pressure on it.

As a "Rule of Thumb" for this situation the greater separation distance of either 600mm or 3 x the "Upsize" dimension should be applied (the "Upsize" dimension is the outside diameter expander minus inside diameter defective pipe). These safe working distances of course need to be increased if the consequence or likelihood of damage is higher normal ie a high pressure line or an old deteriorated earthenware / asbestos cement pipeline. The likely position of anchor blocks also needs to be considered.

2.3 WORKING SPACE

Large scale projects involve larger plant and machinery, as well as more ancillary equipment, the need for mud ponds and larger product pipe laydown area's. Not being able to provide the necessary area/space to the contractor is going to prohibit the works from proceeding on a large scale. As such, the works would need to be completed either by a series of smaller scale operations; which will result in impacts to the client of cost, time, liability and image.

2.3.1 ISSUES ASSOCIATED WITH WORKING SPACE

2.3.1.1 Horizontal Directional Drilling Installation

Notwithstanding that each contractor/tenderer will have their own specific methodology for carrying out the works, there are a number of set common factors, with respect to working area's, that the designer must allow for, if large scale maxi rig HDD is the proposed methodology. These area's are the drill rig footprint, the mud mixers and recyclers, the mud settlement ponds and the pipe stock/welding/laydown area. Noise control may also be an issue of a contractor's methodology.

For a typical maxi rig HDD shot of 1,000m the working space at the Rig side can be up to 70m wide by 100m long and 30m wide by 50m long at the respective pipe side. The Rig side of an HDD site includes the area where the drill machine and rods are, the separation equipment, slurry mixing and pump equipment are, as well as the offices and slurry ponds. The pipe side includes such aspects as the cuttings settlement pits, the pipes to be jointed and the drill rods. Similarly, whatever the proposed pipe installation length, that same length needs to be available, to string the pipe out, on the pipe side. It may be possible to break the whole full length into sections, but this has other issues associated with it. The pipe laydown either needs to be clear of all driveways and road crossings/intersections or appropriate traffic management needs to be in place. This is generally not possible outside of working hours.

Rig side!

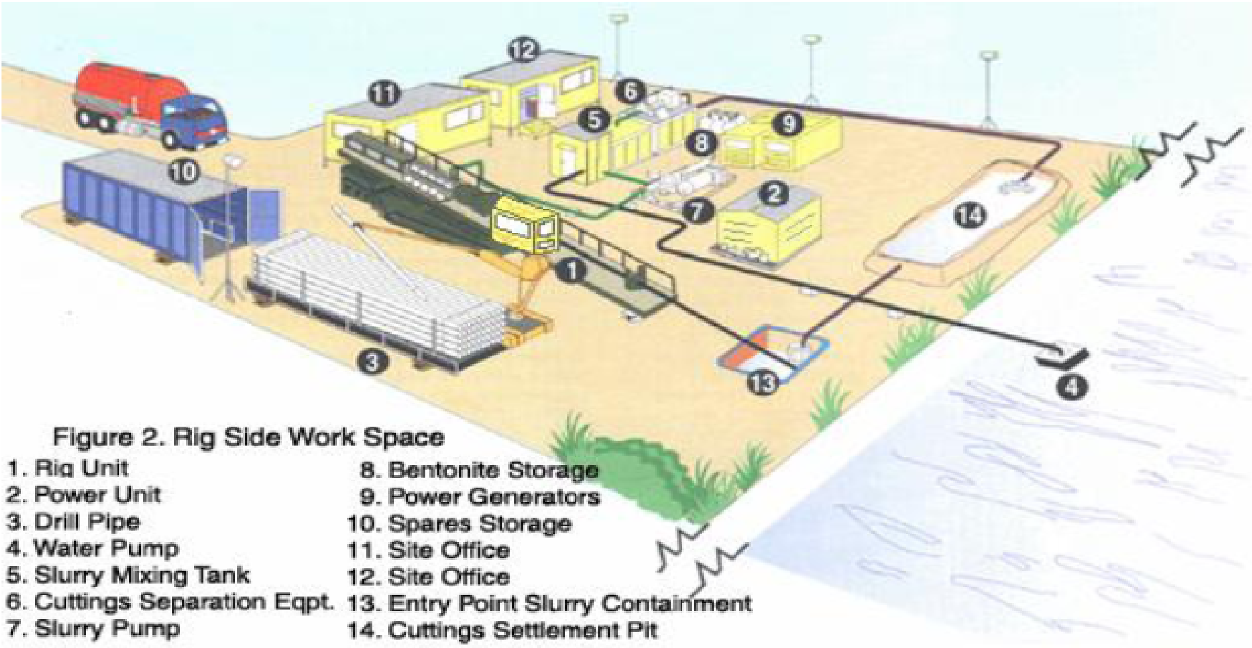

Figure 2a: Typical Maxi HDD Site Setup

Pipe side

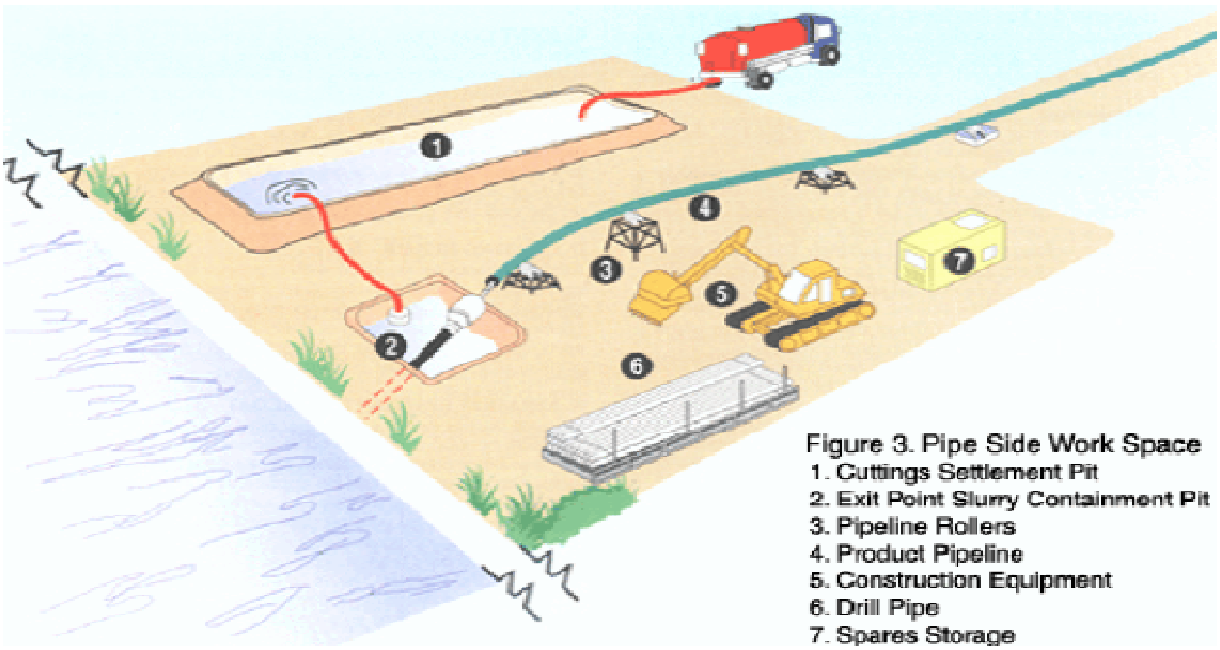

Figure 2b: Typical Maxi HDD Site Setup

Photograph 1: Pipe Laydown Area

2.3.1.2 Micro Tunnelling

In the case of micro tunneling, the size and location of the launch and exit shafts and their ancillary equipment is the critical defining factor. The pipe stock will still need to be adjacent on-site, as well as the slurry mixing and settling tanks.

Whereas, in the case of HDD, the positioning of the drill rig and equipment may be able to have some flexibility, as the drill can be set back from the actual pipe alignment and the rods extended, as required, this is not the case with micro-tunnelling. The launch and retrieval shafts can only be on the pipeline alignment. Therefore, not only does this limit the options, but also increases the criticality that there is sufficient clear working space for the shafts.

The location of underground services, as well as being critical for the tunnel alignment, also needs to be confirmed for the shaft installations. Note that, dependant on the size of the tunnel bore to be completed, the launch shaft can range in size from as small as 3.5m diameter to 10m diameter or more. Quality construction of the shaft is paramount and critical to the success of the tunneling operation and one of the key aspects/elements in ensuring the quality construction of the shaft is the impact of any underground services in the near vicinity of the shaft position.

Photograph 2: Sediment Settling Tanks

Photograph 3: Launch Shaft

2.3.1.3 Pipe Bursting and Slip Lining

With respect to pipe bursting and slip lining techniques, similar aspects to both HDD and micro tunneling apply, in so much as, the pipe laydown area consideration with regard to pipe bursting and continuous slip lining and the launch pit location for sectional or segmental slip lining is similar to micro tunneling. Failure to investigate fully these aspects may result in the pipe installation procedure not being able to be completed as planned resulting all four of the key risk elements occurring.

2.3.1.4 Pipe Rehabilitation

The consideration of working space, with respect to pipe rehabilitation, is concerned with access to the manholes, both upstream and downstream and the ability to get the necessary plant and equipment to the manholes. Insufficient room and/or lack of accessibility may result in either the works not being able to proceed and/or significant changes to the methodology, both impacting on the four key risk elements for the client, cost, time, liability and public image perception.

2.4 CONDITION OF THE EXISTING PIPELINE

The existing pipeline to be replaced either by renewal or rehabilitation will have defects, hence the need for replacement. The defects can be categorized into two groups, those that need investigation so as to ensure a successful replacement and those that are classified as latent defects. A latent defect, dips and deflections, for example, will not prevent the replacement but will still remain, post a pipe bursting replacement or a lining. The latent defect issue is for the client to determine, whether it is acceptable to them or not, but it does not impact on the four key risk elements of a project. However, the other elements of the pipeline condition that will impact could be a collapsed section, large debris build up, a bend or a change of material.

A current pipeline CCTV inspection is therefore critical to a successful project. It is not uncommon for there to be a 6 month or longer time period between project initiation and the actual carrying out of the physical works. If a pipeline is in a degraded state, then the potential that any defects may have further deteriorated, is greatly enhanced. A six month old CCTV is not acceptable to mitigate the risks of accelerated degradation and the impact that may have on the successful completion of the works.

2.4.1 ISSUES ASSOCIATED WITH THE EXISTING PIPELINE CONDITION

2.4.1.1 Pipe Bursting

The occurrence of any of the four defects, shown in Figure 2, is likely to prevent the successful completion of a pipe bursting pipeline replacement project and hence need to be investigated. Similarly, the existing pipe material needs to be confirmed and any change in material also needs to be clearly identified.

Any of these scenario's will result in all of the four key risk elements being realized. The risk increases dramatically, if one of these defects, happens to be under a structure. Therefore, as well as an up-to-date CCTV, the position of any significant defects also needs to be noted on a topographic plan or logsheet to determine the risk consequence that the defect has. An example of this would be the risk associated with a large collapse under a house and the consequences of the bursting head getting stuck or going off course under a house. How would the head be retrieved and the product pipe installed ? In some cases, pipe bursting may de-stabilise a pipe in poor condition which may then cause a collapse ahead of the bursting head.

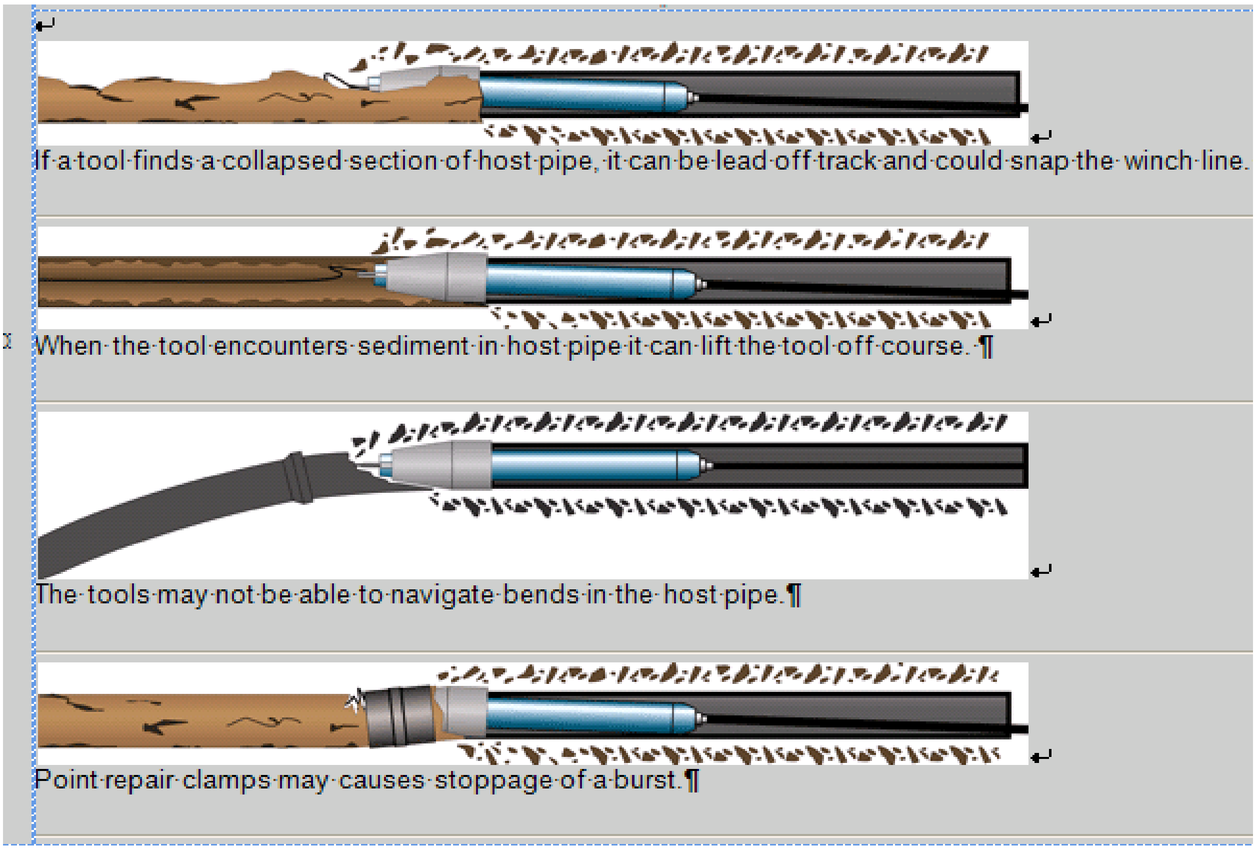

Figure 2: Problems During Pipe Bursting

The existing pipe material is important as this will dictate the bursting head type and technique necessary. Different material types require different heads and techniques, for example the difference between Asbestos Cement pipes to Cast Iron pipes to PVC pipes. Also critical is any change in pipe material, not only because of the potential need to change bursting equipment but also any material change is often carried out by use of an external clamp e.g. a gibault connector. These types of connectors are likely to prevent the bursting head from progressing. In a gravity drainage pipe, CCTV often will show these changes of material, however in a pressure pipe, it is often not feasible to insert a camera. In these case, asset and maintenance repair data is critical and must be relied on top provide the information as to where these repairs, material changes are likely to have occurred.

2.4.1.2 Pipe Lining

The trenchless renewal techniques/methodologies considered under this section included Slip Lining, Spiral Wound, Form and Fold and Cast-in-Place Pipe (CIPP). From the point of view of type and level of investigation, these can all be considered as similar.

The existing pipeline condition is the key element that needs to be confirmed. The extent of investigation is similar to Section 2.4, in that a current CCTV confirming the current condition and any major defects is required. Acceptance, or not, of any existing latent defects, that do not prevent lining, is the prerogative of the client.

Typical major defects that need to be identified to ensure a successful pipeline rehabilitation included large open/displaced joints, protrusions, obstructions (temporary and/or permanent), large root intrusions, bends and collapses. The unconfirmed or un-identified presence of any of these defects will affect the pipeline rehabilitation, most likely requiring the pipeline to be excavated to be repaired, resulting in, not only losing the benefits of a trenchless installation, but also incurring time, cost, liability and image perception impacts for the client.

2.5 LATERAL CONNECTIONS

Determination of the location and status ie Live or Dead/Blank of all of the service connections on the pipeline is critical to the successful completion of the pipeline rehabilitation. Failure to incorrectly identify the status of a lateral may result in either an overflow, as a result of a live lateral not being re-connected or unnecessary dead laterals being re-connected undermining the project objective's. It should be noted that the location and status of all connections can be carried out as a subsidiary work package to the main pipeline CCTV investigation ie done at the same time.

2.5.1 ISSUES ASSOCIATED WITH LATERAL CONNECTIONS

2.5.1.1 Pipe Bursting and Slip Lining

The positions of house service lines that connect to the pipeline also need to be determined and then accurately plotted onto a topographic plan as these will need to be excavated to be re-connected. These positions and depths should also be shown on the surface of the pipe alignment by pegging and photographed. Although uncommon, it is not unheard of, that the lateral connection may be under a structure or even a significant tree that prevents the excavation. In the most extreme case, a house lateral connection was underneath the concrete slab foundation of the house, resulting in the owners being re-located for two weeks and the floor slab excavated to re-connect the private drainage.

The downstream sewer from the collapse was Pipeburst next. It was a short segment of 213 feet but it turned out to be one of the most difficult segments since the City of Reno started Pipebursting. The main was underneath two structures. Both structures were slab-on-grade construction. The City was lucky with the first structure because the lateral came outside the foundation footprint and dropped down to the sewer. The lateral from the second structure was in the center of the residence and connected to the sewer directly over the pipe. The City's only option was to cut a new trench through the inside of the residence (Figure 13) and drive the lateral out to the street then connecting it to the new sewer. The property owner was displaced for almost three weeks while this work took place.

Photograph 4: Trenching through bedroom

2.6 NON CRITICAL INVESTIGATION ISSUES

Aside from the above discussed issues there are still a number of other issues that need to be considered for a trenchless project; issues that will not impact on all four of the risk elements and can be managed through alternative methods eg through the contract procedure or methodology. Every project will have it's own specific issues and the same issues will not apply to every project.

Management of these types of issues is best covered through either the agreed methodology to be used and/or contract scheduled items and rates and contingency planning between the client and contractor, at the start of the project, or even during tender award discussions with the preferred tenderer. These issues typically are of the type that are "when they occur, not if" and have smaller, lower risk consequences. As such, contingency can be included in a contract to cover any cost and time related effects, as well as methodologies determining a defined course of action, so that "when" the event does occur, everyone knows what to do. This also leads towards minimizing the impact of the event, from a publicity, liability, lost time and cost perspective.

Aside from the issues relating to the carrying out/completion of the physical works, there are other issues that need to be considered as part of the design and whether the methodology proposed is feasible. Some examples of these issues are:

- Bending radii, both of drill rods and pipe
- Volumes and type of By Pass pumping ie constant or variable flows
- Damaged laterals preventing Lateral Junction repairs to be installed

2.7 SUMMARY MATRIX

Table 1 is a summary matrix of key critical issues that need to be considered for the various trenchless techniques and a brief description of the optimum level of investigation that each requires, from a cost versus risk minimisation perspective.

Issue	**Methodology**					**Risk Minimisation**
	New Installation			Replacement	Rehabilitation	
	Medium HDD	Maxi HDD	Micro Tunnelling	Pipe Bursting	Lining	
Ground Conditions	✓	✓	✓	✓	N/A	Geological bore samples at minimum 200m spacing.
U / G Services	✓	✓	✓	✓	N/A	Desktop review of U/G service plans to determine high risk services and available corridor space. Pot holing / strip trench on site to confirm locations and sufficient clearance.
Working Space	N/A	✓	✓	✓	✓	Designer to be aware of area required for all plant and equipment. Product pipe laydown area. Adequate room for launch and exit shafts.
Condition of Existing Asset	N/A	N/A	N/A	✓	✓	Current CCTV to identify all major defects. Plot position of defects on topographical plan.
Lateral Connections	N/A	N/A	N/A	✓	✓	Confirm source and status. Plot connection position of defects on

						topographical plan and peg on site.

Table 1: Trenchless Project Risk Minimisation Matrix

3 CONCLUSIONS

Modern trenchless installation and renewal techniques and technologies provide many advantages and benefits to network owners. However, insufficient planning and investigation, at a project's initial design phase, can mean that all of the benefits of the trenchless technique are lost or overwhelmed during the actual construction and the client suffers from the four key risk elements of a project; cost, time, liability and public image perception. From the perspective of risk management/mitigation there is a cost effective amount of investigation that needs to be carried out to ensure a successful project.

For a trenchless project, of varying scales, the issues that need to be investigated are; ground conditions, location of underground services, site working room, the condition of the existing pipeline and lateral connections.

Management of these issues at the initial design stage will manage the clients risks throughout the project and help towards achieving a successful project outcome.

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