THE LONGEST SINGLE PIPE INSTALLATION IN NEW ZEALAND USING HDD

D. Londer, L Thien Yet
Sinclair Knight Merz, North Shore City Council, Auckland, New Zealand

ABSTRACT

Ever increasing development within the catchment pushed the existing trunk sewer servicing Birkdale beyond its capacity, resulting in severe overflows during wet weather conditions.

The preliminary design was based on a combination of micro-tunnelling and open cut, where the micro tunnel section was to follow the road reserve at depths of up to 17 metres and the open cut section was to follow the original trunk sewer route along a walking track surrounded by native bush.

A review of the proposed installation methodology considering latest advances in technology and the capability of local contractors resulted in the identification of an alternative alignment previously believed to be un-constructible.

The opportunity to install a gravity sewer utilising long distance (960m) directional drilling was identified after reviewing the potential alignment and its geology as well as equipment available to penetrate rock varying from soft to very hard at flat gradients at depths of up to 32 metres.

Long distance directional drilling is used around the world to install infrastructure but mainly in applications where grade is less of a concern, such as pressurised systems. The Birkdale trunk sewer has to achieve 1.2% grade over nearly half of the installation distance Therefore a key consideration was appropriate risk mitigation, through the design and procurement process as well as on site.

This paper covers the general technological aspects of directional drilling and the specific aspects relating to Birkdale C including procurement strategy and lessons learned.

KEYWORDS

Horizontal directional drilling, HDD, trenchless pipe installation, long distance drilling

1 INTRODUCTION

As part of Project CARE, North Shore City Council's initiative to improve beach water quality and minimise wet weather sewer overflows onto beaches the council decided to duplicate the existing trunk sewer servicing the Birkdale catchment. The existing system which was constructed in the mid Sixties had deteriorated significantly over the years and is severely under capacity, resulting in frequent sewage overflows.

This required the design and installation of approximately 3.5 km of new pipeline ranging in size between 450mm and 1050mm internal diameter.

Due to the length of the proposed sewer and the complexity of the work the upgrade was split into three areas, each being constructed as separate construction contracts. The implementation of "Birkdale Area C" or "Upper Catchment" is the subject of this paper.

In order to minimise the construction impact, trenchless technologies were favoured from the beginning of the design process, with micro tunnelling being the initially favoured methodology because of the flat gradients.

After reviewing latest advances and successes in the directional drilling industry an alternative alignment was considered, utilising a "Maxi Drill" to install the entire pipe in one single drill.

Installing a pipe over a continuous length of 960 metres has never been undertaken in New Zealand but has been carried out overseas, where pipes in excess of 2 kilometres have been installed.

2 HORIZONTAL DIRECTIONAL DRILLING

Horizontal Directional Drilling (HDD) is a trenchless installation technique that relies on four phases to install a pipe, although Phase 3 and 4 may be carried out at the same time.

Phase 1 – Establishing the ground profile and determining possible areas of interference

Prior to the drilling, a ground survey is carried out to establish ground levels along the proposed drill alignment, which in turn is used to work out drill depths at known points (the drill plan).

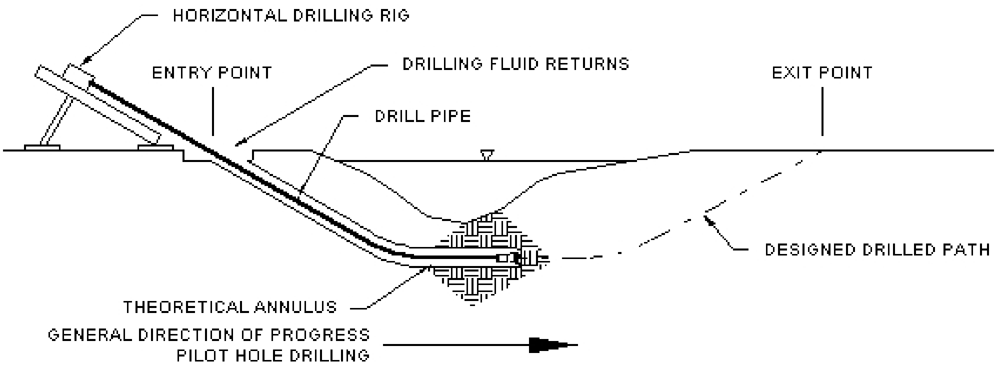
Once the drill plan is completed the alignment is "pegged out" and a walkover survey is carried out with the drill head locating equipment (if a walkover system is used) to determine possible areas of interference to the locating equipment. Any area of interference needs to be recorded prior to commencement to avoid potential mistakes during the pilot drill.

Phase 2 – The Pilot Drill

Once the drilling machine is set up, a small diameter hole is drilled following a pre-determined drill plan.

The drill head, which is connected to the drilling machine via drill rods, sends a signal to the locating unit via a sonde. The sonde transfers three pieces of information to the locating equipment: the pitch, the roll and the depth of the drill head. This information is used to determine the current location of the drill head and is also used to steer the drill head to the next target point. The drilled material is transported out using a drill fluid.

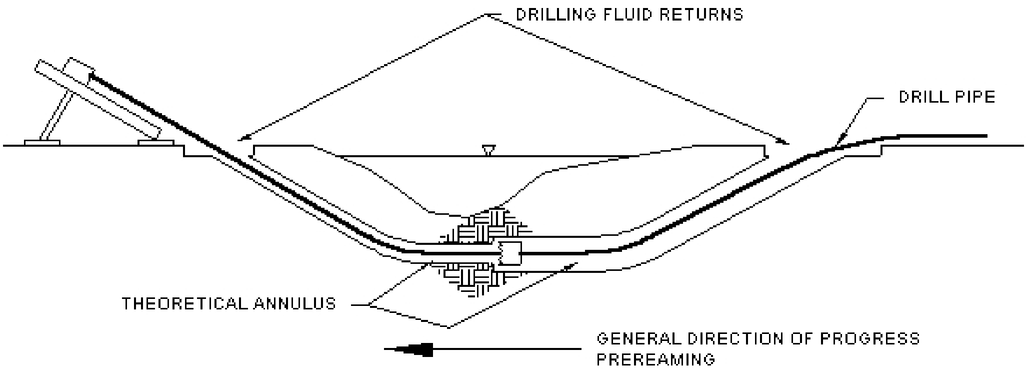
Figure 1: HDD pilot drill (Courtesy of J.D. Hair & Associates Inc)



Phase 3 – Back Reaming

With the pilot drill successfully completed a "reamer" is attached to the drill string and pulled back to the drilling rig to enlarge the pilot hole. This process may be carried out several times in order to achieve the required size hole. The final size reamed hole is in general 1.25 to 1.5 times the diameter of the pipe to be installed.

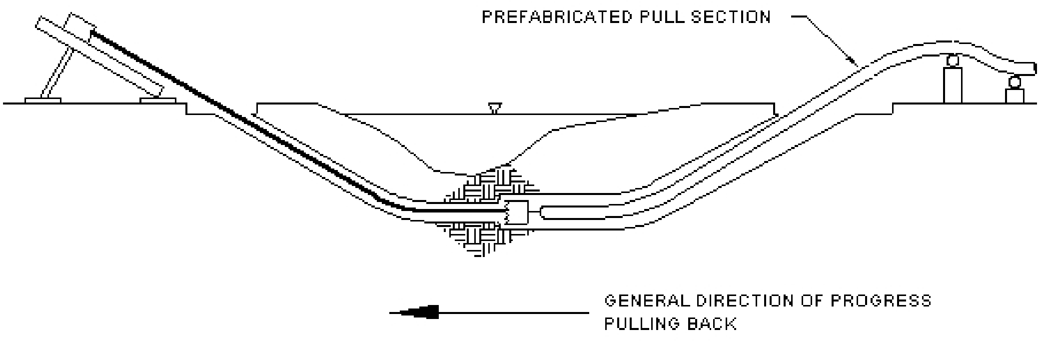
Figure 2: HDD back reaming (Courtesy of J.D. Hair & Associates Inc)



Phase 4 – Pipe Installation

Once the hole is the required size the pipe is attached to the drill rod and pulled into the ground in a continuous operation. A reamer may be attached to the drill string in front of the pipe in case sections of the hole have collapsed.

Figure 3: HDD pipe installation (Courtesy of J.D. Hair & Associates Inc)



2.1 LOCATING SYSTEMS

In most cases a **walkover system** is used, as it is very cost effective and user friendly. In order to establish the depth of the drill head and its location, a hand held device is used above ground to pick up the signal sent by the sonde located in the drill head. The downside of walk over systems is their limitation to pick up signals at greater depth, the decrease in accuracy with depth and the potential interference from power cables, steel structures, reinforcement, salt water etc.

Wire line systems are similar to walkover systems but have a cable inside the drill stem connecting the sonde with the drilling machine. The pitch and the roll of the drill head are transmitted via the cable to the drilling machine regardless of the drill depth but the depth and location of the drill head are still determined from the surface. Where the drill depth exceeds the capability of the locating equipment the drilling is solely based on a drill plan. This technology is used for long and deep bores. This system is more costly and requires highly trained staff.

Steering tools are adapted from use in the oil field. The data from the drill head is either transferred via the drill stem or a cable and in this case all data is transferred to the drilling machine, not requiring a walkover system at all. Steering tools are very accurate but due to their cost and the need of highly skilled personnel, the operator and the equipment are generally hired specifically for the duration of a contract.

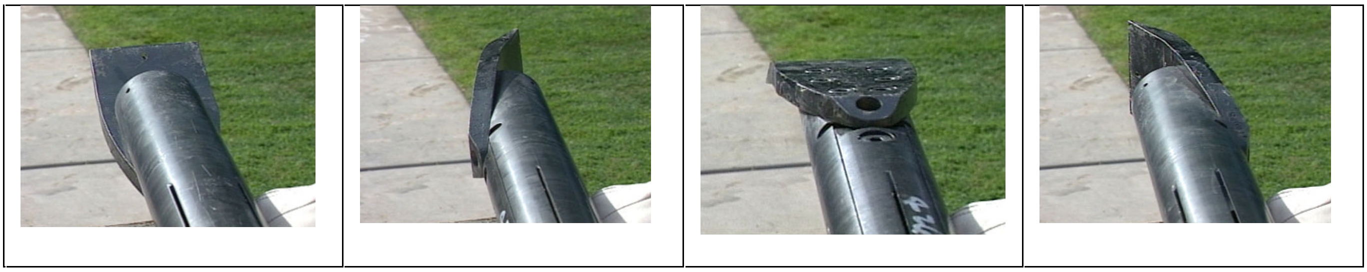
(www.jackson-creek.com/soil-remediation/remediation/chapter04)

2.2 DRILL HEADS

Drill heads come in many sizes, shapes and styles and depending on ground conditions different drill heads are used. The drill head is used for steering as well as forming the pilot hole. Some commonly used drill heads are described below:

The **Duckbill** is used in soil and has an angular steel plate welded to the drill head. The steel plate is used to steer the drill head as well as to cut the soil. In order to cut the soil the drill rod is rotated and at the same time pushed forward. If a change in direction is required the angular plate is turned to 3, 6, 9 or 12 o'clock (or any location in between) and then the rod pushed forward.

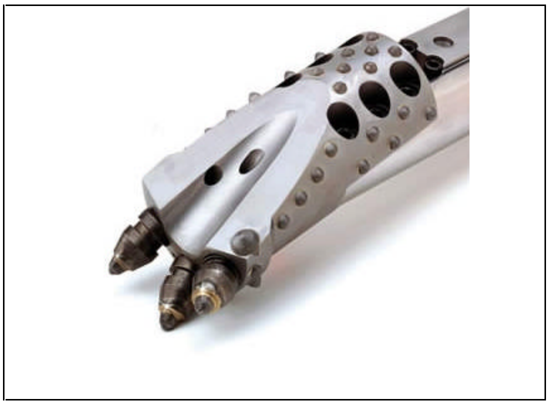
Photograph 1: The Duckbill (Courtesy of Pipeworks)



12 o'clock (up) | 3 o'clock (right) | 6 o'clock (down) | 9 o'clock (left)

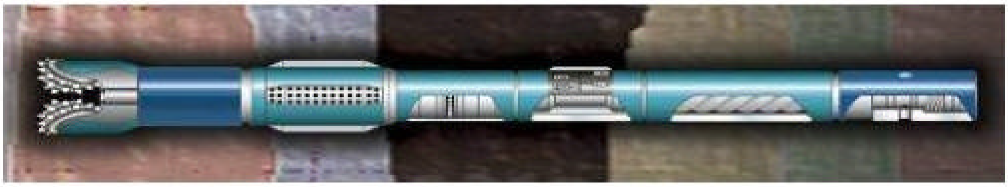
The **Railhead** operates in a similar way to the Duckbill. Sections of the steel plate have been replaced by cutting teeth in order to grind out rock. Steering in rock is achieved in the same way as described above although the drill head may be partially rotated (wiggle steering), chipping out the rock. Once the desired change in direction is achieved the drill head is turned and pushed, maintaining the new alignment. Changes in direction can only be achieved very gradually.

Photograph 2: The Railhead (Courtesy of Railhead Underground Products)



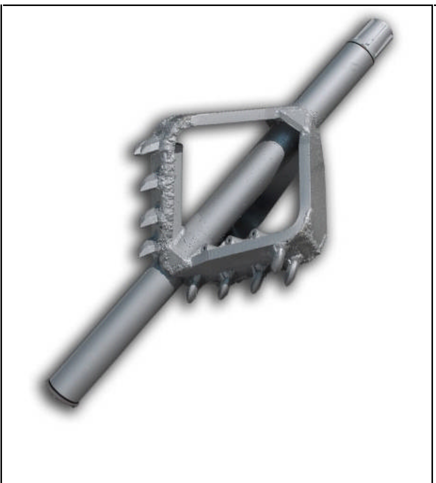
The **Mud Motor** operates very differently. The head is actually a motor that rotates a cutting bit or tri-cone and is powered by the drill fluid being forced through it. Steering with a mud motor requires a "bent sub" between the mud motor and the drill stem. It is the positioning of the bend in the sub that determines the direction that the head travels. Mud motors require large amounts of drill fluid as the fluid is not only used to cool the head, transport the cuttings and maintain the hole open, it is also required to rotate the cutting bit. (www.jackson-creek.com/soil-remediation/remediation/chapter01)

Photograph 3: The Mud Motor (Courtesy of Kalsi Engineering)

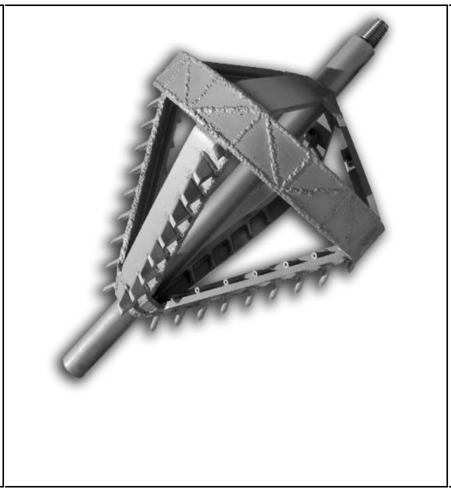


2.3 BACK REAMERS

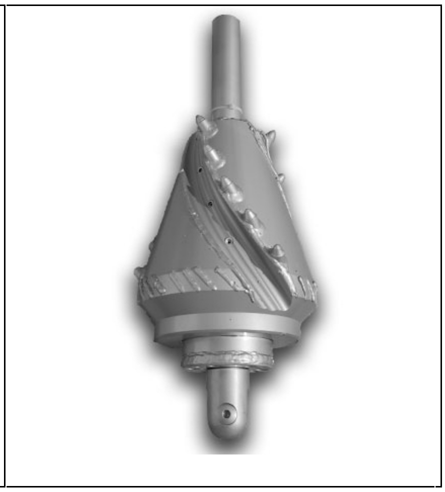
Photograph 4: Back reamer samples (Courtesy of Universal Horizontal Directional Drilling)



Blade reamer



Ring cutter



Fluted reamer

One function of a back reamer is to enlarge the bore hole sufficiently to allow for the installation of the required pipe. However, the mixing ability of the back reamer is equally important. During the back-reaming process, the main objective is to mix the cuttings from the back reamer with the drilling fluid to create a slurry that can be displaced to the side of, or discharged out of, the bore hole during the pipe installation. (www.jackson-creek.com/soil-remediation/remediation/chapter01)

2.4 THE DRILL FLUID

The major base component of any drilling fluid is water and there are numerous products on the market that can be added to the water to enhance the drilling fluids performance. Which additives to use will largely be dictated by the ground conditions encountered.

A drilling fluid should provide cooling for the drill head and the sonde, lubrication of the drill rod and the pipe being installed. It suspends the cuttings and flushes them out of the hole but also retains the drilling fluid in the hole without having it infiltrating the surrounding ground.

Bentonite is widely used as a drilling additive. When bentonite is added to water, it breaks up into microscopic disk-shaped particles. When used while drilling, the platelets have a shingling effect and form a filter cake on the sidewalls of the hole. It is this filter cake that helps prevent the fluid from escaping into the surrounding ground of the bore. Bentonite also helps to suspend cuttings in the hole.

Polymers are also widely used in drilling fluids for two specific reasons. First, polymers are attracted to clay, and when introduced into the soil, they will wrap themselves around the individual clay particles. This slows down the clay particle's ability to absorb fluid, which in turn reduces the clay's ability to swell and become sticky. The second main function of the polymer is to provide lubrication in the bore hole which reduces friction on the drill rod and on the pipe being installed.

Non foaming detergent is a further substance used as an additive in drilling fluid. It leaves a thin film on the drill rod which helps prevent sticky clays from attaching to the drill rod.

(www.jackson-creek.com/soil-remediation/remediation/chapter03)

The mud mix for a drill shot may change several times due to changes in ground conditions and using the right mud mix is vital for the drilling and the pipe installation.

2.5 DRILL ACCURACY

A pipe installed using directional drilling is unlikely to be perfectly straight. The best result that can be achieved is a pipe installed without dips. This is due to the sonde being located behind the drill head, hence only transmitting a position behind the drill head rather than the position of the drill head. In general measurements are taken every drill rod length, which could be every 3 to 10 metres, depending on the length of the rod. The information submitted is the depth of the sonde as well as the pitch (inclination) and the roll (rotational position of the drill head).

When drilling at depths exceeding the walkover system's capacity, the location of the drill head is determined by measuring its location in terms of magnetic north. To avoid interference the drill head may be fabricated from non magnetic steel or non magnetic rods are installed between the drill head and the sonde. The further the drill head is away from the sonde the greater is the inaccuracy.

Other factors such as changes in the ground material, soft or hard spots in the soil and the rotation duration of the drill rod will also impact on the pilot drill accuracy.

Despite all of the above, gravity pipelines have been successfully installed (possibly with only minor under-verticals) using Duckbill or Railhead drill heads to grades as flat as 0.4%.

Accuracies with a mud motor are far less and mud motors should only be used for pipe grades greater than 2.5% or when a straight alignment is of lesser importance. This is again due to the location of the sonde in relation to the drill head, which is further back when compared with other drill heads.

3 PROJECT SPECIFIC INFORMATION

3.1 THE PROCUREMENT STRATEGY

The implementation of the Birkdale contract was fast-tracked from 6 to 4 years to keep an imposed development moratorium on the catchment as short as possible. A procurement strategy was implemented to secure competent contractors in a buoyant market, reduce construction issues by ensuring contractor's input during detailed design and consenting, and to encourage investment into new equipment where required.

A review of the market capability identified two contractors within New Zealand with equipment capable of undertaking a long directional drill shot as well as the potential for a small number of contractors to align themselves with overseas partners to boost their capabilities.

With such a small number of suitable contractors available it was decided to directly approach selected contractors to participate in the design and tendering process and confirm availability of key staff and plant as part of the process.

As part of the procurement strategy a risk table and associated mitigation options was established, as outlined in Table 1.

Table 1: Procurement Risks and Mitigation

Risk	Mitigation
Drilling machine used at other project	Early contractor involvement. Early tendering to secure drilling machine. Build sufficient float into construction programme.
Drilling machine arrives late from overseas	Early tendering to secure drilling machine. Build sufficient float into construction programme.
Different drilling machine capabilities and construction methodologies	Early contractor involvement. Develop detailed construction methodologies.
Contractor capability partly dependant on operator availability	Early contractor involvement to secure interest. Contract requirement to identify key personal. Key personal part of tender evaluation.
Pipe may not be available on time	Early tendering. Consider early purchase of pipe.
Delays due to consenting issues	Develop construction methodologies with each contractor. Consenting process to run parallel with procurement process.

3.2 THE TENDER PROCESS

Three specialist contractors were short listed to tender for the Birkdale C contract; each of them proposed different methodologies, having varying track records and intending to use drill machines which varied widely in sizes.

In order to assess the risks and costs associated with the individual proposals the tender evaluation was carried out generally following the Price Quality Method Special used by the New Zealand Transport Agency (NZTA) which requires an explicit assessment and valuation of risk. In concept it is similar to the Weighted Attributes method but converts the non price attribute scores to equivalent dollar amounts, rather than converting the tender price to a numerical score. This enabled North Shore City Council (NSCC) to include performance risks associated with the three different contractor's methodologies and equipment in the tender assessment.

Contractors were assessed for a number of explicit criteria.

Table 2: NZTA guidance for the scoring of non-price attributes

Range of Scores (points out of 100)	Achievement	Definition	Other Descriptors
90, 95 or 100	Excellent	Only awarded when all requirements are met in an outstanding manner.	Extremely Related, Superlative, Significantly within Budget, Consistently Ahead of Deadline, Directly Applicable.
75,80 or 85	Good	Where requirements are fully covered in all material aspects.	Very Related, Exceeds Requirements, Well Within Budget, Frequently Ahead of Deadline, Very Related.
60, 65 or 70	Above Average	Where requirements are adequately covered.	Particularly Related, Requirements Fully Met, Within Budget, Occasionally Exceeds.
50 or 55	Average	Adequate with some deficiencies which are not likely to have any adverse effect.	Related, Acceptable, On Budget, On Time, Meets Requirements.
40 or 45	Below Average	Barely adequate and would need minor improvement if selected.	Barely Related, Needs Improvement, Exceeds Budget, Misses Deadline, Adequate.
35 or less	Poor	Generally unacceptable and ruled out of further consideration.	Not Related, Unsatisfactory, Significantly Exceeds Budget, Frequently Misses Deadline, Barely Adequate

In addition to the price and non price attributes (NPA), a list of project risks was prepared and a worst-case-scenario cost assigned to each risk. The sum of these costs is the Maximum Risk Consequence (MRC), which represents the potential savings and benefits that a "perfect" contractor with a NPA score of 100 would deliver. Alternatively it represents the cost a completely incompetent contractor would face encountering every risk.

The NPA score is then used to establish the Supplier Quality Premium (SQP), a sum which is deducted from the tender sum of the higher scoring contractor, to represent an additional quality premium the Client would be prepared to pay to reduce risks.

SQP = MRC x NPA score difference/100 (1)

Table 3 below gives an example of how the SQP is applied.

Table 3: Example assuming an MRC of $3M

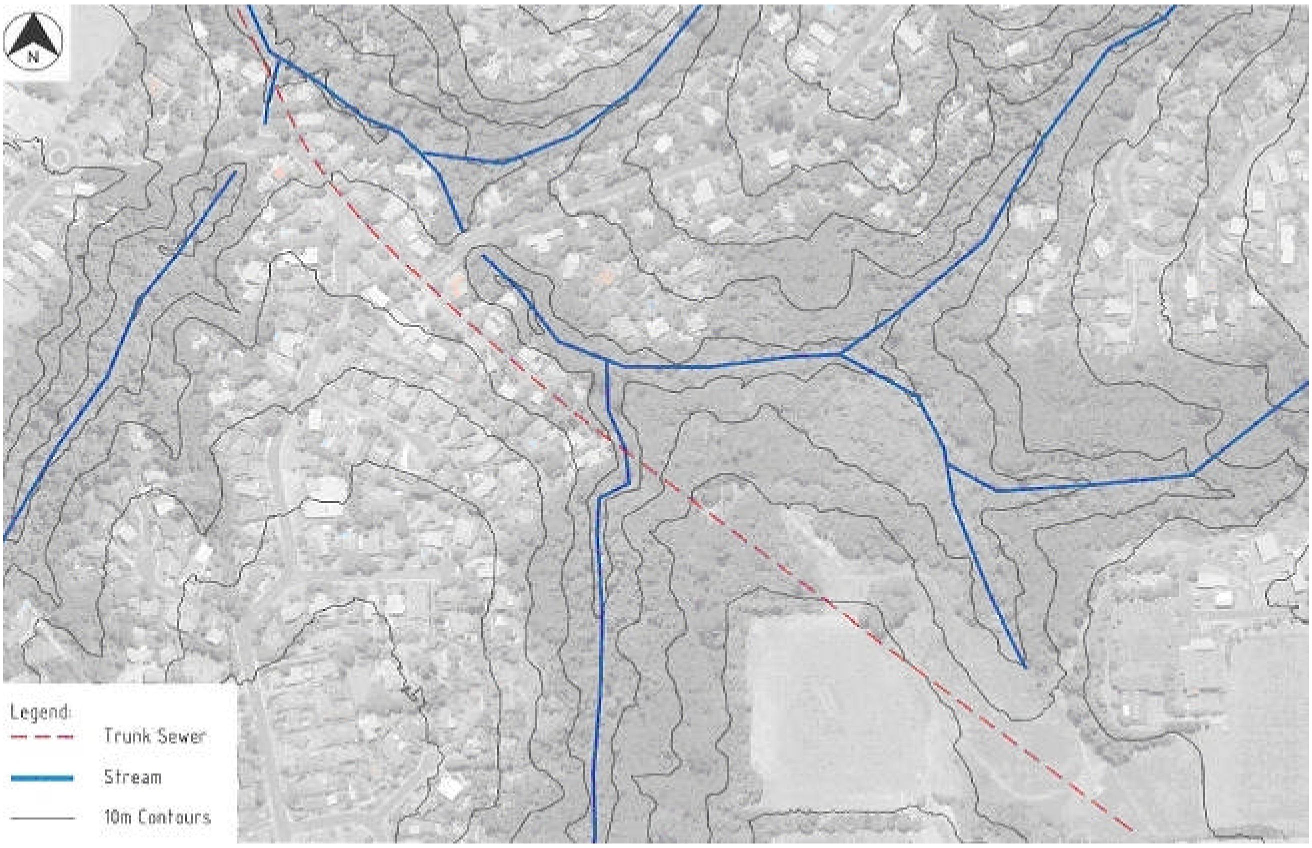
	Contractor A	**Contractor B**	**Contractor C**
Tender price	$3.5M	$3.2M	$4.1M
NPA	96	84	80
SQP	-$480K	-$120K	-$0
Total	$3.02M	$3.08M	$4.1M

Contractor A would be the final preferred tenderer.

3.3 BIRKDALE C CONTRACT DETAILS

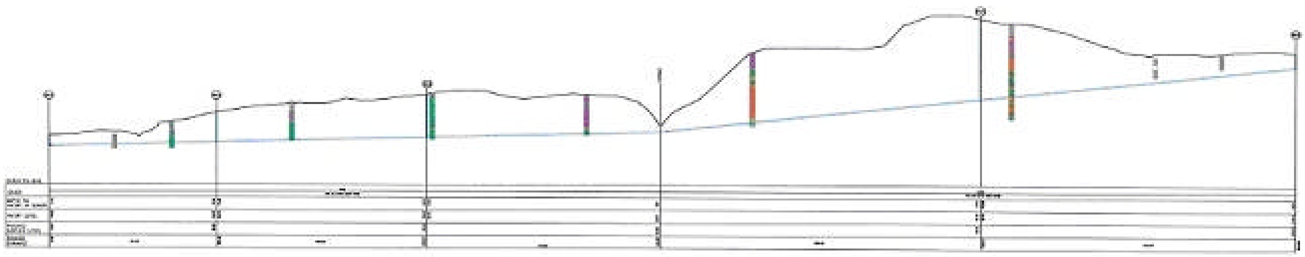
The Birkdale C catchment is characterized by large areas of native bush in the upper half and residential housing along the lower half, with both areas being incised by streams which have formed deep valleys.

Figure 4: Catchment layout with trunk sewer alignment



Keeping the construction impact to a minimum it was decided to install the new trunk sewer in one single drill.

Figure 5: Trunk sewer long section



The new trunk sewer is 960 metres in length and has an internal diameter of 450mm. The pipe material used was PE100 SDR 11.

The pipe grade ranges between 1.2% along the lower section and 5.3% along the upper section, with pipe installation depths of up to 32 metres.

In order to gain maintenance access to the trunk sewer and to cross connect sub-catchments three manholes (being between 13 and 32 metres in depth) form part of the scheme.

3.4 THE DRILLING MACHINE

In 2008 Smythe Contractors purchased their latest and New Zealand's biggest directional drilling machine, an American Auger DD 440T, with a 200t pullback capacity and 30t rotational torque.

DD 440T's have been used overseas to install large pipes up to 2000 metres in length.

Photograph 5: DD 440T delivered to site (Courtesy of Smythe Contractors)

3.5 THE LOCATING SYSTEM

As mentioned earlier the drill depths at Birkdale C are up to 32 metres with nearly 60% of the pipe being deeper than 15 metres.

Smythe Contractors used the DigiTrak Eclipse SST computerised steering system to drill the pilot hole. This Wire Line system utilizes an induced current down a wire through the drill stem to steer the drill head. A walkover system is required to establish the drill depth and the drill head location.

The system records and displays the compass heading, depth, lateral deviation, pitch, roll and temperature at real time on a remote display.

As a first step the drill alignment is set out by a surveyor on site and ground levels are established at set intervals. These ground levels are then used to prepare a bore plan where for each surveyed reference point the Yaw (location of the transmitter in terms of the earths magnetic north) and the Pitch is determined.

Once the drilling machine is set up and the SST transmitter installed its reading is checked against the required offset to magnetic north and once correct the drilling can commence.

(DigiTrak Eclipse SST Guidance System Operator's Manual 2008)

The drilling is carried out based on the bore plan and where possible (due to shallow depths) the depth and location is verified with an above ground receiver. Corrections to the Yaw or the Pitch are carried out at set intervals.

Photograph 6: SST components (Courtesy of DigiTrak)

Left- walkover system; middle – bore plan, right – remote display, below - sonde

3.6 THE DRILL HEADS

The geotechnical investigation carried out prior to the design start identified that the majority of the proposed pipe alignment would be within silt and sandstone of the East Coast Bays Formation. Rock samples were tested for their Unconfined Compressive Strength (UCS) and results varied between 2.1 and 5.9 MPa except for one sample which exceeded the testing equipments breaking capacity of 18 MPa. This was not unexpected as during previous construction work within the Birkdale Catchment rock lenses were found exceeding 40 MPa.

Based on the geotechnical investigation Smythe Contractors decided to use a combination of Railhead and Tri-cone to carry out the pilot drill. They had successfully used these types of drill heads before in rock where flat pipe grades were required. Any rock lenses that could not be penetrated with the proposed drill heads would be drilled using an air hammer.

The drill heads are built from non magnetic steel and connected to the drill stem via a non magnetic rod. The drill sonde is installed directly behind the drill head in a non magnetic housing, with the housing creating a gap of between the sonde and the first steel rod to prevent interference.

Photograph 7: Drill heads used for the pilot drill (Courtesy of Smythe Contractors)

3.7 THE BACK REAMER

Back reaming had not commenced by the time this paper was submitted. Additional information will be provided at the paper's presentation.

3.8 PIPE WELDING AND INSTALLATION

Welding a 630mm OD SDR 11 PE pipe into a 960m continuous pipe string is a major undertaking which needs careful planning. In this case several pipe strings had to be pre-welded and finally joined together during the pipe pulling phase due to space limitations.

Items that were considered for the Birkdale C project include:

a) The original methodology was to weld 5 pipe strings of up to 200 metres in length and join them together during the pipe pulling operation using fusion couplers. This methodology was abandoned as fusion couplers are designed to withstand internal pressure and not longitudinal pulling forces. In addition fusion couplers would reduce the available cross sectional area of the pipe installation hole, which may increase the risk of the pipe getting stuck.

b) As fusion couplers could not be used to join individual pipe strings the welding methodology changed to welding a 200 metre lead pipe and several 45 metre pipe strings which were connected to the lead pipe one by one as the pipe pulling progressed. Having to limit the subsequent pipe strings to 45 metres was due to the limited pulling capacity of the welding machine.

c) The pipe pulling will be carried out as a continuous operation. Depending on the pipe length this may take several days and nights.

d) Moving the pipe from the welding area to the installation site required the removal of trees.

e) When pulling the pipe overland the minimal pipe bending radius was considered so as not to cause structural damage to the pipe. Anchor structures were required in order to facilitate moving the pipe along the required path.

4 PROBLEMS ENCOUNTERED AND LESSONS LEARNED

4.1 SPACE REQUIREMENTS

The DD 440T is 15 metres long, 2.5 metres wide and weighs 45t. In addition to the large footprint of the drilling machine space was required for mud pumps, drill fluid mixing and storage units, mud recycling units, storage and mud drying ponds.

Mud storage facilities are required at each end of the drill shot and they were sized to deal with up to four times the volume of material to be removed from the drill hole (estimated 1300 m3 in this project).

Drill fluid volumes as well as mud volumes need to be established early to ensure sufficient space is available and required consents are applied for.

A detailed work plan considering space requirements for plant, machinery and storage facilities as well as material movements and potential mud pumping requirements needs to be established.

4.2 INTERFERENCE WITH THE DRILL SONDE

To achieve flat pipe gradients, Duckbill or Railhead type drilling heads are required. These drill heads are commonly and successfully used on small drilling machines (up to 50t pulling capacity) for short pipe lengths.

"Maxi Drills" are commonly deployed for long drills and large pipes where pipe grades are of lesser importance, enabling the use of mud motors.

The Birkdale C Project is a combination of the above resulting in the use of prototype drill heads. All of the drill heads used on this project to date caused interference with the sonde, affecting the accuracy of the pilot drill. The reasons for the interference are still being determined.

Whilst the sonde interference caused deviations from the horizontal and vertical alignments, re-drilling of the alignment was not required. In addition there was the option to utilise the proven accuracy of a smaller drilling machine for the pilot drill process if necessary whilst keeping the superior power of the DD 440T for the back-reaming and the pipe installation process.

4.3 PIPE WELDING AND INSTALLATION

Due to the nature of trenchless work the contractor faces many risks and tends to focus more on the drilling operation. However attention must also be given to issues such as the pipe welding and the space requirements for dealing with the mud. This is particularly important when using large drilling machines and installing large diameter pipes over long distances.

The following issues needed to be addressed early during the contract, preferably prior to consenting, to avoid unnecessary delays and additional cost:

- Location of the pipe welding area.
- Removal of trees due to the pipe welding.
- The pulling capacity of the welding machine and the maximum pipe string length when producing more then one pipe string.
- Time that it takes to connect the individual pipe strings.
- Night work consent due to noise.
- Pipe pulling radius and anchor structures required to guide the pipe towards the installation hole.
- Mud volume created during the pipe pulling and how it will be transported to the storage facility.
- The size and location of the required mud storage facilities.
- The drill fluid volume required to lubricate the pipe during the installation.
- The capacity of the drill fluid pump, drill fluid mixing unit and the mud recycling unit.
- The space requirements to efficiently treat the solids produced by the mud recycling unit.

5 CONCLUSIONS

In summary, there are a number of issues that need to be addressed in installing long pipes using HDD.

The benefits of involving contractors in the design phase of a project to improve constructability and clarify consenting needs.

The Price Quality Method Special is an effective tool to assess high risk construction contracts as it enables the Client to reward innovative methodology, good performance and superior equipment.

HDD is an effective mechanism to install large diameter pipes over long distances on grade, as long as ground conditions are favourable and sufficient space is available to set-up the equipment required.

Drill fluids have a multitude of functions and it is vital for the success of a HDD contract that ground conditions are assessed at regular intervals and drill fluids adjusted whenever required.

The employment of a “Mud Engineer” should be considered where difficult ground conditions are encountered.

Vast quantities of drill mud are produced during the pilot drill, back-ream and the pipe installation phases. Mud has to be stored, transported and treated and this has to be assessed in detail.

Sonde interference problems need to be resolved to drill long distances at flat grades. This was addressed at Birkdale C by having an option to utilise the proven accuracy of a smaller drilling machine for the pilot drill process if necessary whilst keeping the superior power of the DD 440T for the back-reaming and the pipe installation process.

In general it will be difficult to find space to weld long sections of pipe in urban areas. The time, noise and consenting implications associated with the jointing and pulling of long sections of pipe need to be assessed early in the project.

Increasing the pulling capacity of welding machines would drastically decrease the pipe installation time, which would lessen disruption and reduce costs associated with consenting, noise reduction measures and consultation.

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