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New dense wastewater marine outfall system for Richards Bay

The existing dense wastewater marine outfall pipe system operated by Mhlathuze Water in Richards Bay is at present being upgraded in order to handle the required discharge within the requirements and licence set by the Department of Water Affairs and Forestry

RICHARDS BAY, recognised for its fast growing export and import industries as well as having the largest coal export terminal in the world, is also known for having the only dense wastewater marine discharge pipeline in South Africa, and one of the few in the world.

Wastewater from marine sewerage outfalls, the likes of which can be found in a number of coastal locations around the country, has a density lower than that of sea water and is thus designed and treated as buoyant wastewater. In comparison, dense wastewater has a density greater than that of sea water and requires a completely different hydraulic design, discharge and dilution approach.

Mhlathuze Water is responsible for disposing of wastewater via two marine pipelines into the Indian Ocean at Richards Bay. This includes buoyant wastewater via the 5 400 m long A-line and dense wastewater via the 4 300 m long B-line. The dense wastewater consists of a gypsum slurry by-product from Foskor's local phosphoric acid plant.

Both outfalls are owned and operated by Mhlathuze Water and were designed and commissioned in 1985. In addition to these, a third section of pipe (C-line) was installed from the beach, through the surf zone for a length of about 700 m. This was intended for future extensions. The A-line has largely operated satisfactorily since this time. The B-line, however, has experienced significant problems relating to accumulation of insolubles inside the pipeline, blockages of the diffuser ports and the deposition of gypsum sediment and insolubles adjacent to the pipeline on the seabed.

As an interim emergency measure, while the design of a second dense effluent pipeline and diffuser was under way, a 300 m long new diffuser section was installed at midway distance from the shoreline and came into operation in August 2004.

The installation of a second dense effluent pipeline and diffuser system, inclusive of a pump station, was necessitated by the fact that the B-line was the only means available to Foskor to dispose of its gypsum by-product. A second discharge facility would add the benefit of increased maintenance opportunity on an installation critical to the operation of Foskor. The addition of a second discharge facility would also reduce the risk of unplanned interruption to Foskor's operation, a risk that ranks among the top ten risks identified at Foskor.

1 Layout of marine outfall systems A-, B- and C-line
2 Dilution calculations using CORMIX plume modelling software

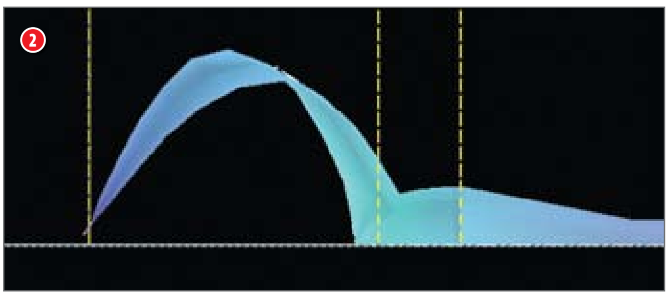
AIMS AND OBJECTIVES

In order to keep within the license conditions set by the Department of Water Affairs and Forestry (DWAF), the aim of the project was to review the whole system and to propose modifications to ensure that a new diffuser system can effectively discharge the gypsum wastewater without causing blockages or forming large mounds near the pipeline. All this had to happen within the limits set by environmental legislation and meeting the needs of the growing industries.

Specific attention had to be given to the transport of the gypsum sediment in the pipeline, as well as the velocity and dilutions of the discharge plume at each diffuser port.

Lessons could be learnt from the existing system which had operated for some 23 years. The objective was thus also to investigate these and build on the lessons from the past.

It was crucial that the current pipelines remained in operation throughout the construction phase.



DESCRIPTION OF THE PROJECT

In January 2004, Entech (now WSP Africa Coastal) was appointed by Mhlathuze Water as engineering consultant for the dense wastewater diffuser replacement project. A number of studies were carried out and various options considered as part of the feasibility report, which was completed in May 2004. Thereafter, during August 2005, Entech was appointed for the detail design and construction phase as well as project management of the entire project.

From these studies and recommendations the decision was made to construct a new dense wastewater outfall, called the C-line, which would replace the partially dysfunctional current B-line and tie up with the section placed through the surf zone in 1985. In addition, the existing B-line will be refurbished to act as a standby backup for the new line.

The C-line would be 4 300 m in length and manufactured in 900 mm diameter HDPE (High-density polyethylene) pipe. The last 450 m would be a tapered diffuser section with discharge ports at specific intervals and terminating in a water depth of 25 m. To provide stability and weight, 462 number concrete weight collars would be spaced along the marine pipes, ranging from 5 tonnes to 2 tonnes each.

The refurbishment of the B-line would also include a new 450 m diffuser, which will act as replacement of the emergency diffuser installed in 2004.

In addition to the marine side of the project, a new slurry pump station capable of 1 500 ℓ/s would be constructed about 400 m from the beach and a new 1 000 mm diameter HDPE landline from the pump station would connect up to the existing section of the C-line buried at the low-water mark.

The marine, civil, as well as mechanical and electrical sections of the project were undertaken as separate contracts and were planned to run concurrently in order to minimise project time and possible losses incurred by Foskor.

This article focuses on the marine engineering side of the project.

3 GRP-wrapped ceramic port ready for installation on diffuser section
4 Blanked-off HDPE flange where ceramic diffuser ports will be installed
5 Butt-welding of lengths of HDPE diffuser section
6 Closed-up stub and flange connection with sacrificial anode protection on main pipeline
7 Concrete weight collars in pre-cast yard
8 Launching of 900 mm diameter pipe strings into the harbour. The female section of the mating piece is already attached to the pipe front and the male piece to be attached to the back of the string can be seen on the left
9 Pipe string (900 mm diameter) with pre-cast weight collars attached during launching
10 Top and bottom sections of concrete weight collars ready for fitting on the launch way
11 Towing of 910 m long pipe string through the harbour mouth (Mhlathuze Water)
12 Towing the 910 m long pipe string into position
13 & 14 Divers preparing to facilitate string connection on the seabed
15 Pipeline during the sinking process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DESIGN COMPONENTS

General

The following design criteria had to be met:

- Meet requirements set by DWAF
- Although the average load of gypsum is about 12 000 tonnes per day, Foskor required that a maximum of 18 000 tonnes per day needs to be discharged through the new pipeline. These values were set in the DWAF license and may not be exceeded
- Build-up of gypsum deposits on the seabed had to be eliminated. This means that the gypsum concentrations in the seawater should be lower than its solubility, approximately 1,5-2 g/ℓ.
- There should not be gypsum settlement in the pipeline that may block ports
- Similarly, heavy metal concentrations and fluoride levels at the edge of the mixing zone shall not exceed the marine water quality standards as specified by the DWAF in the license
- Although shorter pipe lengths are feasible as well, the existing permit from DWAF stated that the discharge must be located at a distance 4 330 m from the pump station
- Design should be for a serviceable lifetime of 50 years, which includes stability of the pipeline during storm events
- The pipeline should be able to be constructed by recognised and proven techniques that are preferably locally available

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Environmental impact

As part of an environmental impact assessment, possible use of the gypsum by-product was investigated extensively. Amongst other, the use for agricultural purposes, manufacturing of gypsum board for the construction industry and use as additive to concrete were investigated. Although some options were viable, these proved significantly lacking the ability to handle the daily volume produced.

The CSIR has monitored the environmental impact offshore of the marine outfalls twice yearly since 1985 when the pipelines became operational. Studies on benthic communities started at Richards Bay in 1980, well before the outfalls were installed, and serve as a valuable benchmark. The overall conclusion from this monitoring is that the impact of the outfalls is limited and is generally restricted to the immediate vicinity of the diffuser systems.

Dilution calculations

Discharge dilutions must adhere to the South African Marine Water Quality Guidelines. Indications are that if the gypsum can be efficiently dissolved through high dilutions, then the other constituent criteria will also be adhered to.

In order to reach the required dilutions at the discharge ports a number of different approaches were investigated and results compared. Achieved dilutions are mainly a function of the jet velocity through the ports. The smaller the port diameter, the higher the achievable dilutions. On the other hand, owing to the presence of insolubles in the wastewater, ports need to be large enough to prevent blockages. It is interesting to note that operational experience with the ports has shown that over the last 23 years, ports have never blocked as a result of particles becoming stuck in them.

The dilution calculations were also evaluated for ocean current conditions and incorporated into the design. It was found that even a relatively small current of 0,1 m/s will increase the dilutions by about 50 %. Ports were directed and angled so that the prevailing ocean current could facilitate dilutions.

A number of different outfall pipeline and diffuser configurations were evaluated in order to optimise the achievable dilutions. For the preferred configuration, dilutions were confirmed using CORMIX modelling software.

The above resulted in a diffuser section with 23 single ports at approximately 20 m spacing. Owing to the high discharge velocity through the ports – in the order of 15 m/s to 16m/s – a ceramic material was used to limit scour. The ceramic top of the diffuser port is removable and can be replaced should excessive wear occur.

Pipe hydraulics

In order to prevent gypsum settling inside the marine line, velocities need to be kept sufficiently high. Alternatively, a mixing mechanism would have to be introduced at certain positions in the pipe.

During May and June 2006, physical modelling tests were done at the University of Stellenbosch regarding the efficiency of various mixing mechanisms. The use of these proved not suitable, however, as the influence distance of such a mechanism is relatively short. Tests did show that the diffuser must have tapered sections in order to keep velocities high enough and ensure an even gypsum distribution across the pipe diameter.

With the old pipeline, it was suspected that gypsum particles had segregated and was dragged along the invert of the pipeline. So-called scavenger diffuser ports picked up the high gypsum loads from the invert of the diffuser, but were not successful to achieve the required dilutions. Gypsum sediment mounds formed adjacent to the pipe on the seabed, eventually blocking the ports. Occasional low flow velocities in the pipeline and high sediment/insoluble loads have increased these problems.

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16 Aerial view of the new pump station being constructed adjacent to the existing A & B-line pump station (Icon)
17 Construction of pump station bays and piling for electrical control building in progress
18 Pump station construction in progress
19 Beach connection and cofferdam for new 1 000 mm diameter landline section (Icon)

Route, length and pipe stability

Although the pipe route and length were mainly determined by the existing marine outfall, an underwater reef section had to be negotiated.

Numerical modelling software SWAN (Simulating Waves Nearshore), was used to convert deepsea wave data to the near shore and hence establish a near shore wave climate to allow the determination of load conditions on the pipeline.

Modelling of pipe stability during these wave and current condition were done according to three different methods, namely the Det Norske Veritas Simplified Stability Analysis, a dynamic analysis with modelling software PONDUS that uses a finite element method to solve movement in the time domain, and the Scandinavian Design Procedure.

The pipeline was designed to be dynamically stable during a 1-in-100-year storm event where a deep-sea significant wave height of 6,70 m could be expected.

Because of the location of the marine line, the effect of tropical cyclones had to be incorporated in the stability design. Although waves from cyclones were found to be higher – in the order of 8 m – the wave direction, being less perpendicular to the pipe, has a less critical effect on wave loading in comparison to the waves from extra-tropical cyclones which approach from the south-southwesterly sector.

Based on the above, it was recommended to use submerged pipe weighting of 500 kg/m over the full length of the 900 mm diameter pipe. The weighting is reduced across the diffuser section. Reinforced concrete collars were designed in order to provide the required stability. Weighting was optimised so that minimum additional buoyancy would be needed during the pipe tow and placing process.

CONSTRUCTION COMPONENTS

Marine pipeline

Approved HDPE pipe sections were delivered in 24 m lengths to the contractors' yard in Richards Bay harbour. These were butt-welded into 455 m lengths and pressure tested.

(20) Excavation and dewatering for landline beach connection under way. Connection was made at 4,5 m below mean sea level at the low-water mark
(21) Wave overtopping during neap high-water tide

Three strings of 910 m each and one 450 m diffuser segment was prepared by inserting stub and flange connections and sacrificial anode configurations. These strings were placed on a launch way, fitted with the pre-cast concrete weight collars and pushed into the water at a rate of about 10 to 12 collars per day.

Towing and placing of the weighted pipe had to be carefully planned and co-ordinated. The installation method made provision for measures to prevent structural buckling of the pipe wall during the sinking process.

The first string had to be connected to the existing 700 m section in shallow water depths of about 7 m. From this point, successive strings were connected and placed on the demarcated route. Inspection dives by the marine contractor revealed an alternative reef crossing point that required substantially less rock excavation work.

The flexible HDPE pipes were surface towed into position. Hereafter the nearshore end was connected onto the existing pipe on the sea bed via a special designed mating piece to ensure an aligned connection. This was later replaced by a spool piece. The remainder of the pipe length was then sunk in a gradual S-bend movement by allowing flooding on the near shore end and allowing air to escape, controlled through a compressor, on the offshore end. Axial tension was applied to the pipe to prevent buckling and structural failure of the pipe wall.

The diffuser section needed additional external buoyancy in order to float and the marine contractor used approximately 180 Norwegian buoys to provide the necessary lift force.

The last 40 m piece was sunk separately and weights installed on the seabed.

Even with a well-thought-out method of pipe placing, the success is still determined by the chosen weather window. Because of the long lengths of the strings, the ocean current proved to be the main concern and regular check dives were done to monitor conditions until suitable weather conditions occurred. Wave height was found to be less of a concern, except during the placing of the pipe sections that needed additional external buoyancy, where the concern was that waves could tear fixings and the pipe could sink in an uncontrolled manner at the wrong location.

Pump station and mechanical and electrical work

The pump station consisted of over 2 100 m^3 of concrete and required an 8 m deep excavation to a level of 5,5 m below mean sea level. The pipe connection on the beach at the low-water position required the construction of an earthworks cofferdam the core of which was made up using 500 number 5 tonne geofabric sandbags. With the tie-in level at 4,5 m below mean sea level, 17 number 100 mm dewatering pumps were used to control the ground water. Work took place around the clock in order to make best use of the available tidal window. During the design of the landline, horizontal directional drilling (HDD) was investigated, but proved more expensive than traditional open cut.

New slurry pumps were installed, allowing for a two duty, one standby pump configuration, equipped with variable speed drives and capable of providing a head of 68 m. Pumps were installed in separate bays to ensure that the function of the entire pump station is not jeopardized in the event of a pipe or valve failure. Each bay is equipped with an emergency dewatering vertical pump and is linked to an overflow trench that will direct the spill back into the system.

PROJECT STATUS

The complete length of the new marine dense wastewater C-line has been installed on the seabed as well as diffuser ports and spool pieces fitted. Refurbishing work on the B-line will start after the C-line has become active.

Civil works to the pump station have been completed, as well as the land section of the new C-line. Mechanical and electrical work is in its final phase of testing.

Preparations are currently being made for final commissioning of the C-line system, which is scheduled for early August 2008.

Photographs: WSP Africa Coastal Engineers, unless specified otherwise

Project Team

- **Client** Mhlathuze Water (Pty) Ltd
- **Principal design consultants for marine and civil work and overall project management** WSP Africa Coastal Engineers (Pty) Ltd
- **Subconsultants for all M&E design work** SSI Engineers and Environmental Consultants (Pty) Ltd
- **Main contractor on marine work** Group Five Civil Engineering (Pty) Ltd
- **Subcontractors on marine work** Subtech (Pty) Ltd / NRB Piping Systems (Pty) Ltd
- **Main contractors on civil work** Icon Construction (Pty) Ltd
- **Subcontractors on civil work** Flexicon Piping Specialist / Beatus Civils cc / Musazonke Trading cc
- **Main contractors on M&E work** ABB South Africa (Pty) Ltd
- **Subcontractors on M&E work** Unicorn Engineering cc / Samco Pumps (Natal) (Pty) Ltd
- **Contract value** R155 million
- **Contract duration** 80 weeks (for entire project, except refurbishment work on B-line)
- **Site Engineering Representative** Gerhard Kapp (WSP Africa Coastal)

Source:
http://www.saice.org.za/downloads/monthly_publications/2008/CivilEngJul08/#/0