

# **REFURBISHMENT OF LARGE DIAMETER PRE-STRESSED CONCRETE PIPELINES: B7 PIPELINE, A CASE IN POINT**

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## **ABSTRACT**

Rand Water was established in 1903 as a Bulk Water Supplier. Rand Water is a State Owned Enterprise based in South Africa. It provides bulk potable water to more than 12 million people in Gauteng, parts of Mpumalanga, Free State and North West Provinces. The area of supply is 18 000 km<sup>2</sup>. This area has been extended by another 13 000km<sup>2</sup> by Act of Parliament.

Rand Water's distribution network consists of over 3 300 kilometers of large diameter pipes (ranging from 450mm diameter to 3 500mm diameter). About 10% of Rand Water's pipelines are pre-stressed concrete pipelines and the rest are steel pipelines. Water is supplied to 58 strategically located service reservoirs, the largest of which is the Klipriviersberg reservoir with a capacity of 650 megalitres.

Our customers include metropolitan municipalities, local municipalities, mines and industries. Although Rand Water is a State Owned Enterprise, it has remained financially self-sustaining throughout its existence.

Rand Water supplies all its potable water from two water treatment plants, namely Zuikerbosch and Vereeniging. These water treatment plants are situated approximately 70 km away from the secondary booster pump stations.

B7 pipeline supplies potable water to the western suburbs of Johannesburg from engine room 3 of Zuikerbosch Water Treatment Plant to Eikenhof Booster Pump Station.

Given the condition of this pipeline, a number of technologies needed to be employed to refurbish it. These technologies will be explained later in the paper. Since this pipeline could not be taken out of service for a long time due to operational requirements, the refurbishment work was done in two phases. The paper will address both phase one as well as phase two.

The scope of work for both phases included:

- Eddy Current Scanning
- Carbon fibre repairs.
- Slip lining of portions of the pipeline
- Installation of seals at pipe joints.
- Chambers rehabilitation.

## **ORGANISATIONAL BACKGROUND**

Established in 1903, Rand Water has a proud 107 year history of supplying bulk potable water to its customers. The organisational success is based on sharing in the pioneering spirit that led to the growth of the City of Johannesburg. It is the same spirit that has driven growth in terms of our infrastructure and the quality of our product.

Johannesburg is one of the few cities in the world that was established far away from a water source during the gold rush back in the late 19<sup>th</sup> century. Large amounts of water are pumped to relatively high altitudes in Johannesburg, and that, in ensuring a successful operation, specialised skills have been acquired and maintained in Rand Water, which have benefited the company for many years.

Raw water is abstracted from the Vaal Dam and then purified and disinfected in Vereeniging and Zuikerbosch Purification and Pump Stations. The water is then pumped to Zwartkopjes (our main booster pumping station) and to our other booster pumping stations situated at Palmiet, Eikenhof and Mapleton. From here, the water is pumped again to our 58 large reservoirs located at strategic points within our area of supply. It is from these reservoirs that we deliver the water to our customers.

Our customer base includes metropolitan municipalities, local municipalities, mines and industries and, as such, Rand Water provides clean potable water to 12 million people across the area of supply. Rand Water has an internationally acknowledged reputation for supplying quality water that ranks among the best in the world and on the back of this, we continue to be trusted by various government departments as an implementing agent in various community projects that are aimed at improving the lives of the people of South Africa.

South Africa's map below shows Rand Water's area of supply, with Gauteng being the economic heartland of the country.



Figure 1: South African Map and Provinces

Rand Water supplies on average 4 000 megalitres of water on a daily basis. Its major customers are Johannesburg, Tshwane and Ekurhuleni Metropolitan Municipalities. These top three customers consume about 75% of the total supply.

## **B7 PIPELINE IN THE CONTEXT OF THE OVERALL BULK WATER DISTRIBUTION NETWORK**

B7 pipeline is made up of a 25 000 meter pre-stressed concrete section as well as 20 000 meter steel section with an internal diameter of 2100mm. This pipeline was laid in 1972/3 and supplies 400 mega litres per day at a nominal pressure of 12 to 15 bars. The B7 pipeline can deliver a maximum of 600 mega litres per day. This is further illustrated in figure 2 below, which shows and oversimplified diagram of the bulk water distribution network.

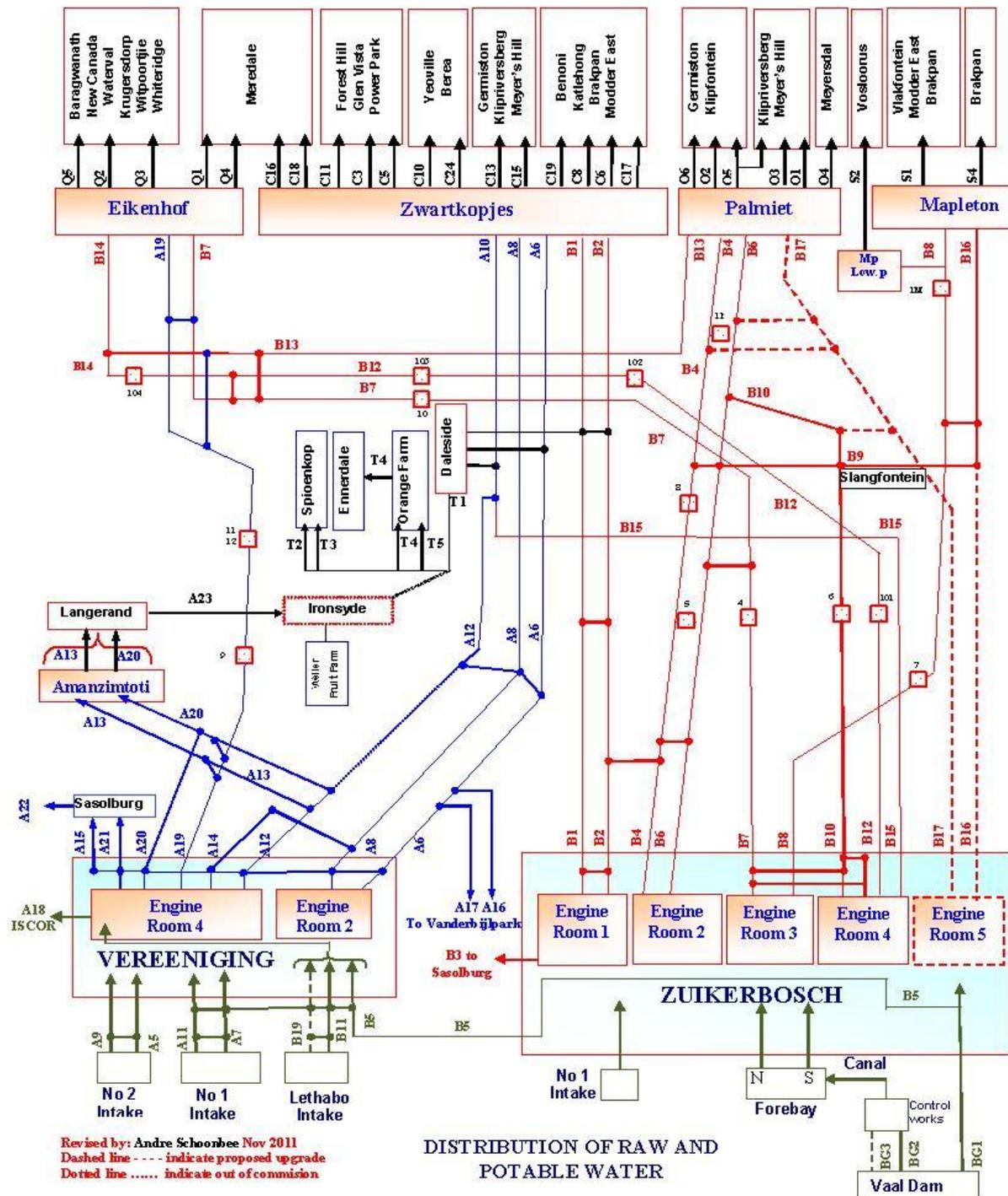


Figure 2: Rand Water Bulk Water Distribution Network

## TECHNOLOGIES AND METHODOLOGY

The objective of this paper is to share experiences regarding rehabilitation of aging large diameter pre-stressed concrete pipelines, under the most challenging circumstances, as well as combining different technologies in order to derive the best solution.

Pre-stressed concrete pipelines have a life expectancy ranging anywhere between 50 to 70 years depending on the quality of pipe, the quality of works at installation and quality of operation. On an on-going basis, Rand Water conducts integrity assessments to its pipelines and infrastructure. In 2007 Eddy Current Scanning was conducted on the PCP section of the B7 pipeline in order to determine the condition of the pre-stressed wire bindings.

The results indicated that in certain pipe sections, there were wire breaks ranging from 1 to 6 wire breaks.

Due to the criticality of this pipeline it became necessary to only target the winter months for rehabilitation, as the demand is slightly lower during those months.

Phase 1 project was thus carried out during June to August of 2011.

The phase 1 scope of work included:

- Eddy Current Scanning of 25 000m of pipeline.
- 20 Carbon fibre repairs.
- Slip lining of a total 3500m stretch of pipeline at three different areas.
- Installation of 2 400 Ethylene Propylene Diene Monomer (EPDM) rubber seals at pipe joints.
- Chamber rehabilitation.

Phase 2 was carried out during April to July of 2012

The phase 2 scope of work included:

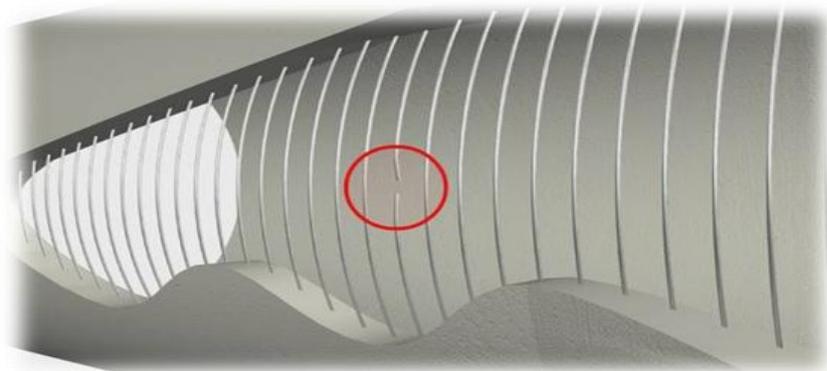
- Slip lining 1050m of 2025mm OD steel pipe
- Slip lining 5805m of 1950mm OD steel pipe at different areas
- Installation of 91 EPDM rubber seals on joints that will not be affected by slip lining
- 10 Carbon Fibre repairs for wire breaks
- Valve replacements and Chamber rehabilitation

## **BRIEF EXPLANATION OF EMPLOYED METHODS AND TECHNOLOGIES**

### **EDDY CURRENT SCANNING**

Modulated electromagnetic waves are sent through the concrete via probes that detect and register the reflection of these signals. Software visualises these results which are compared with the calibrated image to determine the exact number of wire breaks.

Modulated electromagnetic waves are sent into the pre-stressed concrete pipe and High precision detectors register the reflection of these signals. The electronic software visualises these results and a verification technique enables us to identify both the area of the wire break(s) as well as to quantify the number of wire breaks. Pre-stressed concrete pipelines in the range of 600mm to 4 000 mm can be scanned. The analysing tool enables Rand Water to obtain results of the number of wire breaks as well as the position of the wire break along the length of the pipeline (Figure 3).



*Figure 3: Schematic depicting wire break in PCP*

Depending on pipe diameter, two to ten kilometres can be scanned per day.

However the application of these technologies requires that pipelines must be greater than 600mm in diameter and that the pipeline is taken out of commission and dewatered.

While non-destructive technologies e.g. Eddy Current Scanning represents the most accurate means of determining the integrity of the pipeline, operational challenges prevent a more regular means of

assessing its integrity. As such, there is a need for the use of non-interruptive technologies to assess the risk of the probability of failure.

### **CARBON FIBRE (STRUCTURAL REPAIR OF CONCRETE PIPES)**

Depending on the pressures of the pipe, a carbon fibre design consisting of variable layers of specific fabric, specific resins and infusion methods are utilised. The repair is finished off with a flow coat, and the complete repair gives rise to a wholly protected defective pipe section returning the pipe to fit for purpose.

The repair method is conducted in a fast and cost effective manner. The versatility of the method ensures the remediation on broken pre-stressed wires.

Carbon Fibre repair can be applied for all structural repairs, (internal as well as external). High pressure pipelines (greater than 60 bar) can also be repaired with this technique. Internal repairs are possible in pipes that range from diameters at 800 mm to 4 000 mm.

The actual application is a result of calculations based on a number of factors including, maximum pressure and pipe diameters.

A sequence of installations procedures follow from cleaning to initial drying and sealing methods, before the first ply is applied. The number of ply's is predetermined and a final vacuum infusion of resin takes place under ideal conditions to ensure a quality, long lasting, indestructible installation.

The carbon fibre product complies with all the requirements for use in the potable water industry. Safety standards from the oil industry and applied. Every repair comes with its specific material data sheet.

All quality control procedures are documented and reported. Figure 4 below shows the completed carbon fibre repair in the pipe.



*Figure 4: Carbon Fibre Repair*

### **SLIP LINING OF PRE-STRESSED CONCRETE PIPELINES**

In this case, we insert a steel section within the defective pre-stressed concrete pipe leaving an annulus of approximately 75mm between steel and host pipe. This annulus is grouted with a cementitious grout of suitable pH that protects the steel pipe. The spigot and socket pipes are joined together and are ended with either steel to concrete conversion joints or welded to existing steel sections.

Based on the location of the defective pipes, several launch pit locations were identified, taking into account location of bends, inline valves together with their respective steel sections and reducers.

This is to enable the installation and fixing of steel pipe within the concrete pipe

With an internal diameter of 2 100mm, the best solution was to use high grade steel pipe sections of 5.1m length with spigot and socket joints as the slip liners. The length of 5.1m was based on the slight vertical and horizontal bends to be encountered; minimising the risk of steel pipe not passing bends.

The plan is to cut into the existing concrete pipe to create a launch pit through which the steel pipe sections will be inserted into the host pipe.(See Figure 5).



*Figure 5: A typical Launch pit*

The steel pipes are transported to the furthest points either side of the launch pit, where they are centralised. The remaining pipes are launched and fitted to one another through spigot and socket joints that are fillet welded together.

Grout nipples are installed to enable grouting of the annulus between the steel pipe and the host concrete pipe. Air/breather holes are established at predetermined locations to ensure the complete grouting of the annulus with a cementitious grout.

The ends of the first pipe launched and placed either side of the launch pit is fixed to the host concrete pipe with a steel to concrete conversion kit that is suitable to withstand the operating pressure of the pipeline.

There are major cost savings to be realised when opting to slip line rather than replace pipe or lay a new pipe. No need for land acquisition or property right issues etc.

Shorter shut down periods are required, leaving the pipeline productive with integrity intact sooner.

The life expectancy of the newly slip lined concrete section will have been extended to another possible 50 to 70 years at the reduced cost.

## **REPLACING EPDM SEALS AT JOINTS**

A general internal inspection shall be performed to ascertain the correct diameter of the various pipes. This detail is of paramount importance to the correct manufacture of the seals. It will also assist in determining the correct quantity of seals required’

EPDM rubber seals are used to seal pipe joints of aging pipes where the original fish tail seals begin to fail, preventing leaks when the pipe is under pressure. The design of the seals enables joint movement if warranted and are robust and non-abrasive. Stainless steel straps are pressured against the rubber at a predetermined pressure ensuring an even distribution of pressure throughout the circumference of the seal.

A defective seal is one of the primary reasons for the corrosion of the steel coils that surround prestressed concrete pipes. Long term leakage can create large voids under the pipeline, resulting in pipe movement which in turn leads to catastrophic failures at the joints of this type of pipe. Properly installed seals will prevent all leaks at the pipe joints. Most pipelines cannot be taken out of service for extended periods of time due to operational constraint of water supply. As such a rapid and reliable repair method is required.

The movement of pipes due to earth movement or water hammer can result in pipe pinch which could lead to exposure of the original fish tail seal and failure. Joint gaps should be within a certain tolerance beyond which an internal seal is recommended.

We use an internal seal made of a high performance EPDM rubber. The profile of the rubber seal is designed in such a way that internal pressure of the stainless steel rims would result in a perfect seal. These rubber seals are fixed with pacified stainless steel rims. Integrity of the pipe is restored with the added benefit of flexibility at the joints.

#### **Installation procedure**

- Wire brush joint area to remove loose surface.
- Apply an epoxy coating which is approved for the potable water industry (See figure 6)
- Install rubber seal with two stainless steel rings
- Jack to designed pressure – weld stainless steel straps into position
- Passivate welds to prevent oxidation.



*Figure 6: Installation of EPDM Rubber seal*

When multiple consecutive pipe segments are defective and the external environment does not allow for concrete pipe replacement, one of the few solutions is to slip line the existing concrete pipe. In the case of the B7 project, 3.5km of 2 100mm ID pre-stressed concrete pipe was slip lined at various locations along the 23km concrete section of the pipeline.

The award of the contract was finalized on the 13<sup>th</sup> May 2011 with the pipeline due to be handed back on the 29<sup>th</sup> July 2011 with proofing/charging of the line to be completed by the 5<sup>th</sup> August 2011.

During the project execution stage, pipe supply was interrupted by a strike from National Union of Metals Workers of South Africa (NUMSA). The contractors had built up a pipe float of 2 weeks by the 4<sup>th</sup> July 2011, the same day the strike action commenced. The strike action ended on the 18<sup>th</sup> July 2011.

The float had been eroded, and on site production fell behind almost three weeks. The net effect was that actual works on the pipeline would complete on the 7<sup>th</sup> August and proofing and charging finalised on 14<sup>th</sup> August.

The schedule for pipe launching, welding and grouting not only show the effect of the strike in week seven but also illustrate that these three activities were so closely harmonised to ensure that all three major activities completed within a couple of days of one another.

The slip lining work was completed after 14 weeks as compared to the initial contractual duration of 12 weeks. The timeframe for carbon fibre repairs was eight weeks after the results of the eddy current scanning were accepted. This also allowed for the importing of the carbon fibre fabric.

The timeframe for installation of seals at joints was 11 weeks which also allowed for the manufacture of the seals after determining the exact internal diameters of all joints along the full length of pipeline.

Safety and quality are of utmost importance, with safety files containing risk assessments for all activities being approved before the site can be handed over to contractors. A dedicated Health and safety officer was assigned to the project to ensure that the contractors worked in accordance to the approved regulation within the safety file.

A dedicated quality inspection officer was assigned to the project to ensure that all methods and quality plans were followed strictly ensuring an acceptable product on completion.

## **B7 PROJECT RESULTS PHASE 2**

The pipeline was drained and taken out of commission on the 28 March 2012, preparatory work for the assessment commenced the day after. A visual inspection checking for longitudinal and circumferential cracks, joint gaps, root intrusions etc. was then conducted. To detect further deterioration of the wire breaks, a condition assessment was conducted using a non-destructive electromagnetic technology. Slip line locations were prioritised allowing for the sections with the most concentration of defects being earmarked for repair

Sixteen (16) Launch pits were identified for insertion of the steel pipes into the pre-stressed concrete pipe. The steel pipes were supplied in 5.1m lengths with a spigot and socket. The short lengths were to ensure ease of the pipe insertions.

Two different contractors were appointed for phase 1 and phase 2 projects as per the outcome of the internal tendering processes.

As the contractors were relatively inexperienced in this type of work, the Rand Water project team gave advice based on their previous experiences of similar work. During the execution of works, the contractors deviated from the approved method statement for launching the pipes, welding and grouting, this impacted the progress of the works.

To ensure successful pipe launching, the steel pipes were to be launched and welded in reasonable increments per sections. Upon launching and welding, grouting will have to immediately follow to ensure stability of the launched pipes.

Pipes were launched for longer lengths than specified on the method statement; welding and grouting were left for a later execution period.

The industry was also generally experiencing a shortage of skilled welders. Welding activities commenced almost two months after the pipe launching activities. The impact of this was a delay in the following:

- Grouting of pipes
- Epoxy joint repairs
- Valve installation
- Overall programme of works

The welding thus had to be done round the clock so as to catch up on the programme. To ensure safety of the workers, extractor fans were acquired to alleviate the fumes in the work areas.

When pumping the grout, the pipes were not adequately propped, and the mix was pumped at a higher pressure, in an effort to fill the annulus. This resulted in buckling of sections of the steel pipe as can be seen in figure 7 below.



*Figure 7: Buckling of slip-lined pipe*

These sections were repaired by:

- Cutting out and removal of the buckled pipes
- chipping out the grout
- new sections of steel pipes were then launched to replace the damaged pipes

- adequate propping was employed

This caused further delays to the project. The delays in the grouting exercise extended the commissioning date to 10 August.

The pipeline was charged with water on 10 August 2012, two weeks behind schedule. During the pipe charging process, leaks were detected at three different positions along the pipeline, i.e. Leaking area at Pit no. 1F, Pit 2 and leaking scour valve as shown in figure 8 below.



*Figure 8: Leaking Scour Valve*

The pipeline had to be drained so as to allow repairs to be conducted on the leaking areas. The welds were dye panned and showed no anomalies, and mass concrete was placed around leaking joints. New adapter flanges were also installed. The work was successful, but upon commissioning of the pipeline leaks resurfaced.

The Pipeline Asset Manager then requested for a non-destructive leak detection and CCTV survey to be conducted along the sections of the leaks. The acoustic leak detection and CCTV survey method posed to be the best way of assessing the pipe as it reduces the impact of the day to day operation of the system, as well as loss of revenue and risk associated with draining and subsequently refilling the pipeline. The method is able to pinpoint the location of the leaks, while at the same time inspecting the internal condition of the pipeline using a combined acoustic hydrophone with integrated CCTV camera. This system uses the Sahara insertion platform and is capable of being inserted into live pipelines.

An operator controls camera deployment and views the video output in real time. A second operator uses a tracking tool to mark the surface locations of items of interest, in a similar manner to leak location.

The CCTV operating specifications are as follows:

- Maximum operating pressure: = 12 bar
- Flow velocity required is: >0.6m/s
- Pipe Diameter for Standard Insertion: 400mm and bigger
- Minimum Entry Point: 50mm diameter (80mm preferred)

The quality of the CCTV footage is adversely affected by the turbidity of the water. The efficiency of the live CCTV inspections will always be assessed first before making a collective decision to proceed.

The results from the leak detection and CCTV survey showed no anomalies. The pipeline was then left in operation. Further assessments and repairs will be conducted when the next shutdown is offered during off peak season. The contractor was requested to do some external repairs on the three leaking areas. The leaks have since subsided.

### **CHALLENGES FACED DURING B7 PROJECT PHASE 1**

It is important to note that for any project to be deemed successful, it has to be delivered on time, within budget and with all quality expectations reached.

The following challenges were encountered during this project:

Late adjudication and awarding of work. The B7 project was delayed by two weeks during these processes.

Delay of the procurement of coil by pipe manufacturer. The knock on effect of a late adjudication was that the contractor delayed his order to the pipe manufacturer, who in turn delayed his order for steel coil, resulting in the first pipes being delivered to site two weeks later than anticipated.

Isolation and draining of the pipeline. The isolation and scouring of the pipeline commenced 2 weeks before the final approval from the Tender Committee. It is a worthy note to confirm that the pipeline does not drain totally and that it took another week to open the access manholes and dewater using submersible pumps, impacting on the ability to Eddy Current scan the entire line in one continuous effort. Furthermore, the opening of manholes and dewatering as early as possible is crucial for ventilation and drying of the walls to assist with the Carbon Fibre application process.

Supply interruption of slip lining steel pipes due to industrial action. All the planning to ensure that the pipe manufacturer would have suitable steel coil from Accelor Mittal and ensuring that the manufacturer would have a confirmed slot to roll 3.5km of pipe did not prepare us for the unexpected industrial action called by the National Union of Metalworkers South Africa (NUMSA) on the 4 July 2011.

This strike went on for 2 weeks with a further 4 days for workers to get up to speed with the production of pipe. Without saying, this activity was on the critical path.

### **CHALLENGES FACED DURING B7 PROJECT PHASE 2**

Time was a major constraint in the project, as the work can only be executed during winter periods when the water demand is generally low. The following were the key baseline milestone dates:

- Start of pipeline isolation – 29 March 2012
- Commencement of construction- 31 March 2012
- Completion of construction activities – 21 July 2012
- Commissioning of pipeline – 28 July 2012

Slow Pipe Delivery. The steel pipes are the most crucial component for the construction of such a project, and thus require utmost adherence to delivery time frames. The pipe supplier had a contractual obligation of delivering +/- 700m of pipes on a weekly basis starting from April 2012. The delivery process commenced in time, but quality problems were soon encountered. The challenges included, pinholes in the steel pipe lining, difficulties in the fitment of the spigot & sockets and cracks on some collars. Due to these quality problems, pipe deliveries were less than 100m per week in some instances. That in turn hindered the rate of production on the construction

site.

Slow Construction Progress. To ensure success completion and delivery of the project, the contractor was handed the site earlier to ensure adequate planning. As the project was based on a tight construction schedule, the project activities had to be sequenced to allow day and night shift in order to meet the commissioning target date.

Buckling of the pipeline. Grouting of the pipes also commenced at a late stage of the construction period. The activity was delayed by two months due to the delay of acquiring welders. At that point an average of 94m<sup>3</sup> of grouting was required to be pumped in order to reach the target hand over date of the 28 July.

The contractor tried to source the grout mix from different suppliers, with an effort of trying to reach the daily supply of 94m<sup>3</sup>. Suppliers were not able to assist with the required demand, and as a second try, the contractors deviated from the approved grout mix. They used a grout mix with an accelerator.

Leaking sections of the pipeline. The leaks at Pit no 1F & 2 were believed to be caused by welds which could have cracked when the pipeline was being filled with water.

The scour valve leak was believed to have been because of the stolen adapter flanges which then created the leak problem.

## **CONCLUSION**

Owing to the challenges which were faced in this project, it became apparent that not only do we need to consider just engineering solutions to our problems. Socio-economic challenges such as strike actions that face our country continue to impact projects of this nature, and it requires seasoned professionals to be able to come up with alternative solutions in order to achieve success.

It is apparent that phase 1 project had its own challenges which are not necessarily similar to those of phase 2. Amidst all these challenges, both phase 1 and 2 of the B7 pipeline rehabilitation project were successful.

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