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2011: Fibreglass Pump Stations: 10 Years Experience in New Zealand. Presented at NZ Water Conference, Rotorua Novemebr 2011. Includes case histories of pump stations installed over previous 10 years, including ones that have been through the Christchurch earthquakes of 2010 and 2011.

FIBREGLASS PUMP STATIONS: 10 YEARS EXPERIENCE IN NEW ZEALAND

Presented at the Water New Zealand Conference, Rotorua, November 2011

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ABSTRACT

Pump stations constructed in fibreglass have been successfully used for handling municipal and industrial wastewater for ten years in New Zealand. This paper reviews these experiences, and the engineering details that have contributed to this success.

The engineering properties of fibreglass are well known. Fibreglass is a flexible material with strain to failure of 2%. Yield strength and ultimate strength are the same. Design safety factors of three to ten are used, so that the design point is well away from the yield point. This design gives good resistance to sudden shock loads, such as earthquakes.

The service life of a fibreglass pump station is dependent on the chemical resistance of the resin. Isophthalic polyesters are used in municipal pump stations, and vinyl ester resins are used in industrial chemical pump stations where chemical concentrations and temperatures are higher. Both resins are resistant to hydrogen sulphide gas. The 50 to 100 year design life required in municipal wastewater networks is achieved by fibreglass. When properly engineered and constructed, fibreglass has an indefinite life in these applications.

Fibreglass pump stations achieve engineering benefits because they are fabricated, assembled, and fitted out in a factory so that on-site work is minimised. Factory 'butt and strap joints' are easily done and quality assured, and this eliminates future leaks and infiltration. Bases are moulded with sloping sides to optimize pumping and minimize solids settling. Pump hold-down bolts are factory fitted; with anchoring plates located outside the pump station. These are captured in concrete on installation to ensure pump security. The weight of backfill on a factory fitted anti-flotation ring provides the required anti-flotation force. The lightweight of fibreglass reduces transport and installation costs.

Case histories are presented of a variety of installations, including municipal stations and one in a dairy factory handling CIP wastes. Four of the pump stations reviewed endured the Christchurch earthquakes of 2010/11.

LCC (life cycle cost) analysis shows that fibreglass pump stations have the lowest cost over a 100-year life. Whilst costing more at the time of initial purchase, the installed cost can be similar or less than conventional concrete pump stations. Further during the 100 year period, the fibreglass pump station needs minimal maintenance whereas others would need maintenance and replacing, or at the very least re-coating, on a regular basis.

KEYWORDS

Fibreglass, pump stations, wastewater,

1 INTRODUCTION

Fibreglass is a composite material of fibres and a polymer matrix. The fibres provide the strength, and are typically glass. The polymer matrix binds the fibres together and provides protection from the chemical environment they are exposed to.

Worldwide, FRP (fibreglass) is a material of choice for handling corrosive gases and liquids. The pulp and paper industry has been using fiberglass since the 1950s, for handling corrosive chemicals, such as, chlorine and sodium hypochlorite.

Wastewater networks are a key part of society infrastructure, and need to be designed for a long service life. Wastewater can be both corrosive and an environmental hazard, so networks need to be designed, built and maintained accordingly. Because of its corrosion resistance and other properties, fibreglass has been widely used in wastewater treatment plants for pipes, covers, ducts, fans, scrubbers, and tanks.

Photograph 1: Fibreglass Ducting, Fans, Scrubber, and Tank at Wastewater Treatment Plant

Factory manufactured and fitted out fibreglass pump stations, often referred to as 'packaged pump stations', in the size range one to three metres in diameter and up to seven metres deep, have now been in successful service in municipal wastewater networks in New Zealand for over 10 years. This paper reviews a cross section of case histories, and the engineering details that have contributed to their success.

2 PROPERTIES OF FIBREGLASS

2.1 FIBREGLASS PROPERTIES

Typical properties of fibreglass compared to concrete, steel, and HDPE (high density polyethylene) are given in Table 1. Fibreglass is a 'flexible' material with a typical strain to failure of approximately 2%. The actual properties of any fibreglass laminate vary depending on the materials used and the method of manufacture utilised.

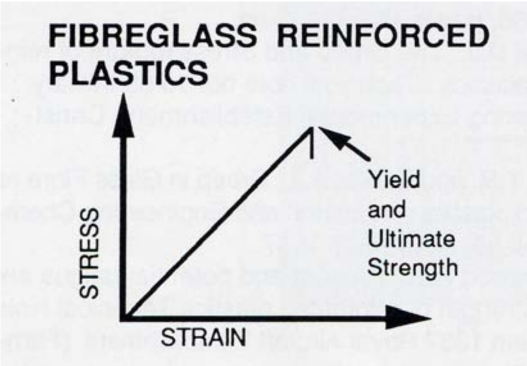
Table 1: Typical Properties of Materials Compared

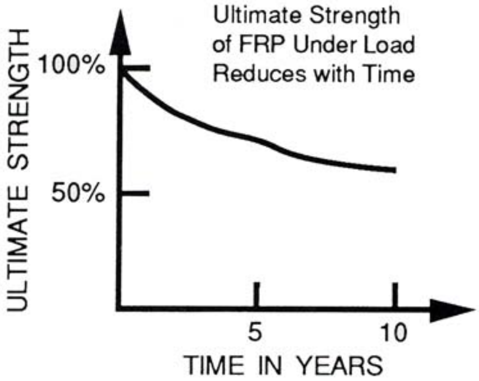
Material	Concrete	Mild Steel	FRP	HDPE
Density, kg/m^3	2700	7800	1500	940
Ultimate Tensile Strength, MPa	3	531	103	15
Elongation to failure, %	0.0	0.2	2	500

2.2 DESIGN SAFETY FACTORS

Yield and ultimate strength for fibreglass occur at the same point in the stress/strain curve (Fig 1), so that failure is sudden once the ultimate strength is reached. Fibreglass is also a plastic material subject to creep (Fig 2). For constantly loaded fibreglass, the ultimate strength reduces by about 50%.

Fig 1 (Left): Stress/strain curve for FRP. *Fig 2 (Right): Creep curve for FRP*





As a direct result of the above properties, design safety factors used with fiberglass generally range from 3, to over 10 for constantly loaded parts. This means that the design point for fiberglass on the stress/strain curve is kept well away from the yield point. These safety factors are specified in standards, and have been developed from experience and the analysis of past failures in actual installations. The high safety factors used enable fibreglass to better survive unexpected one-off loads.

2.3 CORROSION RESISTANCE

The resin used determines the corrosion resistance of a properly cured fibreglass laminate. Isophthalic polyester resins and vinyl ester resins have the required water and corrosion resistance; the vinyl ester resin has chemical resistance to a wider range of chemicals (Table 2), and is often used in industrial chemical sewer pump stations. Standard low cost orthophthalic polyester resins cannot be used.

Table 2: Chemical resistance of pump station construction materials.

Materials	Concrete	Stainless 316	FRP Isophthalic	FRP Vinyl Ester
Hydrogen sulphide gas	NR	NR	R	R
Dilute sulphuric Acid	NR	R to 5%	NR	R
Dilute hydrochloric acid	NR	NR	R to 5%	R
Dilute nitric acid	NR	R	R to 5%	R
Dilute sodium hydroxide	NR	R	NR	R
Acid chloride salts	NR	NR	R	R
Lactic acid	NR	R	R	R
Bleach	NR	NR	NR	R
Municipal wastewater	NR	R	R	R
Dairy CIP wastewater	NR	NR	NR	R

Hydrogen sulphide is commonly found in pump stations at concentrations from a few ppm (parts per million) to 100 ppm and more (Holyoake & Kotze, 2010). Higher concentrations are often associated with high temperatures, long sewer runs, rising mains, pressure sewer systems, and long pump stations residence times.

Sulphur consuming microorganisms feed on the hydrogen sulphide, producing dilute sulphuric acid, which attacks steel, concrete, many coatings and other materials. Fibreglass is inert to both hydrogen sulphide and dilute sulphuric acid (Table 2).

Industrial chemical drains and pump stations may be exposed to more corrosive chemicals. For example, food factories commonly use CIP (clean-in-place) chemicals including nitric acid, sodium hydroxide, oxidants, anti-bacterial chemicals, and hot water. The chemical wastewater network must withstand these wastewaters at temperatures up to 90ºC. Fibreglass made with vinyl ester resins are used for this application.

2.4 CONTACT MOULDING

Fibreglass laminates made by contact moulding, also called hand lay-up, have the highest resin to glass ratios of 70:30 when compared to alternative manufacturing methods. As it is the resin that gives a fibreglass laminate its chemical resistance, this high ratio makes contact moulding the preferred fibreglass manufacturing process when the highest degree of chemical resistance is required. In contact moulding, the main laminate is reinforced mainly with non-continuous glass fibre, and this limits the spread of any chemicals within the laminate should it be exposed or damaged.

The tops and bases of pump stations are always manufactured by contact moulding. The straight walls of the pump stations discussed in this paper were also all manufactured by contact moulding.

3 PUMP STATION DESIGN REQUIREMENTS

3.1 MINIMUM LIFE

The minimum requirement for the design life for wastewater pump stations in New Zealand is typically specified between 50 and 100 years. The corrosion resistance of the pump station to the wastewater handled is the main issue that directly affects its design life and useful service life. Fibreglass has been demonstrated to meet this minimum requirement based on past performance both in New Zealand and elsewhere.

The expected life of fibreglass in municipal wastewater service is indefinite. This is not the case for traditional concrete pump stations. In Wellington, pump stations are scheduled to be rehabilitated or replaced every 20 years (USEPA, 2003).

3.2 PUMP STATION DESIGN

Pump station design starts with the system duty points. These determine the selection of a suitable pumping solution. This, along with any emergency storage requirements, and other site-specific factors, assists with determining the desired dimensions of the wet well and valve chamber. The custom built nature of fiberglass pump stations offers the designer a wide variety of options to choose from.

3.3 DESIGN LOADS

The determining design loads on pump stations are external loads: soil pressure, water table, and superimposed dynamic traffic loads. The pump stations must handle these external forces when empty, so typically the pump station wall requires a minimum stiffness to resist buckling. This stiffness is generally achieved in fibreglass pump stations by either wall thickness, or external ribs.

3.4 FLOTATION

Pump stations are often sited in low-lying positions, where high water tables can cause flotation of the entire pump station. This can occur at any time, as the pump station is essentially empty after it has pumped down. It can also occur during installation, before the pump station is backfilled. Fibreglass is light in weight, and this increases the likelihood of flotation. This is overcome with external 'anti-flotation flange' fitted to the base of the straight wall of the pump station and uses the weight of the backfill material to provide the hold-down force needed to overcome flotation forces. A partially installed 'anti-flotation flange' can be seen in Photo 2. Furthermore, concrete can be poured around the pump station base to achieve secure anchorage, and adding substantial mass to counteract flotation.

4 ENGINEERING BENEFITS OF FACTORY CONSTRUCTION

4.1 LIQUID TIGHT ENVELOPE

The custom manufacturing process in factory-controlled conditions, achieves a liquid tight envelope for the fibreglass vessel. Problems of infiltration of water into the pump station and leakage of wastewater out of the pump station are eliminated.

The standard fibreglass jointing technique is the ‘butt and strap joint’. Two fibreglass parts are butted together and a fibreglass strap is applied over the outside of the joint, with a sealing strap placed over the inside of the joint. This completes the integrity of the liquid tight envelope, and results in joints that are stronger than the individual parts themselves due to the additional thickness of the fibreglass strap.

Photograph 2: Fibreglass pump station being manufactured. ‘Butt and Strap Joints’ provide total water seal.

4.2 MINIMISING RESIDUAL WASTE VOLUMES

Solids buildup is higher in conventional flat-bottomed wet wells, compared to wet wells with contoured bases (Photograph 2). In fibreglass, pre-formed contoured bases are readily manufactured to the required slopes. The contouring is designed to optimize pumping hydraulics and minimize the residual waste volume in the base of the pump station after it has pumped down. These bases have been successfully incorporated in New Zealand installations.

4.3 SECURE PUMP ANCHORAGE

Pump anchorage in fibreglass pump stations can be either on the floor, or on the sloping side just above the base (Photographs 3,4). The discharge foot bolts through the base and can be embedded in concrete to provide secure anchoring. The mass of the concrete can then absorb any out of balance energy. This optional extra poured concrete has proven very effective in New Zealand conditions, and is preferred by many installation contractors and Councils.

Photographs 3, 4: Contoured base with discharge bends mounted.

4.3 SMOOTH INTERNAL SURFACES

Fibreglass manufacturing techniques result in smooth sidewall finishes on the inside of the vessel. Wastewater solids can still stick to the walls, but are easily and quickly cleaned down with a standard hose or well washing regime.

Photographs 5 & 6. Fibreglass pump station before and after 5 minutes cleaning with hose.

4.4 LIGHT WEIGHT

Fibreglass pump stations are comparatively lightweight, reducing transport and installation costs. The packaged pump stations are transported on cradles for ease of handling at site (Photograph 7). It also facilitates site checking that no damage has occurred during transport, and that the liquid tight envelope has not been compromised.

Typical experience in New Zealand is that onsite excavation machinery can be used to install the pump station (Photograph 8), saving the contractor time and money on expensive resources. This is particularly important at remote and difficult access sites.

Photograph 7. Fibreglass pump stations are lightweight.

Photograph 8: Excavator installs pump station

4.5 PACKAGED PUMP STATIONS MINIMISE SITE WORK

With all the internal assembly work done in the factory, the pump station arrives at site as a complete unit. The need for multiple contractors on site is minimized. One contractor (Hill, 2008) stated this made scheduling installation and managing subcontractors more straight forward, and reduced costs significantly. Reductions can be achieved in many areas of time sensitivity, like machine hireage, de-watering costs and hireage of necessary safety and ancillary equipment.

4.6 CONFINED SPACE ENTRY & SAFETY

Safety is paramount at any construction site. Confined space entry in wastewater pump stations as a minimum requires: gas tests, safety harnesses, personnel lifting equipment, ventilation equipment, protective clothing, extra people on safety watch, and a trained safety supervisor to be present; all requiring additional time and project expense. Safe excavation practices must also be used, to ensure there is no danger of cave-ins.

For packaged fibreglass pump stations, the requirement for confined space entry at site is much reduced. The pump discharge feet, discharge piping, guide rail system, inlet piping, ducting and any other equipment are already factory installed. There is no need to enter a factory manufactured fibreglass pump station during the installation phase.

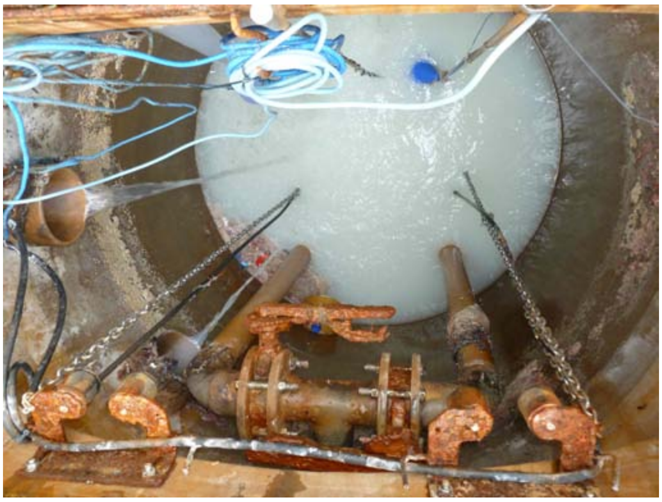
5 CASE STUDIES OF NEW ZEALAND FIBREGLASS PUMP STATIONS

5.1 PALMERSTON NORTH DAIRY

A fibreglass pump station was installed in a Dairy Factory in 2000. It was manufactured in vinyl ester resin, and handles CIP effluent including up to 5% nitric acid, up to 5% caustic, hot water, and milk wastes. Evaporator water has at times exceeded 95ºC. The thermal shock from sudden changes in temperature has caused surface crazing on the internal surface of the fibreglass pipe (Photograph 10) that drains the evaporator to the pump station. This is superficial only, and has not led to failure. The resin rich interior surface of all fibreglass parts is reinforced and strengthened with a fine glass tissue, giving it improved physical characteristics to handle these thermal stresses. All parts of the pump station are contact moulded for the highest degree of chemical resistance, and this is especially needed in this application. The main laminate is reinforced with non-continuous glass fibre, and this limits the spread of any chemicals within the laminate should significant cracks develop.

Valve handles and other non-stainless steel metal parts within the pump station are being corroded (Photograph 9).

Photographs 9 & 10. Fibreglass pump station at Dairy factory after 11 years service handling milk products and CIP chemicals at temperatures to 95ºC. Internal surface of inlet pipe has crazed, but is still structurally sound.




5.2 HAWKES BAY PRISON

A fibreglass pump station was installed in the Mangaroa Prison in Hawkes Bay in 2005. After 6 years operation, it is in excellent condition. The load is intermittent, with low-level buildup of hydrogen sulphide gas. Non-stainless steel parts within the pump station have corroded, and will need maintenance in the future.

Site personnel advised that the pump station is hardly ever touched, other than being cleaned out every 3 to 4 months. Management of the prison changed in 2010, and servicing had possibly been neglected in the past. The spider webs present (Photograph 11) confirm there has been minimal servicing. The fibreglass pump station itself has not suffered as a result of infrequent service.

Photographs 11. Fibreglass pump station at Hawkes Bay prison handling wastewater is in excellent condition, despite minimal servicing. Non-stainless steel metal parts are being corroded by hydrogen sulphide gas.

5.3 LINDEN GROVE PUMP STATION, CHRISTCHURCH

The Linden Grove Ave pump station (PS96) was installed in 2008. It is located about 4km southwest of the city centre, and has endured more than 6,000 earthquakes during 2010 and 2011, without damage. The pump station and valve chamber are located close together. They are connected by rigid ductile iron piping, and a reinforced concrete slab ties the two together. The lack of damage is likely due to the two being tied together, so that there is minimal differential movement during an earthquake.

Photograph 12: Linden Grove Pump Station, Christchurch (PS96). No damage during earthquakes of 2010 and 2011. Pump station and valve chamber are close, and tied together with concrete slab.

5.4 BIRCHGROVE PUMP STATION, CHRISTCHURCH

The Birchgrove pump station (PS97) was installed in 2009. It is located to the east of the city centre, closer to the area worst affected by the 2010 and 2011 earthquakes. The two 50mm diameter pump station discharge pipes include flanged fibreglass spools at the pump station wall, followed by a ductile iron pipe to the valve chamber. During the 22 February 2011 earthquake, both discharge pipes sheared immediately outside the pump station in the fibreglass spool section (Photograph 13). The liquid tight envelope of the fibreglass vessel itself was not broken.

An unusual aspect of the Christchurch earthquakes was the significant vertical acceleration that occurred, in addition to the normal horizontal acceleration. A significant amount of the damage to Christchurch City buildings, and pump stations, was a result of this vertical acceleration component.

When excavated, the pipes were found to be displaced both horizontally and vertically by 20mm to 50mm. It is likely the pump station and valve chamber moved during the earthquake, and that the backfill around the discharge pipes compacted downwards. As the discharge pipes were rigid ductile iron, there was no flexibility to take up any movement, and the breakage resulted.

Photograph 13: Birchgrove Pump Station, Christchurch (PS97): Discharge pipes broke during 22 February 2011 earthquake at fibreglass spool just outside pump station wall.

Breaks

Repairing the breaks in these fibreglass pipe spools was relatively straight forward, as the break was outside the pump station. The rigid ductile iron pipes have been replaced with HDPE piping, and trial 'Carrier Pipes' were installed. This provides more flexibility and room for movement of the pipe connecting the pump station and valve chamber. The 'Carrier Pipes' are fibreglass, with a diameter between 4 and 6 times the discharge pipe diameter. They also provide protection to the HDPE piping during any future excavation.

Photograph 14: Birchgrove Pump Station, Christchurch (PS97) Earthquake Damage Repairs: (1) Fibreglass nozzles strengthened, HDPE pipe used, and 'Carrier Pipes' being installed to provide room for movement.

5.5 BLACK ROCK PUMP STATION, LYTTLETON

The Black Rock pump station (PS625) was installed in 2008, and is near the epicenter of a number of the 2010 and 2011 Christchurch earthquakes. It is installed on the edge of an extinct volcanic rim, where the bedrock is close to the surface. The pump station was built above this bedrock, and retaining walls were constructed around it. This pump station handles wastewater from a new subdivision, with only a few houses constructed to date.

The earthquakes further consolidated the fill, resulting in significant cracks to the concrete and asphalt surrounds (Photograph 15). There was no damage to the pump station or discharge pipework.

Photograph 15: Black Rock Pump Station, Lyttleton (PS625): Earthquakes cracked concrete surrounds.

5.6 WIGRAM PUMP STATION, CHRISTCHURCH

The Wigram pump station was installed in 2011 in a new subdivision. The pump station and valve chamber are 4 metres apart, and 150mm diameter ductile iron discharge pipes connect the two. The pump station was commissioned immediately prior to the series of earthquakes in June 2011. The earthquakes fractured the discharge piping just outside the pump station in the fibreglass spools (Photograph 16). The liquid tight envelope of the fibreglass vessel itself was not broken. Again, there was both vertical and horizontal displacement of the pipes; the maximum vertical displacement measured was 80mm downwards.

Photograph 16: Wigram Pump Station, Christchurch (PS101): Both 150mm diameter discharge pipes to the valve chamber fractured in the fibreglass pipe spool at the pump station wall.

It appeared that the ductile iron pipes (and not the pump station) were forced downwards by the earthquake, and as a result the fibreglass pipes fractured. The pump station and valve chamber were subsequently surveyed, but no significant movement vertically of either was found. It appears the earthquakes compacted the backfill around the pump station, forcing the discharge pipes downward, with the observed result.

The fibreglass spools were strengthened and gusseted (Photograph 17), so that the weakest point is further out from the pump station wall and more accessible if damaged in the future. HDPE discharge piping was installed, and is now the standard for this work in Christchurch. It is not possible to totally stop earthquakes causing damage, but the measures taken will minimize any future damage and make subsequent repairs easier.

Photograph 17: Wigram Pump Station, Christchurch (PS101: Strengthened and gusseted fibreglass outlet pipe.

5.7 EKETAHUNA PUMP STATION, TARARUA DISTRICT

The Eketahuna pump station was installed in 2010 to handle wastewater from the lower parts of the rural town of Eketahuna. The installation included a fibreglass valve chamber. The supervising engineer from the Tararua District Council stated (Bonny, 2011) that the installed cost was about the same, or a little lower, than building it in traditional all concrete. He stated that there were huge savings in reduced health and safety costs, as no one needed to enter the pump station during construction. These savings in time, resources, supervision, and labour are often difficult to quantify. Total project cost analysis showed that the costs of the fibreglass vessels were only 30 percent of the total pump station and valve chamber project cost.

Photograph 18: Eketahuna Fibreglass Pump Station and Fibreglass Valve Chamber

6 LIFE CYCLE COST ANALYSIS

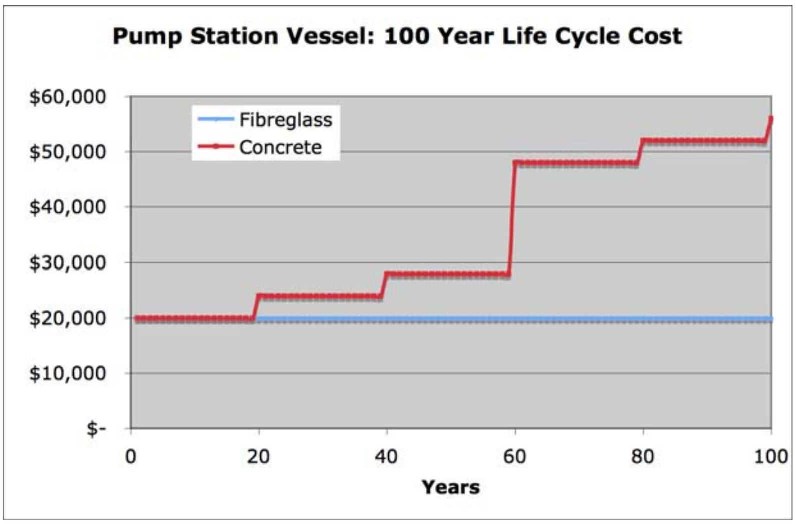
Fibreglass pump stations have a similar, if not lower, total project cost than concrete ones (Hill, 2008; Bonny, 2011). While the costs of the individual parts for a concrete pump station are lower, it is the total installed cost that must be taken into account in any life cycle cost analysis. It has not been possible to obtain accurate detailed costing data comparing the installed costs of fibreglass pump stations projects to traditional concrete pump station projects. For the fibreglass pump station, it is difficult to quantify the savings associated with reduced management of subcontractors, supervision, health and safety costs, and shorter time of construction.

A fibreglass pump station has an indefinite life. There are no ongoing maintenance or replacement costs for the vessel itself. Maintenance would be required on non-stainless metal parts, the pumps, instruments, controllers and other equipment; everything else other than the fibreglass vessel itself.

By comparison a traditional concrete pump station requires regular maintenance, rehabilitation, and/or replacement. For example, Wellington plans for this to be done every 20 years (USEPA 2003).

In any 100-year life cycle cost analysis comparing two alternatives of equal value, the one requiring regular maintenance will always have a significantly higher life cycle cost. Figure 3 compares the 100-year life cycle costs of a fibreglass to a concrete vessel, both with an initial installed cost of $20,000. The fibreglass vessel requires no maintenance, in contrast to the concrete vessel requiring maintenance every 20 years (recoating) and full replacement after 60 years.

Fig 3: 100 Year Life Cycle Cost for Fibreglass and Concrete Pump Station Vessel



Over a 100-year period, the life cycle cost of the concrete pump station vessel is almost 3 times that of the fibreglass pump station vessel.

7 CONCLUSIONS

Fibreglass pump stations have been used successfully for more than 10 years in New Zealand. The fibreglass vessels themselves have not deteriorated in this service, and are expected to have an indefinite life in wastewater service.

Fibreglass pump stations have a secure liquid tight envelope, as all joints are factory sealed, minimizing leakage and infiltration.

The discharge pipework is the part of a pump station most likely to be damaged, as occurred in the 2010 and 2011 Christchurch earthquakes. Improved design and the use of more flexible HDPE discharge piping can minimize this happening. 'Carrier Pipes' may also be useful in this regard.

The installed cost of a fibreglass pump station is approximately the same as for a traditional concrete station. The fibreglass vessel has a significantly lower 100-year life cycle cost compared to a traditional concrete pump station vessel, due to the need for regular maintenance of the latter.

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