THERE'S A LIGHT AT THE END OF THE TUNNEL!

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ABSTRACT

Project CARE is North Shore City Council's strategic wastewater improvement project being implemented in a densely populated, urban environment, with iconic beaches and reserves and amenity much valued by the residents. There are many challenges affecting the implementation of this ambitious improvement project which necessitate an innovative approach to problem solving. A Principal Consultancy of SKM with subconsultants Opus was established at the beginning of 2000, to assist in implementing Project CARE. The project team is involved in various major capital projects arising from Project CARE, enabling an efficient, consistent approach to works, along with continuous learning and associated improvements for the ten years of the project life so far.

North Shore City Council has always considered holistic costs and impacts when installing new trunk sewers; with ease of consents, level of community disruption, effect on trees, all factoring into the installation methodologies chosen. A significant amount of the works undertaken in developed areas is installed using trenchless technologies. This reduces disruption and environmental damage. The risks associated with directional drilling and micro-tunnelling technologies are well understood, but opportunities continue to be identified.

A project has recently been completed to install a new trunk sewer in the Birkdale catchment of the North Shore to address capacity issues in the existing line, and to allow for future development and population growth in the catchment. The project was separated into three stages for ease of buildability – the lower section of large pipe on flat grade was installed by micro-tunnelling, and is the subject of another paper. The middle section was originally planned to be installed by directional drilling, and the upper section by a combination of micro-tunnelling and open cut.

At design stage for the upper section, a review of the proposed installation methodology, latest advances in technology and the capability of local contractors resulted in the identification of an alternative alignment previously believed to be un-constructable because of plant limitations. The new alignment required installing a gravity sewer utilising long distance (960m) directional drilling through rock varying from soft to very hard at flat gradients at depths of up to 32 metres.

NSCC, as client, decided to embrace new (to New Zealand) technology and equipment to install the trunk sewer, once the potential improvement in system performance, potential cost savings and reduction in disruption and environmental damage were identified.

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, something many directional drilling contractors struggle to achieve on even short distances. A paper was presented at the conference last year on key risk mitigation, through the design and procurement process and early lessons learnt on site. However, the use of such innovative technologies will always bring challenges.

This paper will cover the differences between 'standard' directional drilling projects for gravity sewers and long distance directional drilling that have been encountered. It will identify specific technological aspects of long distance directional drilling, such as steering technology, which were used on the project, plus the outcomes of NZ's longest on-grade pipe drill, and the lessons learnt.

KEYWORDS

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

1 INTRODUCTION

Project CARE is North Shore City Council's strategic wastewater improvement project to reduce sewage overflows and improve stream and beach water quality. During the implementation of this major initiative, North Shore City Council has embraced many new technologies and encouraged innovative thinking and solutions, setting many examples for other local authorities to follow.

SKM as the Principal Consultant with OPUS as sub-consultant have been involved in Project CARE since early 2000 and during this period have designed and implemented 3 storage tanks varying in size between 4.0 and 6.5 mega litres, designed and installed 16 km of trunk sewers using various trenchless technologies, upgraded Torbay tunnel (a strategic trunk sewer installed in a narrow tunnel), future proofed many pump stations as well as provided planning and design input for upgrades of the local sewer network.

One of the latest catchments being upgraded as part of Project CARE is the Birkdale catchment. The existing system, which was constructed in the mid sixties, had deteriorated significantly over the years and is severely under capacity as a result of population expansion, resulting in extremely frequent sewage overflows.

Picture 1: Overflowing manhole at Birkdale C

The upgrade required the design and installation of approximately 3.5 km of new pipeline ranging in size between 450mm and 1050mm internal diameter. The quantum of existing overflows led the Council to implement a development moratorium until the new sewer was installed, which in turn led to a commitment by the project team to deliver the project in 4 years, fast tracked from 6 years.

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.

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 tortuous walking track surrounded by native bush.

A review of the proposed installation methodology considering latest advances in technology resulted in the identification of an alternative alignment previously believed to be un-constructable. In addition, this new alignment reduced estimated construction cost by $1M, and reduced some considerable consenting constraints, giving better certainty of delivery as well as good value for money.

Using a "Maxi" Horizontal Directional Drilling rig to install a pipe over a continuous length of 960 metres up to 32m deep and at "flat" grades has never been undertaken in New Zealand and is a challenge even considering world standards.

2 TRENCHLESS TECHNOLOGIES

Conventional trench excavation (open cut) can be quite disruptive and invasive, and is depth limited. There are significant advantages in using the various trenchless technology processes available.

A brief description of the various trenchless technologies and their attributes follows.

2.1 HORIZONTAL DIRECTIONAL DRILLING (HDD)

A pilot hole is drilled between two pit locations. The drilling system incorporates a steerable head, remotely controlled, to ensure that horizontal and vertical tolerances are met. The line need not be straight and often is deliberately curved.

A back reamer is fitted to the drill string and the pilot hole enlarged sufficiently to accommodate the final pipe with an "overcut" allowance. It may be necessary to make more than one pass at backreaming. The pipe is then attached to the backreamer and pulled through the enlarged hole. The pilot and backreamed hole are supported by slurry, which also lubricates the pipe as it is pulled into position.

On completion of the pipe installation, the annulus between the excavated hole and the pipe is filled with grout.

A disadvantage is that unintentional dips can often occur in flat grades. A major advantage is the long lengths that can be installed in a single pull.

A variation to HDD could be termed "Long Distance Directional Drilling (LDDD)". The significant differences are covered in more detail later on.

2.2 MICRO TUNNELLING/PIPE JACKING

Pipes are fitted behind a tunnel boring machine (TBM) and driven through the ground by hydraulic rams. Excavation of the face is carried out by the tunnelling head and spoil is removed by slurry pumping, conveyor or auger.

Applied force is distributed between the tunnelling head and the last pipe in the pipe string.

The micro tunnelling head is equipped with individual steering jacks for directional control. The annulus around the pipe may be lubricated to reduce frictional loads. Intermediate jacking stations may be introduced to reduce jacking loads and thereby increase the range.

The key advantage of micro tunnelling is that vary flat grades can be achieved very accurately. However this comes at a significant cost uplift.

Installation lengths of up to 240m are feasible for pipe diameters 900mm or less. For larger pipe sizes (>900mm) much longer lengths are possible.

Pipe jacking is a simplified form of micro tunnelling, where again pipes are driven through the ground by hydraulic rams. However excavation is generally carried out by hand. There is no pilot hole.

The lead pipe may be fitted with a sharp edged cutting shield offering limited steering capabilities.

Typically manual pipe jacking is used for installation lengths of up to 50 and perhaps 100m.

2.3 PIPE BURSTING/REAMING

The systems mentioned above are used to install a pipeline along a new alignment, Pipe Bursting/Reaming on the other hand installs a new line along the alignment of an old pipe by breaking it out.

In order to install a new line along the alignment of an old the old pipe is broken, cut or reamed out by an oversized tool which is either self propelled or pulled thru the original pipe using steel cables or rods. The “enlargement tool” is immediately followed by the new pipe.

By using different types of “enlargement tools” virtually any pipe material can be replace/upgraded. With this method pipes can be upsized by as much as 100% but it is typically limited to one or at most 2 nominal pipe sizes.

2.4 SLIP LINING

With slip lining a new pipe is installed inside an existing pipe but without destroying the existing pipe.

The new pipe is either pushed or pulled into the ground and is either a continuous section of pipe or made of segments.

Slip lining is always associated with a cross sectional loss and grouting of the annulus may be required.

2.5 CURED IN PLACE – SPIRAL WOUND – FOLD AND FORM SYSTEMS

These are all trenchless renovation technologies where a fully or semi structural liner is installed inside an existing pipe.

The new pipe material is inserted into the existing pipe and inflated/wound into position and cured/locked into place.

A cross sectional loss is associated with all of these systems but grouting is in general not required.

2.6 CONCLUSION

There are many trenchless construction options available but only a few will be suitable for a specific task. One of the major challenges to designers and construction companies alike is to select the option that will give the best outcome at the best possible price.

3 THE HDD PROCESS

HDD has been used in New Zealand for several decades and the process and associated risks are in general well understood. Despite the long history there are only a few companies in the market who are capable of installing larger pipe systems on grade and over reasonable distances.

This section gives a brief overview of the standard HDD process which is further on compared to the LDDD used in the Birkdale C contract in the next part of this paper.

Setting up and calibration

As a first step the pipe alignment is marked out and a detailed ground survey carried out to establish a drill profile or drill plan defining direction, inclination and depth along the entire planned alignment. Once this is achieved the drill rig can be aligned and the steering tool guidance system calibrated. Some guidance systems use magnetic north to steer along the required alignment and where possible verify the drill head location with a walkover system. When using these systems walking the full alignment to establish potential areas of interference with the steering/locating tool is vital and any areas of interference should be recorded to avoid potential mistakes during the pilot drill.

The pilot drill

With the pilot drill a small diameter hole is established along the pre-determined drill plan. Note, the pilot drill is the only phase where the location of the drill head is known or can be monitored and therefore steering can be undertaken. During reaming and the subsequent pipe pull, the work will in general follow the pilot drill alignment, hence it is vital to get this right.

Steering

The drill head is connected with the drilling machine via drill rods. A signal is sent from the drill head to the drilling machine and/or a locating device, identifying the pitch and roll of the drill head. The locating device can also establish the depth of the drill head as long as the drill head is not too deep in the ground. 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 drill fluid

A major component of the drill fluid is water but other materials such as bentonite, polymers or non foaming detergents are added to aid the drilling process.

The drilling fluid has to be very versatile as it provides cooling for the drill head and sonde, and lubrication for the drill rod and pipe, suspends cuttings and flushes them from the drill hole typically; it also functions to support the drill hole and prevent the drill fluid from infiltrating the surrounding ground.

Drill fluid compositions may change several times during a drill process and may strongly influence success or failure.

The back reaming process

Once the pilot drill is successfully completed a “reamer” is attached to the drill string and pulled back to the drill rig to enlarge the hole. This process may be carried out several times in order to achieve the required hole size. The final sized hole may be up to 1.5 times the diameter of the pipe to be installed.

Pipe welding

In general a continuous string of pipe is pulled into the finished reamed hole. PE is the most common pipe material and the standard way of joining the individual sections of pipe is by welding. A successful weld will provide a joint which is close to equal strength to the pipe material.

The pipe pull

It is not uncommon in small size directional drill that a pipe is damaged during the pipe pull due to the pulling forces exceeding the tensile yield strength of the pipe. On the other hand many pipes have become stuck when the pipe weight and the drag on the pipe exceeded the pulling capacity of the drilling machine. Considering the pipe pull as a design case when sizing the pipe, using drilling machines with sufficient spare pulling capacity, using appropriate drill fluids and assessing the advantages and disadvantages of pulling a pipe open or closed ended are just a few measures to ensure a successful pipe installation.

4 LONG DISTANCE DIRECTION DRILLING (LDDD)

4.1 LDDD USED TO CONSTRUCT BIRKDALE C

In 2006 the preliminary design on Birkdale C started and at this stage HDD was commonly used in New Zealand to install services over relative short distances and gradients well exceeding 1%. HDD was therefore not seen at the time as a practical option for Birkdale C with its complex terrain, flat pipe grade and installation depths, so other construction techniques were focused on. Birkdale C was split into two areas, a section where the pipe would be installed deep and at flat grade using micro-tunneling and a section of shallow depth at varying pipe grades using open cut.

It was foreseen that the proposed micro-tunnel and open cut solution would cause major disruption along the road alignment, would have to cross underneath buildings and would result in the loss of hundreds of native trees along an environmentally sensitive area, but this was accepted as being at that stage, the “best” environmental and cost effective solution.

In late 2007, after many discussions with New Zealand’s leading HDD contractors, an alternative option using LDDD was identified. This alternative option required the construction of a 960m long trunk sewer in a single drill operation, something never attempted in New Zealand.

Carrying out the installation in a single drill operation would reduce the disruption to road users, the environment and the general public and concentrate the disturbance to two isolated areas, as well as offer significant construction cost savings, although the gradient had to be closely monitored.

The new option was to install a 450mm internal diameter pipe, 960m long at grades of 1.2% along the lower half and 5.3% along the upper half, in one go. The installation depth varied between 6 and 32 metres, and included the construction of 3 deep manholes (13, 17 and 32m deep).

4.2 STEERING SYSTEMS

Services installed by HDD are generally installed at shallow depths (1 to 6m) and over short distances (50 to 200m). For these installations walkover system are used to cross-check the location and the depth of the drilling head.

Just behind the drilling head a battery powered sonde is located which transmits the rotation and angle of the drill head to a handheld device. Using the signal transmitted from the sonde the handheld device can also calculate the depth of the sonde. This information is continuously used to calculate how to steer to the next target point.

When drilling at depths where a walkover system is no longer viable, due to the limitation of the handheld device to detect the signal transmitted by the sonde, alternative systems such as “Wire Line Systems” or “Steering Tools” are required. These alternative systems are very costly and require very experienced operators in order to give the required result. “Steering Tools” have not been used in this project and are not further referenced in this paper.

At the Birkdale C project two different “Wire Line Systems” were used to complete the task.

4.2.1 THE SST GUIDANCE SYSTEM

The SST wire line guidance system utilizes an induced current down a wire through the drill stem to supply the sonde with power but also to transfer data from the sonde to the drill operator. The system records and displays the compass heading, depth, lateral deviation, pitch, roll and temperature at real time on a remote display.

The horizontal alignment is achieved by drilling towards an offset to magnetic north. Utilizing magnetic north for the steering requires that only non magnetic parts are used close to the sonde. Therefore the drill head, the sonde housing and a minimum 3m long transition piece to the steel drill rods must be non magnetic. The SST system is therefore vulnerable in areas with magnetic interference. (DigiTrak Eclipse SST Guidance System Operators Manual)

4.2.2 THE PARATRACK II GUIDANCE SYSTEM

The Paratrack II is also a wire line guidance system. It uses sensors installed close to the drill head to detect an artificial magnetic field produced by a magnetic source installed on the surface. The drill head transfers the detected data to a computer where the location of the sonde is calculated and displayed on the driller’s display screen.

The horizontal alignment, location, as well as the depth is calculated using the magnetic field produced by a guide wire (AC or DC), a beacon (AC) or a rotating magnet (AC). Using an AC magnetic field is particularly advantageous in areas with magnetic interference. (http://www.prime-horizontal.com/paratrack2.htm)

4.3 THE PILOT DRILL AND DRILL HEADS USED

When drilling short distances at shallow depths drill heads such as the “Duckbill” for soil and the “Railhead” for rock are used.

The drill head is connected to the drilling machine via steel drill rods and the rotation as well as the thrust of the drill head is applied by the drilling machine. The strain on the drill rods can be excessive when drilling long distances as the drill head is turned from several hundred metres away. The steering also becomes difficult as the drill rod at the drilling machine may have to complete several turns in order to achieve any rotation at the drill head.

Picture 2 (left): The Duckbill (Courtesy of Pipeworks)

Picture 3 (right): The Railhead (Courtesy of Railhead Underground Products)

To overcome the steering problems and the strain on the drill rods when drilling long distances "mud motors" are generally used. The mud motor is installed immediately behind the drill tool. The main difference between a standard drill head and a mud motor is that the fluid pumped through the drill stem and circulated through the motor generates the rotation effect to turn the drill head, ie the rotation of the drill head is not initiated by the drilling machine, hence the strain on the drill rods is largely reduced. In order to steer with a mud motor a "bent sub" is installed between the bottom-most drill collar and a mud motor. A "bent sub" is a short cylindrical device which deflects the drill head off vertical to drill a directional hole.

Picture 4: The Mud Motor (Courtesy of Kalsi Engineering)

A disadvantage of mud motors is their accuracy limitation in terms of grade. Until recently the recommendation was to use mud motors only on grades > 2.5% to avoid dips.

Having to achieve a grade of 1.2% over half of the drill alignment, the Contractor decided against the use of a mud motor. Instead they initially used a "Railhead" specifically manufactured for the Birkdale C Project. This was subsequently replaced with a "Tri-cone" drill head. The Tri-cone drill head used has a similar layout to a mud motor drill head, with the exception that the drill cones are not turned by the drill fluid.

Picture 5: Drill heads used for the pilot drill (Courtesy of Smythe Contractors)

4.4 SPACE REQUIREMENTS

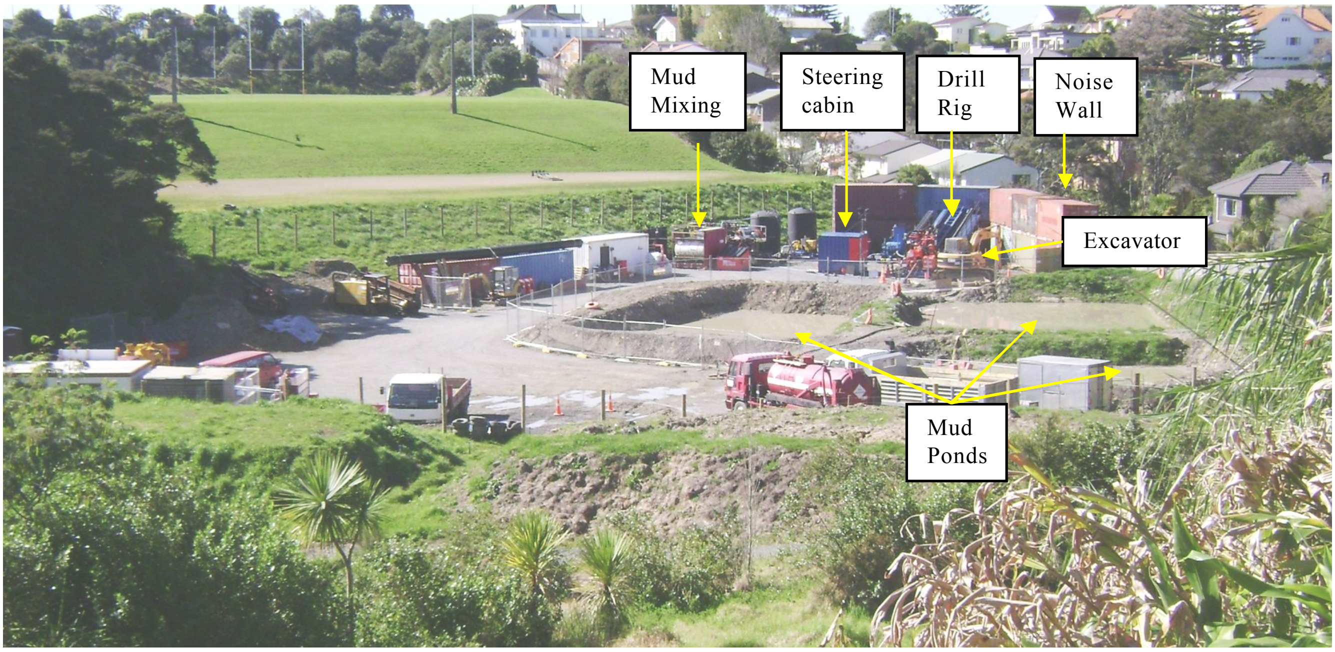
4.4.1 THE DRILL SITE

Standard drilling machines are the size of a medium car or smaller and can easily be set up in most areas. A rod box forms part of the drilling machine and the loading of the drill rods is automated. Drill mud is mixed on a trailer mounted unit and drill fluid volumes can mostly be controlled by small to medium sized sucker trucks or portable pumps.

The "Maxi Rig" used at Birkdale C is approximately 15m long and 2.5m wide and weighs 40t. In order to operate the drilling machine following equipment is also required:

- A digger to load and unload the 10m long and approximately 125mm diameter drill rods.
- A mud mixing unit to supply the drilling rig with drill fluid.
- Storage tanks to cater for up to 1000 l of drill fluid per minute.
- A recycling unit that separates the soil particles from the drill fluid.
- A mud pump to feed the drill fluid into the drilling machine (max drill mud pressure is 103 bar).
- Sucker trucks and pumps transporting the drill mud from the downstream collection points to the mud recycling unit.
- And in the case of Birkdale C several ponds to store the drill mud prior to the recycling.

Picture 6: The drill site



Space requirements can be reduced by using mud storage containers over mud ponds and by using mud mixing and treatment facilities that are adequately sized to cater for the requirements of a large drill rig but even then space requirements are onerous and need careful consideration.

4.4.2 THE PIPE WELDING/PIPE PULL

One of the activities causing disruption when using HDD is the pipe welding/pipe pull, even for short distances. In order to utilize HDD a continuous pipe string is required, which is normally pulled into place in a continuous operation. For LDDD the challenge of enough lay-out space is considerable.

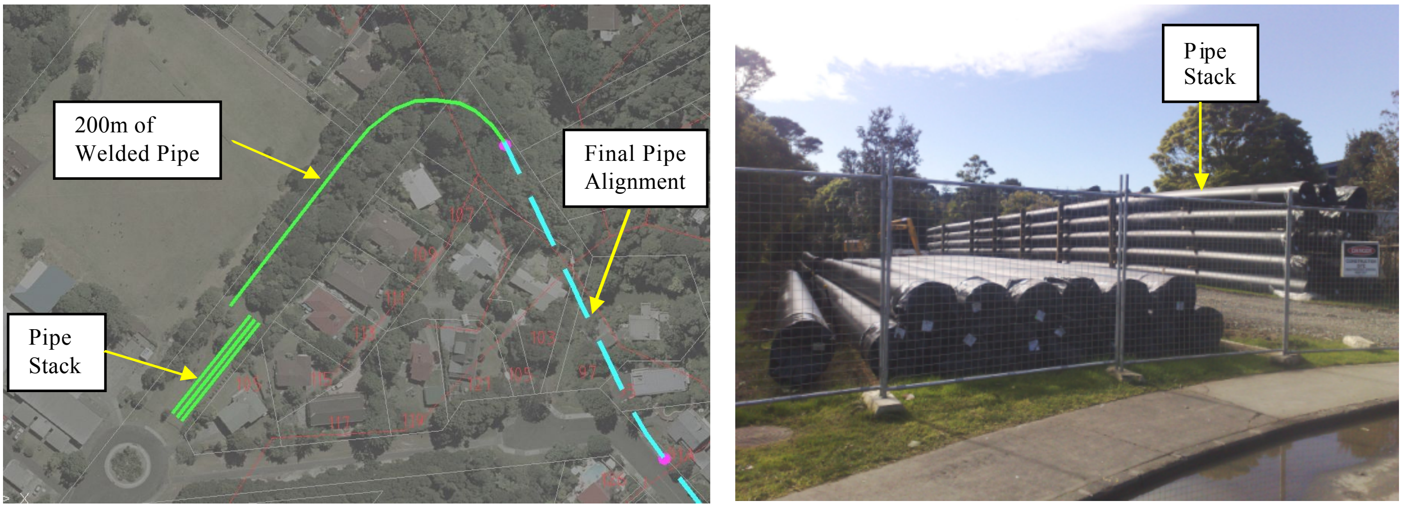
The pipe welding

Welding sections of pipe together is a time consuming operation and when using PE pipes, the most commonly used pipe material for HDD, set parameters are followed to achieve a successful weld. In some cases parks or green fields can be used to form the pipe string but many times the welding has to be carried out in the road reserve, blocking access to and from properties for several days.

For the Birkdale C contract a 560mm outside diameter pipe had to be welded into a 960m long string in order to be inserted into the pre-reamed hole. Being in an urban setting a 960m long pipe string would have caused major disruption to countless properties and road users for many weeks and had to be discounted.

After assessing many options the contractor decided to weld a single 200m long pipe section along a walking track perpendicular to the pipe alignment. The remainder of the pipe was welded into 45m long pipe sections and stored in a pipe stack. The 45m sections of pipe would progressively be welded onto the already installed pipe during the pipe installation. Each pipe weld taking approximately 1.5 hours.

Picture 7 & 8: Pipe welding area and pipe stack



The pipe pull

Pipe pulling durations are highly dependant on the pipe diameter, pipe length, soil conditions, etc but in general for typical HDD a pipe pull is carried out as a continuous operation over a period of a few hours.

The LDDD pipe pull operation for the Birkdale C project was initially also proposed as a single operation, taking up to 4 days, 24 hours a day, as overnight delays would introduce risk of “freezing”, i.e. not being able to move the pipe in the morning.

The long duration was due to the fact that after pulling 45m of pipe a new section of pipe had to welded onto the already installed pipe, with the welding taking up to 1.5 hours per weld.

With the district plan limiting noise levels to 55 dB or less between 8pm and 6:30am noise consent was applied for to enable the continuous pipe pull.

During the back-reaming operation the Contractor experimented with a new drill fluid additive, a material that would keep the drill cuttings in suspension for long periods of time and revert from a gel to a fluid state with little energy input, even after long rest periods. This new additive reduced the risk of “freezing” exceptionally well and the Contractor changed the pipe pull methodology to pulling during the day only.

In the end it took 7 days to pull 960m of pipe, stopping every hour to weld on a new 45m section of pipe.

The maximum pull force applied was 60t, which is astonishing considering that the pipe itself weighs around 75t and was pulled uphill, covering a height difference of 31m.

4.5 THE DRILL MUD

As mentioned earlier, the drill fluid has several functions and is vital for any HDD or LDDD operation. When mixing the drill fluid with the cuttings drill mud is produced.

For small diameter pipes at short to medium installation distances the volume of drill mud to deal with is often too small to warrant recycling of the drill mud. The drill mud may simply be collected using sucker trucks and taken off site.

The drill mud volumes of the Birkdale C project were of a scale that simply carting the material off site was commercially not viable, hence most of the drill mud was recycled and re-used.

Space limitations at the downstream end forced the contractor to drill the pilot drill from the top, some 31m above the downstream end ground level. Needing to force the drill mud back to the upstream end and if at all possible avoiding a mud "frac out" along the alignment, the Contractor decided to keep the drill mud as light as possible by pumping up to 1000 l of mud per minute into the pilot hole. The drill mud returns were stored in ponds next to the drilling machine prior to being "cleaned" of the drill cuttings and recycled. Drilling the pilot hole took an average of 63 minutes per 10 metres and requiring large amounts of drill fluid.

The back-reaming was carried out from the bottom to the top, with all drilling mud flowing to the downstream end. The expectation was to capture the drill mud in a pond constructed at the downstream end and transport it with tankers or sucker trucks to the recycling unit and drilling machine 1 km away. Soft ground towards the downstream end closed off the 800mm diameter reamed hole and forced the drill mud into the nearest manhole already built during the pilot drill operation. Initially this was thought to be problematic due to the depth of the manhole (13m) but in the end removing the drill mud from the manhole proved to be faster and less disruptive than using the pond constructed in the reserve at the downstream end.

4.6 GROUNDWATER INGRESS

When drilling at shallow depth and short distances groundwater is in general not an issue and can largely be ignored.

Deep and long distance drills on the other hand need to consider the possibility of groundwater ingress as well as quantities very carefully, as the groundwater may impact on the drill fluids ability to suspend and transport the drill cuttings, increase the volume of mud to be recycled, required more additives when mixing new drill mud, increase disposal costs and delay the work.

There can be many sources of groundwater ingress and they will be difficult to predict. Areas of particular concern are fractured rock and when drilling through interfaces between rock and soil. Whilst LDDD does not alter the ground permeability risks, longer drill lengths will leave larger open faces through which water can flow.

4.7 FRAC OUTS

Micro tunneling surface effects are generally related to settlement, whereas HDD and LDDD surface effects are mainly related to ground heave or mud eruptions.

When directional drilling, drill fluid is pumped via the drill rods to the drill head. The drill fluid is used to help with the cutting of the drill face, transport material to the surface, support the drill hole etc. When the pressure of the drill fluid/mud exceeds the overburden of the soil or the friction losses along an alternative flow path, an uncontrolled mud eruption or "frac out" occurs. Frac outs may occur at any stage of the drill operation.

As a rule of thumb, as soon as the return mud flow reduces or seizes completely the drill operation has to stop and the cause be investigated. In a best case scenario drill mud may surface in an area with easy access for a clean up, in a worst case scenario major damage to buildings and/or landslides may occur.

Frac outs may be controlled by introducing pressure relief holes at set intervals and these can easily be constructed when the drilling at shallow depths.

Nearly 90% of the drill alignment at the Birkdale C contract exceeded 10m in depth and while ground heave was not anticipated to be a problem, the risk of frac out remained.

Discharge of large amounts of mud in hard-to-access areas on the other hand was considered as very likely. Due to the depth of the alignment it was not considered feasible to introduce pressure relief holes and therefore the strategy to deal with a frac out was to create containment areas at strategic sections and to rely on sealing agents to rapidly stop any leaks.

4.8 NOISE

Trenchless technologies such as HDD are in general thought of as being low impact construction solutions.

This is certainly the case for the areas between the drilling machine and the pipe entrance point where often affected parties are not even aware of any activity. It is also the case for short distance drilling where the duration of the work at any given point is reasonably short.

At the Birkdale C contract we faced two very different challenges when it came to construction noise. Property owners along large portions of the alignment complained about lack of visible progress as neither noise nor vibration impacted on their daily routines. A very different picture on the other hand emerged at the drill site, the deep manholes and the mud collection points where construction noises were concentrated for many months.

Picture 9 (left): The drilling site

The worst affected area was the drill site, where it took 10 months to complete the pilot drill, the back-ream and the pipe installation. During this period the drilling rig and its support equipment was virtually in continuous operation and the installation of a noise barrier was vital. The placing of the barrier was determined by a combination of monitoring and modeling of effects in relation to topography and land use.

Picture 10 (right): The manhole construction

Three manholes were built as part of the contract varying in depth between 13 and 32m. The contractor decided to build the manholes from the top down by first boring a hole and then progressively inserting and suspending the manhole rings from the top down until they were in position. Once in position they were grouted into place and the suspending frame removed. After this the rock at the manhole base was broken out and the base slab, wall and benching formed.

The drilling and riser installation was completed in less than 2 weeks but required cranes capable of carrying loads up to 200t. Breaking out the rock at invert and forming the manhole base on the other hand took months, which impacted heavily on the residents.

Picture 11 (left): Mud removal from manhole

As mentioned earlier, uncontrolled mud discharge may occur anywhere and at any time and measures dealing with an uncontrolled mud break out (in our case potentially up to 1000 l/min) may in a worst case scenario have to be put in place for the majority of the drill and the pipe installation phase. Sucker trucks or pumps and tankers are standard solutions.

5 LESSONS LEARNED

There are some specific differences between HDD and LDDD which need to be considered to ensure a successful project outcome.

5.1 THE STEERING SYSTEM

Relying on a system that uses earth magnetic north to steer the horizontal alignment, such as the SST System, is only advisable when a secondary verification system can be used (such as a walkover system). This is applicable when drilling from a relative shallow (max 8m deep) start section to a relative shallow end section. These shallow sections need to be long enough in order to enable the alignment to be corrected using the walkover system, should this be required. Drilling deep over long distances without having verification points every 200m is not advisable.

Another of the issues using earth magnetic north is that earth magnetic north readings differ even over short distances (hundreds of metres). Problematic is the vast number of sources that cause magnetic interference such as power cables, vehicles (the bigger the vehicle the bigger the interference), metal structures above and below ground and reinforced concrete structures such as manholes. For example; a bus passing deflects a compass by several degrees!

Using a system that creates its own AC magnetic field such as the Paratrack II has on the other hand proven very successful during this project where areas causing tremendous problems to the SST system could be accurately steered through.

Which ever steering system is used in the end it needs to be noted that highly experienced operators are a must to guarantee success as steering remains very much an “art” rather than a science.

5.2 DRILL HEADS FOR DRILLING IN ROCK

The “Railhead” proved unsuccessful at the Birkdale C project as pushing the three cutting teeth into the rock whilst rotating the drill rod resulted in large rotational forces on the drill rods, even only a few hundred metres away from the drilling machine. Despite giving good steering ability the Contractor decided that the risk of breaking a drill rod was too great. Therefore the drill head was changed to a “Tri-cone”.

The “Tri-cone” with its 3 drill heads covered with small cutting teeth was far less responsive to directional changes but did not pose the same risk due to torque as the “Railhead”. The difficulty with the “Tri-cone” was to find the right angle on the “bent sub” in order to achieve the required grade and alignment without compromising accuracy. The setting on the bend sub was such that along the lower section of the pilot drill only the alignment could be achieved but the grade was compromised.

A mud motor was not used as part of this project as all indications were that the pipe grade of 1.2% would not be able to be achieved. Since the start of the Birkdale C project shortened mud motor assemblies have been successfully in Australia and New Zealand achieving even flatter grades.

5.3 SPACE REQUIREMENTS

As mentioned earlier, welding a 960m continuous section of pipe is next to impossible in an urban setting.

This problem was successfully overcome with innovative thinking on the Contractor's behalf, although the real answer to this problem lies in the welding equipment. A welding machine with pulling power capable of pulling the weight of several hundred metres of large diameter pipe will reduce installation times considerably.

As displayed in Picture 8 the pipe was aligned on a sharp angle towards the insertion hole due to space restrictions and in order to be pulled into the ground. Trees flanked the pipe along the entire alignment and steel ropes with rollers attached to ground anchors were used to guide the pipe and prevent any damage. It was surprising how easily this heavy wall PE pipe was able to be pulled around an apparently tight corner, causing next to no strain on the support structures.

5.4 FRAC OUTS

Drilling long distances, deep and in varying soil types will limit the opportunities to preempt frac outs. The following points should be considered during the design and discussed in detail with tenderers during the tender stage:

- Stream crossing are likely problem areas as the ground cover will most likely be at its minimum but more importantly as experienced at Birkdale C the soil even metres below the stream bed may be extremely soft, in our case closing off even a 800mm diameter reamed hole. As a result the drill fluid/mud never managed to get past this obstruction and had to be removed in an alternative location.
- Fractures in the rock can lead to mud discharge in multiple locations some distance away and they may not be able to be sealed off. Drilling relief holes may be the only temporary solution, which emphasizes the need to keep the pipe alignment (where possible) in accessible areas.
- When approaching a potential discharge area contingency measures need to be in place to deal with a mud frac out. This will avoid lengthy delays and extra cost due to machinery, plant and labour standby time.
- The tender specification should identify all areas where frac outs are expected and the client should request detailed contingency measures covering these areas. General contingency measures should be established for the remaining areas and the Contractor and Client should establish before tenders are accepted how often these measures are expected to be implemented.

5.5 NOISE

Using trenchless technologies to install a pipeline has in general little impact on the traffic, the public and the environment considering the overall picture but has a very high localized impact and this impact increases with the length of pipe being able to be installed in one piece.

In terms of Birkdale C the entire pipe installation process was carried out from the upstream end, concentrating the majority of the construction noise in one area for a continuous period of 10 months.

Although noise mitigation measures were implemented to stay within the noise levels permitted under the district plan the impact on the residents was significant and additional mitigation measures could have been included in the contract to further reduce the impact.

Mitigation measures also need to be established for frac out areas, as work in these areas may have to continue until the pipe is installed, which could take several months. Catering for these events is particularly difficult as an uncontrolled mud discharge may occur almost anywhere.

6 CONCLUSIONS

NSCC as an innovative Council has taken a lead in trialing the new technology, because of the potential benefits to ratepayers, local residents and the environment. It has successfully utilized trenchless technologies for many years, particularly in waste water implementations through Project CARE, but also in stormwater; standard HDD is part of "business as usual" for the Council, and the project team was well placed to understand and manage the additional risks of LDDD.

The main difference between a standard HDD operation and LDDD is that any problem encountered has the potential to become a major and costly issue. This puts far greater emphasis on identifying potential problem areas during the design, discussing construction methodologies and risk mitigation options with contractors prior to tendering, and including specific scheduled items in the contract documents that deal with potential problem areas to encourage proactive thinking by the Tenderers.

The SST steering system remains a very cost effective solution when drilling at depths where a secondary system (walkover system) can be used at appropriate intervals to cross check the location and depth of the drill head. When drilling deep and having to intercept structures such as manholes with the alignment or meet close grade tolerances, other steering systems such as the Paratrak II are recommended. Whatever steering system is used, highly experienced operators are a must.

In rock a Railhead type drill head may create excessive rotational forces on the drill string when drilling a long distance away from the drill rig and its application should be considered very carefully. Using a mud motor for long distance drills in rock reduces the risk of drill rod failure dramatically and recent successful applications of mud motors for drilling flat gradients have made it a strong contender for drilling services to grade at even below 1% grade.

When considering space requirements two key areas need focusing on; *the drilling site* with all the equipment and machinery required to keep the drill operation going, and the *pipe welding and pipe pull site* where long lengths of pipe need to be prepared and stored for the pipe pull.

There are two options dealing with a mud frac out; either sealing the escape route or capturing the mud and transporting it to a treatment or disposal facility. Sealing a frac out is often not possible, which only leaves the capture and transport option. In every case contingency methods for capture and transport should be developed at tender stage. A frac out at any particular spot could be a problem for months (on and off) and it is therefore important that potential frac out areas are identified during the design phase and a detailed methodology on how to deal with frac out is requested as part of the tender assessment.

Noise is a major issue, as it is focused on a few areas for long durations. Specifically identifying noise minimization measures for plant and equipment as well as requesting detailed noise shielding proposals at tender stage is advisable. Noise mitigation measures should also be established for the eventuality of a mud frac out, while they can happen anywhere the noise impact could be significant and cannot be disregarded.

Choosing the right contractor, with a good understanding of risks and a proactive approach to problem solving will help enormously towards managing site problems. Having had the largest drilling rig in New Zealand available to carry out the task of the most difficult directional drilling operation this country has seen to date has reduced risks substantially particularly in relation to reaming and pulling such long pipe lengths.

Although the project had a learning curve, the pipeline was installed successfully, with very little disruption to most residents. It is likely that these types of installations will become more standard across New Zealand and Australia, increasing the range of options available to pipeline infrastructure providers.

ACKNOWLEDGMENT

North Shore City Council

Smythe Contractors

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