Sewer Relining in GRC

GRC sewer lining segments
Sewer Rehabilitation:
‘The Economical Option.’

Mouldform GRC Ltd

Abstract
It is becoming apparent that our sewer systems are in need of rehabilitation. Some are in such a bad state that the only option is for them to be excavated and new concrete pipes laid. In some areas such as the south of England, this also provides an opportunity to upgrade the existing mains to handle the increased demands that have been put upon them. But what about the miles of old brick Victorian sewers that run beneath the streets of all our major towns and cities?

There are systems available that provide efficient methods of re-lining these old brick sewers whilst causing minimal disruption to the streets above. One of these systems is the use of rigid liners that can slide down the inside of the existing sewer, then be fixed to provide new life to the sewer. These rigid liners can be one piece or segmental and manufactured from either Glass Reinforced Cement (GRC) or Glass Reinforced Plastic (GRP).

The use of structural and non-structural liners is becoming a more popular option as Water Authorities discover the advantages of using such systems and realise the cost savings involved over that of laying new sewers.

The purpose of this paper is to present all the technical data of the Glass Reinforced Cement linings to show their ability and versatility, providing an excellent alternative to other more costly systems.
1.0 Introduction
Beneath all major cities are miles of man entry sewers. Many are built from double skin brickwork and date from Victorian times. Although skillfully built by craftsmen they are now in need of rehabilitation. Providing the sewer has not collapsed, relining provides an efficient solution with minimum disruption to traffic on the street above.

GRC (Glassfibre Reinforced Concrete) has been used to produce pre-formed GRC sewer relining segments for over 20 years and although there are many rivals it has proved to be cost effective and the most versatile of the competing systems.

Since its invention in the late 1960’s, GRC has established itself worldwide as an accepted construction material. Its ability to provide a material combining the high strength of alkali resistant glassfibre and the rigidity of a cement-rich matrix in lightweight, easily formed thin sections has already been exploited in a wide range of civil engineering, mining, tunnelling and sewer relining applications.

2.0 Categorisation of Linings
Three design methods/approaches are considered applicable for assessing the long-term structural requirements for renovated sewers. These are as follows:

2.1 Type I - For pipe linings that form a bond to the grout and/or the sewer wall, so that the renovated sewer acts as a composite section. Materials available for this technique include:

- Gunite
- Glass Reinforced Cement (GRC)
- Polyester Resin Concrete (PRC)
- Glass Reinforced Plastic (GRP)

2.2 Type II - For pipe linings that form no bond between grout and the sewer wall. The structural improvement resulting from the strength of the lining. Materials include:

- Polyethylene
- Glass Reinforced Plastic pipes > 5mm thick
- Insituform > 6mm thick
- Polypropylene
2.3 **Type III.** For all very flexible linings, that act as permanent formwork and other, segmental linings with no reliable bond to the grout, any structural improvement being provided by the grout. Present recommended materials:

- Glass Reinforced Plastic < 5mm thick
- Insituform < 6mm thick
- Segmental linings that do not form a reliable bond to the grout.

3.0 **What is GRC?**

GRC is a combination of cement, fine aggregates and glass fibres and in many respects may be regarded as a thin high quality concrete.

GRC is usually produced with a water/cement ratio lower than 0.4, which is low in comparison to most concrete, and also has a cement content of not less than 800 kg/m3, which is high for concrete.

It is a well-established fact that the high durability of concrete is dependent on high cement and low water/cement ratio, factors that affect the strength and permeability of the material. On this basis the performance of GRC in an aggressive environment is likely to be superior to that of concrete.

3.1 **Permeability of GRC**

The rate of chemical attack on GRC depends upon the extent to which reactive elements in the cement are exposed to aggressive agents in the environment, and the rate at which reaction products are leached out.

The importance of permeability must be emphasised. Its effect can outweigh that of the type of cement. This is confirmed by BRE studies on concrete considering the effect of sulphates in soils, which suggests that, in some cases, the type of cement is less important than the quality of the concrete.

The permeability of cement paste increases considerably with water/cement ratio and above a value of 0.70; permeability rises to very high values, indicating poor durability. On this basis, correctly manufactured GRC with a water/cement ratio of less that 0.4 can be expected to show low permeability and high resistance to aggressive environments. This point is emphasised by reference to BS 8110 ("The Structural Uses of Concrete"), which defines maximum water/cement rations for reinforced concrete subjected to different environments, and suggests a maximum of 0.5 for exposure to abrasive conditions. Measurements carried out at the BRE have shown the following results:
3.1.1 Permeance to Water

(a) BS 4624 “Methods of Test for Asbestos and Asbestos – Cement Building Products” involves subjecting the material to a 250mm head of water for 24 hours. Absence of water drops on lower surface is acceptable. GRC passes this test and also passed a more severe test using a 750mm head of water for two months.

(b) B.SSEN 490: 1994 "Concrete Roofing Tiles and Fittings. Product Specification" and B.SEN 491: 1994 "Concrete Roofing Tiles and fittings. Test Methods" measures the flow water into the sample after 24 hours under a 200mm head of water. GRC of a cement/sand ratio of 2:1 and a water ratio of 0.33; 5% fibre, 6-10mm thick after 7 days cure and 21 days in air gave a permeance of 5.0 – 33.0 metric perms.

There was no detectable difference between direct spray and spray de-watered GRC (Note: metric perm = g/m² 24 h mm Hg).

3.1.2 Permeance to Water Vapour

This is dependent on specimen age, storage conditions and initial water/cement ratio. Initially for GRC of 0.35 w/c ratio it can be up to 8.5 metric perms, but reduces with time in most external environments. For material of 0.25 w/c ratio it remains constant at 2 metric perms. This compares well with asbestos cement (5.5 mp) and structural clay tile (7.6 mp).

It is important to note that the permeability of cement paste is not necessarily related to its porosity, but depends on the size, distribution and continuity of the pores as well as their volume.

It is apparent (from figures relating to all three solutions) that the presence of 0.35% sulphate in aqueous solution produces little or no fall off in properties relative to the effect of water itself. Increasing the Sulphate concentration to 1.5% causes only a slight decrease. On the other hand, a 5% solution of ammonium sulphate can be considered aggressive.

In spray de-watered GRC: similar trends were shown, although final strengths were higher in accordance with higher start strengths.
GRC samples produced using ‘Sulphacrete’ sulphate resisting cement and fibre have been aged in a 5% (by weight) copper sulphate solution at 50°C for up to 56 days, and showed similar behaviour to samples aged in water at 50°C. Hence, the presence of 5% copper sulphate had no detrimental effect on the mechanical properties of the GRC, although samples suffered black discoloration after seven days.

### 3.2 Acids and Alkalis

Portland cement releases calcium hydroxide during hydration and is, therefore, highly alkaline (pH 12.5). Consequently, alkaline solutions present no particular hazard to concretes, whereas acid constitutes a potential danger.

Acidic conditions can arise from dissolution in moisture of S0₂ and CO₂ from the atmosphere and also from peat and other forms of decomposed vegetation releasing humic organic acids and carbonic acid.

The rate of deterioration will be greatest where acid effluents are continually flowing over GRC. However, in many natural acidic environments, e.g. in soils of pH4, the rate of acid replenishment is often slow, as is removal of reaction products.

Results are available for GRC, produced with neat RHPC and SRPC cement, stored for five years in the following soils:

- i. Peat Soil (pH 4.0)
- ii. Acid Soil (pH 3.9-4.5)
- iii. Neutral Soil (pH 6.5)
- iv. Keuper Marl (pH 8.3)
- v. Alkaline Soil (pH 8.5)

After five years, the highest Modulus of Rupture (MOR) was in alkaline soils, as might be expected, with an increase in Limit of Proportionality (LOP) and MOR values for de-watered materials.

After two years, all soils gave similar results, however, after that time results started to diverge. Peat soil was found to be more aggressive than other soils, producing lower values of MOR and Young’s Modulus for both RHPC and S.R.P.C. composites after five years.

Fibre strength in all soils and from both types of cement were found to be similar to fibre strengths of GRC stored both in water and in natural weather. Therefore, the fibre itself is relatively unaffected by acidic environments.
GRC is normally made with a water / cement ratio of less than 0.40 and a cement content of not less than 800kg/m³. These factors result in low permeability giving good resistance to chemical attack.

3.3 Strength retention of GRC immersion for 2 years in effluent and fresh water.

<table>
<thead>
<tr>
<th>EXPOSURE</th>
<th>MOR % RETENTION</th>
<th>LOP % RETENTION</th>
<th>IMPACT % RETENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 years Submerged in effluent</td>
<td>67</td>
<td>112</td>
<td>76</td>
</tr>
<tr>
<td>2 years Above effluent</td>
<td>78</td>
<td>132</td>
<td>72</td>
</tr>
<tr>
<td>2 years Fresh water at 17°C</td>
<td>62</td>
<td>132</td>
<td>40</td>
</tr>
</tbody>
</table>

Percentage strength retention of mechanical properties in and above the effluent were greater than the respective properties of GRC aged in wet and dry conditions in the BRE series of tests.

After six months coupons which had been immersed in sewage had become blackened, but those above the sewage were visually unaffected.

3.3.1 Water

At 20°C the MOR of RHPC GRC falls to about 20 N/mm² in 1-2 years and retains this value to five years. The LOP increases steadily over the period, whilst Impact values fall in a similar manner to the MOR, but level out at about 6 Nmm/mm².

3.4 Resistance to water flow

The surface of Mouldform GRC segments is smooth and therefore less resistant to water flow than other cementitious materials. In Manning’s Equation, used to calculate velocity flows in channels the lower the value of Manning’s Coefficient of Surface Roughness, ‘n’, the less is the material’s resistance to water flow. GRC is estimated to have a coefficient of 0.015 and ‘Shotcrete’ has coefficients in the region of 0.017 to 0.023.
4.0   Manufacture

The Water Research Council (WRC) controls the quality of all materials used in sewer relining. For GRC, the important parameters are 28 days flexural strength and skin thickness to ensure consistency.

Mouldform GRC is manufactured by the machine spray dewatered technique. Using a high water cement ratio and sulphate resisting cement, the GRC is sprayed onto a dewatering mould by means of an auto traverse. The sprayed GRC is vacuum dewatered and cut to the required size. This process gives greater tensile strength, density and uniformity of membrane thickness than GRC produced by conventional hand spraying.

The cut sheet is lifted using a specially designed lifting pad and located on the mould. The mould is manufactured from a site-produced template, which ensures the best possible fit to the sewer. The GRC sheet is compacted against the mould and is given a textured finish to improve the bond between the GRC and the grout.

Test boards cut from the main GRC sheet are immediately tested for glass content and at 7 and 28 days for flexural strength.

Mouldform GRC combines the compressive properties of cement-based mortars with the flexural and tensile properties of the glassfibres to give a material with the following characteristics:

- Dense and crack resistant
- Non-combustible
- Impermeable and water resistant
- Easily formed into thin lightweight sections in a wide range of shapes
- Compatible with cementitious grouts and concrete
- Safe, easy to handle and work

4.1  Load carrying capacity

GRC was included in the early field loading trials of the Water Research Centre – Engineering Centre’s investigation into the structural performance of lining systems. These trials, on a GRC relined section at Newmarket (WRC report 33E 1981) were significant in the testing of GRC for compliance with BS5400 1978 specification for loads. The system is now categorised by WRC as a Type 1 lining (fully structural).

Mouldform GRC liners can be confidently designed to be at least of equal structural capacity to a new sewer.
4.2 Design Parameters

Mouldform GRC sewer lining sizes are calculated to give the outside collar dimension taken from the approximate existing sewer size given, then allowing for a minimum annulus thickness of 25mm.

The thickness of the lining material is calculated using the outside collar dimension, allowing for:

- Internal heights of existing brick sewer
- Internal widths of existing brick sewer
- Wall thickness of existing brick sewer = normal standard at 225mm
- Vertical pressure on sewer – \( P \) = \( P = 0.1N/mm^2 \) as given in WRC manual, figure 4.10 for overburden and type ‘A’ main road
- Ratio \( K \) = 0.4 No suspected voids
  or 0.0 if voids suspected.
- Design Long term Tensile Stress = 6 N/mm\(^2\)
- Max Long-term bending stress = 9 N/mm\(^2\)
- Max Short-term bending stress = 10 N/mm\(^2\)
- Max Short-term bending modulus = 17000 N/mm\(^2\)
Typical Design

PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Calculation</th>
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</thead>
<tbody>
<tr>
<td>Pressure on sewer</td>
<td>N/mm²</td>
<td>p</td>
</tr>
<tr>
<td>K</td>
<td></td>
<td>K</td>
</tr>
<tr>
<td>0.4 voids suspected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4 voids not suspected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crown bending moment coefficient</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Mean width of existing sewer</td>
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<td>d</td>
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<tr>
<td>Wall thickness of existing sewer</td>
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<tr>
<td>Estimated minimum annulus thickness</td>
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<td>t₁</td>
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<tr>
<td>Lining thickness of GRC</td>
<td>mm</td>
<td>t</td>
</tr>
<tr>
<td>Long term tensile stress</td>
<td>N/mm²</td>
<td>s</td>
</tr>
</tbody>
</table>

CALCULATIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lever arm</td>
<td>m</td>
<td>0.67t₁ + t₁ + 0.5t</td>
</tr>
<tr>
<td>Crown bending moment</td>
<td>N mm</td>
<td>M = CPd²/4</td>
</tr>
<tr>
<td>Lining tensile force</td>
<td>N</td>
<td>F = M/t₁</td>
</tr>
<tr>
<td>Lining tensile capacity</td>
<td>N</td>
<td>T = St</td>
</tr>
<tr>
<td>Check factor of safety</td>
<td></td>
<td>T/F ≥2 OK</td>
</tr>
</tbody>
</table>

GRC Lining

Existing Brick Sewer

Grout Filled Annulus

Invert

Crown
5.0 Installation

- Survey sewer, manufacture templates. Clean sewer and replace any large areas of missing brickwork.
- Starting at the upstream end lay the invert sections to line and level and repeat with the crowns. The jointing systems will allow for slight bends but cutting can accommodate tighter bends or use specially made curved segments.
- Using mechanical fixings, secure joints at 300mm centres.
- Make any necessary side entry connections.
- Isolate length of completed section by forming mortar around circumferential joints.
- Drill holes into the linings and install grout.

Discussion

The attributes of GRC liners against the use of GRP

Mouldform GRC Liners are available as either a single section unit or as a segmental unit, offering ease of handling and more cost effective transportation. All units comply with the relevant provisions of IGN No. 4-2-04 (1986) and are categorized as Type l.

GRC liners offer greater stiffness than its GRP counterpart although the GRP unit is lighter for handling, this can be a disadvantage when considering the effects of flotation. GRC, being cement based material, will bond well with the grout lining and essentially become part of the sewer structure. GRP will not.

Exposure to high pH values should not unduly effect GRC. As a generalization acid attack is modest at low levels but becomes more severe by liquids with pH of less than 5.5. This is not the whole story since it is known that GRC has a better chemical resistance than concrete, principally because it is less permeable.

GRC liners are manufactured as single skin units, unlike its GRP counterparts that are a composite sandwiched between two thin skins of GRP which if cracked or damaged will lower its initial chemical resistance.
A GRP liner does not form a reliable bond to the grout long term. Because of this factor it is necessary to consider the effect of external water pressure acting on the sewer lining. The grout is considered likely to crack due to small ground movements, etc. Ground water may percolate through these cracks and act at the interface between the lining and the grout due to the absence of reliable bond. Thus it becomes appropriate to consider the effect of external water pressure in design checks.

GRC liners, being a cementitious material with a textured finish to the grouted face ensures a reliable long-term bond to the grout. It is unrealistic to assume that the annulus of grout will be totally free from cracks and small defects and hence external water pressures acting on the lining. But if a lining is fully bonded to the grout on either side of a crack or small defect then it is considered that no problem will occur and therefore it is not appropriate to consider the effects of external water pressures.

There have been reports in recent years of cases where plastic pipes and lining systems have failed due to the evidence of rodent attack! - whereas such animals show no signs of having an appetite for concrete!

**Conclusion**

GRC liners are versatile and flexible. They perform in many situations equal, if not better than any of their counterparts. It is our conclusion that there are not many situations where a GRC liner could not be used. It is only the lack of awareness of the product and a limited knowledge of its ability that prevents it becoming a specified material in many sewer rehabilitation projects.

GRC liners are classified as a type 1 liner, that when bonded to the grout and existing sewer wall can provide full structural support at a cost saving over its GRP counterpart.