GLASS REINFORCED PLASTIC (GRP) IN THE DESIGN OF A BORE WATER TRANSFER SYSTEM

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ABSTRACT

Glass Reinforced Plastic (GRP) was selected for the design of a bore water transfer pipeline to service the Jacinth-Ambrosia (J-A) mineral sands mine, currently under development in South Australia. The transfer pipeline is required for the conveyance of untreated bore water from a borefield to the mine process area, at a total distance of approximately 32 kilometres.

Although relatively new to the Australian market, particularly for large-diameter and long-distance applications, GRP was found to have many advantageous properties over “traditional” pipe materials in relation to this specific application.

GRP comprises a series of composite laminar layers, the raw materials of which include glass fibres, polyester resins and fillers such as silica.

This paper discusses the improvement in performance of the J-A water supply infastructure, as a result of selecting GRP pipe for the transfer pipeline.

INTRODUCTION

Project description

The Jacinth-Ambrosia (J-A) mineral sands mine site is located in the Eucla Basin, north-west of Ceduna in South Australia. The mine site is currently under development by Iluka Resources for the exploitation of the mineral zircon, with production scheduled to commence in early 2010. The design and construction of the J-A mine is being completed by an Alliance between Iluka and Parsons Brinckerhoff (PB).

A reliable source of water is required for both the construction and operational phases of the mine. The water will be sourced from an aquifer located approximately 32 kilometres south-west of the mine process area. The groundwater has been extensively sampled, and was found to be hyper-saline and moderately acidic.

The groundwater will be extracted from a linear configuration of twelve production bores, and then pumped through a collector pipeline approximately four kilometres in length to a transfer pumping station. This collector pipeline will be constructed from a combination of Orientated Polyvinyl Chloride (oPVC) and GRP, and will telescope in size from DN250 to DN450. The use of oPVC was required as GRP is not readily available in sizes less than DN375.

Water will be pumped from the transfer pumping station along a DN600 GRP transfer pipeline (the subject of this paper) to the process plant, where it will be stored in a 96 ML terminal storage dam. A portion of the water will be diverted prior to discharge into the dam, and treated using reverse osmosis (RO) technology in order to meet the potable water demands of the mine.

The GRP transfer pipeline has a total length of 31.25 kilometres, with an increase in elevation of approximately 75 metres between the transfer pumping station and the terminal storage dam. The transfer pipeline was sized at DN600 with a pressure rating of PN20 (200 metre pressure head) in order to transfer water as efficiently as possible, with regard to both hydraulics and expected power costs over the design life of the mine.

Taking into account the demands for both process and potable water, the average expected flow rate during normal operating conditions for the first seven years of mining operations is 262 L/s. This will increase to 300 L/s for the remaining life of the mine, a further four to eight years. In addition, a flow rate of 360 L/s will be required during peak processing times, for a maximum period of approximately three months per year.

Prior to installation of the permanent water supply infastructure, temporary “construction water” infrastructure will be installed to provide water for construction activities at the mine site.

Application of GRP

PB's design engineers have traditionally selected metallic pipe materials for large-diameter water conveyance projects such as mining operations. Materials used have typically been steel or ductile iron, with an internal cement mortar lining to protect against corrosion from poor water quality. Although plastic pipes such as High Density Polyethylene (HDPE) and PVC are hydraulically smoother than metallic pipes, the primary reason for their exclusion in large diameter applications is that they are not cost-competitive with metallic pipes.

For the above reasons, the original material specification for the J-A transfer pipeline called for Ductile Iron, Cement-mortar Lined (DICL) pipe. However, the recent emergence of an Australian-based and Australian-owned manufacturer of GRP now provides a cost-competitive alternative to metallic pipe materials for large diameter applications. As such, both DICL and GRP were evaluated during the detailed design phase of the project, and the advantageous properties of GRP for this application became apparent.

This paper will describe in detail the major benefits for the J-A project arising from the selection of GRP for the transfer pipeline. In summary, the key benefits are as follows:

- GRP pipe is highly resistant to internal and external corrosion from the aggressive (hyper-saline and moderately acidic) groundwater, which removed the need to apply protective coatings or sleeving;

- GRP pipe is non-conductive, and given the proximity of the transfer pipeline to a high-voltage powerline along much of its alignment, this removed the need for earthing;

- Multiple fittings may be cast monolithically into a single length of GRP pipe, thereby reducing the number of individual fittings and flange connections required. This reduced supply costs, as well as the cost and time associated with installation of the pipeline;

- The modulus of elasticity for GRP is significantly lower than for DICL pipe, resulting in lower transient wave speeds during water hammer events. This meant that expensive water hammer mitigation infrastructure was no longer required, resulting in significant cost savings;

- GRP pipe has a smoother internal surface than DICL pipe, resulting in fewer friction losses along the transfer pipeline. This in turn reduced the required pumping head by approximately 10 metres, lowering the capital costs for the J-A transfer pumps and also resulting in energy savings during their operation;

- GRP pipe can be supplied in lengths of 12 metres, which is double the standard length of metallic pipes. Consequently fewer pipe connections were required, resulting in faster installation time and associated cost savings;

- GRP pipe is approximately half the weight of metallic pipe per unit length, which results in faster transportation (as more pipe can be transported in a single load) and pipe installation;

- GRP pipe can be stored outdoors in aggressive environments indefinitely without any effect on performance. This was advantageous as the J-A site is located in an arid environment, and is subject to extreme UV exposure and high temperature fluctuations;

- The standard jointing system for GRP pipe consists of a spigot and removable rubber-ring-joint socket coupling. This method of jointing has several advantages including compatibility with Australian Standard fittings in all materials, and the ability of each spigot-coupling joint to be deflected by up to 3° (1.5° per pipe). This meant that the most cost-effective combination of valves, fittings, and sweep bends could be incorporated into the design;

- The dimensions of each length of GRP pipe is checked at the factory, and those within the required tolerance for diameter are marked "adjustment pipe". These may be cut on-site to any length required, which was useful for accomodating minor design changes as required by conditions on-site;

- GRP pipe is manufactured in Adelaide, South Australia. Due to its relative proximity to the J-A site, the pipe lengths could be delivered approximately 10 weeks earlier than DICL. This allowed the pipeline to be incorporated into the "construction water" infrastructure, thus removing the need for a temporary pipeline.

DISCUSSION

The selection of GRP for the transfer pipeline has resulted in numerous benefits to the J-A project, as previously summarised. These benefits are described in greater detail below.

Non-corrositivity

One of the most important aspects to consider with regard to the material selection for the transfer pipeline was the quality of the water to be conveyed. The water extracted from the J-A borefield is characterised by high salinity (TDS > 50,000 ppm) and moderate acidity (pH 5.5). As such, the resistance of the pipeline to internal corrosion was an important consideration.

Testing has shown that GRP pipe can withstand long-term exposure to aggressive internal and external enviornments. An investigation was conducted by *Amiantit Fiberglass Industries*, a Norweigan manufacturer, who excavated a 25-year-old GRP pipe from salt-laden soils, immediately downstream of a sewerage discharge tank. This pipe was subjected to a series of tests, after which it was found that the physical and chemical integrity of the pipe had not diminished (Amiantit 2005).

The non-corrositivity of GRP negated the need for additional protection measures against internal and external corrosion, such as inert coatings and sleeving. The selection of DICL would have required an internal calcium-alumina cement lining, as well as external protection by means of loose polyethylene sleeving.

The soil conditions on-site were found to be slightly alkaline, with a pH of approximately 8.5. The chemical integrity of the GRP pipes allowed the trench backfill to be conditioned with untreated groundwater. This was important, as the groundwater was the only water source available on-site during installation of the transfer pipeline This removed the need to import water during pipeline installation. Had the pipeline been constructed from DICL, potable-quality water would have been required for soil conditioning.

Figure 1 shows the backfilled trench along the J-A transfer pipeline being conditioned with water to assist with soil compaction.

Figure 1: Conditioning of trench backfill with untreated groundwater from the J-A borefield.

Non-conductivity

The pipeline alignment runs adjacent to a high-voltage powerline for much of its length. Since GRP pipe is non-conductive, earthing of the pipe for protection against induced currents from the powerlines and transformers was not required. This would have been necessary if the transfer pipeline was constructed from DICL.

Monolithic pipe "specials"

A distinctive advantage of GRP pipe over DICL for the J-A project was the ability to construct custom-designed monolithic pipe "specials". This allowed any configuration of required tees, elbows, reducers and flanges to be cast into a single length of pipe. Pipe "specials" were incorporated into the design of the transfer pipeline in a range of configurations, including isolation valve assemblies, scour tees, air valve assemblies, pipe bends and thrust flanges.

This design approach resulted in a significant reduction to the quantity of fittings, flange connections and thrust restraints required for installation of the transfer pipeline. This created an important cost benefit to the project, attributed to a reduction in supply and installation costs arising from a reduction in the number of joints required.

Figure 2 provides an example of a monolithic pipe "special" constructed from GRP. The fittings shown were designed for the isolation valve assemblies located along the transfer pipeline.

Figure 2: GRP monolithic pipe "specials" serving as isolation valve assemblies. Each fitting contains a scour and air valve tee, one flanged end and one spigot end.

Modulus of elasticity

As for the majority of plastic pipes, GRP pipe has a modulus of elasticity that is much lower than for metallic pipe materials such as DICL or steel (24,000 MPa for GRP compared to 165,000 MPa for DICL). This property has a direct effect on the transient wave speed (celerity) propagating through the fluid medium during water hammer events. The lower modulus of elasticity associated with GRP considerably reduces the celerity and therefore the impact on the water supply infrastructure associated with water hammer effects. The calculated celerity in a DN600, PN20 GRP pipe is approximately 610 m/s, compared to approximately 955 m/s for the equivalent size and pressure rating in DICL.

This was a significant factor in the decision to select GRP over DICL for the J-A transfer pipeline, as the lower celerity associated with GRP pipe negated the need for expensive water hammer mitigation infrastructure. This resulted in a potential saving in excess of $0.5 million for the project.

Smooth internal surface

The most significant advantage of GRP with regard to operational efficiency is the smooth internal surface that is characteristic of plastic pipes. GRP pipes have a roughness height of approximately 0.035 mm (Iplex Pipelines Australia 2008) whilst DICL pipes have a roughness height of approximately 0.15 mm (Tyco Flow Control 2000). GRP pipe will maintains its smooth surface for a number of years, whilst DICL is prone to pitting and scaling of the internal concrete surface over time.

The smooth internal surface of GRP pipe results in significantly lower frictional head-loss during operation. Consequently, a lower pressure head is required to pump the water through the transfer pipeline during the life of the mine. This will create cost benefits through the selection of a smaller pump, leading to a reduction in power consumption during operation, as well as the immediate savings in terms of capital cost. For the J-A project, approximately 10 metres less pumping head was required to transfer water along the 32 kilometre length of GRP transfer pipeline, compared to the equivalent length in DICL.

Reduced power consumption will also result in lower Carbon Dioxide (CO_2) emissions. This contributes towards demonstrating a commitment to environmental sustainability, an expectation of current mining operations in Australia. Optimal design of engineering systems through reduction of energy usage can has an important role in achieving these goals.

The reduction in operational pumping head whilst maintaining the size of the transfer pipeline also creates the opportunity to increase the flow rate in future without compromising the pressure rating of the pipe. Given the nature of the mining industry in which the size and quality of the deposits are not certain from the outset, this was an important consideration for the J-A project. Furthermore, during the design phase of the project, the client was investigating the viability of an additional mineral deposit in close proximity to the J-A deposits, which could potentially increase the water requirements of the mining operation.

Pipe lengths

GRP pipes are manufactured by means of a continuous winding process, and so can be produced to any length required. However, pipe lengths are generally limited to 12 metres due to the logistics of transportation. This is double the standard length for metallic pipes, including DICL. Where possible, 12 metre GRP pipe lengths were specified for the transfer pipeline, which resulted in fewer joints per unit length. This reduced the time required for installation, with associated cost-savings.

Pipe weight

GRP pipe is less than half the weight per unit length for an equivalent size and pressure rating of DICL pipe. The GRP pipe used for the J-A transfer pipeline, (which is of size DN600 and pressure rating PN20), is approximately 40% of the equivalent weight of DICL per unit length. This "lightweight" characteristic of GRP pipe allows the pipes to be transported and installed more quickly and with greater ease. Figure 3 shows a truck delivering a batch of 12 metre length GRP pipes to the J-A site.

Figure 3: A batch of 12 metre length GRP pipes being delivered to the J-A site. Longer pipes require fewer joints per unit length, simplifying the installation process.

Storage requirements

GRP pipe can be stored outdoors and unsheltered for an indefinite period with no impact to the integrity of the pipe, even in arid environmental conditions. The only effect is some weathering to the outer layer manifest by increased external roughness and discolouration of the pipe. This has no effect on the structural or chemical integrity of the pipeline. In contrast, DICL pipe cannot be left exposed for any prolonged period of time. DICL pipe requires a sheltered storage area, with air-tight plugs fitted to the end of each pipe in order to prevent the cement mortar lining from drying out and the subsequent formation of cracks.

GRP pipe was therefore better suited to storage in the environmental conditions encounted at the J-A site. Lengths of pipe were able to be delivered and “strung out” adjacent to the pipe alignment prior to installation, without the need for an intermediate storage location. Figure 4 shows a batch of pipes laid alongside the trench, ready for installation.

Figure 4: Pipe lengths “strung” along the alignment, ready for installation.

Rubber-ring jointing system

The standard jointing system for GRP consists of a spigot and rubber-ring coupling. This is a flexible jointing system which allows for a maximum deflection of 3° per joint for a DN600 PN20 pipe. This feature was exploited in the design of the J-A transfer pipeline, which incorporated long-radius sweeps into the design in order to change the pipeline direction. This approach removed the need to incorporate additional bends into the pipeline, thus avoiding increased costs for additional fittings and associated thrust restraints.

It is noted that the permissible deflection range of GRP pipe may not be useful for installations in which there are tight space constraints. However, the J-A transfer pipeline was installed within a Miscellaneous Purpose Lease (MPL) corridor of width ranging from 50 metres to 100 metres, which was ample space.

Although the standard jointing system for GRP pipes is spigot-coupling, it is possible to incorporate flanged connections as required. However, the cost of manufacturing flanged GRP pipes is high compared with DICL pipe, and as such the production of these is limited. As an alternative, GRP flange-spigot couplings can be fitted to the end of regular spigot-end GRP pipes. This allows for greater design flexibility, as the flanged coupling can be placed at any location along the pipeline by cutting the pipe as required.

Pipeline systems are modular in configuration and often constitute a variety of pipework and material constituents. The ability of GRP pipe to connect to a variety of Australian Standard metallic and plastic fittings was important, as this increased the options available in the selection of valves and fittings. GRP pipe is compatible for connection to ductile iron, PVC-U, PVC-M, PVC-O, and many asbestos cement (AC) pipe materials. Since all GRP fittings, including pipe flanges, are manufactured by hand, non-standard sizes may also be constructed if required. This flexibility allowed a greater range of fittings and pipes to be incoprorated into the design of the J-A transfer pipeline, allowing the design team to minimise costs and lead-times for its supply.

Adjustment pipes

As part of its quality assurance process, the pipe manufacturer specified that at least 10% of supplied pipes would lie within a specified tolerance on diameter along their entire length. These pipes are marked "adjustment pipe" and may be cut on-site to any length required, which is useful for accomodating minor design changes as required by conditions on-site. The pipe may be cut with simple machining and chamfering of the pipe ends in order to create a spigot connection for connection to a coupling.

This feature of GRP pipe has proved useful for the J-A project. For example, the diameter of receiving tanks at the transfer pumping station, and hence the location of the inlet valve, was unknown. Consequently, the length of the final pipe was not certain at the time of ordering, and so an "adjustment pipe" was specified such that the length may be cut to suit on-site, thus accomodating a range of tank sizes.

Delivery time

A final notable benefit for the J-A project attributed to the selection of GRP for the transfer pipeline relates to its delivery time. Due to the relative proximity of the manufacturing plant to the J-A site and the expedient manufacture and delivery, GRP pipe would be available approximately 10 weeks earlier than DICL pipe. This had important implications for the construction philosphy of the J-A transfer pipeline.

The water supply infrastructure for the J-A project was constructed and utilised in two stages. Stage 1 "construction water" infastructure was to provide water required for the construction of the mine-site, whilst Stage 2 "permanent infrastructure" would provide water for ongoing mining operations. It was originally envisaged that a temporary HDPE transfer pipeline would be installed as part of the "construction water" infrastructure. However, the expedient delivery time for GRP pipe led to the decision to install the permanent transfer pipeline as part of the "construction water" infrastructure. This removed the need for the temporary pipeline, resulting in a cost saving of approximately $1.4 million for the project.

Furthermore, the relative proximity of the GRP manufacturing plant to the mine site led to a reduction in transportation distance, with corresponding reductions in both transportation cost and greenhouse gas-emissions.

CONCLUSION

GRP pipe has physical and chemical characteristics that make it suitable for a range of applications. For the reasons discussed in this paper, it was clear that GRP pipe was the best option for supply of the J-A transfer pipeline.

The benefits to the project resulting from the selection of GRP were significant and wide ranging. The total cost savings for the project that is attributed to the selection of GRP has been estimated at $2.8 million. This does not include many of the non-quantifiable aspects such as logistical and environmental benefits.

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