USING MODERN TECHNOLOGY TO SOLVE PROBLEMS TAURANGA'S WASTEWATER OCEAN OUTFALL

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ABSTRACT

This paper will provide insight into some of the problems facing TCC with its existing Ocean outfall asset and some of the mitigations currently underway to investigate these.

Tauranga's Te Maunga outfall system discharges treated wastewater effluent from Tauranga City to the Pacific Ocean approximately 1km from the shore. The outfall system comprises a number of components: ponds, wetlands, outfall pump stations, UV treatment, and landward and ocean outfall pipeline sections. The outfall is consented to discharge up to 50,000 m^3/day at a maximum rate of 900 litres/sec. The outfall pipeline was designed to deliver a maximum flow of 900 l/s and was constructed in 1976/77 using 600mm ID concrete pipes. However, the ocean section of the pipeline was damaged during construction. Grouting of cracks and defective joints was undertaken at the time. In 2010, following dye testing, further repairs were carried out and bands were installed at identified leak locations. The operational capacity is currently capped at about 600 l/s to protect the ocean section of pipeline.

Tauranga City is experiencing rapid growth and needs to increase the peak capacity of the outfall to 820 l/s by 2029. The condition of the ocean section has a major influence on how this is accomplished.

In January 2022, Tauranga City Council approached Bay Dynamics NZ with a view to creating a customised ROV that could clear pipeline blockages and carry out a CCTV inspection and sonar survey. Bay Dynamics accepted the challenge and agreed to co-fund the development of an ROV on the basis that they could use it commercially.

Bay Dynamics' approach was to create a universal system for carrying out a number of different tasks inside the entire length of the pipe. Initial tasks were to remove the grout debris pieces, visually inspect the internal lining, and 3D sonar scan the pipe for defects. Future tasks would include repairing the pipe. The ROV was designed with a modular front payload system to allow the change out of specialist tools, on the job, as required. This also allows for future job-specific payloads such as injectors, cutters, grinders, and other repair options to be realized without needing to change the ROV itself. Available reports provided limited information on the internal condition of the pipeline so a "worst case scenario" was prepared for. While debris pieces weighing 10kg had been recovered by divers in the past, the debris removal system was designed to lift 30kg of deadweight. Visuals from previous cameras showed poor visibility so a special

machine vision enhancement camera was used to assist in visual inspections. The system is battery-powered and uses a fibre optic cable to feed all data live to the surface and allow real-time piloting. The ROV is capable of handling up to 6 cameras and 8 survey accessories simultaneously to cover as many tasks as possible while also being easily adapted for unforeseen tasks if needed. The ROV was used successfully in February of 2023 removing nearly 120kg of concrete grout pieces.

KEYWORDS

Wastewater, Asset Management, Pipeline Condition Assessment, Underwater Robotics.

PRESENTER PROFILE

Matt Mooney is a director of Bay Dynamics NZ. He has had a lengthy career in the onshore and offshore oil & gas robotics industry worldwide and a six year career in the New Zealand Army. He brings construction and repair solutions to the local and international community.

Chris Thomas is a Senior Project Manager for Tauranga City Council. He has 39 years' experience in the water industry, 20 years as a project manager. He has a degree in Civil Engineering and a passion for building and working with teams to deliver projects.

INTRODUCTION

Tauranga City is located on the east coast of the north island. It has beautiful beaches, a good climate, is a popular destination for travellers and has experienced significant growth over the past decade or so.

Photo 1: The City's Beautiful Beaches

The population is expected to grow from 163,000 (current) to 284,000 in 2100. This will place the City's infrastructure under considerable pressure in the coming years, in particular its treated wastewater effluent outfall pipeline, through which all effluent from the city is pumped and discharged one kilometre out to sea.

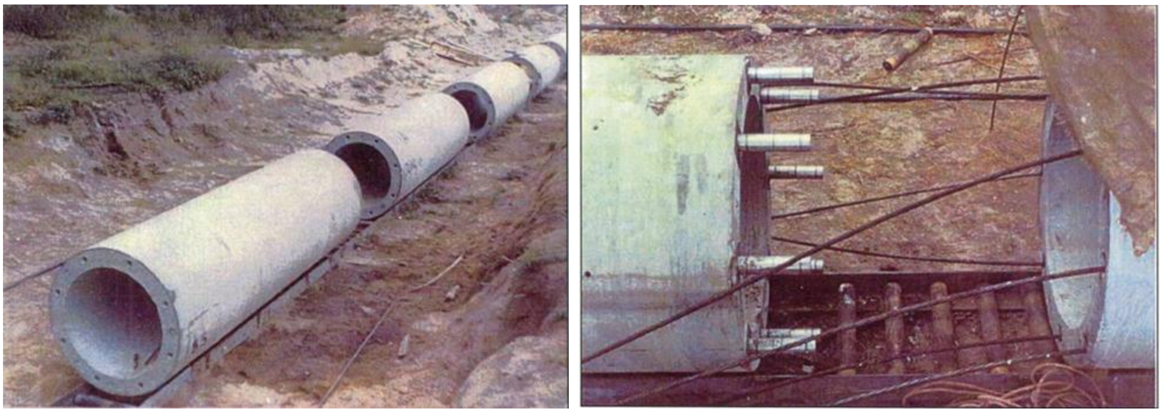
This outfall pipeline is consented to discharge up to 50,000 m^3/day at a maximum rate of 900 litres/sec. The consent expires in 2040.

The outfall pipeline comprises two sections – landward section and ocean section - and was completed in 1977.

Figure 1: Tauranga City's Outfall Pipeline

The ocean section is constructed from 3m long precast spun concrete pipes with a wall thickness of 102mm. During construction, a 950m long pipe string was formed by post-tensioning the pipes together in three stages and sealing the joints between the pipe sections with epoxy mortar. The post-tensioning cable ducts were pressure grouted after stressing. Images of the ocean section pipes are shown below.

Photo 2 :   Ocean Outfall Pipes



The ocean section of the pipeline was badly damaged during construction, when it was being floated into position. Repair work carried out at the time included banding significant cracks, as well as grouting of cracks and defective joints.

Over the years since, the pipeline has been subjected to a number of campaigns aimed at identifying and fixing leaks and inspecting the condition of the pipeline. None of these has been completely successful or managed to confirm the pipeline condition. In 2012 the pipeline failed during another campaign of testing and inspection and had to be repaired. To manage the risk of further failures the operational capacity was capped, until recently, at about 500 l/s.

The landward section was replaced in 2022 with a new 1200mm diameter PE pipeline, improving the overall hydraulic performance of the pipeline and enabling flows to be increased to about 600 l/s.

With the rapid growth in the City, it is expected that the outfall capacity will need to be increased to 820 l/s before the end of the decade.

The option of replacing the pipeline with a new pipeline is not considered feasible within the required timeframe due to opposition to the ocean outfall and the challenges facing a new consenting process. Other options include fixing the pipeline or lining it, both of which require an assessment of the condition of the pipeline.

The ocean outfall is buried, ruling out a comprehensive inspection of the external wall. Internally the pipeline is known to be blocked in two places, making it very difficult and risky to carry out an internal inspection using CCTV. The nature of the blockages is unknown. Removing the blockages using conventional means (e.g. excavate & remove, grapple and rope, drag chains, pigging) is either not feasible or will risk further damage to the pipe. An alternative method of clearing the pipe is required.

USING MODERN TECHNOLOGY TO CLEAR BLOCKAGES

LOCAL EXPERTISE - BAY DYNAMICS

In January 2022, Tauranga City Council became aware of a small local company – Bay Dynamics NZ - with extensive knowledge and experience in the development and operation of underwater robotics. Bay Dynamics was approached with a view to exploring the potential for the design, manufacture and operation of a multifunctional customised remotely operated vehicle (ROV). Discussions led to the a partnership approach under which Tauranga City Council and Bay Dynamics co-fund the design and development of an ROV on the basis that it would be available free of charge for use by the City and could be used commercially by Bay Dynamics.

ROV DESIGN CHALLENGES AND SOLUTIONS

For operational reasons, the outfall pipeline cannot be closed down for longer than 3.5 days. Thus, any works within the ocean outfall needs to be completed within this period.

The ROV development process undertaken by Bay Dynamics was conducted in the following stages.

a) Assessment of historical data.

b) Assessment of existing 'off the shelf' solutions.

c) Possible deployment method options.

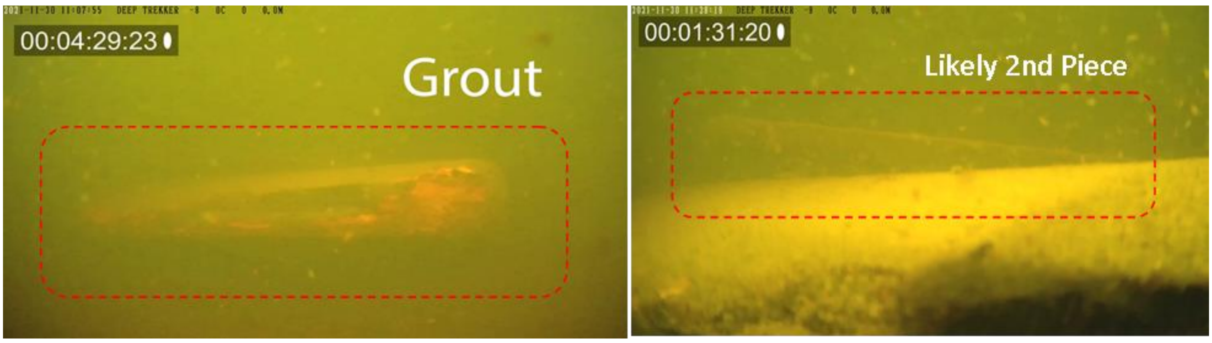
d) ROV Concepts & Development

e) ROV Construction

ASSESSMENT OF HISTORICAL DATA

Bay Dynamic's conducted an initial assessment based on previous data and footage obtained from historical inspections of the outfall pipe. Footage typically showed poor visibility and it was difficult to obtain usable data from it. It did however show what appeared to be a piece of grout blocking the pipe approximately 100m inside the pipe. With no scale of visual reference being readily available, this grout was estimated to be around 400mm in width and 60-80mm thick. Its length could not be accurately established but the footage also indicated a second piece was likely lodged directly behind the first. No further footage beyond the initial blockage was obtained or available for assessment.

Photo 3: Historical Inspection Photos showing debris



Several external/ internal inspections and maintenance tasks had been conducted over the years which recovered several pieces of grout. It was thought that these grout pieces were created by oversupply of grout during historical grouting repairs and became dislodged over time or by previous attempts (chain dragging) to clear the ocean outfall section.

Photo 3: Debris Collected from Ocean Outfall

During the most recent campaign (2020) to inspect the pipeline, the end flange in the photo above was removed and the pipeline was flushed overnight. Some additional grout pieces were flushed out the pipeline. The internal inspection of the pipeline was unable to be completed because of blockages encountered 600m and 300m from the end of the ocean.

The nature of the blockages was unknown, but it was assumed that these were formed from dislodged grout pieces that were either larger than what had already been recovered and were too heavy to be moved by the normal flow of water to the discharge end of the outfall, or were wedged or trapped in some way against either the pipe wall or other anomaly point preventing the pieces from being moved by the normal flow of water.

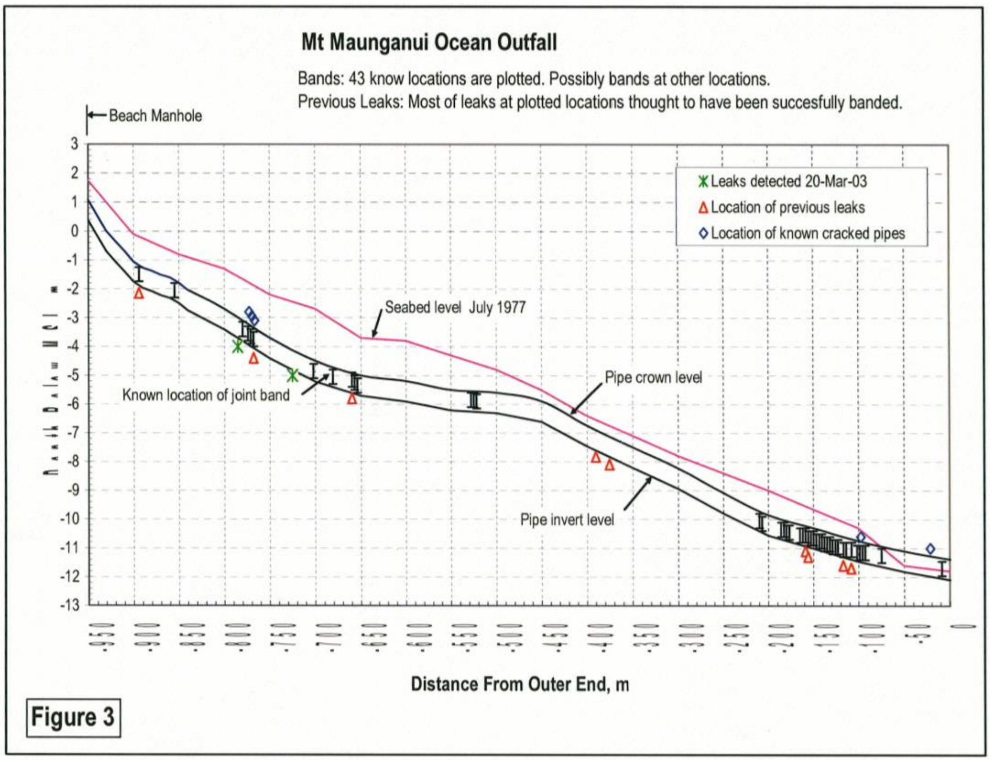
Historical pieces of recovered grout weighed at about 10-12kg. It was decided the target weight for lift would be designed at 30kg. It was also decided that any recovered pieces would need to be lifted from the pipe invert, and clear of the walls, to mitigate further jamming during recovery procedures.

At its discharge end the ocean outfall is 12.7m underwater. Previous pipe plots had indicated the pipe may not be entirely straight or at a consistent incline the entire way, as shown in the Figure 2 below.

Hence, pipe variations needed to be accounted for in the design of the ROV frame to ensure any system would not get accidentally wedged. To allow for deflections at joints it was decided that the maximum cross section of the ROV should not exceeding 480mm.

The length of the pipe dictated the need for a fibre optic communications system capable of being able to transmit data in real time over that distance.

Figure 2: Historical Defects - Ocean Outfall

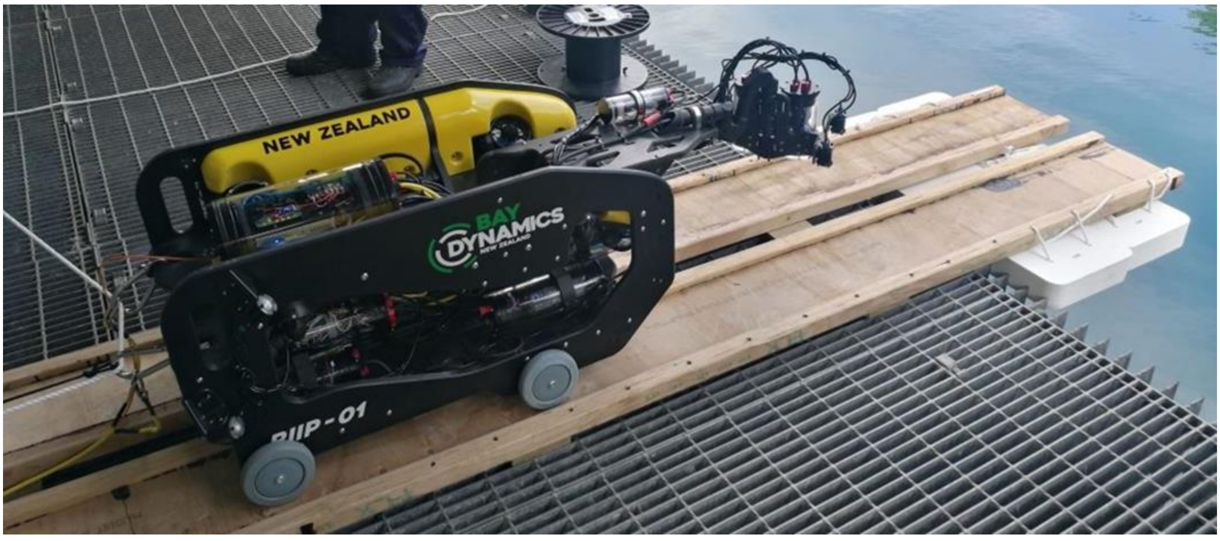


Visibility during previous inspections was poor and the available technology provided very little useful visual data. Thus, the design of the CCTV payload would require measures to improve visibility sufficiently to obtain adequate information from any subsequent inspections.

ASSESSMENT OF POSSIBLE EXISTING SOLUTIONS

Bay Dynamics was already in possession of a tunnel inspection ROV system designed and built by the company. This ROV however was too big to fit inside a 600mm ID pipe as it was designed for large hydro tunnel operations from 1.5m - 10m diameters.

Photo 4: Bay Dynamics' ROV Developed for Tunnel Inspections



A worldwide search was conducted for possible ROV solutions that could work inside a 600mm ID pipe up to lengths of 1000m but still be adaptable to required tasks needed. No 'off the shelf' system was found that would be fit for purpose.

Debris Removal

No system was found capable of accurately lifting and removing any objects.

Visual Clarity

Due to poor turbidity from the wastewater itself it was considered necessary to use vision enhancement cameras allowing for camera imagery to be artificially enhanced using a technique called Frame Phasing. This technique enables a camera to 'see' much further than a normal camera in poor water conditions. A camera from a French manufacturer was assessed as possibly viable for the work.

Lighting significantly influences the ability for any camera system to see correctly underwater. A lighting system with multiple lights and flexibility for in-field adjustment was considered imperative.

POSSIBLE DEPLOYMENT METHOD OPTIONS

There were two options for the deployment of the ROV system.

The first option was to launch any ROV system from land, via a 7m deep manhole in the beach sand dunes and move out to sea as the work progressed. This would involve removing the manhole lid and internal pipe fittings and then replacing these after the deployment was completed. The removal and replacement of the fittings is a 2-day exercise that requires coordination with the tides (at high tide the water level is about 1 – 1.5m high in the bottom of the manhole). This option was not considered viable.

Figure 3: Location of Beach Manhole – Land Based Deployment

The second option was to deploy via the discharge end of the ocean outfall and work in the direction of the shore. In addition to a vessel, this would involve use of divers to assist with the insertion and retrieval of the ROV. It would also need stable weather conditions with a swell height of less than 0.5m and low winds.

Under this option the end flange on the pipeline could be removed in advance of the deployment and be replaced after the deployment, outside of the 3.5 day window for the shutdown of the ocean outfall pipeline. This was selected as the preferred option.

With an ocean deployment in mind the ROV would need to be light enough to launch by hand or with minimal assistance. Consideration of the deployment path was also needed, as the ROV tether needed to go from a deck-based winch and into the pipe without rubbing on the ship or the pipe crown itself. Doing so could cause damage to the cable and risk operational effectiveness.

In collaboration with Pacific Diving who has considerable experience with the ocean outfall, it was concluded to use custom built tether diversion devices at the pipeline end to prevent damage to the fibre optic cable.

SUMMARY OF DESIGN CONSIDERATIONS

Key factors that were to be considered in the design of the ROV were:

- **Weight**. Overall weight needed to be such that a 2-person crew could deploy and recover the unit without additional mechanical assistance.

- **Size**. Size had to be such that it would fit inside the pipe but not exceed a 480mm cross section at any point to account for the nonlinear nature of the pipe variances.

- **Anti Blockage**. The ROV had to have a free-flowing design from a water drag perspective. This was to account for possible restriction in the pipe if the ROV were to be become lodged. In the latter case, effluent flow would be able to pass through the ROV as unhindered as possible.

- **Dead ROV.** Consideration was needed for recovery features in case of mechanical breakdown.

- **Repair.** Ease of in-field repair to avoid operational delays. An easy change housing module system was designed and created enabling quick change of major assemblies with no hand tools needed.

- **Adaptability.** The ROV needed to be adaptable for different tasks without changing the core ROV.

- **Endurance**. It would be a battery powered system so enough capacity was required to ensure the ROV could not only travel the entire distance, and back, but also enough power to be able to work at the full length of the pipe to complete tasks.

- **Accessories.** It needed to be capable of interfacing with as many unknown accessories as possible.

- **Lighting.** It needed to be capable of taking a significant amount of lighting and being able to adjust that lighting in real time to account for environmental conditions.

- **Vision.** Multiple cameras would be required for various tasks. Although 5 cameras were thought to be sufficient, up to 8 were to be allowed for.

- **Communication.** Due to the amount of data likely needed to travel in both directions a fibre optic system was needed.

- **Tether.** The tether needed sufficient tensile strength capable of recovering a full weight system from the full length of the pipe while possibly under load of debris of 30kg. It also needed to be protected enough to be capable of taking abrasive damage from the concrete lining.

- **OTS Parts.** As many 'off the shelf' parts were to be used as possible to keep production costs down and reduce lead time for custom parts.

- **Winch.** A winch was needed to be capable of handling the full length of tether while still providing full bandwidth optical communications through its slipring while the ROV was on the move.

- **Payloads.** Several task specific payloads would be needed, so a "quick change" system was needed to allow for these payloads to be changed on the boat without the need for workshop tooling.

- **Buoyancy.** The entire ROV, with payloads, needed to be slightly positively buoyant. This meant the ROV would always be moving on the crown of the pipe, and when in water would always want to slowly surface on its own in case of breakdown.

- **Protection.** The ROV needed full frame protection from the concrete lining. Unknown debris or protrusions from the pipe itself were assumed so a protection system was needed for the internal housings and cabling within the ROV.

- **Propulsion.** A unique thruster configuration would be required to focus thrust power more in the forward-back direction while still ensuring the ROV could move in all 6 degrees of freedom when needed. This would also ensure the maximum efficiency of power use while in transit in and out of the pipe getting to areas of interest.

- **Thruster Wash**. No water wash from thrusters could be allowed to impact the frame itself.

- **Autonomous Functions.** Functions would be needed to reduce the piloting load. The ROV would be capable of moving to points in the pipe on its own.

- **Redundancy.** Several key components of the ROV control system needed full redundancy in case of parts failure on the job.

- **Crew.** Able to be safely and efficiently operated by a crew of 2.

- **Job Data.** Needed to be capable of recording all data and presenting it in a useful way to a client.

- **ROV Data.** ROV would need to be capable of obtaining its own data such as roll, pitch, heading, depth, altitude, distance down pipe, water temperature, battery voltage, power usage, thruster outputs, light outputs, error alarms, water detection, etc.

- **Expandable.** The design would need to have allowance for size expansion in case heavy loads, such as mortar, had to be carried in to the pipe for repair work.

ROV DESIGN

In the absence of an 'off the shelf' ROV system, it became obvious that a bespoke ROV system would have to be designed from scratch, using as many existing sub components as possible to reduce R&D costs and to increase reliability of any final solution.

The ROV, together with its payloads, was designed and built in-house by Bay Dynamics.

Some elements, such as subsea housings, and lights were purchased from international suppliers. Where necessary, printed circuit boards were custom designed and made specially for this ROV build alone. All internal cabling was installed by hand.

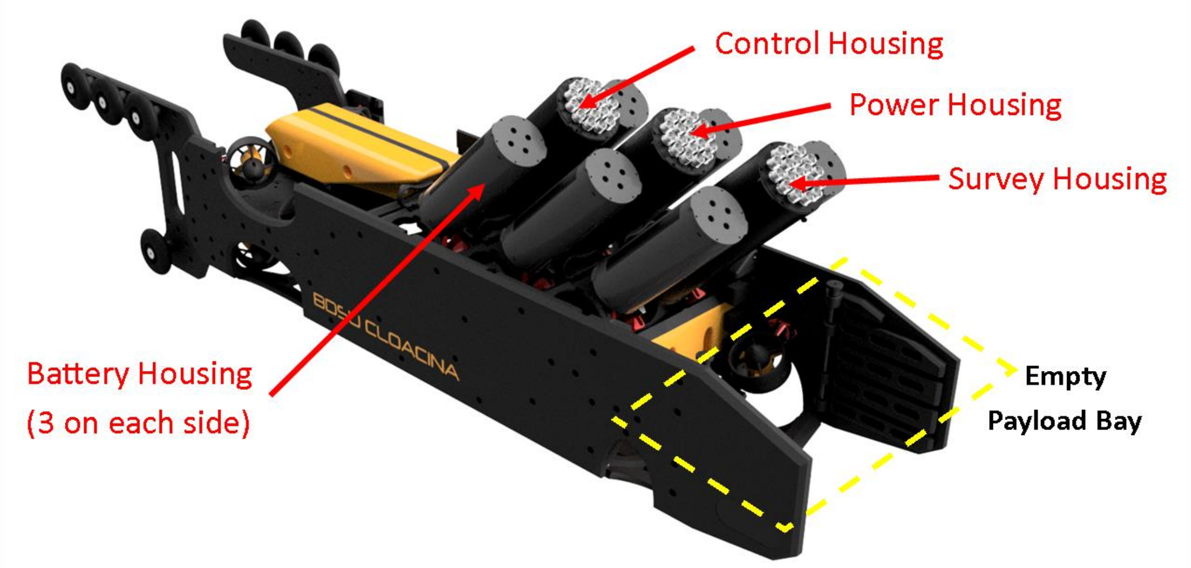
The ROV was designated "BDSU Cloacina". BDSU is for Bay Dynamics Service Unit. The name Cloacina is from the Roman goddess who preceded over the Cloaca Maxima in Rome, its main sewer and storm water system.

Final renders of the ROV, prior to construction, are shown below.

Figure 4: Final ROV concept renders prior to construction

The ROV consists of three main control housings, and six battery housings. The battery housings were designed to be easily removed without hand tools by means of an "quick release" clamping system.

Figure 5: Exploded Render showing Electronic Housings



The ROV is capable of open ocean operations and can orientate in any direction or angle. The open front area was designated the payload bay, and was designed to take different payloads, or modules, for different tasks specially for working inside pipes and restricted close in spaces.

Photo 5 : Core ROV – No Payloads

Three payloads were designed for the tasks required in this pipe.

PAYLOAD DESIGN - DEBRIS REMOVAL

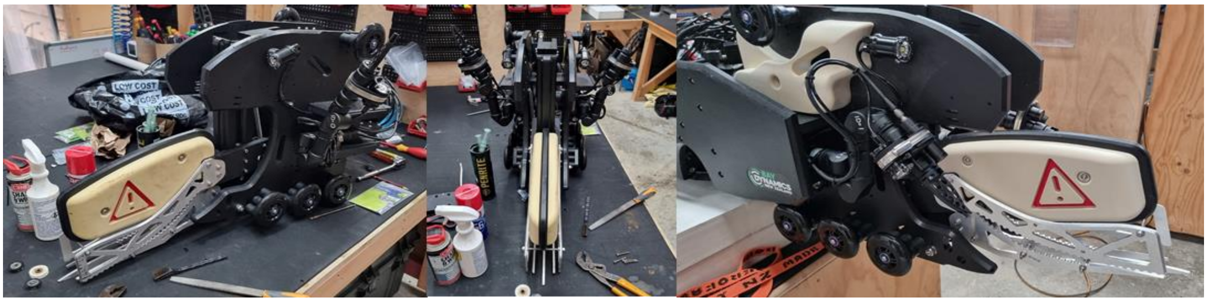
This payload was primarily designed around a high torque mini winch that was made and installed at the center of the payload. Through a series of pulleys a mechanical advantage of 60:1 was obtained. This allowed for roughly 600N or applied force possible at the jaws.

Figure 6: Renders of Debris Removal – Detached and Installed

This winch and pulley system were combined with a separate mechanical balancing system designed to work with the features of water specifically. This meant the jaw could be opened and closed, and the size of the debris adjusted for, and have it all tilt off from the floor under load. This was all done with a single mechanical mechanism. The buoyancy uplift on the jaws were in a constant balancing act with precisely placed springs with the winch mechanism being able to tilt the balance one way or another to work as needed.

The addition of a robotic arm on either side allowed for cameras and lights to be moved around during recovery tasks to better assess any items being lifted.

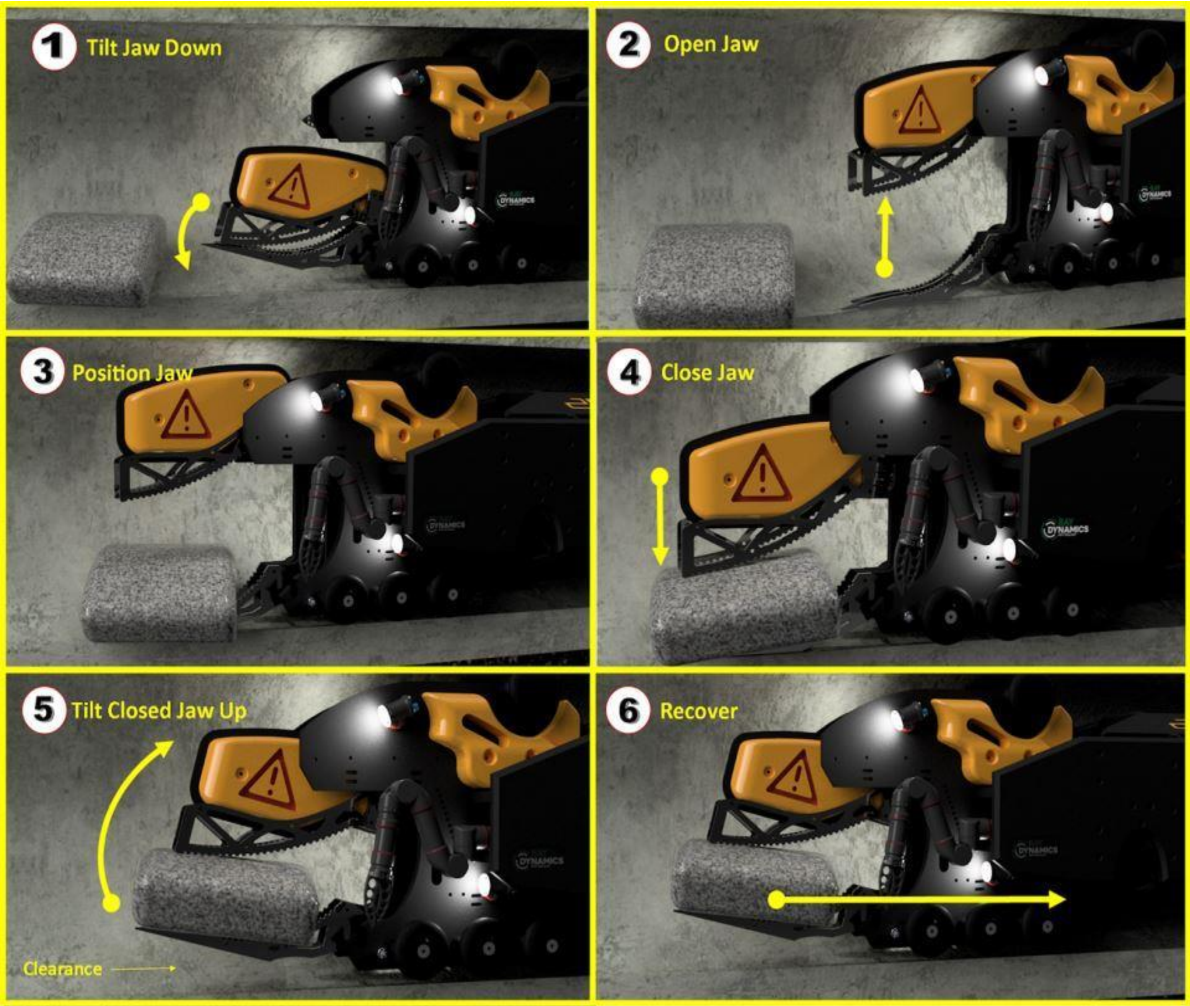
Photo 6: Debris Removal Payload during Testing



The operational sequence for debris is shown in Figure 7. As the ROV approaches debris (Figure 7, step 1) the jaws are tilted down to their lowest position, usually just below horizontal. The jaws are then opened up to full extent (2). This is performed using a winch to change the mechanical balance of the system allowing the jaws to float upwards and open. Once the jaws are positioned under an item (3) they are closed (4) using the winch. Once closed the closing force is transferred to the tilting mechanism, to tilt (5) the item from the floor. Once the jaws are tilted to 15 degrees there is enough clearance to recover (6) the debris without that debris rubbing or catching on the pipe walls.

With the load inside the jaws and tilted, the weight is shifted to the six wheels on the ROV. These wheels each have 3 rubber bobbin suspensions on them. These bobbins are adjustable so the flex in this system can be changed from soft to stiff depending how much load, or how rough the surface under the wheels is. These wheels allow the ROV to still recover debris while under load on rough ground, such as rough grout in the pipe invert.

Figure 7: Operation Sequence for Debris Removal



The wheels are designed to the pipe curvature and keep rolling independent of each other. While a pair of wheels might be deflecting due to rough ground, the others still holding their full weight. As the ROV travels down the pipe this weight transfers across the wheels one by one in sequence.

This system only works because of the counter lever wheels at the rear of the vehicle that pushes against the crown at the same time. Without these the front jaw system would tilt the ROV down rather than lift the debris up.

Figure 8: Wheel System

PAYLOAD DESIGN - INSPECTION

This payload was designed for inspection of the pipe walls.

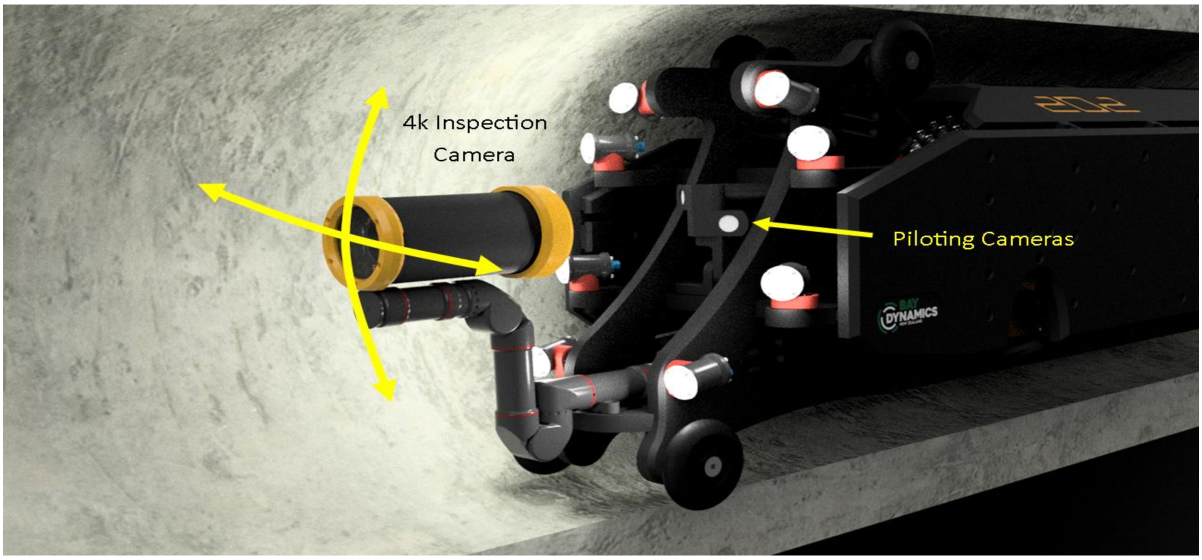
This payload was designed around the Reach Robotics Alpha 5 Manipulator which is a robotic arm capable of moving itself on 5 separate joints in any direction as needed. It is fully electric and can be adapted as needed for various tasks.

The inspection payload was originally designed to incorporate the i2S Orphie Camera which is a Machine Vision enhanced camera capable of eliminated moving particles in water to create real time enhanced imagery. The manipulators were fitted with small HD cameras capable of moving very close to the pipe wall for close up inspection of any anomalies discovered. An initial trial was performed during the debris removal campaign which generated good visual results but raised issues with the manipulators.

This led to further development of the inspection payload design, the outcome of which was higher resolution images closer to the walls and at better angles than a typical centrally aligned camera could get.

The Alpha 5 manipulator was retained but this time attaching a high resolution 4K inspection camera with x20 zoom and short focal range. This camera was designed and made in house at Bay Dynamics.

Figure 9:   CAD Model of Final Inspection Payload



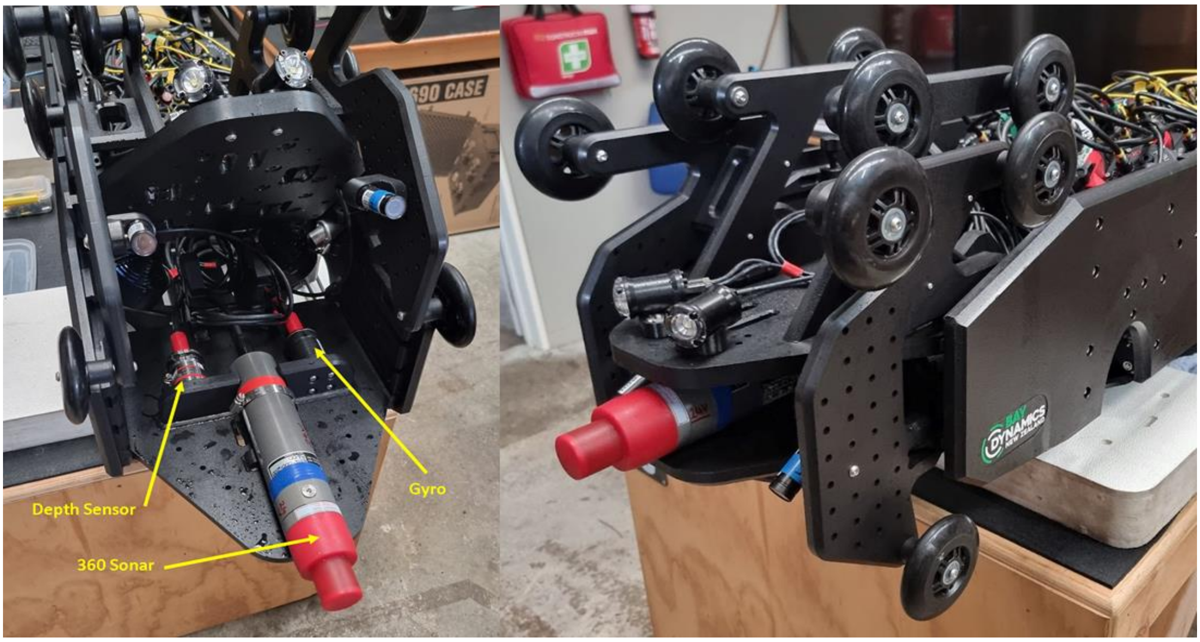
PAYLOAD: 360 SONAR SCAN

The purpose of this payload is to digitally scan the pipe for a dimensionally accurate point cloud and digital mesh of the pipe with the goal of taking measurements and analyse any anomalies for repair planning.

This is done utilising the Imagenex 831L Pipe scanning sonar. This sonar is a single beam rotating echosounder with the ability to measure pipes up to 5m in diameter with range resolutions down to +/-0.5mm. This sonar operates by sending out an encoded pulse, waiting for this signal to return, then calculating the time of flight and using the properties of water to determine the distance travelled by the pulse. Immediately after the pulse, the sonar head turns 0.9 degrees and repeats the range measurement. This process is repeated continuously through the full 360-degree range of the pipe profile. One disadvantage of this sonar type is the need to travel very slowly to avoid the "corkscrew" effect where the ROV moves forward in between each full rotational scan creating non complete cross-sectional scans. Each complete rotation scan in this pipe takes about 1.3 seconds.

The sonar is accompanied by a survey grade Gyro, which measures Roll / Pitch / Heading, and also a survey grade depth sensor capable of measuring total water depth to a resolution of +/-1mm. When this information is combined together with the digital cable counter on the ships deck, the total information can be combined to create a globally referenced 3D point cloud, and subsequently a digital mesh of the pipe itself.

Photo 7: Sonar Payload with Gyro and Depth Sensor



OPERATIONAL PHASES

The operations were conducted from the back deck of a 24m work boat. With the assistance of divers, the ROV was inserted into the pipe, and the subsea tether pulley installed to ensure the cable did not rub against the pipe crown.

Photo 8: Deck Set Up

Debris Removal

The first operation phase was debris removal which took three days to 'dismantle' the blockages and clear the pipe of debris. Approximately 120kg of grout debris was removed, the largest being 20kg in weight and measuring approximately 500mm in length. Three blockages were located removed. At the locations of these blockages, it was evident that over-grouting had created ridges on the pipe floor trapping large grout pieces and causing additional grout pieces to pile up and become wedged. The blockages formed significant cross-sectional restrictions to water flow.

Photo 9: Grout Debris Removed on Day 2

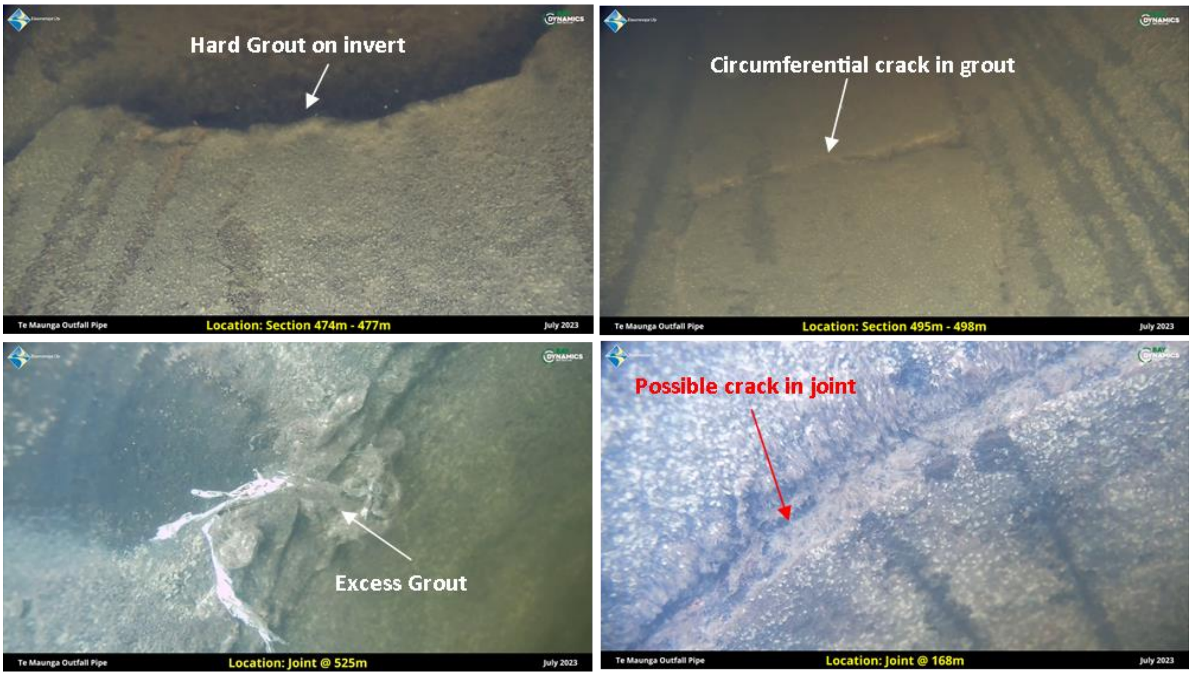
Visual Inspection of Pipeline

The second operational phase involved using the high resolution camera to inspect the internal pipe wall and joints. This inspection established that a significant number of joints had excessive grout protrusions into the pipe.

Photo 10: ROV with Inspection Payload

The inspection yielded very good images and detected some type of anomaly on almost every one of the 316 joints. The most common anomaly was the excessive grout protruding into the pipe.

Photo 11: Screenshots from Inspection



At the time of drafting this paper the imagery collected is in the process of being assessed and catalogued.

Sonar Scan

It was decided to delay the sonar scan until after all the visual inspection data collected has been analysed and critical areas identified.

An alternative scanning method may be considered, using laser scanning to get resolution accuracy of +/-0.4mm. These scans would yield better results than a sonar-based capture. The equipment can be accommodated in the same payload.

FUTURE PAYLOADS

The ROV is designed with the front payload system as its primary focus. This allows for any number of payloads to be designed and built in the future to expand the ROV's capability.

Possible future payloads, some of which are in the design stage, include:

- Grinding Payload: This will allow for the removal of excess concrete or grout from a pipe wall.
- Pressure Injection Payload: This will allow for cracks or spalling to be filled in with underwater concrete for patch of area repairs. Used in conjunction with the Grinding payload this will enable permanent internal repairs to be realised.

- Patch Lining Installation: This could allow for small patches of lining material to be installed.
- Forming Payload: For installation of bracing or concrete.
- Cutting Payload: For cutting soft material such as wood or organic growth.
- Jack Hammer Payload: To allow the breaking up of concrete or hard material that is not mobile.
- Photogrammetry Payload: Allow for textured 3D models of pipes or tunnels to be made

CONCLUSIONS

The rapid development of new technologies is opening up opportunities to explore alternative means of addressing problems in safe and efficient way to deliver similar or better outcomes to conventional means.

This project has demonstrated that it is possible to engage in a partnership with a local supplier to develop an innovative methodology using the latest available technology to overcome challenges and generate positive outcomes for both parties, namely

- For Tauranga City by removing blockages without causing further damage; by obtaining high resolution images that were not previously possible; by providing a vehicle free of charge for ongoing works inside the pipeline.
- For Bay Dynamics by enabling them to build a system that can be used commercially to solve similar problems elsewhere in the Country.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of Pacific Diving, in helping with the design of the tether, providing a stable vessel deck, providing access to the pipeline and with inserting and retrieving the ROV from the pipe end.

REFERENCES

None