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# CONCRETE

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## ON AN UPWARD TRAJECTORY

Professional qualification/certification solutions for industry career development

## QUALITY MATTERS

Considering supplementary quality and testing measures for GRC

## CORROSION CONTROL

Analysing 15 years of hybrid anode performance data

# 4CP (CIRCUMFERENTIALLY COMPRESSED COMPOSITE CONCRETE PIPES)

**A new corrosion-free concrete pipe option that weighs significantly less than conventional reinforced concrete pipe (RCP), is stronger and more tolerant of soil settlement, has improved sealing at the pipe joints, a longer service life, and lower carbon footprint. Consistent with the 2045 Transportation Plan, these improved features benefit agencies responsible for stormwater and drinking water management systems. Mark Schumacher and Rinaldo Pinchiroli of FSC Tech report.**

**BELOW LEFT:**
Figure 1 – 4CP pipe.

**BELOW:**
Figure 2 – standard reinforced concrete pipe.

4CP (circumferentially compressed composite concrete pipes) are the latest innovation in drainage, sewer, and drinking water pipes. To understand the innovation, we need to take a brief look at history.

Unreinforced pipes were the first kind of concrete pipes produced and most of the 100+ year-old pipes in still service are unreinforced. Their long life reflects the lack of steel to corrode, but this exceptional durability is off-set by the fact that once the maximum crushing load is reached, pipes collapse catastrophically.

Starting in the 1930s, unreinforced concrete pipes of medium and large diameter started to be replaced by steel-reinforced concrete pipes (RCP). The steel reinforcement allowed the pipes to take higher and more variable loading in the field, and also offered some internal pressure capabilities. RCP can have a 100-year service, but it must have a suitable installation environment. The steel reinforcement is subject to corrosion and therefore must have minimum depths of concrete cover to protect it. Cover requirements increase the wall thickness and correspondingly the weight and cost of the pipe. This is acutely evident in diameters below 900mm (36-inch) when comparing the specifications for unreinforced and steel reinforced concrete pipes.

The unnecessary wall thickness has made the product more expensive, opening the market to alternative materials that do not have the corrosion issue.

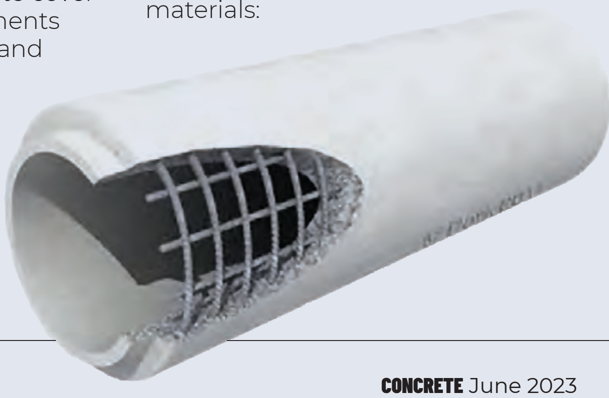
## LIMITED PRESSURE CAPABILITY

In pressure applications, the steel reinforcement needs to be sized to avoid any cracking, otherwise the fluid will leak through the pipe. Because of the very low tensile strain capacity of concrete, the steel has to work to a very low tensile stress making it very difficult to exceed 3.5 bar of internal pressure with traditional mild steel reinforcement.

## MARKET ERODED

From 300mm (12-inch) and larger, the reinforced concrete pipe market has been eroded by flexible pipes that are taking advantage of the soil interaction, which gives them increased load carrying capacity without having to make the wall thickness greater to provide strength.

When sizes become larger than 900mm (36-inch), the cost of RCPs become less expensive, but despite this, other materials are now used, even if more expensive. Here are the most common reasons why engineers specify other materials:



| | £ per tonne | Admissible compressive strength (MPa) | Admissible tensile strength (MPa) | Compressive + tensile admissible stress | £ per MPa of total admissible stress | £ per MPa of compressive admissible stress | £ per MPa of tensile admissible stress |
|---|---|---|---|---|---|---|---|
| Steel | 2000 | 300 | 300 | 600 | 3.33 | 6.67 | 6.67 |
| HDPE | 900 | 15 | 24 | 39 | 23.08 | 60 | 37.5 |
| PVC | 900 | 17 | 28 | 45 | 20 | 52.94 | 32.14 |
| Concrete | 50 | 30 | 2 | 32 | 1.56 | 1.67 | 25 |
| Advanced composites | 8000 | 15 | 1200 | 1215 | 6.58 | 533.33 | 6.67 |

**ABOVE:**
Table 1 – Compression and stress of different pipe materials.

**RIGHT:**
Table 2 – Carbon footprint savings per metre – 4CP vs other pipe options.

| ID (mm) | RCP (%) | PVC (%) | HDPE (%) | GRP (%) |
|---|---|---|---|---|
| 300 | 83 | 95 | 63 | 79 |
| 450 | 77 | 93 | 60 | 79 |
| 600 | 82 | 96 | 86 | 93 |

** 4CP is using low-carbon binders*

**ABOVE:**
Figure 3 – flexible pipe problems – delamination, buoyancy and buckling.

- better joint sealing
- greater durability to aggressive fluids and soils
- better ability to carry internal pressure.

Other reasons come from installation parameters:

- longer lay length
- lighter handling equipment requirement
- lower failure rates in job-site leakage tests.

## FLEXIBLE PIPE PROBLEMS

During this time, flexible pipes have shown their own problems:

- GRP pipe delamination – the most common failure of GRP pipes is triggered by the separation of the layers between the fibre and resin.
- Buoyancy – the light weight, while an advantage in installation, makes them very susceptible to becoming buoyant, which results in line failure.
- Buckling – attempts to reduce the total resin volume in plastic pipes result in decreasing pipe stiffness as the diameter increases. These thin wall sections are increasingly susceptible to wall buckling at 45° from the crown as the resin material itself has low compressive strength.

## 4CP PIPES

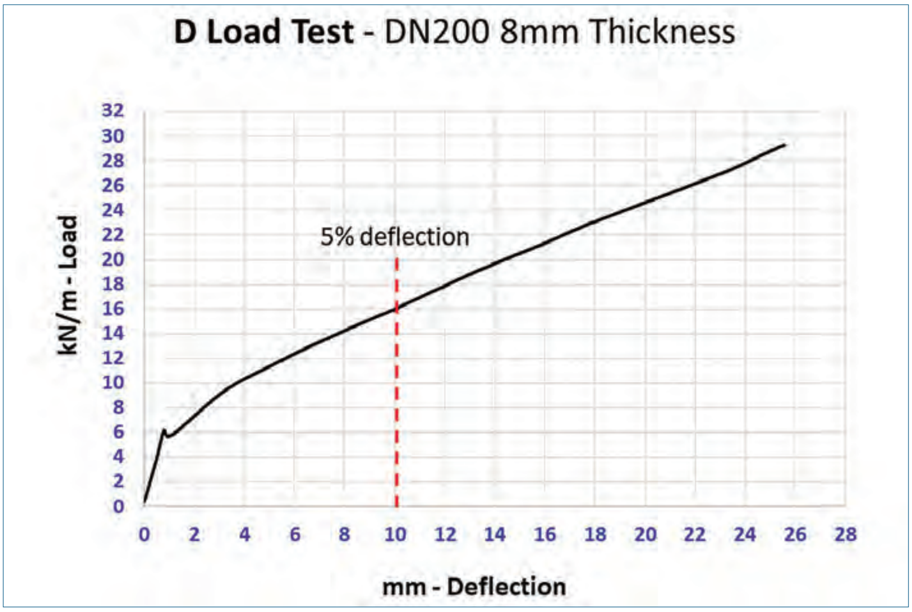
4CP pipes overcome the limitations of RCP, plastic and GRP, providing concrete with the opportunity to recapture market share lost to alternative materials. Concrete is a very good material for pipes. The high compressive strength of concrete installed in an arch-type configuration is significantly less expensive than any other construction materials for pipes (see Table 1) and has a cost per unit of stress that is eight times better than the closest material.

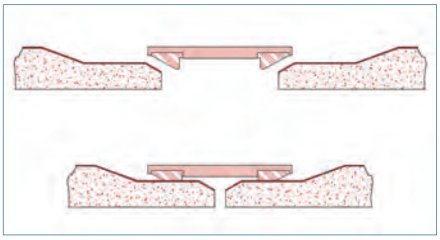
This new innovation is a standard concrete pipe with no steel reinforcement but is wrapped on the exterior with FRP 'in tension'. This puts the concrete core in a status of post-compression and provides an envelope that protects the pipe, eliminates leakage through the wall and enables a very watertight joint. The 4CP pipes can be produced with a much thinner wall section with a corresponding weight reduction, longer lay lengths, and lower cost. The number of wrapping laps determines the level of post-compression. The solution is customisable to meet particular project requirements.

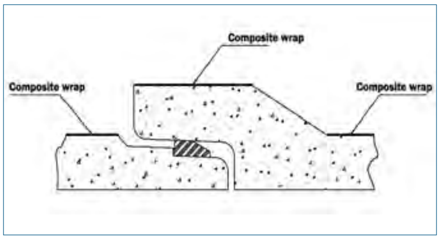
## 4CP MAIN FEATURES

Starting from DN 150mm – 6-inches diameter – with a thickness from 1/25 of the internal diameter, the 4CP pipes have the following main features:

- They do not leak, because the spiral-wound FRP (that is applied in tension with a small amount of resin) provides a watertight envelope for the pipe.
- They are capable of pressure applications, hypothetically without any limit. It is just a matter of sizing the 4CP pipe correctly.
- They can be laid on aggressive soils, because the FRP protects the concrete and there is no steel to protect.
- The specific production process allows the formation of an ultra-high-performance concrete layer a few millimetres thick on the pipe. Since this type of concrete has small pore size and an absence of $Ca(OH)_2$ it increases the chemical resistance of the pipe ID.






## 4CP STRUCTURAL BEHAVIOUR

The 4CP pipes can be designed as rigid, semi-rigid or elastic. Applying the wrap significantly increases the crushing-load capacity and it is now possible to significantly reduce the wall thickness for the same required crushing load. Producers and specifiers can now decide the pipe rigidity by adjusting the level of post-compression and/or the concrete wall thickness in the design stage.

In the case of elastic behaviour design – with a stiffness many times greater than the plastic/GRP pipes – the load/deflection graph in Figure 4 shows a first section up to the first crack, which occurs at 0 and 180°. This corresponds to the highest point of the steep part of the graph. Then, as the load increases, the pipe deforms for a long time without breaking. By reducing the load, the pipe exhibits an elastic behaviour and returns to its original shape. The failure occurs due to compression of the concrete, at 90 and 270°, and this occurs for loads and deformations much greater than those of the first crack. Given that if the pipes have a deflection capacity of more than 5%, the design is *not* dependent on the adjacent soil envelope to carry significant load as is the case with steel, plastic and GRP pipes. Of course, in the field if the pipe starts to deflect a significant amount it will mobilise the surrounding soil envelope in the same way the flexible pipes do, but the 4CP pipe is not *dependent* on this.

The first crack at 0 and/or 180° does not affect the structural behaviour of the 4CP pipe, because the pipe is still able to carry the same load *without* creep. Also, it does not affect the functional features; as the pipes do not leak, they are still suitable for pressure applications.

## JOINTS

There are a number of joint options for 4CP as shown in Figures 5–7. By placing the sealing surface on the 4CP composite wrap, there are several advantages (see Figures 5 and 6):

- continuity of the impervious surface, even if the concrete cracks or is porous
- in pressure application, every portion of the concrete core has post-compression
- by placing the gasket on the collar, it has the advantage of also being compressed from the internal pressure.

## 4CP JACKING PIPES

4CP jacking pipes have many advantages:

- They have internal pressure capability without the need to use the concrete pipe just as a sleeve in which other pipes are installed.
- Axial compression capability, the true design capacity of a jacking pipe, is normally increased from two to 3.5 times (it depends on the amount of wrapping applied).
- The pipe OD becomes corrosion-resistant and can be jacked in aggressive soils.
- The FSC jacking pipes have a reduced friction coefficient due to the FRP wrap, which generally reduces jacking forces.

## CARBON FOOTPRINT SAVINGS

The absence of reinforcing steel and associated corrosion extends the useful life to hundreds of years and finally the possibility of using low-carbon binders greatly reduce the carbon footprint of the pipes (see Table 2). Even in this field, the 4CP pipes perform much better than any other option. C

**TOP:**
Figure 4 – load/deflection test of 4CP pipes.

**ABOVE LEFT:**
Figure 5 – collared joint design.

**ABOVE RIGHT:**
Figure 6 – jacking pipe joint.

**BELOW:**
Figure 7 – traditional concrete pipe joint FRP reinforced.