ARMY BAY WWTP OUTFALL PROJECT – RECORD BREAKING INNOVATION

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ABSTRACT (500 WORDS MAXIMUM)

The Army Bay Wastewater Treatment Plant (WWTP) and Outfall Pipeline service the peninsula of Whangaparaoa, North of Auckland and the surrounding Orewa Region. Similar to other parts of Auckland, this region has experienced extensive growth and the existing aging pipe was starting to struggle with the flows. To manage current and enable future growth Watercare required a new outfall within the Shakespear Regional Park (SRP) – a sanctuary for native species surrounded by a large pest-proof perimeter fence and sea, across Watercare and New Zealand Defence Force (NZDF) land.

The challenge was to install the new outfall with minimal impact on the local flora and fauna, which included newly released Kiwis, and accommodate an NZDF training facility, which included live-firing ranges located between the treatment plant and the outfall location.

Watercare Services Ltd awarded the contract to McConnell Dowell Constructors Ltd based on a proposal to utilise an innovate tunneling technique called Direct Pipe®. The Direct Pipe® method was developed by Herrenknecht in 2007, and had never before been used in the Southern Hemisphere before. On completion, the team set a world-record for the longest Direct Pipe® drive at 1,929 m, surpassing the previous record of 1,495 m set in Texas, US in 2017

In addition to the challenge of learning to operate a new machine and push it to new boundaries, the construction team had to install over 900m of 800mm High Density Polyethylene Pipe (HDPE) pipe in the fast flowing Tiritiri Maitangi channel, retrieve the Direct Pipe® machine from its seabed breakthrough point and slip line 1,929m of 1,100mm HDPE pipe in single push.

This paper outlines the trials that the Watercare Services Ltd and McConnell Dowell Constructors Ltd team overcame to successfully complete this high-risk project with no injuries, within the Watercare budget and on time.

KEYWORDS

World Record, Direct Pipe, Marine, Slipline, Innovation, Collaboration

PRESENTER PROFILE

Stuart has over 10 years' experience in the civil engineering industry in New Zealand and internationally. His considerable construction knowledge has been amassed from a wide-range of civil infrastructure projects. As the Project Engineer for the Army Bay Wastewater Plant and Outfall Upgrade he was responsible for coordinating all design works for both permanent and temporary works. Key components of this project were modifications to the existing live pump station, creation of a works platform to facilitate the Direct Pipe® TBM and the marine works which included the pipeline construction, transportation, installation and a seabed TBM retrieval. In addition, to this Stuart was also a key interface with important stakeholders. The work was to be completed within an operational WWTP, on NZDF land used for live-fire training exercises and within a sensitive regional park area so these relationships were critical to project delivery and required the development and implementation of detailed environmental, security and safety controls.

1 INTRODUCTION

The Shakespeare Regional Park (SRP) at the end of the Whangaparaoa Peninsula is a pest-free enclave, home to more than 20 Little Spotted Kiwi breeding pairs, as well as Little Blue Penguin (Kororā) and the endangered Moko skink. It is also home to a New Zealand Defense Force Training Facility, and the Army Bay Waste Water Treatment Plant. Army Bay plant is a Watercare Services Ltd (WSL) facility that services the peninsula and surrounding area. It has an ongoing upgrade programme to manage the asset as it ages and future proof the plant as the population in the area grows and flow rates increase.

Figure 1: Location Plan of Army Bay WWTP

In March 2017 McConnell Dowell Contractors (MCD) and their design partner McMillan Jacobs Associates (MJ) were awarded a design and construct contract to install a new wastewater outfall, upgrade the existing pump station and build a new ultraviolet disinfection facility at its Army Bay Wastewater Treatment Plant.

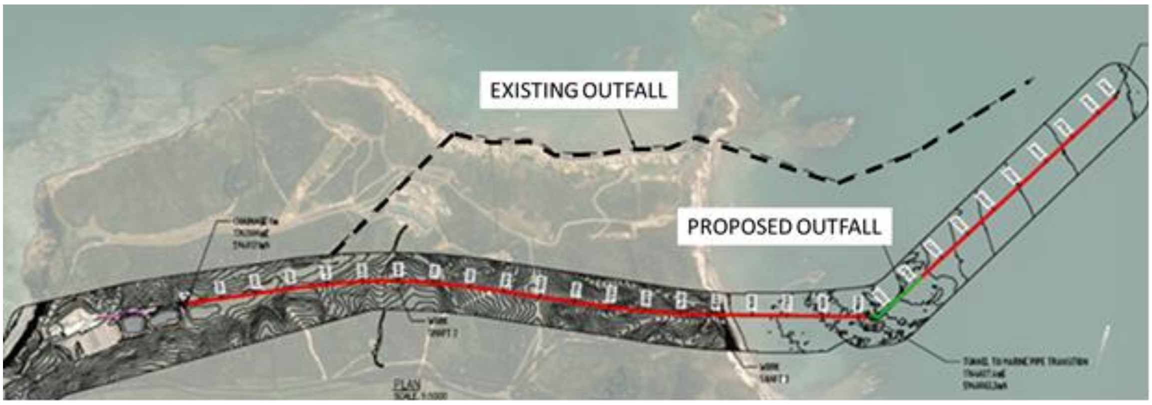

Figure 2: Existing and Proposed Outfall Plan

A technically challenging project for its high risk operations in an environmentally sensitive location, WSL and MCD opted to use innovation to reduce the risk on the environment.

The key to solving the complexities of this project was a new state-of-the-art tunneling method that has been successful in tunneling operations overseas, but never used in the Southern Hemisphere. This tunneling method is called Direct Pipe® a patented Herrenknecht (HK) tunneling boring machine (MTBM). The challenge was to install 1,929 metres of pipe in a single drive, pushing the known capabilities of the machine and method. Our efforts surpassed the previous record of 1,495 m set in Texas, US in 2015 by 30 per cent.

This paper will focus on some of the major challenges that the team overcame completing this project and how it was delivered to a world-class standard, on time, with no injuries, within a sensitive receiving environment and how a collaborative approach led to the implementation of innovative engineering methodologies, ultimately mitigating risk.

2 THE PROJECT

The Army Bay WWTP Outfall project was a design and build contract awarded to MCD with design completed by MJ. The project consisted of the following design and build works:

- New outfall pipeline capable of conveying 1.4 m3/s from Army Bay WWTP to the marine diffuser.
- 1929m of pipeline installed with the trenchless Direct Pipe® method
- 950m of pipeline installed by float and sink method.
- Wet Retrieval of MTBM
- High-level emergency overflow from the effluent storage ponds to the new outfall pipeline.
- A trenched rising main from the upgraded Duty Pump Station.
- New UV channel structure to accommodate a state of the art UV System, the rising main connection and gravity discharge with an integrated confluence chamber discharging to the outfall.
- Modification of existing Duty Pump Station structure for upgrade.

3 THE CHALLENGES

All construction projects present challenges, none more so than this project. From the outset when the need for an outfall replacement was required, significant work was required by WSL and Aecom, Watercare's Technical advisor, to turn the concept into a reality. Most of the challenges faced on this project stem from its geographical location.

The Army Bay WWTP is situated within the confines of the Shakespear Regional Park (SRP). In 2011 a 1.7km pest proof fence was constructed across the peninsula enclosing an area of about 500 hectares that has since had its pest eradicated to produce a sanctuary for native wildlife. Since then the Shakespear Open Sanctuary Society Incorporated (SOSSI) has released the rare spotted kiwi and helped preserve the other flora and fauna that inhabits this park. In addition to the regional park, the peninsula is home to a NZDF training facility and the marine outfall is located in the middle of the busy TiriTiri Matangi Channel within the shooting range safety zone.

Minimising impacts on the sensitive environment was critical. WSL embraced MCD's recommendation to use Direct Pipe® rather than the originally intended Horizontal Directional Drilling (HDD) to significantly reduce the impacts on this sensitive environment, minimising the construction footprint and eliminating the risk of frac-out. The fundamental approach taken by client and contractor was that the decisions were undertaken on a best-for-project basis, using open forums where all parties could suggest ideas and raise concerns.

3.1 DIRECT PIPE® ™

So what is Direct Pipe®?

The Direct Pipe® method is ideal for installing pipelines in sensitive areas. Herrenknecht's patented pipeline installation method uses an AVN machine. The pipe string is attached to it and simultaneously inserted during the tunneling process. This is done with the help of the "Pipe Thruster". With pushing power of up to 1250 tonnes, it thrusts the pipeline under the ground. Pipeline installation takes place in one step. In this way, the environmental impact is kept low and the landscape remains intact.

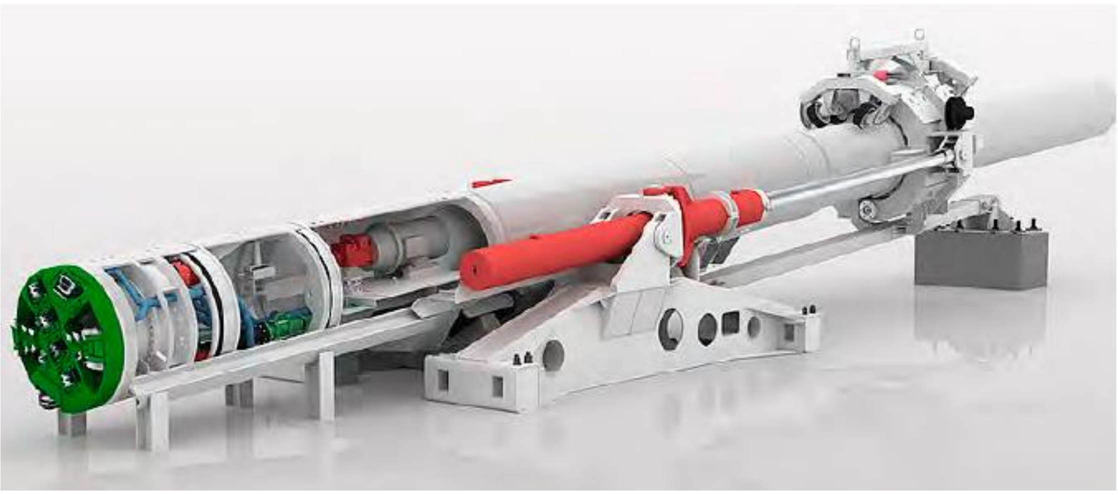

Figure 2: Model image of the Direct Pipe® Machine

The varying ground conditions were a key driver for our decision to use the Direct Pipe® method. McConnell Dowell took the Direct Pipe® technique and adapted it to the unique needs of the Army Bay project. Although used commonly overseas, Direct Pipe® is new to New Zealand, and to our knowledge has never been used to deliver an outfall of this complexity. Typically, the technique is used to install pipelines over relatively short distances under rivers and beds of water.

Figure 3: Overhead view of the Direct Pipe® Machine before launch – 500t thruster at the front and 750t thruster at the rear.

3.1.1 ENVIRONMENTAL BENEFITS

Direct Pipe® offered the ability for ease of recovery if any issues were encountered, a significant environmental benefit compared to a typical recovery of a pipe jack machine.

The inclusion of shafts were a precautionary measure given the risk of driving a distance not attempted before, this provided the ability to pick and choose the best locations for the shafts identifying locations that had already been disturbed.

The biggest footprint for the operation was the drive shaft and welding platform in the WWTP, but this was still smaller then alternative methods meaning the project had less of an impact on this area as well.

The challenging environment placed significant restrictions on how the tunneling works could be undertaken, requiring vigilant planning and ongoing liaison with Auckland Council, Watercare and NZDF. We worked closely with Auckland Council and local volunteers at SOSSI to mitigate environmental risks and the NZDF to ensure safety was a priority.

Figure 4: A Little Blue penguin successfully relocated from Shaft 2

3.1.2 PLANNING

During the tender period McConnell Dowell evaluated three options for the outfall installation, HDD, pipejacking and Direct Pipe. A thorough Safety in Design (SiD) process identified items such as;

- variable ground conditions of weak broken mudstone with high strength and abrasive turbidite deposits,
- Large elevation change from entry to exit
- Large drive distance requiring higher jacking demands

Direct Pipe® was selected due to the ability to deal with the full range of ground conditions at the lowest risk and adjusted price compared to the other methods.

While the Direct Pipe® technology is new to New Zealand, McConnell Dowell had previous experience with Direct Pipe® installing four drives on the Fourth Parallel Project in Thailand. Data from the Fourth Parallel, combined with local knowledge of ground conditions and McConnell Dowell's experience with relatable parts of the technique, like the slurry separation, wet marine recovery and large diameter steel pipe welding allowed McConnell Dowell to accurately predict the costs and independently confirm the methods ability to go much further than the 1.46K previous record. A 2km drive was seen as achievable but was finally confirmed following detailed technical review from MCD Engineering and our designer MJ who developed a ground model and completed thrust demand calculations which confirmed theoretical thrust loads required for such a drive including both vertical and horizontal integrated curves. After assessing ground conditions and drive parameters we elected to install both the 750t thruster and 500t thruster in line to mitigate any possible performance risks. A lack of geotechnical information and known variable ground conditions highlighted a potential risk of increased head wear on the MTBM meant a decision was made to mitigate this risk by adding two intermediate access shafts to intercept the MTBM. Checks on the condition of the head could be completed with changes made. These intermediate shafts would also mitigate risk in the event that the MTBM needed other repairs.

With the technical box ticked the techniques other attributes just made sense.

The Army Bay area is a beautiful place, wild life abound and the area is renowned for its fishing - the client was rightly focused on the lowest possible environmental impacts. The risk of frac-out was able to be eliminated with a combination of the technique, which provided accurate face pressure control and specific operating techniques honed by McConnell Dowell on previous outfall projects.

Sitting above most of the drive was an active Army training ground and the drive was at depth (70m), making any potential recovery of the machine very expensive and unpalatable. A further consideration was the potential to encounter ground with compressive strengths of up to 80Mpa and the effects that would have on the cutter head tooling. To address this, the Direct Pipes ability to be retracted was particularly attractive and a key attribute that the other techniques could not match.

3.1.3 SET UP

Previous example projects of the Direct Pipe® operations are undertaken in areas where the pipe strings can be assembled in a single piece and cranes are used for holding the pipe while it is being installed.

Figure 5: A sample of a standard Direct Pipe® Operation

The luxury of space was not something that the Army Bay WWTP had, and although the Direct Pipe® technique offers the advantage of a smaller construction footprint than alternative methods, the pipe fabrication area is significantly bigger. This required an extremely detailed approach to planning and setting up the entire operation.

Figure 6: On the left a photo of the site at the early stages of earthworks, on the right a photo at full mobilization.

When designing the welding bed location and the roller system for the pipe strings, the operational requirements of the Direct Pipe® machine had to be considered. The Direct Pipe® machine is designed to be pulled back should an emergency mechanical event occur. The inclusion of two maintenance shafts, Shaft 1 at Chg. 591.03m and Shaft 2 at Chg. 1498 split the tunneling operation into 3 as shown below in the table.

Location	**Chg. (m)**	**Drive distance between shafts (m)**	**Depth below Ground level (m)**
WS1 – Entry	0	N/A	5.68
WS2 – Shaft 1	591	591.03	43.1

WS3 – Shaft 2	1498	907	14.7
Marine Transition	1929	431	11.3 (below MSL, -2.5 below sea bed)

Table 1: Drive distances

This meant the welding bed had to be designed to allow for a potential scenario when the MTBM would have to be pulled back, but also to keep enough pipe ready on the fabrication line to keep pace with the tunneling operations. The length of the site was limited by the available space which worked out to be 84m (seven pipes at 12m each). The width of the site was also a limiting factor, with a fine line between taking too much space that increased the environmental impact to the site, and not taking enough slowing the operations down. The team opted to make a welding bed capable of handling five pipe strings equating to 420 meters of pipe. Including the drive string, this would allow approx. 520m of useable area for pipe. This was enough for drive 1 and 3, with the risk lying in the second drive.

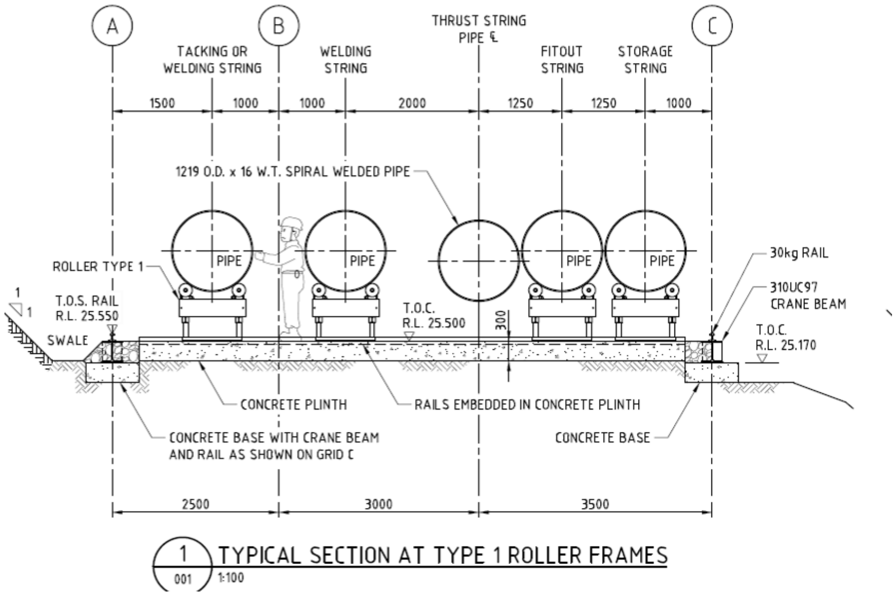

Figure 7: Design drawing showing the welding platform assembly

The welding team chose to use a state of the art semi-automated orbital welding system, because of its speed and quality, to complete 161 welds, and fabricate the 23 individual strings. The pipe strings had to be transported around the welding platform with each 84m pipe string weighing approx. 39 tonnes. A series of pipe rollers were manufactured that allowed the pipes to be rolled around its circumference to find the best fit for butt welding the troublesome spiral welded pipe. These pipe rollers also incorporated a function allowing transverse movement of a completed pipe string onto the drive alignment. The main drive line to the headwall utilised a more traditional roller system which allowed the pipe to be rolled into position. The pipe strings were winched down near the Direct Pipe® machine for the "Golden Weld" to be completed between the new and installed pipe strings.

Figure 8: Welding bed with two pipe strings fabricated

To manage the challenges of crane access, a 20t gantry crane was installed along with running rail the full extent of the works, to service the TBM and help lift the steel pipe from the pipe storage cassettes into the welding zones. The heaviest item to be lifted was the clamping unit on the 750t thruster, this weighed 36tonnes and required a special custom gantry. This was chosen in place of increasing the 20t gantry due to the increase in costs for both the gantry and the rail system due to the poor ground conditions adjacent the existing WWTP ponds.

Figure 9: 750 tonne Thruster weighting 36 tonnes lifted with custom gantry

3.1.4 SHAFTS

Topography and the utilization of existing clearings required the first shaft situated on a shotgun firing range to be 46m deep, whilst the second shaft close to the foreshore reached a depth of 17m. The shaft dimensions also needed to account for MTBM deviation from the alignment, as the Direct Pipe® machines utilize a gyro for navigation, with a typical lateral accuracy of 1 mm/m. This required a shaft of adequate dimensions to account for this level of deviation.

The chosen method of construction was utilizing a 70T piling rig to bore and then reem the shaft to a 2.6m diameter. A steel casing was then inserted into the hole in two sections, requiring butt welding together partway through the installation. Following installation of the lining, our specialist shaft crew began to hand break a 5m x 4m bell out at the base of the shaft to allow for the MTBM deviation. This bell out was supported using traditional support of rock bolts and mesh as both were constructed in the capable ECBF. Spoil was removed via crane mounted clamshell.

Driving a Direct Pipe® machine through a shaft had never been attempted before, so MCD and MJ developed an innovative design and temporary works solution to enable the shafts to receive the MTBTM. The challenge with Direct Pipe® machines is the alignment deviation whilst entering the shaft. The true position of the machine is only realized when the machine breaks though, so the reception wall and positioning of the eye seal needed to allow for this.

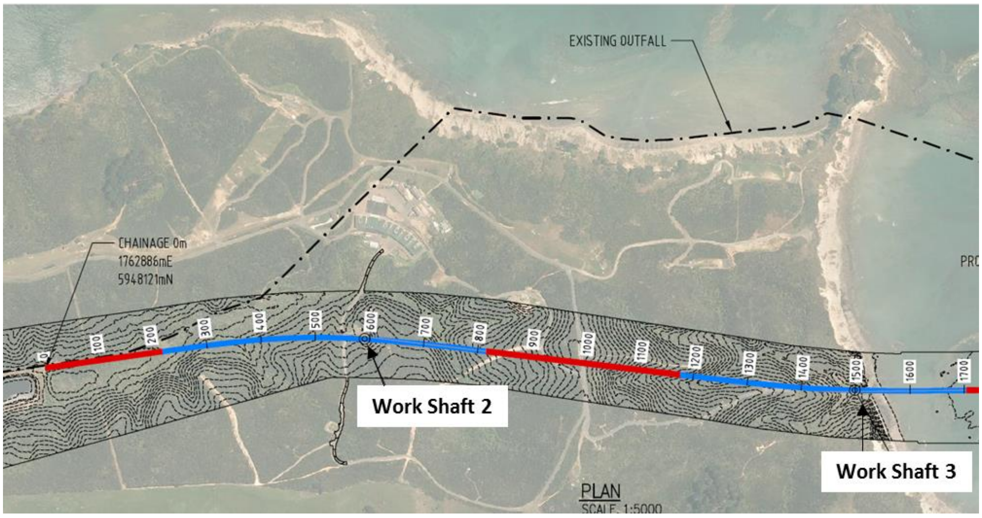

Figure 10: Locations of Shaft One and Two

The approach taken by the tunneling team was to modify the annulus bentonite approaching entry into the shaft. This allowed the eye seal to be fitted after breakthrough of the machine without any great inflows of water or annular bentonite. The slurry circuit of the MTBM was used to dewater any inflows of bentonite and water into the shaft, so it could be treated appropriately at the separation plant at the launch site.

With direct access to the outside of the machine, the MTBM position could be exactly determined without the need to have surveyors traverse down the inside of the pipeline. The gyro was then updated with the true position, and the learnings in gyro deviation applied to the next drive. Following MTBM checks, the machine was then ready to continue on the second and longest phase of the drive which exceeded 900mts between shafts.

The installation of these maintenance shafts became worthwhile during the final stretch of drive, following the second maintenance shaft. A leak in a seal within the MTBM was witnessed on the CCTV feed, significant catch considering the machine was soon to tunnel onto the sea floor. Using the thrusters the MTBM was pulled back into the final shaft. The tunneling team then set about dismantling the MTBM underground and repairing the leaking seal. 48 hours later the machine was tunneling again, marking the first time a Direct Pipe® machine has been dismantled and repaired underground.

3.1.5 MARINE BREAKTHROUGH

Extensive planning of the marine breakthrough had identified a number of questions that needed to be answered to make sure the operation ran smoothly.

1. How do we retrieve a MTBM 2.5m deep in sandstone rock?
2. How do Divers gain access to the Bolts to disconnect?
3. How do the services get removed from the tunnel before flooding?
4. How do we control pressure differentials between the tunnel and the sea?
5. How do we retrieve it off the sea bed?
6. How do we get it onto dry land?

This broke down the operations to 3 key items

1. Breakthrough of the TBM into the sea
2. Service Removal and Disconnection of the MTBM from the tunnel
3. TBM Retrieval

All three operations needed to consider its impact on the next, and the future operation involving the slip lining works.

Figure 11: Herons Dredge, GPK on site excavating the transition pit

The marine ground conditions were mainly East Coast Base Formation typically consisting of interbedded very weak muddy sandstone, siltstone and mudstone which were easily excavated out with the 150t Excavator.
To provide vertical support for the MTBM upon break through pea gravel was used to backfill the reception pit which would be easier to remove later.

As the Direct Pipe® machine approached the tunneling team modified the bentonite supply and continuously recycled water around the face of the MTBM. A successful breach was completed with the New Zealand Dive and Salvage (NZDS) divers on hand to confirm the presence of the TBM and that there was no loss of annulus bentonite.

From here the NZDS divers used a suction tool to clear out around the bolted connection of the MTBM removing all the pea gravel. Using a new quick release feature of the Direct Pipe® machine the services were remotely disconnected. Over the following week the site teams worked around the clock to pull and strip 2km of services from the new tunnel.

Once the services had been removed, a flooding valve accessible via a hatch on the outside of the MTBM could be opened up by divers to start flooding the tunnel which would balance the pressure. A bespoke lifting beam was attached to the lifting points on top of them MTBM ready to be lifted out at the next available weather window.

McConnell Dowell designed and fabricated a custom-made recovery pontoon fitted with two 4t winches to lift the MTBM from the seabed. The MTBM weighed approx. 27 tonne in the air, but when it was sealed under water the buoyancy weight was reduced to 8t.

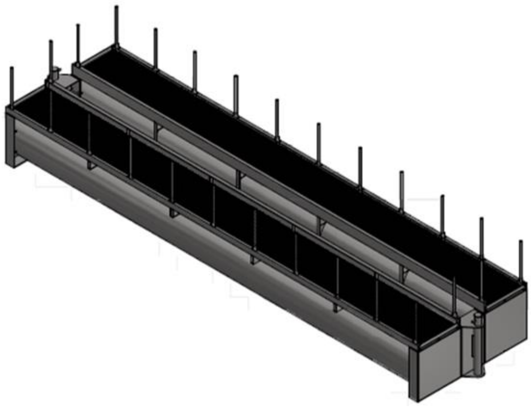

Figure 12: Design drawing of the Pontoon for retrieving the Direct Pipe® Machine

The pontoon was delivered and stored down at the Gulf Harbor Marina until it was required for the operation. Upon successfully attaching the MTBM to the bottom of the pontoon, a 100t straddle lift in the Gulf Harbour Marina was used to retrieve it from the sea and load it onto the back of a waiting truck.

Figure 13: MTBM hoisted into the air by the Gulf Harbor Marina Straddle lift

3.1.6 BLIND (INNOVATIVE) APPROACH

Being the first project in the Southern Hemisphere to use the Direct Pipe® machine was a challenge in itself. Aside from the expert advice from the HK operations team, the project team had to draw on their extensive experience with other tunneling techniques. While not an entirely blind approach, this 'blank canvas' provided a significant opportunity for team in planning the operation. The truth is, the first onsite operations meeting between HK and MCD was eye opening due to the project teams' expectations of what could be done with the Direct Pipe® machine and the HK's knowledge of what has been done with this technology to date. The two groups worked together to help push the capabilities of the Direct Pipe® machine beyond just the World Record Distance. Below is a table of firsts for this Direct Pipe® Machine.

Number	Item	What was done
1	Thruster Restraint	Typically thruster reaction loads are contained using a bored or driven pile array around the thruster. MCD utilized ground anchors to provide a clamping force and utilized friction with the ground to provide restraint.
2	Dual Thruster Usage	Clever programming from the HK team saw Army Bay become the first project to use two thrusters simultaneously to push the Direct Pipe® machine.
3	Shaft Entry and Exit	Exit and entry seals installed post breakthrough. Measures taken to reduce annular flows to ensure this was possible.
4	Shaft Maintenance	Strategic positioning of service shafts to enable preventative maintenance to prevent pull backs
5	Underground Install of seal	Machine separated underground to enable the replacement of damaged seal prior to breaking through to the sea floor.
6	Auto disconnect of the Services	A new feature of the Direct Pipe® machine, this was the first time it had been used in the field.
7	Alignment	Driving the MTBM through 2 horizontal and 1 vertical curve

Table 2: A table firsts for the Direct Pipe®

3.2 PIPE SINKING OPERATIONS

934m of the 2864m Outfall is located on the sea floor of which 900m of this was sunk into position using the "float and sink method". This section of the permanent design required DN800mm HDPE SDR26 pipe complete with 210 Pairs of Ballast blocks weighting approx. 2tonnes each. The transition from the tunnel is situated 12m below MSL with the diffuser positioned approx. 25m below MSL.

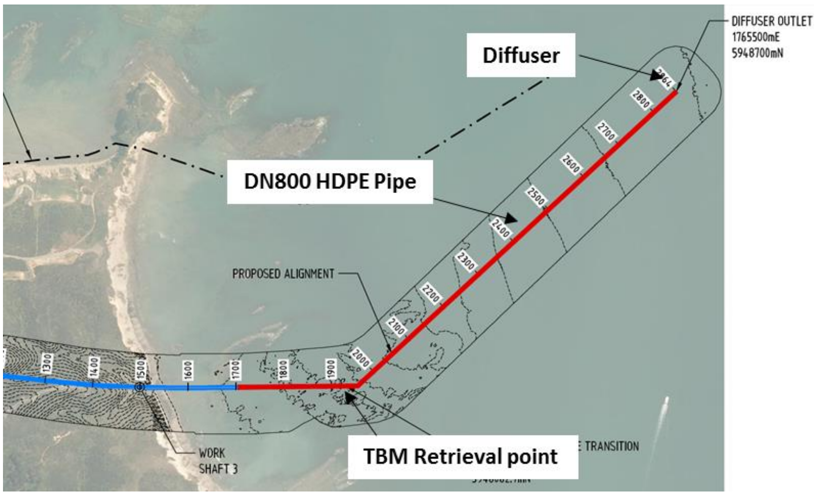

Figure 14: Design drawing showing the Marine alignment

3.2.1 PLANNING

Float and Sink method of installation has been used successfully for outfalls all over New Zealand and the world, but the potential for failures and harm puts these operations into the high-risk category. This naturally raised concerns for all parties, and so the team convened a series of workshops to plan the works and managed the risks. The project team were able to harness the experience within MCD, MJ and its two specialist contractors New Zealand Dive and Salvage (NZDS) and Herons Construction to learn from previous operations, and comfortably settle any fears that Watercare and Aecom had.

The final methodology was to split the 900m section into two more manageable portions at approx. 450m in length, welded at a remote site then attach ballast blocks, towing 40 nautical miles and sinking a fully ballasted pipe into position. Design parameters for the sinking process were calculated by the MCD in house engineering team and a detailed methodology developed for controlling the pipes through the sink process. Coupling this with the Metoceans condition report supplied in MJ's detailed design, the project teams were able to come up with an anchoring system used to provide the controls required for the sinking process.

The sink operations required an optimum weather and sea state window of a minimum three days, one day allowance for launch and tow, one day for the sink and one day contingency. After several meetings with the Harbor Master, Heron submitted a detailed tow plan based on using the lead tug Capricorn Alpha. This plan detailed the tow route, along with wayward points for updates and storage areas should the conditions change.

3.2.2 PIPE STRING FABRICATION

Operating from Kaiaua, a remote worksite in the firth of Thames, two pipe stings were butt fused and stored ready for the ballast block install. Using a specially designed lifting beam, the precast ballast block units were lifted over the pipe and the connecting threaded rod and nuts installed to clamp the ballasts into position. The nature of the sinking operation subjects the pipe to different stresses often higher than the operational stress, so that to be assured that the pipe strings were of a high enough quality, pressure testing and non-destructive bend testing was undertaken to the pipe strings prior to the launch.

Figure 15: Installation of the Ballast Blocks

3.2.3 PIPE LAUNCH, TOW AND SINK

For the launch to the sea from land, several risks had to be controlled as damage to pipe or ballast blocks could require extensive operations to retrieve and fix. A topographical survey was completed at low tide to identify how far out from the shore the ballasted pipe string would need to be before it floated and to help identify any locations that could cause issues. The ballasted pipe string had a 1.7m draft so it was programmed that the site team would need to work between tidal movements to relocate the pipe string into a position that allowed enough depth for the pipe to float.

Three 30t excavators equipped with custom lifting beams that would position slings at each ballast block center were used to snake the pipe out towards the floating point. A plan was detailed that identified maximum tracking distance of each excavator dependent on its position in the lift as to not over stress the HDPE pipe. Working in tandem with a crew of dog men the excavators would complete approx. 20 lifts for a lateral movement of approx. 5 meters. Over two early morning shifts the pipe string was slowly moved out into position ready for the marine fleet to take over the operation.

Figure 16: Three 30t excavators working in tandem at low tide to launch the 1st String

Capricorn Alpha accompanied by, MV Island Leader II, MV Alley Cat and MV Squalus were positioned ready for the tide to come in. With Capricorn Alpha parked out in deeper water the smaller vessels and dive team connected the pipe string up to the Tugs winch line. With the pipe floating, the winch line was pulled in and the support vessels pulled the lateral lines - taking the pipe from shore on its voyage to Army Bay.

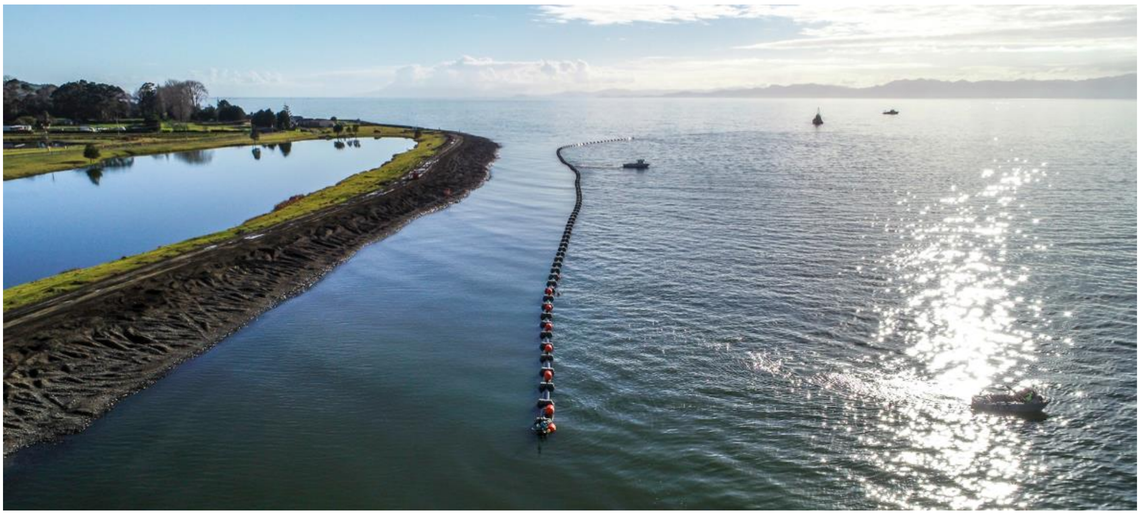

Figure 17: Pipe string 2 ready being launched ready for towing

Arriving ahead of schedule at site the following day, the vessels maneuvered the pipe string away from rocks and onto the anchor lines ready for the sink process to begin. With the pump line, and air release lines connected, the pipe string was pulled into its final alignment and tension applied to keep the pipe string straight. An inshore valve was opened allowing the pipe to flood and the sink speed was controlled by limiting the escaping air on the offshore side. A survey vessel was utilized to confirm positioning of the HDPE in the trench, and visual checks of how many ballast blocks were submerged per minute was used to determine the sinking speed. Over the next couple of hours the pipe was slowly sunk into its final position. Upon completion, the vessels would then plan for the return journey to pick up the next string.

Figure 18: Pipe String 2 being pulled into tension

3.2.4 CONNECTING THE MARINE PIPELINE

With most of the pipe now on the sea floor the final connections between the pipe strings and the diffuser could be completed. The main connection to the tunnel would be completed after the slip lining operations. The dive team completed measurements between pipe faces for it to be fabricated on land ready for lifting into positon. Using the Hi-ab mounted to the dive vessel the connecting pieces of pipe were dropped into position and the bolts slowly torqued up to create a seal. This process was repeated for all couplers and the diffuser on the end of the outfall.

3.3 SLIP LINING

The Direct Pipe® machine had done the hard graft of installing 1929m of 1200 steel pipe, but the Slip lining operation was perceived by the project team to be one of the highest risks on the project. Very rarely are slipline operations attempted past 1km, so attempting 1.9km was seen as impossible. Standard slip line operations are also undertaken from both sides of the host pipe, with the liner pulled into position rather than pushed, due to the increased buckling and loading when pushing a flexible pipe.

This HDPE pipe was an integral part of the final design due to the corrosive properties of the ground water and outfall treated water on the host pipe, and while alternative coatings had been considered the durability of these had been brought into question, an HDPE liner provided a low maintenance option.

3.3.1 PLANNING

As with all the other operations, the team convened several workshops understand and manage the risks. What made these workshops different, was the sheer complexity of the task we were looking to undertake.

Initial concepts considered the basics, such as evaluating the right installation point from the pipe – WWTP or marine side. The logistics of towing, sinking and installing 2km of Pipe made this option a lot more challenging. The next step was about identifying the loads that the PE pipe would be subjected to during the pushing process.

The first results were alarming, 1929m of SDR 17 pipe weighs approx. 380 tonnes, and assuming a coefficient of friction of 0.2 a pushing force of 76 tonnes was required to install the pipe. This was prior to consideration of possible restrictions and bends in the host pipe. Given the creep properties of HDPE, it was also estimated that at this force and distance, by the time the pipe was installed it would have shortened by up to 15m in length. Similar to pushing string up a pipe, the buckling of the PE pipe under load also meant that stroke lengths and restraint would need to be tightly controlled.

These factors concerned the project team and they began to reconsider the option of pulling the pipe into position. These discussions raised a simple idea that would make something that was starting to look overwhelming, potentially a lot more manageable. This was utilising the buoyant nature of the PE pipe. The idea was raised that the frictional force of a PE pipe floating in water, was going to be substantially less that the weight of the pipe in air. Initial estimates lowered the installation forces down to a potential maximum of 10 tonnes, with allowance for restrictions due to ovality and weld location in both pipes. Using this as the basis of the methodology the project team proceeded with making plans to fully submerge the tunnel section and design a thrusting unit to install the PE pipe.

The final design component of this portion of the works consisted of the following

- Full 1929m to be lined with 1100mm SDR 17 PE pipe
- A DN160 SDR21 pressure measurement riser located at Shaft 2
- The annulus to be sealed and grouted between Shaft 2 and the marine transition (approx. 430m)
- A sealed annulus from Worksite 1 at the start of the tunnel to Shaft 2 (approx. 1500m)

3.3.2 TOP HAT AND ACCESS SHAFT INSTALLATION WORKS

The first requirement was too fully seal the tunnel to allow it to be filled with water while also considering what was to be required once the PE pipe was installed. The final design required installation of riser at Shaft 2, meaning access to the PE pipe would be required.

Before removing the service trolleys from the tunnel and flooding for the removal of the MTBM, sections of the tunnel were removed in both shaft 1 and shaft 2 and access hatches installed to allow access to the annulus of the steel pipe without having to cut blindly through the steel.

After recovery of the MTBM, the end of the tunnel could be resealed to allow the pipe to be floated in. This was completed with the design and installation of a 'Top Hat configuration': a steel top hat made of multiple units to facilitate the HDPE pipe pushing out past the end of the tunnel for its sealed connection on to the main outfall pipe.

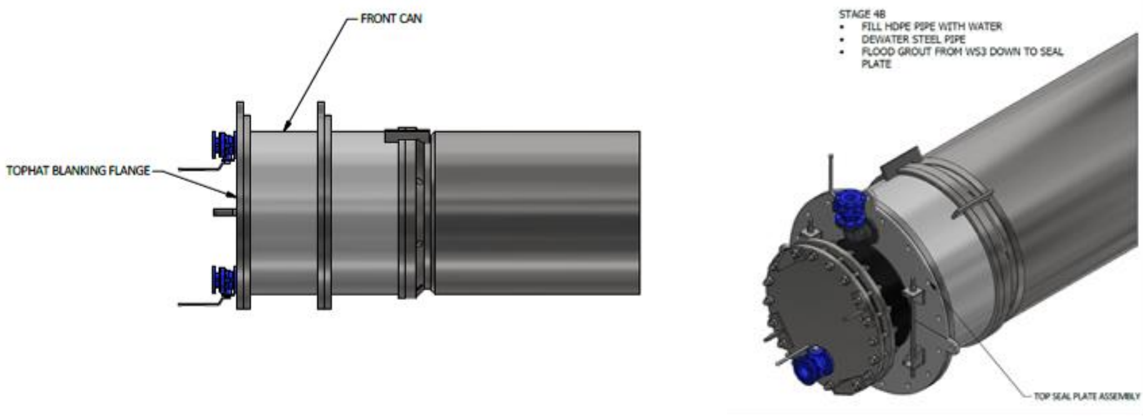

Figure 19: Top Hat – Temporary works design Full unit (Left) Liner installed (Right)

The body was made of two sections bolted together, with a blank plate on the front face that had valves to allow for draining the tunnel once the PE pipe was installed. Following installation of the HDPE pipe, the front can of the Top hat could be removed to expose the end of the PE pipe and a two piece sealing flange was then installed to again seal the annulus. This was required as Shaft 2 was located below sea level.

The dive team successfully completed the top hat installation using the vessel mounted hiab to install and remove the sections as required.

3.3.3 PIPE INSTALLATION

The pipe installation was a critical path operation that had to be completed efficiently to a high quality and within the same confines experienced with the steel tunnel installation. The lessons learnt from the steel welding would be used for the welding of the PE pipe with some modifications to locations for each weld. Two welding machines and crews supplied by Fusion Welding would be utilized to complete the works. Several options were assessed for the welding process as this would be the operation that would govern the speed of the PE pipe installation.

- Option 1 - Weld long strings in a separate location and transport to site 200-300m plus – this method was discounted due to complexities of transporting
- Option 2 – Weld strings the same length as the tunnel section approx. 86m in length. – Discounted due to slower efficiency.
- Option 3 – Weld strings into 34m lengths (2 x 17m lengths) with the second machine welding these directly onto the drive line. – Option used.

Figure 20: Butt fusion welder in white tent and gantry helping liner down to the tunnel

The first section of the liner compromised a 7m section of 800mm HDPE (matching the sea bed pipe) complete with a steel plate and guides to keep the HDPE liner central to the steel tunnel and prevent the backing ring from snagging up.

To install the pipe, the project team worked together to develop a clamping unit that mimiced the installation process of the Direct Pipe® machine, but instead of using rams to push the clamp a series of pulley lines to two 4 tonne winches were used to pull the pipe into position.

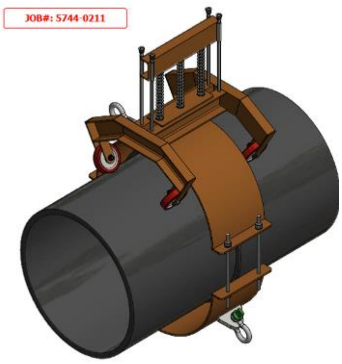

Figure 21: Clamping unit design

The installation was completed by a team of three. Two operators worked either side of the clamp to engage and disengage the unit with rattle guns, the third team member operated a fly winch that pulled the clamp back into position for its next stroke. The installation process had a stroke of 15 meters, and took a couple of minutes to pull the pipe into position.

Figure 22: HDPE Liner Installation

With 17m lengths and a total of 1929meters, a total of 114 welds, (not including test welds) were required to weld the full liner. Crews worked split shifts to install the full liner in less than three weeks.

3.3.4 TIE-IN

Following installation of the liner, the pipe could then be jointed to the marine pipe to connect the full outfall pipe. Surveying the final position of the pipes the divers worked on installing the remaining pipe. Using the same method as for the Direct Pipe® retrieval but in reverse, the remaining sections of the outfall were loaded out using the straddle lift and transported around to the sea bed location where they were connected into position.

4 CONCLUSIONS

The environmental significance of the land surrounding the Army Bay WWTP created a project that required several innovations to manage the risks. An open relationship between the Client, Watercare Services Ltd and Contractor, McConnell Dowell Constructors, created an environment that fostered innovation and enabled the successful completion of the project. Despite involving some of the most high risk construction activities (tunneling and marine works), the project was completed with an impressive Total Recordable Injury Frequency Rate of 0.

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All people that had any involvement with the Army Bay WWTP Outfall Project.

REFERENCES

"[Click here to Type References]"