SURGICAL PRECISION: MICRO TUNNELLING IN SUBURBIA

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ABSTRACT

North Shore City Council (NSCC) has carried out numerous major wastewater upgrade projects under their Project CARE scheme since its implementation in 2000. NSCC approach their projects in terms of not only considering their whole life costs, but evaluating other parameters including the level of public disruption, environment sustainability and the ease of consenting. A significant number of the projects have been built using trenchless technology including by micro tunnelling and directional drilling methods.

Micro tunnelling has been successfully used by NSCC to install wastewater gravity sewer pipelines at various gradients, including some that are extremely flat. Its use presents some specific and unique risks from design to construction that need to be clearly evaluated and closely managed to ensure the project is to achieve or surpass its objectives.

The main feature of micro tunnelling is the ability to install straight lengths of pipeline underground to a very consistent and accurate grade. This is the ideal situation for gravity sewer pipelines.

This paper will describe the features of NSCC's projects that have resulted in the use of micro tunnelling as the adopted methodology, and look at key attributes, risks and challenges when considering this methodology. Specific projects on the Project CARE scheme will be referenced. The paper will conclude with successes and lessons learned on micro tunnelling projects which have been incorporated into further stages of the Project CARE scheme as a whole.

KEYWORDS

Micro tunnelling, Pipe Jacking, Wastewater, Pipeline, Trenchless Technology, Risk Management

1 INTRODUCTION

Apart from some very limited combined drainage systems built for the earliest coastal settlements on the North Shore of Auckland in the early 1900's, the majority of the primary wastewater sewerage infrastructure network on the Shore was built in the 1960's. Few new major sewers were then built until after NSCC adopted their Project CARE scheme to plan and prioritise a suite of wastewater network developments and upgrades in 1999.

By the time Project CARE started to be implemented the North Shore had become an extensively built suburban environment. Furthermore, it was no surprise that the sewer upgrades most needed were in areas where significant building development had taken place either nearby or directly above previously built pipeline infrastructure.

The use of trenchless technology for piped infrastructure is a consequence of the need to work around significant constraints that have always existed in busy suburban environments and, in particular, the need to reduce disruption to the public.

The first wastewater sewer pipeline on the North Shore built using micro tunnelling was completed in 2000. An 1140mm diameter concrete pipeline was installed in Birkley Rd, Bayswater. Since then, more than 7 km of wastewater gravity sewer pipelines have been installed in the North Shore by micro tunnelling in pipe diameters ranging from 450mm to 2100mm and at a capital cost of $35m.

2 BEFORE AND AFTER PROJECT CARE

Prior to the advent of Project CARE, the sewer network was constructed typically by open trenching. Where gravity sewers had to be built through ridges, traditional tunnelling methods were adopted using steel sets and timber lagging. The majority of sewer pipelines laid by open trenching were rather shallow, with the deepest pipelines typically never more than 4-5 metres deep.

Outputs from the NSCC's Project CARE model completed in 1999 led to implementation of network upgrades focussing firstly on large scale storage projects to deal with the worst wastewater overflow problems. Primarily, the overflow behaviour was a consequence of wet weather flow entering the wastewater network.

The initial upgrades comprised gravity fed detention storage strategically located around the Shore. Some old storage tanks were rehabilitated. Three new storage facilities entailed construction of two large off-line reinforced concrete tanks (total 11,000 cum) and 1km of a 2.1m diameter micro tunnelled on-line storage sewer pipeline. These projects were constructed between 2001 and 2005 at a total capital cost of $24m.

Subsequent implementation of CARE involved construction of a significant number of gravity reticulation trunk wastewater sewer pipelines. Most of the new gravity pipelines have been built using trenchless technologies, either by micro tunnelling, pipe-jacking, or by horizontal directional drilling (HDD). Large scale in-situ pipeline rehabilitation work throughout the city has also been implemented.

Given that the North Shore is now well developed and the large remaining expanses of open land that do exist comprise mainly of valuable native flora and fauna and leisure areas, open trenching to install trunk infrastructure is less common because it is considered disruptive and difficult to obtain consent for.

To implement the sewerage network upgrades required under Project CARE, NSCC has had to face major suburban constraints and effectively manage them. They have had to identify clearly suitable methodologies to complete construction work economically, without causing levels of disturbance intolerable to the community or compromising environmental sustainability. Micro tunnelling has been a useful methodology in this context.

3 MICRO TUNNELLING

Micro tunnelling and pipe-jacking can be defined as pipe units being pushed one by one into final position to form a pipeline from a launch or jacking shaft / pit towards a reception / retrieval shaft behind a micro tunnelling head that bores a hole cut to a slightly larger diameter than the pipe. Pipe-jacking is the method of actually pushing pipes or a steel sleeve beyond a lead shield or the micro tunnelling head. Soil is cut from the leading face or micro tunnelling head and transported either in solid form or as slurry along the pipeline internally, where it is retrieved to the surface at the jacking shaft. As soil is cut at the face, the pipeline is concurrently jacked toward the reception shaft.

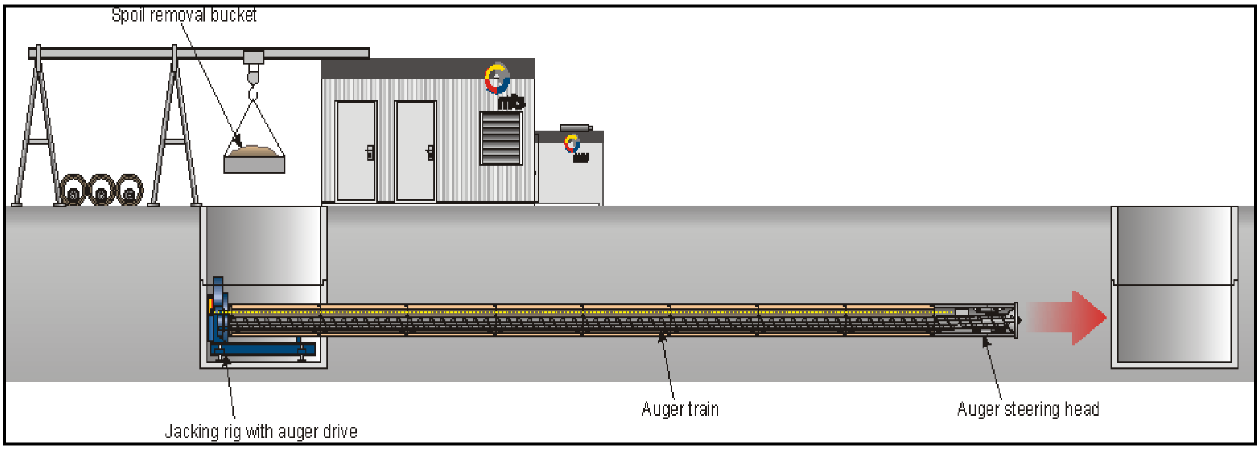


Figure 1: Elevation of Micro tunnelling Operation, as used in Browns Bay, North Shore, courtesy of MTS website

Photographs 1 to 3: Browns Bay 2.1m diameter pipeline - Installing Pipes Prior Jacking / Jacking Shaft / Micro tunneling Machine Head Entering Reception Shaft

By the 1990's, trenchless technology for installing pipelines was becoming widely used in Western Europe and North America, however in New Zealand its use remained rare. This was mainly because of the absence of new technology.

Now a considerable knowledge exists about the various trenchless systems available and their criteria for success as a consequence of improved technology transfer, experience and lessons from completed projects. Because of the recent significant advances in the trenchless technology field and increased understanding from project experiences, infrastructure owners and their designers now have access to a large range of information to assist them in choosing the most appropriate trenchless technology solution for their project.

4 ECONOMICS

There is a perception that trenchless methods are much more expensive than traditional (open trenched) methods. Because of the significant advancements in trenchless technology in recent years in NZ, and project experiences gained, trenchless pipeline construction contractors understand the risks involved more fully and are better able to competitively price to successfully complete the projects.

NSCC has more than one decade of experience in the use of trenchless methods, including micro tunnelling, on their projects. NSCC, their supporting consulting engineers and trenchless construction contractors have gained a thorough understanding about the features of certain trenchless methods and pertinent risks, including those specific to North Shore conditions, and how to manage them. This has enabled specific risk assessments for each project at an early stage, and strengthened the ability to properly scope and identify realistic budgets for each project. Furthermore it has enabled NSCC to utilise reliable financial data from the past decade of the Project CARE wastewater upgrades to develop future upgrade budgets on the scheme.

It is not always the case that the use of trenchless technology is the most suitable answer, and economic evaluation is only one of a number of considerations in determining whether trenchless technology is an appropriate solution or not. One challenge that remains is to robustly quantify the cost of disruption.

4.1 PROJECT CARE COST DATA

To date the Project CARE expenditure since the start of its implementation in 1999 is $130m. The capital cost of wastewater sewer pipeline projects constructed using trenchless methods is $51m, of which $36m has been specifically on micro tunnelling projects. This highlights that fact that trenchless installation and particularly micro tunnelling has been a major component of the Project CARE expenditure in the congested suburban North Shore environment. 7.5km of wastewater sewer pipelines have been constructed using micro tunnelling and pipe jacking since 1999 out of a total approximate 16km of pipelines built using trenchless methods.

5 ATTRIBUTES AND REASONS FOR MICRO TUNNELLING

5.1 EVALUATION CRITERIA

The installation of pipelines in suburban areas using trenchless technologies is now a well known and effective method to reduce public disruption. However, it should be known that although the temporary works at the surface are at isolated positions along the pipeline route, they can still be relatively disruptive. It is hence important to select the right method of trenchless technology to be employed on the specific project at hand. Options analyses carried out at the concept design stage on NSCC projects frequently identified that not only trenchless methods were the most suitable method of construction, but also identified the most appropriate type of trenchless method, for example micro tunnelling or directional drilling. The Options Identification and Evaluation process then progressed. At the outline design stage, a multi criteria analysis would be used to determine the most appropriate options which considered:

- Determination of pipe sizing to meet service level required, including dry weather flow and wet weather containment level.
- Economics of a gravity pipeline compared to pumping the flow.
- Suitable routes for the new pipeline. Council's strong preference is to use public land, e.g. roads and park reserves rather than private land wherever practicable.
- Whole of life cost economics.
- Disruption level during construction work. Finding solutions that can be built without overly disrupting the public is important, but notwithstanding that construction disruption is brief compared to the pipeline's operational life span.
- Ease of gaining landowner and resource consents. Whether a solution offers the best certainty in gaining resource consents or whether there are significant risks. It has been much easier to gain consents for deep gravity pipelines compared to new pumping stations. It may be noted that utility works built in road reserve in the North Shore enjoy the benefit of Permitted Activity status under the Resource Management Act in NSCC's District Plan.
- Solution that requires minimal maintenance, including avoiding dips than may cause silt build up and odour nuisance.
- Buildability. This includes the possible methodologies for constructing the pipeline, suitable work sites, access to the sites, and working with stakeholders so that their requirements are addressed and reasonably satisfied.
- Environmental effects.
- Social and cultural aspects such as interfacing with other stakeholder requirements, for example park reserve enhancement works after construction work takes place.
- Overall project risk and ability to mitigate significant risks.

This combination of criteria often directs the designer towards consideration of micro tunnelling as a preferred option.

5.2 MICRO TUNNELLING SUCCESS ATTRIBUTES

Every project that has been proposed to be constructed by micro tunnelling on the North Shore has a unique set of attributes. Knowing their appropriate combination before the project commences construction, together with effective management throughout the construction phase has greatly assisted in achieving project success. The key attributes for micro tunnelling projects have included, but not been limited to:

- Having appropriate equipment for the ground expected.
- Having available temporary work sites along the route spaced at intervals achievable by micro tunnelling.
- Suitable diameter of pipe to meet both the hydraulic design criteria and the machinery available.
- A good understanding of what the ground might unexpectedly contain and how this will be managed using the construction method and specific machinery to be used.

- Analysis of realistic surface disruption, on the “macro” scale being the expected level of community disruption and on the “micro” scale being the expected surface settlements caused by the pipeline installation process and shafts construction work.

5.2.1 GEOTECHNICAL CONDITIONS

A good understanding of the expected geotechnical conditions is a vital aspect in the design for a pipeline to be installed using trenchless technology, and in particular micro tunnelling. For micro tunnelling, the ground conditions need to be known to sufficient detail to determine the arrangement of the boring machine head and soil treatment system. It is essential that the design of the micro tunnelling machinery is appropriately selected to cater for the expected ground conditions. However, it is also extremely beneficial and cost effective that the machine can not only handle the expected conditions but is capable of dealing with the unexpected ground conditions that may be encountered. Both open and closed face micro tunnelling systems have been used on NSCC micro tunnelling projects where the ground has consisted of a various conditions including low permeability and stiff clays, silt, very weak to weak rock and clay with peat inclusions. On the Browns Bay Trunk Sewer 7 storage sewers, a closed-face micro tunnelling system was used because ground conditions expected (and encountered) were alluvial sand and silt with the pipeline alignment below the groundwater surface level. The micro tunnelling machine designs on the NSCC projects have proven to be a vital aspect for success. Machines designed for weak rock have had to cater for areas of clay, and machines designed for alluvial ground have had to pass through buried timber.

Ground cutting and handling has been a significant challenge on the NSCC’s micro tunnelling projects, and has been highly successful for a number of reasons including thorough soil investigation at the design stage, appropriate machine selection, appropriate handling and treatment system, and highly skilled personnel operating the machinery and managing the process.

5.3 REASONS FOR CHOOSING MICRO TUNNELLING

There are a significant number of attributes of projects where micro tunnelling is preferred and these are covered below.

5.3.1 DEEP PIPELINES

Micro tunnelling is obviously a viable option where pipelines are required to be deeper than can be safely and economically trenched, or where trenching is completely impractical such as under buildings and busy roads. On North Shore’s Birkdale (Stages A, B and C) and Hillcrest (Stage A) projects, 5 km of new wastewater gravity sewer pipelines was built using trenchless technology with pipeline depths ranging from 5 metres upwards with considerable lengths at more than 15m. 2km of pipeline completed using micro tunnelling had temporary work shafts from 5 metres to 20 metres in depth.

5.3.2 FLAT PIPELINE GRADIENTS

The layout of new sewers on the North Shore has often necessitated pipelines to be installed to very flat vertical gradients, a characteristic reliably achievable using micro tunnelling. Main reasons for flat gradients on new sewers are:

- fixed levels of existing pipeline end connections,
- augmentation of existing old pipelines which have flat grades,
- the need to install the new pipe on a slightly longer route between end connections and

- topographical constraints such as needing to pass beneath a stream rather than have a pipe bridge through the stream's wet weather flow.

Achieving an accurate and consistent vertical gradient, particularly on flat gravity sewers where self cleansing velocities are near their required minimum, is important to minimise sediment build up and odour. Very flat vertical grades have been successfully achieved using micro tunnelling on the North Shore projects listed in Table 1 below.

Project (Completion Date)	Depth of Pipeline (To Invert)	Pipeline Diameter and Total Length	Vertical Grade
Trunk Sewer 4A, Wairau (2004)	4m to 8m	1050mm, 1.65km	0.2% - 0.5%
Trunk Sewer 7, Browns Bay (2005)	5m to 7m	2100mm, 1.08km	0.2% - 0.3%
Browns Bay Stage 2 and Stage 3 projects (2007)	3m to 6m	450mm, 0.99km	0.5 %
Birkdale Stage A (2009)	5m to 23m (mostly 15m +)	1080mm, 0.83km	0.17% throughout
Hillcrest Stage A (2010)	3m to 10m (mostly 7m+)	1050mm, 0.87km	0.45% throughout

Table 1: Gradient and depth data for micro tunnelled sewers in North Shore

5.3.3 SITE CONSTRAINTS

Physical site constraints have been a major element to consider and manage during the planning and construction phase of virtually all of the NSCC's wastewater pipelines built under Project CARE. The choice of pipeline routes has depended heavily on the position and layout of existing features including utilities, buildings, large native trees, topography, streams and roads. New pipeline routes have been selected to circumvent the constraints and this has commonly necessitated placing new pipes at deeper depths than before and therefore open trenching options have not been feasible.

The original trunk sewer that was augmented by Birkdale Stage A pipeline exists beneath 30 private properties, running directly beneath houses and crosses three streams within the storm water flow path. It was not feasible to construct a new pipeline along the same route therefore the new pipeline was built along a road. However, so that the ends of the new pipeline could connect to the existing network the pipeline was installed at a depth ranging from 5m to 23m. Being able to construct a route along the road removed the requirement for private landowner consents, potential compensation under the Public Works Act and resource consenting issues.

5.3.4 DISRUPTION MITIGATION

The public are now increasingly aware that buried pipeline infrastructure has been built by trenchless methods elsewhere, so when a new pipeline project is to take place in their own surroundings, they often have an expectation that significant trenching and disruption to their community can be avoided. A major reason for the use of micro tunnelling as opposed to open trenching is to minimise public disruption and avoid damage to existing services and ground conditions.

Avoiding damage to existing utilities has become increasingly important due to safety issues, high expense of repair (particularly for fibre optic cables) and disruption implications including fines and major public inconvenience. Micro tunnelling is generally considerably deeper than other utilities, and typically only affects utilities at temporary shafts, where service diversions can be planned in advance of the shaft construction. Nevertheless, trenchless construction is far from disruption-free and can be criticised for unfair distribution of the disruption that still results. Consultation requirements during the consenting phases can become more difficult as a result and need to be appropriately managed.

Photographs 4 and 5: Jacking Shaft Sites in Suburban Areas

6 RISKS AND CHALLENGES

6.1 OVERVIEW

The use of micro tunnelling involves a unique set of risks and challenges to be addressed for each specific project. Risks need to be clearly identified at an early stage and appropriately managed to have the best possible opportunity to achieve or surpass project objectives. Challenges include selection of appropriate plant, choice of skilled operators, understanding ground conditions and variability, likely settlement, and appreciation of the expected level of disruption. The micro tunnelling process involves a set of steps being performed repeatedly and efficiently while continuously managing the risks and challenges.

Risk identification and management has been undertaken by NSCC and their consulting engineers on each micro tunnelling project including at the planning stage, design and resource consent phase, contractor selection and award, throughout the construction management process, and ultimately for the system operation.

Overcoming the challenges has been a vital aspect in achieving successful delivery of micro tunnelling projects, and delivery of NSCC's Project CARE scheme as a whole.

6.2 DESIGN STAGE RISKS AND CHALLENGES

Risk register preparation is undertaken at the outset of the planning and design phase to enable mitigation through design and the construction process as well as to manage risks in the consenting process. This involves identification of the risks at an early stage and discussions with NSCC and project stakeholders. To prepare the risk register, some pre-work is necessary such as meetings with stakeholders to understand their issues, studying the environment where the project is to be built, ground condition investigations, public interaction, reviewing likely construction impacts, District and Regional Plan requirements and identifying uncertainties or gaps in the project data.

From experience gained on the NSCC's micro tunnelling projects, the main management measures during the design, resource consenting and contractor procurement phase have included:

- Planning the route in such a way to minimise the number of landowner consents required to install the pipeline. Knowing and understanding the resource consent requirements early, so the process can be timely managed. Designing in such a way to streamline the consenting process.
- A clear understanding of the level of disruption expected, enabling appropriate communications to be made to the public about the work scope, expected timings and relatively definitive information for property owners in advance of work taking place to clearly detail the impacts to them. The experience gained on the NSCC's projects to date facilitates reliable information being offered to the public for each new project.
- Data gathering to assess ground risk. The requirement to have a good understanding of the ground conditions, how hard or soft, the likelihood of hard lenses within soft ground, whether sandy or silty strata exists, groundwater levels, ground permeability, whether water bearing layers may exist, and the likelihood of obstructions such as the existence of timber, organics or completely foreign objects.
- Predicted surface settlement assessment. Assessment of the likely level of settlement is very important for micro tunnelling projects. This has been done on the NSCC projects by the use of geotechnical modelling and comparing with actual survey records from previously completed micro tunnelling projects. Settlement along pipelines installed by micro tunnelling and around shafts can be an issue if the geotechnical conditions and the expected construction methodology are not well understood. A substantial amount of experience has been gained on the NSCC projects in assessing and monitoring settlement and has resulted in having a well defined monitoring programme before construction of the project and survey results at appropriate positions. Not only does the monitoring provide results to compare whether damage, if any, to surrounding features including buildings has been caused by the construction work, it also offers an early warning of settlement.
- Clearly specifying the work and payment basis to achieve the greatest level of cost and time certainty at the time of tendering. This is an obvious process to minimise construction claims.
- Having a procurement strategy to get the right contractor for the project with appropriate skills and equipment. The micro tunnelling contractor market in NZ is rather small, albeit highly skilled, and as a result projects need to be specified in such manner that the contractors are not constrained in identifying and pricing suitable machines in their tenders.
- Having a clear understanding of contractors' drivers and risks. Early contractor involvement has been invaluable on the NSCC projects where designs need to be finalised to enable resource consenting to take place which minimise the need to vary consents while on site. Discussions with contractors can confirm buildability for a range of machines, giving better certainty in consenting.

The following sections explore these in more detail.

6.2.1 PIPE AND MACHINERY DIAMETER

The major wastewater trunk gravity sewer pipeline upgrades in the North Shore on the Project CARE scheme implemented from 2000-2010, where micro tunnelling has been used, have required design pipe sizes of internal diameters from 350mm to 2500mm. Most projects have been tendered to construction contractors on the basis of specifying the minimum required internal pipe diameter. However the actual pipe diameter installed is sometimes the nearest, most economic larger diameter, and in the case of micro tunnelling tenders it is usually the nearest diameter of the machinery proposed by the contractor, often upsized to allow man access for increased cost effectiveness in the installation process.

On the Browns Bay Trunk Sewer 7 Upgrade, constructed in 2004-2005, the design was for a 2.5m internal diameter pipeline for wet weather on-line storage. Tenders were called for provision of detailed design and construct, based on the NSCC's specimen design. The contractors' offers included several different solutions and each contractor proposed a different diameter pipeline with length adjusted to meet the required storage volume. The pipe diameters that tenderers proposed, we believe, were both a result of the tunnelling machinery they had available as well as the contractors' assessment of the project risks and their proposal to successfully and competitively complete the project. After hydraulic assessment, 2.1m internal diameter pipeline was constructed, by pipe-jack micro tunnelling several drives, with the maximum jacked length of 600m which was at the time believed to be New Zealand's longest single micro tunnel drive.

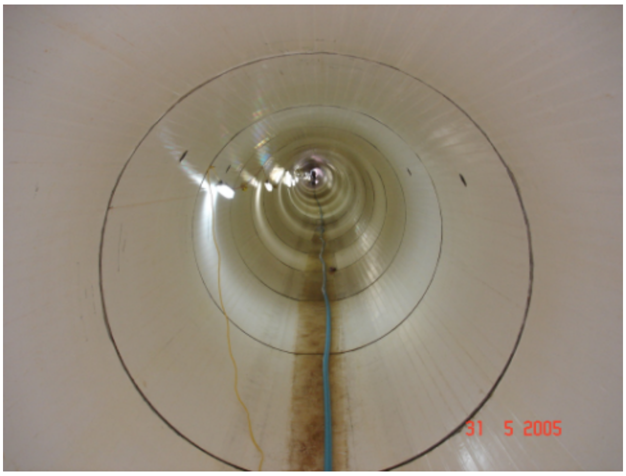
6.2.2 PIPELINE ALIGNMENT

It can be argued that micro tunnelling offers the straightest pipeline installation of any construction method. The pipeline is installed from start to finish with laser guidance permanently placed inside the pipeline during its installation. The laser is typically directed from the jacking shaft to a point and the rear of the micro tunnelling head and the operator knows the position of the laser at all times during pipeline installation. Obviously, it is crucial that the correct grade is set into the laser level when commencing the pipeline drive, and regular periodic survey checks are done during pipe installation - mistakes have been made in the past ending up with a straight pipeline, but installed to the wrong grade!

While it is known that gradually curved drives are feasible with micro tunnelling, they are uncommon and considered to be more difficult than straight drives. As discussed previously, a benefit of micro tunnelling is the ability to install a straight pipeline, and typically between jacking shaft and reception shaft endpoints. Although jacking shafts can be used as the position of bends in the pipeline, ideally the shafts should the minimum number required for the micro tunnelling operation. For economic reasons the same shafts should also be used for placement of permanent access points such as manholes. On the NSCC's Hillcrest A project, a jacked pipeline in the shape of a gradual vertical curve has been successfully completed so as to pass beneath another existing utility.

6.2.3 PIPE MATERIALS

A feature of pipe jack micro tunnelling is the necessity to use rigid pipe units such as reinforced concrete pipes or Polycrete pipes, being a polyester resin with an aggregate and without steel reinforcement. If there are any particular corrosion issues or an extended design life necessary, then the concrete specification for the pipe can be enhanced, or a plastic surface liner can be used. NSCC have commonly used for their wastewater sewers reinforced concrete pipe made using sulphate resistant concrete and having additional internal (sacrificial) concrete thickness to the reinforcement. They have also used Polycrete pipes on one project (Trunk Sewer 4A upgrade) and Ameron PVC T-Lock liner for the Browns Bay Trunk Sewer 7 storage pipeline. PE pipe which is widely used for horizontal directional drilling is not known to be suited to pipe jacking because if its lack of structural rigidity. However concrete pipes can be PE lined internally, again using a T-lock type system. Unlike horizontal directional drilling, micro tunnelling does not necessitate long lengths of pipe to be strung out above ground and therefore permits installation to take place in relatively confined areas.



Photograph 6: PVC T-Lock Liner in Browns Bay 2.1m diameter sewer

6.2.4 SURFACE SETTLEMENT CHARACTERISTICS

Surface settlement predictions should be considered for any micro tunnelling project, particularly if work is to be done beneath roads, in hard-surfaced areas or near and beneath buildings and sensitive structures such as railways and existing services. The outputs of a predicted settlement model analysis will offer the designer information to assess whether the micro tunnelling operations, including effects of overcut or shaft excavations, will impose damage to nearby structures and paved surfaces. The amount of settlement may necessitate the designer moving the pipeline route or shaft positions to be away from vulnerable structures or utilities.

Considering steps to minimise the risk of damage to utilities, buildings and paved surfaces from settlement during shaft existence and pipeline installation by micro tunnelling is imperative during the design and planning stage. Implementing steps to measure and monitor settlement during the construction stage is essential, as is contingency planning.

6.2.5 MACHINERY AND CONTRACTOR LOGISTICS

As noted, the micro tunnelling contractor market in NZ is a niche area, with only a few specialist contractors. Because there are a limited amount of machines available in NZ, the required pipeline diameter is often adjusted to suit the available machinery, or to the diameter that the machinery can be economically modified to suit. The capital cost of micro tunnelling machinery is relatively expensive, and unless the contractor has other machine sizes available, for the scale of projects typically done in NZ it is generally only economic to complete the project using one machine diameter. In comparison, the same scenario does not need to be applied to horizontal directional drilling where one drill rig can install every pipeline diameter within the rig's maximum loading capacity on a given project.

6.3 CONSTRUCTION RISKS AND CHALLENGES

The process of identifying and managing the construction risks starts during the planning and design phase. Every new construction project, including micro tunnelling projects, has its own particular challenges. To date, NSCC has a credible record of successfully completed micro tunnelling projects being to an acceptable quality, within their budgets and completed on time. Close monitoring and management of the projects during construction has been done on the NSCC micro tunnelling projects, and is essential for successful completion.

As noted above, and particularly from the contractor's perspective, it is imperative that the repeated series of steps required to install the pipeline by micro tunnelling are efficiently executed, while continuously managing the risks and challenges.

Particular site challenges include not only the process of installing the pipeline, but appropriately managing the community disturbances such as traffic management and public thoroughfare around the work sites and, particularly in the interests of the contractor and NSCC, achieving realistic progress targets. Below, some construction challenges and risks are covered in more detail.

6.3.1 SITE LAYOUT

An efficient micro tunnelling operation requires work sites to be set out in well organised manner to manage operational matters and environment, health and safety risks. Installation of the pipeline takes place from the jacking shaft site and this is where the operations need to be exceptionally well organised.

Given that jacking sites involve the establishment of a considerable amount of plant, then it is optimal to complete the maximum possible pipeline drive from each jacking shaft. Considerations when planning the location of jacking shaft sites include good site access for trucks to deliver pipes and remove soil, suitable craneage area, keeping a sufficient distance from buildings to minimise settlement, vibration damage or disruption to them, and being sufficiently clear of existing utilities.

The photographs below show the significant amount of plant that exists at a jacking shaft site, highlighting the importance of laying out the site appropriately for efficient operation.

Photographs 7 &8: Jacking shaft site on micro tunnelling project in Browns Bay

6.3.2 CONSTRUCTION PROCESS

It is no surprise that the construction process involves a significant level of risk and number of challenges.

The importance of selecting appropriate plant and skilled personnel is highlighted above. Nonetheless, it is still vital that these resources are closely managed throughout the construction process. Depending on the type of micro tunnelling machinery, and generally where pipeline diameters exceed man entry size, personnel are required to be working underground for lengthy periods during the construction period. The safety risks are therefore significant, but quite manageable should experienced persons and the right equipment be used. In particular, shafts need to be designed and built using appropriately qualified and skilled personnel. Shaft designs are often prepared by specialist geotechnical design firms and then built by the contractor using skilled personnel. To meet NZ safety regulations, and in the case of deep shafts the Mining Regulations call for a qualified Tunnel Manager during deep shaft construction and use. Shafts need to be designed not only to cater for the ground conditions, but also cater for the jacking loads applied on them during pipeline installation.

In relation to the micro tunnelling machinery itself, typical challenges experienced on NSCC projects have included:

- Allowing time for the learnings with new machinery,
- having the right method of soil recovery and water treatment system to cater for the ground conditions,
- fine-tuning the machinery for optimum performance during the soil cutting, soil recovery, soil handling and treatment process and as ground conditions change during the pipeline installation process,
- having sufficient overcut on the machine face to install the pipeline without excessive jacking loads but at the same time avoiding excessive overcut that could result in surface settlement above the pipeline,
- having good laser guidance system. The laser needs to remain clear on the target at the machine during its installation.
- having an appropriate steering that enables the machine operator to correct any deviations to the pipeline alignment as the machine bores its way through the ground,
- having a good forced ventilation system to maintain a safe working atmosphere inside the pipeline. This is a considerable challenge on long pipeline drives and tunnels, and essential for safety of the operation.

The pipe design needs to suit the installation loading requirements and particularly the applied jacking loads. The pipe designer should provide the micro tunnelling contractor with the maximum permissible jacking that can be applied to the pipe associated with such joint deflections so that the pipe is not damaged during installation. It is vital that the jacking loads are appropriately transmitted along the pipeline without imposing uneven loads, particularly at the pipe joints, that could result in pipe rupture or joint damage. It is essential that pipes are manufactured to a good quality, particularly in terms of good dimensional accuracy at the joints to avoid the jacking process from applying uneven load on the joints.

6.3.3 COMMUNITY INTERACTION

As noted above, trenchless construction cannot happen in busy suburban environments without some form of community disruption. During construction of NSCC's wastewater projects under the CARE scheme, communications with the community made during the project planning stage have been followed up at the start of and during the construction process. For each specific project, the community has been kept well informed about the construction activities and programme, and in particular nearby residents are informed about impacts they can expect during the construction work. Based on public feedback to the NSCC and the construction teams during the construction work, it is clear that the local community surrounding each project built to date have appreciated being kept up to date about the construction activities and how long they will take to be completed. Given the significant challenges in the site operations, experience has shown that it is usually best to be somewhat pessimistic when informing the community about expected completion dates of the construction work.

7 OUTCOMES AND SUCCESSES

A wealth of experience has been gained during the wastewater pipeline installations completed by trenchless methods, particularly micro tunnelling, in the North Shore during the past decade. From a micro tunnelling projects perspective, overall the projects have been completed to an outstanding level of quality, including meeting grade tolerances, having minimal surface settlements, and to a level of disruption that has in general been tolerated by the community.

In particular, virtually all of the pipelines installed by micro tunnelling on the Shore are well within the specified grade tolerances and it could be said that they are "rifle bore" straight. The very minor surface settlements, where they have occurred along the pipelines and around shafts at the time of construction, have been within the values estimated during the design stage. In particular, surface settlements around a 20m deep shaft built in clays on the Birkdale Stage A project did not exceed 10mm. Settlement at adjacent residential buildings to the shaft, with the nearest building being 12m from the shaft was 7mm. No damage resulted to the buildings from the construction work.

The methodology used for temporary shaft construction has also been an important aspect in minimising disruption and settlement. Where ground conditions have permitted, some shafts have been built using steel soldier piles with timber wall lagging instead of sheet piles. Use of solder piling has required a minimal amount of vibration and led to a significantly lower amount of resident complaints than where sheet piling has been used.

The significant amount of planning work undertaken including thorough risk identification and management is considered, based on the project successes, to be fruitful.

From consultation undertaken by the NSCC wastewater projects team with the NSCC's political community groups, being the voice of the North Shore public, it is believed that at the early stages of Project CARE the community was gravely concerned about the significant impacts the wastewater construction work would have on them, and in particular to commercial business operations. Given the significant amount of major wastewater projects successfully completed in the past decade on the Shore, it is the authors' perception that the community politicians have been satisfied that disruption during the construction work was managed effectively and they are now more amenable to the impacts of temporary construction work from wastewater projects.

The outcomes and successes, in particular on the micro tunnelling projects, have obviously included reducing wastewater overflows to streams and North Shore beaches. Disturbances from the construction work have not led to any significant or ongoing grievances from the community – to the contrary, the amount of public complaints during micro tunnelling projects have been minimal. The surface settlements by the construction work on micro tunnelling projects has not caused any damage to buildings and has only caused very minor movements to roads which have been rectified by resurfacing in conjunction with the NSCC's road maintenance programme. Furthermore, there have been no breaches of resource consents issued in respect of the NSCC's micro tunnelling projects, no abatement notices served, for example on environmental issues, and to date no significant injury accidents.

8 LESSONS LEARNED AND TAKEN FORWARD

There has been a substantial amount of learnings and lessons over the duration of the NSCC's micro tunnelling projects. They have been carried forward, as they have eventuated, to future Project CARE works. In particular to micro tunnelling projects, the main lessons learned are covered below.

- The need to discuss with the project stakeholders at the outset of the project to enable preparation of the *project risk register*,
- The need to thoroughly *investigate ground conditions* at the project planning stage,

- Good awareness of the micro tunnelling market in NZ, including the *machinery and contractor skill available*,
- The importance of the *procurement method* in obtaining an appropriate trenchless method and contractor,
- Good awareness of an appropriate scope of *community consultation* relevant to the level of the work, the consenting process and the design process to enable the easiest method of consenting,
- *Awareness of construction activity timeframes* including equipment establishment and pipeline installation rates,
- Ability to offer the community and project stakeholders reliable information about the *level of disturbance expected*,
- Ability to determine the feasibility of pipeline route options based on good awareness of *temporary work space requirements*,
- Ability to interpret the geotechnical modelling of *surface settlement predictions*, based on previous settlement data,
- Good understanding of the range of project risks and plan how to manage risks proactively,
- Appreciation of the construction contractors' risks, potential mitigation measures and good understanding of appropriate construction monitoring to assist in project success and claims avoidance.

9 CONCLUSIONS

Success of micro tunnelling in the suburban environment of the North Shore has been a consequence of understanding the problem, thoroughly identifying the scope, risks and challenges, and then continuously managing them until the project goals are met. NSCC's projects completed by micro tunnelling have been highly successful in terms of their installation quality, community disruption level and financial outputs.

The successful delivery of micro tunnelling projects has contributed to the success of Project CARE as a whole.

As the paper title reads, "surgical precision" is not only the pipeline being installed by micro tunnelling to very consistent and accurate grade. It is also the surgical precision of the method by which the NSCC wastewater projects team have identified the scope of their projects, risks and challenges, and then appropriately managing them throughout the projects' duration.

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REFERENCES

NSCC Project CARE data: obtained from NSCC and Sinclair Knight Merz – Opus' records.