Major Pipe Jacking for Perth Desalination and Main Sewer Projects

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This paper presents case studies of two major projects incorporating large diameter pipe jacking. The paper includes all aspects of project delivery including planning, design, procurement and construction from the unique perspective of the client, the designer, the contractor and the pipe manufacturer. In detail the paper includes:

1. *A description of the projects, the Perth Desalination – Water Supply Trunk Mains and Perth Main Sewer, which included the installation of DN1500 & DN1800 concrete jacking pipes in variable soil conditions including sections below the water table with drive lengths in excess of 200 m.*
2. *Key risks and challenges of the projects including major road and rail crossings, a new outlet pipeline into an existing reservoir and installing large diameter sewers in a congested urban area. Any delays or errors would place other associated major projects at risk (valued at hundreds of millions of dollars).*
3. *Risk mitigation incorporated into the design of the pipelines and specification of the jacking pipe & pipe jacking methods, procurement and contractor selection.*
4. *The contracting strategy and contractor selection process including pipe jacking equipment, design and location of shafts.*
5. *The design and manufacture of concrete jacking pipes and the pipe jacking construction including challenges and achievements.*

These projects by a major Australian water authority are an excellent model of how a cooperative approach between the client, designer, constructor and supplier can provide a technical solution to mitigate serious project risks associated with microtunnelling in a congested urban environment.

1 INTRODUCTION

In 2005 and early 2006, pipe jacking techniques were used in the delivery of two strategic projects of the Water Corporation, namely the Perth Desalination – Water Supply Trunk Mains and the Perth Main Sewer Section 5 Stage 2. Although the projects are quite different in nature, they both employed pipe jacking methods using closed–face, remotely controlled laser guided steerable tunnelling equipment, or to use the North American definition, microtunnelling (ASCE 36-01). This paper describes how a cooperative approach between the client, designer, constructor and supplier can provide a technical solution to mitigate serious project risks associated with pipeline construction in an urban environment.

2 DESCRIPTION OF THE PROJECTS

2.1 Perth Desalination – Water Supply Trunk Mains Project

In mid 2004 the Western Australian Government gave final approval to proceed with a reverse osmosis seawater desalination plant and associated infrastructure which would provide a rainfall-independent solution to the long running drought in Perth. The desalination suite of projects included the desalination plant (located at Kwinana), a DN1200 trunk main from the desalination plant to Thomsons Reservoir in Beeliar, a DN1400 trunk main from Thomsons Reservoir to a new major pump station in Forrestdale and modifications at Thomsons Reservoir.

2.1.1 Major Road and Rail Crossings

The DN1200 trunk main was 10km long and the route traversed varied developed land including the major industrial area of Kwinana and included crossings of two major rail lines and a major highway.

The DN1400 trunk main was 12km long and included an important crossing of the main Kwinana Freeway where works were already underway for the construction of a major passenger rail line in the Freeway median.

2.1.2 Thomson's Reservoir

Storage at Thomsons Reservoir consists of a single concrete lined pond of 93ML capacity constructed approximately 53 years ago as a local zone storage reservoir. However with higher inflows from the Perth Desalination Plant, a larger inlet and outlet were required to increase the reservoir outflow capacity to deliver bulk water into the integrated water supply scheme as well as the local zone.

2.2 Perth Main Sewer

The Perth Main Sewer included a major upgrade of a section of one of the original main sewers in Perth at Leederville, approximately 5 km from the city centre. The existing sewer was constructed in the 1930's using unlined reinforced concrete pipes which had been significantly corroded by hydrogen sulphide attack. The section to be replaced included 865 metres of main sewer over which shops and buildings had been built. The works also included over 1000 metres of reticulation sewers in existing roadways.

3 DESIGN AND PROJECT SPECIFICATIONS (THE DESIGNER'S PERSPECTIVE)

3.1 Perth Desalination Projects – Water Supply Trunk Mains

The design of the trunk mains was undertaken in traditional stages of preliminary design, engineering design and detailed design. Due to commitments to limit interruption to road and rail traffic, four locations were identified where trenchless construction was considered necessary. Risk analysis identified different drivers and design issues at each location, which are summarised in Table 1.

Table 1 - Design Risks and Mitigation

Location	Ground Conditions	Design and Risk to be mitigated
Kwinana Railway DN1200 MSCL[1] (two locations)	Wet sand Possible limestone pinnacles	• Sleeve mandatory for protecting railway in the event of main failure • Tolerance on sleeve to permit subsequent installation of welded MSCL pipe • No interruption to rail traffic
Rockingham Road DN1200 MSCL	Dry sand Limestone pinnacles	• Limit interruption to road traffic
Kwinana Freeway and Mandurah Railway DN 1400 MSCL	Wet sand	• Sleeve under future railway • No interruption to freeway traffic • No impact on freeway pavement running surface • 120 metre drive under both freeway carriageways and railway in median • Earthing of sleeve and product pipe in relation to the railway electric power system

1. MSCL = Mild steel cement lined

All of the railway crossings required a sleeve to protect the railway embankment in the event of a failure of the pressurised water main. Agreements were reached for tunnelling under these crossings but tight constraints were imposed including fine tolerances on settlement and vibration.

Due to the length of the Rockingham Road crossing, and the nature of the rocky ground, it was considered that construction of the water main inside a sleeve was justified in that this construction method would provide the lowest risk to the corrosion protection on the outside of the water main.

Hence the four crossings were bundled into a single contract with a common requirement to install a sleeve using microtunnelling and retrofit the welded MSCL water main inside the sleeve. This bundle was tendered as a design and construct package with specific design issues to be addressed in the tender. These included:

- Submission of computations for loading stresses on the sleeve pipe due to jacking loads and surface loads;

- Tolerance on the constructed level of the sleeve pipe so that a minimum annulus around the water pipe was maintained, and assuming that the water main is a rigid pipe, i.e., the steel water main cannot be bent around bends in the product pipe due to construction tolerance;
- Specified closed face, pressure-balanced machines to minimise settlement, or voids on the outside of the sleeve pipe. This was considered necessary to minimise the risk of any settlement on voids threatening the operation of the railway, or the riding surface of the freeway pavements;
- Minimise voids by limiting the size of the cutter head to be not more that 10 mm greater than the sleeve pipe diameter;
- Installation of threaded ports in every 4th precast concrete sleeve pipe to allow lubrication and later grouting;
- Detailed construction planning to be submitted in advance to ensure well thought out procedures and contingency plans;
- Sleeve pipe joints to be water tight to control any lubrication and grouting fluids from entering to the inside of the sleeve pipe;
- Tunnelling machine to be steerable to control tolerances;
- High electrical resistance of the sleeve to mitigate possible induced voltage differences between the sleeve and the steel product pipe.

The annulus between the sleeve and the product pipes was grouted with low strength cementitious grout as it was considered that this provided a conservative yet cost effective solution to prevent possible corrosion of the inaccessible exterior of the product pipe.

3.2 Thomsons Reservoir

Thomsons Reservoir is a large concrete lined and roofed earth reservoir approximately 6 metres deep. Construction of a new DN1400 outlet was identified as a significant risk to the integrity of the 53 year old reservoir structure due to:

- Construction impact on the relatively thin concrete lining and jointing system; and
- Introduction of a possible leakage path along the outside of the pipeline.

The reservoir concrete lining is highly sensitive to any form of soil displacement beneath the structure. In addition, crane access to the interior of the reservoir was limited due to load limitations on the existing access ramps, and foundation limitations for large cranes with the capacity to reach over the top of the embankments.

At the time of the design of the reservoir outlet, it became evident that the equipment proposed by the successful tenderer for the desalination pipelines would also be suitable for the reservoir outlet. Cost assessment of the options also showed that it was slightly cheaper. Previous use of this method of construction at the Water Corporation’s Albany South Coast Reservoir Pond No. 2 in mid 2003 proved that this was also a lower risk option. Accordingly, the reservoir outlet was designed with this equipment in mind.

Effective grouting of the exterior of the sleeve pipe to seal it into the reservoir embankment was essential to prevent any possible leakage from the reservoir and as such threaded ports were specified in every pipe.

To maximise the usable volume in the reservoir, the new outlet pipe was required to exit the reservoir from a deep pit in the floor of the reservoir. The outlet structure was designed to serve the dual purpose of receival shaft for the tunnelling machine and the permanent outlet structure for the reservoir. A rectangular caisson shaft was constructed to achieve this.

3.3 Perth Main Sewer

The Perth Main Sewer is at the end of its serviceable life, due mainly to hydrogen sulphide attack on the concrete pipes in the headspace of the sewer. It is being replaced in sections under a program that has been progressive over the last 10 years or more. The extent of corrosion and the high cost and disruption of bypass pumping makes relining of the old sewer impractical.

It was planned that this particular section would be replaced using conventional open cut and plastic lined reinforced concrete pipes. This planning work was done several years previously and it became evident that significant traffic growth in the meantime would result in major impacts to both commuters and the local business area if open cut methods were to be used.

The alignment of the sewer has a significant impact on road traffic, a busy high-speed bike path and adjoining mature trees. In addition, as the level of the sewer is below the water table in free draining soil, open cut construction would require significant well-point dewatering. Disposal of the groundwater presented an undesirable environmental impact and temporary lowering of the groundwater table presented a high potential risk for structural damage to nearby structures.

A review of the estimates taking into account current steel sheet piling costs revealed that trenchless technology offered not only a significantly reduced construction impact, but also offered an approximate 25% cost saving.

4 CONTRACTOR SELECTION (THE CLIENT PERSPECTIVE)

4.1 Perth Desalination Projects – Water Supply Trunk Mains and Thomsons Reservoir

Contractor selection for the microtunnelling contracts was preceded by a number of key project activities. Extensive risk assessment workshops were undertaken at key points in the projects from high level down to detailed elements. GIS modelling and multi-criteria analysis together with extensive stakeholder consultation was essential in pipeline route selection and provided the constraints that fed into the risk assessment and contracting strategy. An assessment was also undertaken of market capability and constraints for the various contract options. Importantly, the time to establish and execute the contracts was carefully determined including contingency assessment to ensure the contracting strategy could deliver the assets in the tight timeframe.

Significant risks were identified during the risk assessment process including selection of the right contractors for tunnelling works. Any delays or errors would delay the delivery of water by October 2006, putting at jeopardy hundreds of millions of dollars worth of associated works for the whole of the Perth Desalination project.

From the key project activities, a comprehensive contracting strategy was developed for the complete suite of integration projects including details on the strategy for the microtunnelling contract.

Critical to the microtunnelling contract was a frank assessment of client knowledge and expertise in tunnelling as well as a detailed assessment of industry capability and capacity, equipment availability and personnel. The Water Corporation were fortunate to have two employees with extensive tunnelling experience in Europe, Southeast Asia, the east coast of Australia and previous projects in WA providing a wealth of knowledge in these areas.

The microtunnelling strategy included a “Registration of Interest” during the engineering design stage followed by selective tendering from the pre-qualified tenderers near the end of detailed design. This strategy ensured high quality contractors who could deliver on time whilst also providing a competitive environment for pricing. This resulted in minimisation of risk to costs and schedules. Tenders received were checked for completeness and conformity including a “Tender Response Schedule” against the following components:

- Specific microtunnelling methodology;
- Proposed design details;
- Installation methodologies;
- Site layout including details of launch & retrieval pits;
- Equipment details;
- Sleeve pipe details;
- Grouting details;
- Key contract personnel.

Tenders were then assessed using a weighted points scoring system against the Selection Criteria of:

- Microtunnelling design and methodology;
- Capacity to undertake the contract (including equipment and expertise);
- Key personnel;
- Demonstrated ability to complete the contract in the timeframe;
- Cost; and

- Buy local policy considerations.

Assessment of tenders showed that capacity was a major factor with many interested contractors unable to deliver the project as their tunnel boring machines were tied up in existing contracts either on the eastern seaboard of Australia or overseas.

The contracting strategy proved very successful in contractor selection with assets delivered on time, to a high standard and below budget.

4.2 Perth Main Sewer

The Perth Main Sewer project went out to tender from a list of seven selected tenderers and the tender analysis utilised a scoring system similar to the above but with slightly different criteria and weightings.

5 JACKING PIPE DESIGN AND MANUFACTURE (THE PIPE SUPPLIER'S PERSPECTIVE)

Precast concrete jacking pipes for both projects were designed and manufactured by Humes at their concrete pipe factory in Welshpool, Perth, Western Australia. The pipes supplied were what the pipe supplier refers to as a J Series jacking pipe and these projects were the first significant use this pipe.

5.1 Jacking Pipe Development

Until recently within Australia, and earlier in other countries, reinforced concrete jacking pipe designs have typically been based on a modification of pipes originally intended for installation in open trenches. In Australia this lead to the adoption of two different joint configurations, the butt joint and in-wall (rubber ring) joint, which have typically been recommended for culvert/stormwater and sewer/ pressure pipe applications respectively (CPAA). The pipes have some limitations which means that they are often not suited for use with modern microtunnelling equipment.

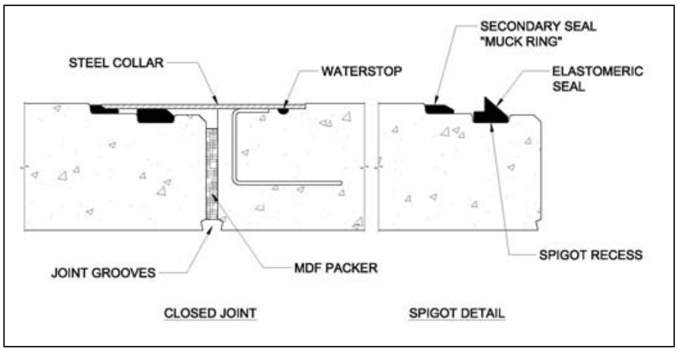

Figure 1 - J Series Jacking Pipe Joint

In 2003, Humes began development of a steel collar jacking pipe that was compatible with modern microtunnelling equipment. One of the key performance criteria identified early was the ability to retain the seal within a deflected pipe joint subject to external hydrostatic pressure due to either groundwater or external lubrication fluid. As part of the product development prototype designs were tested with external hydrostatic pressure applied to the joint. Testing led to the conclusion that the best joint profile included locating the seal in a deep recess on the pipe spigot leading to the adoption of the final joint detail shown in Figure 1. This recess retains the seal inside the joint when subject to either internal or external hydrostatic pressure. DN1800 pipe joints were successfully tested at an external pressure of 500 kPa at 1 degree deflection, prior to the commencement of the Perth projects.

5.2 Jacking Pipe Design

The jacking pipes were designed in accordance with the specification and the contractor's installation requirements. There is no Australian Standard for precast concrete jacking pipes in Australia, although some existing standards are relevant to some aspects of the jacking pipe design and manufacture. In general, the pipe design for both projects involved the following:

- Selection of minimum pipe load class (AS 4058) to suit the permanent loads (earth, road and rail live loads) acting on each section of pipeline in accordance with AS 3725 and AS 4799.
- Maximum allowable jacking forces and associated joint deflections were calculated in accordance with published literature (CPAA-1990); maximum values are listed in Table 2.
- External cover to reinforcement was selected based on the groundwater analysis contained in the Specifications. Other durability requirements for each project are detailed below.

- Four 20 mm internal diameter stainless steel threaded ports were cast into every fourth pipe which included a threaded plug on the inside and a simple non-return valve on the outside face. For the Thomsons Reservoir drive, all pipes supplied included these ports.

For the Desalination Plant pipelines jacking pipes were designed as sleeve pipes. The specification required that pipe joints provide a “tight waterproof seal” and for all crossings the joint detail shown in Figure 1 was supplied. The flexible joint of the jacking pipe was only required to have a limited life and as such mild steel (uncoated) was selected as the pipe collar.

For the Perth Main Sewer the jacking pipe was the product pipe and to meet the design life requirements for this project thermoplastic lining was cast into the inside surface and collars were manufactured from Grade 316 stainless steel. The internal lining was a 1.5 mm thick plasticised PVC cast into the top 350 degrees of the pipe with a cover strip welded across each pipe joint. Intermediate jacking station pipes were designed in part based on the requirements of an existing Japanese Specification (JSWAS-A2). The lead pipe (or can) was mild steel (epoxy coated) designed to joint into the collar of a standard jacking pipe. The trail pipe was a modified precast concrete pipe that was also lined with plastic. The internal diameter of the lead pipe was greater than the standard pipes allowing for the installation of wider plastic strip welded across the closed joint maintaining the continuity of the plastic lining along the full length of the completed pipeline.


(a) Joint External Hydrostatic Testing


(b) PMS – Pipes in storage


(c) Installation of Interjack Pipes

Photograph 1 - Jacking Pipe Testing, Storage and Installation

5.3 Pipe Manufacture

Details of pipes manufactured for projects are contained in Table 2. Pipes were manufactured using the centrifugal spinning process which gives an off form finish on both ends (jacking faces) of the pipe and consistent concrete quality throughout. Steel collars were fabricated to tight tolerances ($\pm$1.5 mm on diameter) and then placed on a machined former in the mould which ensures the collar both held firmly in place and round during casting. The pipe spigot is formed using a machined former fixed to the mould.

Table 2 - Jacking Pipe Details

Internal / External Dia. (mm)	Pipe Length (m)	Pipe Mass (t)	Pipe Jacking Capacity [1] (t)
1500 / 1800	2.32	4.85	800 / 430
1800 / 2150	2.32	6.72	1050 / 600

1. Jacking forces (tonnes) listed included the maximum allowable values for straight and deflected (0.5 degrees) joints.

6 CONSTRUCTION OF JACKED PIPELINES (THE CONTRACTOR’S PERSPECTIVE)

The projects involved a total of eleven separate drives of both DN1800 and DN1500 pipes as detailed in Table 3. The Perth Main Sewer project also involved the installation of 1000 m of reticulation sewers.

6.1 Pipe Jacking Equipment and Personnel

The DN1800 pipes were installed using a Herrenknecht AVN 1800 slurry shield tunnelling machine and the DN1500 pipes were installed using a Herrenknecht AVN 1200 slurry shield machine with conversion kit. Cutting wheels for the drives ranged from soft, mixed and rock, dependent on the expected ground conditions. With these machines, drilling fluids were pumped to the excavation face via slurry charge pipes and material excavated at the face passes through a cone crusher to the slurry discharge pipes. Slurry pumps were used to transport the slurry (fluid/soil mixture) to settlement tanks at the surface where the solids were separated and the water was recycled back into the system. For the Perth Main Sewer project slurry pipelines were supported on specially designed frames that resulted in zero damage to the plastic lining during both jacking and removal of slurry lines at the completion of jacking operations (see photograph 2b).

The contractor employed only experienced crews on all stages of the microtunnelling operations. In particular all tunnelling machine operators had installed many kilometres of pipe of this diameter using the same equipment in similar soil conditions.

Table 3 - Summary of Drives for DN1500 & DN1800 Pipes

Line No.	Description	Pipe Dia. (mm)	Line Length (m)	Cover to top of pipe (m)	No. of Interjack Stations	Duration / Shift [1]	Max Jack Force (t) / kPa [2]
Perth Desalination Plant – Water Supply Trunk Mains & Thomsons Reservoir							
#1	Rail Crossing at Kwinana	1500	65	2 - 3	0	8 / S	78 / 2.1
#2	Rockingham Road Crossing	1500	52	2	0	11 / S	64 / 2.1
#3	Rail Crossing at Quarry	1500	50	2 - 4.5	0	4 / S	72 / 2.5
#4	Kwinana Freeway Crossing	1800	109	2 – 6	0	6 / D	156 / 2.1
#5	Thomsons Reservoir Inlet	1800	45	2 - 8	0	3 / S	74 / 2.4
Perth Main Sewer Section 5 Stage 2							
#6	Ch. 39 to AC N1814	1800	148	2.0 – 3.5	1	9 / S	167 / 1.6
#7	AC N1814 to N1815	1800	137	2.5 – 3.0	0	7 / S	146 / 1.5
#8	AC N1815 to N1816	1800	93	2.5 – 3.5	0	5 / S	116 / 1.8
#9	AC N1816 to N1817	1800	102	3.0 – 3.5	0	4 / S	158 / 2.2
#10	AC N1817 to N1818	1800	226	3.5 – 4.0	1	6 / D	176 / 1.1
#11	Ch. 21.8 to 144.9	1500	123	1.8 – 2.5	0	7 / S	132 / 1.9

1. Durations stated are days of actual pipe jacking only. S = single shift, D= double shift (24 hour operation).
2. kPa figures listed = (maximum jacking force) ÷ (external surface area of the full length of jacked pipeline).

6.2 Shaft Construction Methods

For the Perth Main Sewer project, 7m diameter reinforced concrete caissons were specified for the jacking and receival pits and these were designed and constructed by the contractor. Shafts were poured on site in nominal lifts of approximately 1.5 metres above ground, cured and then lowered by excavating mostly using a clamshell. A concrete plug cast at the base of the shaft provided both stability and a watertight structure. Steel reinforcing was excluded from the shaft at pipe exit and entry locations. A thrust block was cast on the back wall of the shaft to provide the necessary reaction to the 850 tonne jacks. On the opposite wall an entrance seal, consisting of steel ring and single gasket, was bolted to concrete cast against the circular shaft, preventing the ingress of soil and water into the shaft as jacking pipes passed through the opening.

6.3 Steering and Monitoring of Line and Level

The tunnelling machines used were laser guided and remotely control from a cabin at the surface. The specified tolerance on line and level for each of the projects were:

- Desalination Plant Pipelines - tolerance on line only with "*the maximum deviation from straight shall be 10 mm over any 2.0 m length and 25 mm over any 12.0 m length of installed pipe".*
- Perth Main Sewer - as above and a "*25 mm tolerance on vertical alignment*".

All lines were installed within the specified tolerances with no backfall or low points on the very flat grade (1 in 20) of the sewer lines.

6.4 Lubrication, Interjack Stations and Jacking Forces

Lubrication was used on all drives by injection of fluid into the external annulus through the lubrication ports cast into the pipes. Lubrication fluid consisted of a mixture of bentonite and other additives to match the expected ground conditions. Jacking forces were carefully monitored by the operators and controlled by a combination of accurate steering, lubrication (manual system), shift times and the use of interjack stations. As can be seen in Table 2 jacking forces were maintained well below the jacking pipe capacity. Intermediate jacking stations were installed on two drives but were only used on the longer one (drive #10).

a. Perth Main Sewer site

b. Slurry pipes & lubrication lines

c. Installation of MSCL Pipe

Photograph 2 – Construction of Jacked Pipelines

6.5 Post Installation Activities

For the Perth Main Sewer pipelines access chambers (manholes) were constructed within the caisson structures using a combination of precast concrete pipe and shaft sections and insitu concrete construction. Testing involved a visual inspection of the completed pipelines and spark testing of the plastic lining. No leaking joints were detected out of almost 400 pipe joints within the 800 m length of main sewer installed.

7 CONCLUSIONS

The success of the two pipe jacking projects is attributed to the following:

a) Carrying out detailed risk assessments at key stages in the projects;

b) Identifying and specifying project and design solutions that mitigate the identified risks. The key risk mitigation measures included selection of appropriate pipe installation techniques, specification of minimum tunnelling machine and jacking pipe requirements and required use of caissons for entry and exit shafts for the Perth Main Sewer;

c) A tendering process that ensured only appropriately experienced contractors with the correct equipment and personnel were selected; and

d) Close cooperation and interaction between the client, designer, pipe jacking contractor and pipe manufacturer during key stages of the project from design through to commissioning.

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