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SPECIFICATION FOR GLASSFIBRE REINFORCED CEMENT (GRC) SEWER LININGS

FOREWORD

This specification is one of a number of specifications which have been prepared by WRc in order to assist engineers responsible for repair and maintenance of sewers. This publication covers Glassfibre Reinforced Cement (GRC) sewer linings suitable for Type I designs as defined in the Sewerage Rehabilitation Manual published by WRc Engineering.

Designers are referred to the Sewerage Rehabilitation Manual for the determination of sizes and acceptable wall thickness.

Compliance with this specification does not itself confer immunity from legal obligations.

This specification does not purport to include all the necessary provisions of a contract. Users of this specification are responsible for its correct application. Guidance on the exchange of information likely to be required before entering into a contract for the supply of linings is given in Appendix A.

This specification calls for the use of substances and/or procedures that may be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety tit any stage.

It has been assumed in the drafting of this specification that the execution of its provisions is entrusted to appropriately qualified and experienced people, for whose guidance it has been prepared.

Attention is drawn to the policy of the Water Industry to purchase products produced to an acceptable Quality Assurance and Third Party Certification Scheme.

Throughout this specification SI Units are used, thus stress and modulus values are quoted in MPa (megapascals)*.

*1 MPa = 1 MN/m^2 = 1 N/mm^2

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1. SCOPE

This specification defines the requirements for construction, materials, dimensional tolerances, joints, design, marking, testing, workmanship, inspection and certification of Glassfibre Reinforced Cement (GRC) segmental linings for the rehabilitation of sewers where the lining is designed to act with the existing sewer fabric and annulus grout to form a composite structure (i.e. Type I design).

This specification relates only to GRC manufactured by spray techniques.

2. DEFINITIONS

For the purpose of this specification, the following definitions apply:-

Effective Length of Unit
The distance between planes normal to the unit axis and passing through the real end points of the lining unit.

Lining Section
A discrete length of circumferentially continuous sewer lining made up from a joined matching pair of segmental lining units.

Out-of-Squareness of Unit End
The maximum distance between the real end surface and a plane normal to the unit axis and passing through the real end point (see Figure 1).

Out-of-Straightness
The maximum radial distance between the lining inner surface and any line parallel to the unit axis touching the lining inner surface (see Figure 1).

Real Corner Points
The two points at each end of a lining segment at which the real end surface meets the lines along which the inner surface of the lining is intended to be jointed longitudinally to the adjacent lining segment (see Figure 1).

Real End Point
The extreme point on the real end surface (see Figure 1).

Real End Surface
A surface joining the points against which the inner surface of the lining is intended to be jointed to the next lining section (see Figure 1).

Segmental Lining
Circular or non circular sewer lining that is made up from pairs of upper and lower segments, which are jointed longitudinally at or near their springings.

Springings
The highest point at each side of an installed lining where the tangent to the internal surface is vertical.

Total major axis length
The distance between the crown and invert of a lining section.

Type I design (Sewerage Rehabilitation Manual)
The renovated sewer is considered to be acting as a composite section, consisting of the old sewer wall, grout and lining. It is assumed in the design that these three components are bonded together and that the grout is stiff and strong enough to transfer stress to the lining.

Uncured State
The stage in the manufacture of GRC when all physical processes which would alter the composition of the material are complete, but the fibre can still be separated from the matrix by the action of running water.

Unit Axis
The unit axis is a line passing through the mid points of lines joining the real corner points at each end of the segment {see Figure 1).

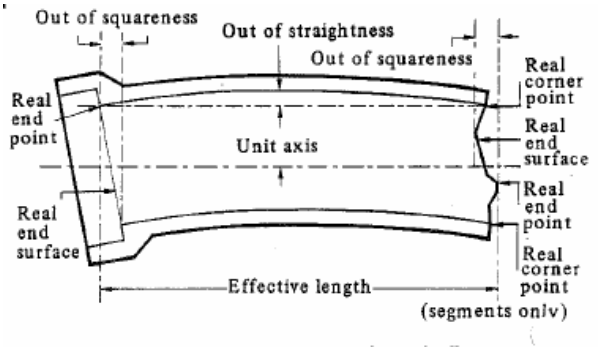

Figure 1 - Section through or plan of, nominally straight lining unit (Diagrammatic only)
Lines marked thus ----------.are either square or parallel to each other.

3. MATERIALS

3.1 Glassfibre

The glassfibre shall be alkali resistant.

The tensile strength ("SIC strength") of the glassfibre when tested using the GRCA test method* shall not be less than 555MPa after 96 hours (= 1 hour) immersion in water at 80℃ (= 1℃) using a cement mortar slurry specified in Note 2 on page 15 of the GRCA publication.

The length of all fibres shall be in the range 32 to 33mm.

The glassfibres shall be free from oil, grease and other contamination.

* "GRCA Method of test for strength retention of glassfibre in cements and mortars". GRCA S01040184. January 1984.

3.2 Cement

The cement shall be ordinary, rapid hardening or sulphate resisting Portland cement conforming with the requirements of BS 12 or BS 4027. The type of cement shall be selected by the manufacturer to provide a lining with the required mechanical and chemical properties. Different cement types shall not be mixed together.

3.3 Aggregate

Only washed and dried high purity silica sand shall be used, which meets the following requirements:

3.3.1 Chemical composition

(a) Maximum moisture content of 2% as a percentage by mass of dry aggregate when determined in accordance with clause 7 of BS 812: Part 2: 1975.

(b) Maximum soluble salt content (i.e. alkali") of 1% by weight.

(c) Maximum sulphate ion content of 0.4% as a percentage by mass of dry aggregate when determined in accordance with clause 9 of BS 3681: Part 2: 1973.

(d) Maximum chloride content of 0.06% as a percentage by mass of dry aggregate when determined in accordance with BS 812: Part 4: 1976.

(e) Loss on ignition less than 0.5%, when determined in accordance with clause 11 of BS 3681: Part 2: 1973.

(f) Organic matter must not affect the setting of the cement.

3.3.2 Grading

100% by weight of the aggregate shall pass a 1.18mm sieve and a maximum of 10% by weight shall pass a 150µm sieve when tested in accordance with BS 812: Part 1 using test sieves of the nominal aperture sizes given and complying with BS 410 full tolerances.

3.4 Admixtures

Admixtures complying with the requirements of BS 5075: Part 1 may only be incorporated into GRC to aid the manufacturing process and provided that they do not adversely affect the properties or durability of the GRC. Combinations of admixtures in one mix should not be undertaken without the approval of the purchaser and consultation of the admixture manufacturers. The manufacturer shall provide for the approval of the purchaser the amount of the admixture to be added to the mix, the method of use including the chemical names of the main active ingredients in the admixture and the reason why the use of the admixture is being proposed. The detrimental effects, if any, of under-dosage or over-dosage shall be established particularly in relation to durability throughout the service life of the lining unit.

The information scheduled in clause 7 of BS 5075: Part 1: 1982 shall be provided.

All admixtures shall be used strictly in accordance with the manufacturer's instructions. Admixtures shall be incorporated using a dispensing system sufficiently accurate to deliver within ± 5% of the approved dosage rate.

3.5 Water

Water used in the mix shall be of potable quality and free from harmful matter.

Where tests are required they shall be conducted in accordance with BS 3148.

4. CONSTRUCTION

4.1 General

Lining units shall consist of the following elements:-

(a) a GRC structural wall,

(b) either a roughened external surface or a bond coat applied to the external surface to provide a bond between the lining and the annulus grout.

GRC shall be manufactured at an air temperature of at least 5°C. This temperature shall be maintained until the units are cured. Materials and moulds shall not be used if frozen.

4.2 Structural wall

The structural wall shall be manufactured from alkali resistant glassfibre. cement, aggregate, admixtures and water in accordance with this specification using a spray application method.

4.2.1 Glassfibre

The glassfibre in the structural wall shall be evenly distributed throughout the matrix. The orientation of the glassfibre shall be random with the fibre axis parallel to the mould surface of the lining unit.

The minimum glassfibre content of the GRC in its uncured state shall be 3.6% by volume.

4.2.2 Cement content

The cement content shall not be less than 50% by weight of the total weight of the mix.

4.2.3 Aggregate content

The weight ratio of aggregate to cement in the mix shall not be less than 0.3 (or greater than 0.5).

4.2.4 Water cement ratio

The water cement ratio of the cementitious matrix in its uncured state shall be less than 0.35.

4.3 Roughened external surface

The external surface, if roughened to pass the shear bond strength requirements of clause 8, shall not compromise the properties of the lining unit.

4.4 Bond coat

If a bond coat is applied in order to pass the requirements of clause 8 it shall consist of an inert material uniformly distributed over the external surface and bonded to the structural wall and shall not compromise the properties of the lining unit.

4.5 Curing

Whilst curing all units shall be protected from direct sunlight and kept in frost free, moist conditions for a minimum of 7 days before transporting.

5. DIMENSIONS

5.1 Section lengths

Lining sections shall be provided to the overall or effective lengths specified by or agreed with the purchaser to within a tolerance of ± 10mm.

5.2 Effective length of segments

The difference in effective length of a pair of segments intended to fit together to form a lining section shall not exceed 3mm.

5.3 Cross section

The width between the longitudinal joints and the depth from the unit axis to the crown or invert of the lining shall be within 1 % or 5mm of that specified by or agreed with the purchaser, whichever is the smaller.

5.4 Wall thickness

The wall thickness of the lining, excluding the bond coat if applied, shall be at least the minimum specified by or agreed with the purchaser.

The maximum overall wall thickness shall be not greater than that specified by or agreed with the purchaser, particularly at the joints.

5.5 Out-of-squareness

The out-of-squareness at each end shall be not more than 2mm ± 0.002L or 5mm. whichever is the lesser,

where L is the average distance between the real end corner points at each end of the segment measured in mm.

5.6 Out-of-straightness

The out-of-straightness of a unit shall be no more than 0.3% of its effective length.

6. JOINTS

6.1 Longitudinal joints

Longitudinal joints between lining segments shall be at the springings. The joints may be flexible or rigid and shall be capable of taking up mismatch of the lining segments due to manufacturing tolerance on squareness and dimensions. The joint detail shall be such that it is fit for the purpose intended and grout infiltration is minimised during installation.

6.2 Circumferential joints

Circumferential joints between lining sections may be flexible or rigid. The joints shall be capable of taking up an angular displacement of 1° in the vertical plane. 2° in the horizontal plane, and mismatch of the lining sections due to manufacturing tolerance. The joint detail shall be such that it is fit for the purpose and grout infiltration is minimised during installation.

6.3 Sealing materials

6.3.1 Rings and strips

Elastomeric sealing rings and strips in joints shall be used in accordance with their manufacturer's recommendations for the particular application, and shall be manufactured from a biodeterioration resistant elastomer meeting the Type D requirements of BS 2494: 1986. Where the lining is to be used to convey deleterious trade effluents a biodeterioration resistant elastomer suitable for use in those conditions shall be used.

NOTE See also IGN No. 4-40-01.

6.3.2 Compounds

Rigid setting or flexible compounds used to caulk or seal the gap between lining units shall be resistant to the sewer environment for which they are intended, and shall be suitable for installation within a confined space taking safety aspects into consideration.

7. PERFORMANCE REQUIREMENTS

The lining shall meet the minimum requirements given in Table 1 when tested in accordance with those clauses indicated. These parameters will be used for the structural design of the lining system.

Table 1 - Lining Performance Requirements

Property	Minimum requirement	Clause Covering test
Unaged modulus of rupture	18.0MPa	8.2
Shear bond strength	1.0MPa	8.3
Aged modulus of rupture	7.5MPa	8.4

8. TYPE TESTS

8.1 General

The tests given in 8.2. 8.3 and 8.4 shall have been satisfactorily completed before linings can claim to have met this specification. All combinations of manufacturing process, glass types, cements and any other components used during the manufacture of linings offered shall be tested. Should there be any modifications to these the tests must be repeated. The Quality Assurance Schedule of the quality system (see 9.1) may require type tests to be repeated at specified intervals.

All tests are the responsibility of the manufacturer. All details and results of test shall be made available to the purchaser or his representative.

Samples of panels used for type testing shall be retained and samples of thickness and composition identical to the order shall be submitted for inspection/comparison purposes by the purchaser or his representative.

8.2 Flexural strength

The lining unit shall be tested in accordance with the method described in Appendix B and shall meet the minimum requirements given in Table 2.

Table 2 - Minimum Requirements

Property	Mean of all results	Individual value
Modulus of rupture	23.5MPa	18.0MPa

8.3 Shear bond strength

The lining unit shall be tested in accordance with the method described in Appendix C and shall attain the minimum requirement given in Table 1. clause 7.

8.4 Aged flexural strength

The lining unit shall be tested in accordance with the method described in Appendix D and shall meet the minimum requirements given in Table 3.

Table 3 - Minimum Requirements

Property	Mean of all results	Individual value
Aged modulus of rupture	13.2MPa	7.5MPa

9. QUALITY CONTROL TESTS

9.1 General

The test requirements of 9.1 to 9.7 are necessary in order to demonstrate a continuing satisfactory level of production quality in day to day production. The manufacturer shall establish a quality system to meet the recommendations of BS 5750: Part 2.

The required sampling frequency for quality control tests is given in Appendix E.

9.2 Dimensions

The overall length, effective length, cross section, out-of-squareness and out-of-straightness of each test sample, shall be determined using a method of measurement accurate to the nearest millimetre and shall comply with the requirements of clause 5.

Wall thickness shall be determined at a minimum of five locations in each test unit using a method of measurement accurate to the nearest 0.1mm. by measuring at each end and cutting at least three cores through the lining wall. Each measurement shall comply with the requirements of clause 5. Generally the locations of cores shall include:-

i) a point of minimum internal surface curvature,
ii) a point near the centre of the test sample,
iii) points near each end of the test sample, but not at a joint.

9.3 Flexural strength

Each test unit shall be tested in accordance with the method described in Appendix B and shall meet the requirements given in Table 2.

The top:bottom ratio (see B7.2.3) shall be within the range 0.80 to 1.25.

9.4 Bulk density, water absorption and apparent porosity

Five test coupons without bond coats shall be taken from each test unit and shall be tested in accordance with clause 5 of BS 6432: 1984.

The mean dry bulk density of the five coupons shall not be less than 2000kg/m^3.

9.5 Shear bond strength

In the absence of a suitable objective test method each test unit shall be compared visually with a panel retained from the type tests (8.6). If it is equivalent in respect of particle shape, size and surface distribution (or other bonding key) it shall be deemed to have adequate shear bond strength. If it differs appreciably it shall be rejected.

9.6 Glassfibre content

The glassfibre content by mass and by volume of the GRC in its uncured state shall be determined at least twice during a continuous production run and shall be greater than or equal to the limit given in 4.2.1 when tested in accordance with clause 3 of BS 6432: 1984.

9.7 Water solids ratio

The water solids ratio of the cementitious matrix of the GRC in its uncured state shall be determined at least twice during a continuous production run in accordance with clause 4 of BS 6432: 1984 and shall comply with 4.2.4.

10. WORKMANSHIP, INSPECTION AND CERTIFICATION

10.1 Workmanship

All raw materials shall be tested at a frequency sufficient to ensure consistency and compliance with this specification.

The manufacturer shall adequately supervise all stages of production and keep records of the raw material batches used and products made each work shift or day.

Manufacture shall be under environmental conditions compatible with producing satisfactory linings and raw materials shall be stored and used in compliance with the recommendations of their manufacturers.

All linings shall be free from cracks and breakages and shall have a smooth Type B internal surface finish as defined in 6.10.3 of BS 8110: Part 1: 1985.

10.2 Inspection

In addition to the manufacturer's own inspection and supervision, the purchaser or his appointed inspecting authority shall have access at all reasonable times to those parts of the manufacturer's works engaged on production and testing of linings for the purchaser and to all relevant test records.

10.3 Certification

The manufacturer shall, on request, furnish the purchaser or purchaser's representative, with copies of a signed certificate for each size and classification of lining unit stating that the construction and testing of lining units supplied comply with the requirements of this specification and giving details of minimum parameters agreed with the purchaser. If required by the purchaser, the quality control test results or a suitable summary shall be provided with the certificate. A typical certificate is shown in Appendix E.

11. MARKING

All lining units shall be permanently marked at each end on the inside face. No method of marking shall prejudice the performance of the lining in service. The marking shall give the following information:-

(a) the manufacturer's name, initials or identification mark.

(b) the number 4-12-04. The marking on products produced to this specification of the number 4-12-04 may only be applied by manufacturers covered by a third party certification scheme acceptable to WRc.

(c) identification of the shift, production line and date of manufacture. Coding of this information is permitted provided that the meaning of the code is available on request.

(d) the letters "OPC". or 'RHPC or "SRPC" to indicate the type of cement used.

12. PROTECTION OF LINING UNITS

Lining units shall be handled, stored and transported in such a way as to prevent damage before receipt by the purchaser.

13. REFERENCES

This specification makes reference to the latest edition of the following publications (except where otherwise indicated), including all addenda and revisions:

Sewerage Rehabilitation Manual, published by the Water Research Centre.

Specification for Grades of Glassfibre Reinforced Cement (GRC) published by the Glassfibre Reinforced Cement Association (publication No, GRCA S 0101/0380).

Method of test for strength retention of glassfibre in cements and mortars published by the Glassfibre Reinforced Cement Association (publication No. GRCA S 104/0184).

BS 12 Specification for ordinary and rapid-hardening Portland cement.

BS410 Specification for test sieves.

BS 812 Method of sampling and testing of mineral aggregates, sands and fillers.
Part 2: Physical properties. Part 4: Chemical properties.

BS 1610 Materials testing machines and force verification equipment.
Part 1: Specification for the grading of the forces applied by materials testing machines.

BS 1881 Methods of testing concrete
Part 115: Specification for compression testing machines for concrete.

BS 2494 Specification for elastomeric joint rings for pipework and pipelines.

BS3148 Methods of test for water for making concrete (including notes on the suitability of the water).

BS 3681 Methods of sampling and testing of lightweight aggregates for concrete.

BS 3892 Pulverised-fuel ash
Part 1: Specification for pulverised-fuel ash for use as a cementitious component in structural concrete.

BS 4027 Specification for sulphate resisting Portland cement.

BS 4551 Methods of testing mortars, screeds and plasters.

BS 5075 Concrete admixtures
Part 1: Specification for accelerating admixtures, retarding admixtures and water reducing admixtures.

BS 5750 Quality systems.
Part 2: Specification for manufacture and installation.

BS 6000 Guide to the use of BS 6001. Sampling procedures and tables for inspection attributes.

BS 6001 Sampling procedures and tables for inspection by attributes.

BS 6432 Determining properties of glassfibre reinforced cement material.

BS 8110 Structural use of concrete
Part 1: Code of practice for design and construction.

WAA SWMC Information and Guidance Note No. 4-40-01 Rubber sealing rings.

APPENDIX A - CONTRACT INFORMATION

A.1 General

This section is intended for guidance only on the exchange of information between purchaser and manufacturer likely to be required for each design situation before each party enters into a contract for the supply of lining materials.

A.2 Information to be provided by purchaser

i) Details of sewer environment (for selection of appropriate materials).
ii) Size and shape of sewer to be lined.
iii) Design approach under consideration (Type I as defined by Sewerage Rehabilitation Manual),
iv) Proposed grouting pressure and method.

A.3 Details to be agreed between purchaser and manufacturer

i) Shape and cross section dimensions,
ii) Wall thickness (maximum overall and minimum structural).
iii) Effective lengths and/or overall lengths,
iv) Joint details.

A.4 Information to be provided by manufacturer

i) Method of manufacture,
ii) Constituent materials and proportions,
iii) Sketch of joint details,
iv) Written recommendations for transport, handling, storage of lining units,
v) Whether products will be covered by third party certification scheme approved by WRc Engineering.

NOTE It is intended to resource and promote quality assurance certification so that schemes acceptable to WRc will become available for all lining materials and systems.

A.5 Samples

A representative sample (including a joint) having thickness, construction and composition as the lining units under consideration shall be submitted to the purchaser upon request.

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APPENDIX B - METHOD FOR DETERMINATION OF FLEXURAL STRENGTH

B.1 Scope

Method of test to determine the limit of proportionality (LOP) and the modulus of rupture (MOR) of cured GRC in the form of coupons cut from sewer linings or test boards.

B.2 Principle

The deflection of rectangular specimens of cured glassfibre reinforced cement material is measured using four-point loading until failure occurs. The dimensions of the specimens are measured and the limit of proportionality and modulus of rupture are calculated from these measurements.

NOTE 1 This method is not applicable to thicknesses of more than 30mm.

NOTE 2 Four-point loading imposes pure bending forces over the middle third of the test specimen and is preferred to the three-point loading test, in which the stress is concentrated at the centre.

B.3 Definitions

Limit of proportionality
The flexural stress at the point where the load/ deflection curve deviates from a straight line (see Figure 2).

Modulus of rupture
The apparent flexural stress developed at maximum load (see Figure 2).

B.4 Apparatus

B.4.1 Testing equipment, capable of operating at a constant crosshead rate and including a load measuring system accurate to Grade 1.0 of BS 1610: Part 1: 1985.

B.4.2 Bending test jig, (see Figure 3) where:-

(a) The test specimen rests on two supports which:
i) are parallel.
ii) can be adjusted to give the distances given in Table 3.
iii) do not deflect significantly under experimental forces.
iv) do not impose significant longitudinal restraint on the specimen.
v) provide line contact with the specimen.
vi) are at least as wide as the specimen.
vii) are of 6mm minimum diameter.

(b) the applied force is transmitted uniformly to two line contacts on the upper face of the specimen by two loading rollers on a beam which:
i) are parallel to the specimen supports,
ii) can be adjusted to give a minor span equal to a third of the major span,
iii) do not deflect significantly with respect to the beam centre, under experimental forces,
iv) do not impose significant longitudinal restraint on the specimen.
v) provide line contacts with the specimen.
vi) are positioned symmetrically about the mid point of the span.
vii) are at least as wide as the specimen,
viii) do not apply a significant load from their self weight.
ix) are of 6mm minimum diameter.

B.4.3 Chart recorder, of the multirange type, capable of continuous recording.

B.4.4 Silicon carbide saw, or other suitable equipment.

B.4.5 Absorbent cloth or paper.

B.5 Test specimens

B.5.1 General

For sewer linings with maximum internal radius of curvature greater than 500mm test specimens shall be cut from the flattest area of wall on a finished production unit such that their longitudinal axes are in the circumferential direction.

For sewer linings with maximum internal radius of curvature less than or equal to 500mm. test specimens shall be cut from flat test boards, identical in composition, manufacturing process, curing and thickness to the finished product.

B.5.2 Preparation

B.5.2.1 Unless otherwise required prepare a minimum of eight coupons from a cured lining unit or test board described in B.5.1 using a silicon carbide saw or other suitable equipment with water cooling in either case. (It is advisable to prepare spare test coupons to replace ones that break outside the central one third during testing).

B.5.2.2 Prepare each specimen with a width of 50 ± 2mm and a length of between 25mm and 50mm greater than the major span dimension for the appropriate specimen thickness as given in Table 4. Specimens shall be rectangular in cross section with parallel sides which are perpendicular to the mould or machine face of the specimen, and marked to identify the mould or machine faces. Where a bond

coat or roughened surface has been applied to the external surface of the lining unit, this shall be ground smooth in the areas where the loading rollers will bear.

B.6 Procedure

B.6.1 Soak the specimens prepared in accordance with B.5 in potable water at room temperature for a period between 4 hours and 24 hours.

B.6.2 Set the major and minor spans of the bending test jig to the appropriate values for the specimen thickness given in Table 4 see Figure 3, and align the loading rollers and supports so that the axes of the cylindrical surfaces are parallel. Record the major span (L).

B.6.3 Remove the specimen from the water, wipe off surface droplets with absorbent cloth or paper and commence test within 2 minutes.

B.6.4 Place the specimen symmetrically across the two parallel supports ensuring that the length of the test specimen is at right angles to the supports, and that equal lengths of the specimen project beyond the supports.

B.6.5 Adjust the testing machine so that its crosshead speed is within the limits appropriate to the specimen thickness given in Table 4 and select the chart recorder speed so that the angle (θ) shown in Figure 2 is between 40° and 70° - generally this will correspond to the chart recorder speed being 100 to 150 times the crosshead speed.

B.6.6 Select the load range so that the limit of proportionality occurs at not less than 30% of the full scale load range and apply the load to failure at constant crosshead speed, while continuously recording the load/deflection curve.

NOTE The chart recorder speed may be reduced after the load/deflection curve has exceeded the limit of proportionality (see Figure 2). to conserve chart paper. The load range may also be changed to keep the maximum load on the chart paper.

B.6.7 Record the load (P_1) at the limit of proportionality, i.e. the load at which the load/ deflection curve deviates from linearity, and the maximum load (P_2) (see Figure 2).

B.6.8 Measure and record the specimen thickness to nearest 0.05mm at a minimum of five points at or near the failure location taking care not to choose places where the specimen may have been expanded during the test.

Thickness measurement shall be taken from between the mould or machine face of the lining and the bottom of the troughs in the outer surface where a lining with a roughened back or bond coat is being tested.

Calculate the arithmetic mean (d) of the thickness measurements.

B.6.9 Measure and record the specimen width (b) to the nearest 0.1mm at or near the failure location taking care not to choose places where the specimen may have been expanded during the test.

B.6.10 Disregard the results from any specimen that breaks outside the minor span and repeat the procedure with another specimen. Record the occurrence of such cases.

Repeat the test procedure described in B.6 so that half of the specimens are tested with their mould face (concave surface) in contact with the major span rollers and the other half with the same face in contact with the minor span rollers.

B.7 Calculation and expression of results

B.7.1 Limit of proportionality

B7.1.1 For each specimen tested according to B.6 calculate the limit of proportionality from:

$$\text{Limit of proportionality} = \frac{P_1 L}{bd^2}\ MPa \qquad (1)$$

where
P_1 is the load at the limit of proportionality (N).
L is the major span (mm).
b is the specimen width (mm).
d is the arithmetic mean of five specimen thickness measurements (mm).

B7.1.2 Calculate and record the arithmetic mean of the results obtained for the limit of proportionality, in MPa. for:

(a) all specimens tested from each individual lining unit or test board.

(b) specimens tested from each individual lining unit or test board tested with their mould face (concave surface of lining units) in contact with the major span supports.

(c) specimens tested from each individual lining unit or test board tested- with their mould face (concave surface of lining units) in contact with the minor span supports.

B.7.2 Modulus of rupture

B7.2.1 For each specimen tested according to B.6 calculate the modulus of rupture from:

$$\text{Modulus of rupture} = \frac{P_2 L}{bd^2}\ \text{MPa} \qquad (2)$$

where
P_2 is the maximum load (N).
L is the major span (mm).
b is the specimen width (mm).
d is the arithmetic mean of five specimen thickness measurements (mm).

B7.2.2 Calculate and record the arithmetic mean of the results obtained for the modulus of rupture, in MPa, for:

(a) all specimens tested from each individual lining unit or test board.

(b) specimens tested from each individual lining unit or test board tested with their mould face (concave surface of lining units) in contact with the major span supports.

(c) specimens tested from each individual lining unit or test board tested with their mould face (concave surface of lining units) in contact with the minor span supports.

B7.2.3 Calculate and record the top:bottom ratio for each lining unit or board tested by dividing the value obtained from B7.2.2(b) by that from B7.2.2(c).

B.8 Report

The test report shall include:
(a) Product or test board identification.
(b) Details of specimen preparation.
(c) Radius of curvature of specimen.
(d) Date of the test.
(e) Number of test units or boards tested and number of specimens tested from each test unit or board.
(f) Individual values of LOP and MOR for each specimen tested.
(g) Arithmetic mean values of LOP and MOR for each test unit or board tested.
(h) Arithmetic mean values of LOP and MOR for specimens tested from each individual lining unit or test board with their mould face in contact with the major span supports.
(i) Arithmetic mean values of LOP and MOR for specimens tested from each individual lining unit or test board with their mould face in contact with the minor span rollers.
(j) Top:bottom ratio of mean MOR values for each lining unit or test board.
(k) The specimens that broke outside the minor span.
(l) Any other relevant information, e.g. visual appearance of glass distribution.

Table 3 - Major and minor span lengths and crosshead speeds for various coupon thicknesses

Nominal coupon thicknesses (mm)	Major span L (mm)	Minor span l (mm)	Crosshead speed min. to max. (mm/min)
Up to 6.7	135	45	1.5 – 3.0
6.8 to 10.0	200	66.7	1.5 – 3.0
10.1 to 12.5	250	83.3	1.5 – 3.0
12.6 to 15.0	300	100	3.0 – 5.0
15.1 to 17.5	350	116.7	3.0 – 5.0
17.6 to 20.0	400	133.3	3.0 – 5.0
20.1 to 22.5	450	150	4.5 – 7.0
22.6 to 25.0	500	166.7	4.5 – 7.0
25.1 to 27.5	550	183.3	4.5 – 7.0
27.6 to 30.0	600	200	4.5 – 7.0

NOTE: Thicknesses greater than 30mm are outside the scope of this particular test method.

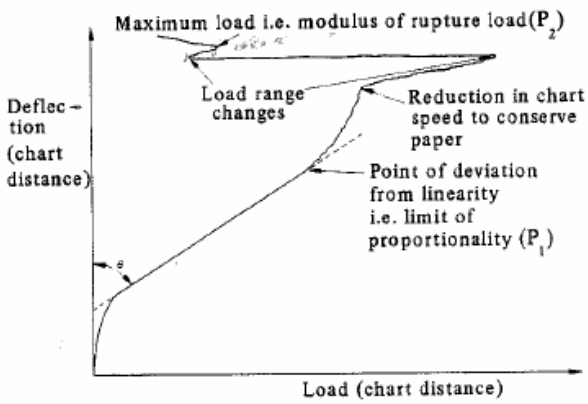


Figure 2 – Typical load deflection curve

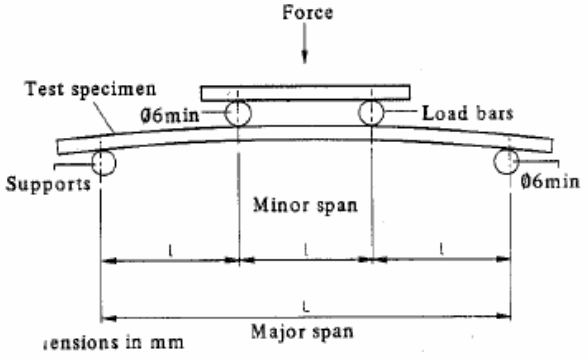


Figure 3 – Position of specimen in bending test rig

APPENDIX C - METHOD FOR THE DETERMINATION OF SHEAR BOND STRENGTH

C.1 Scope

Method of test to determine shear bond strength between cementitious grout and sewer lining by measurement of the shear strength of the bond.

C.2 Apparatus

(a) Compression testing machine accurate to Grade 1.0 of BS 1610: Part 1: 1985 (see BS 1811: Part 115).

(b) Shear testing rig of the form shown in Figures 4, 5 and 6.

(c) Load spreading bar of the form shown in Figure 7.

C.3 Materials

C.3.1 Cementitious grout of the same composition as that to be used during the renovation contract for which shear bond values are required shall be used. If the testing is not applicable to any specific combination of lining and grout, the grout shall comprise 4 parts pulverized-fuel ash (BS 3892: Part 1) to 1 part ordinary Portland cement (BS 12) by weight with a water/solids ratio of 0.40.

C.3.2 At least five specimens approximately 150mm x 150mm shall be cut from the full thickness of the lining unit. (Care should be taken that the sample dimensions do not exceed 150mm), The radius of curvature of each sample should not be less than 400mm. A hardboard or wooden template 150mm wide with convex curved edge of radius 400mm may be used to check the suitability of different parts of egg shaped units.

C.4 Preparation and conditioning

C.4.1 The cut lining samples shall be immersed in water for at least 24 hours prior to testing.

C.4.2 Each lining sample shall be placed in a 150mm cube mould with roughened "outside" surface facing outwards.

C.4.3 The grout shall be mixed in a suitable grout mixer (neither hand mixing or the use of freefall concrete mixers shall be permitted).

C.4.4 Grout shall be poured onto the linings in the moulds to a depth of 100 $\pm$ 5mm.

C.4.5 From each batch of grout cast, three 70.7mm or 100mm cubes shall be prepared and compressive strength at 28 days determined in accordance with clause 15 of BS 4551: 1980 to correlate grout strength to shear strength.

C.4.6 Shear bond moulds shall be covered with damp sacking or plastic sheeting to prevent evaporation and left free from vibration on a horizontal surface for between 5 and 7 days.

C.4.7 The shear bond samples shall be removed from the moulds with care and immersed in water at 20 $\pm$ 2℃ until tested at 28 days after casting.

C.5 Procedure after preparation

C.5.1 The test specimen shall be clamped in the shear bond testing rig as shown schematically in Figure 6 such that the compressive force can be applied to the lining at the grout/lining interface via the load spreading bar. When testing curved linings care should be taken to apply load in the longitudinal and not transverse direction.

C.5.2 Load shall be applied without shock and increased continuously at a rate of approximately 0.5MPa per minute until failure. The maximum force applied to the lining shall be recorded.

C.5.3 A note shall be made of the failure mode, usually either grout or bond failure.

C.6 Calculation

The shear bond strength (MPa) of each specimen shall be calculated by dividing the maximum force (N) sustained by the measured lining surface area (mm^2).

C.7 Report

The report shall include the following:

(a) The identification of the lining and the grout mix.

(b) The individual shear strength results and the mean value (to 0.1MPa).

(c) The failure modes.

(d) The grout compressive strength results.

(e) The period of the test.

Figure 6 – Assembled shear bond apparatus

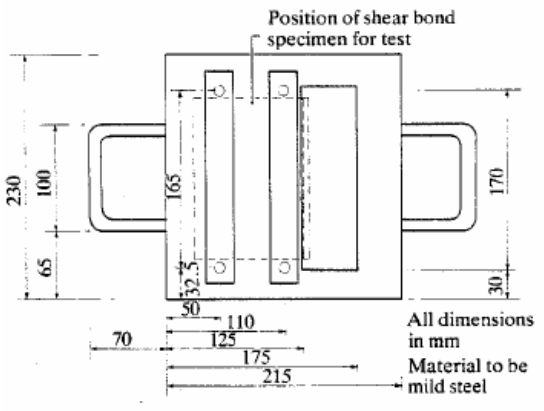


Figure 4 – Plan: shear bond rig

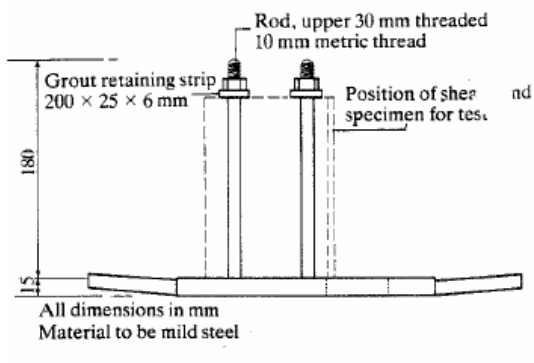
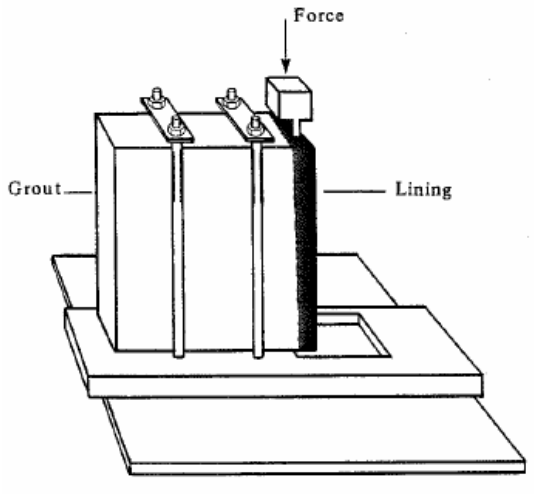


Figure 5 – Elevation: shear bond rig



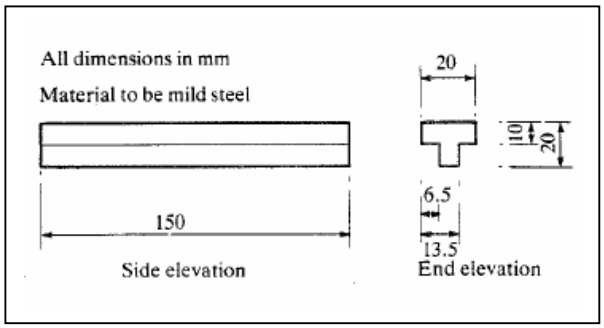


Figure 7 – Load spreading bar

APPENDIX D- METHOD FOR THE DETERMINATION OF AGED FLEXURAL STRENGTH

D.1 Scope

Method of test to determine the modulus of rupture of aged GRC in the form of coupons cut from sewer linings.

D.2 Principle

Cut coupons of cured GRC are aged to an equivalent of 50 years by exposure to warm water at 50℃ for 180 days. The modulus of rupture of the aged material is determined in accordance with the method in Appendix B.

D.3 Apparatus

As described in B.4 with the addition of a water bath capable of maintaining a water temperature of 50 ± 1℃ and a means of preventing rapid evaporation of the water.

D.4 Test specimens

D.4.1 Specimens shall be cut from sewer linings which have been cured for 28 days and have a maximum internal radius of curvature greater than 500mm. The specimens shall be cut from the flattest area of wall on a finished production unit such that their longitudinal axes are in the circumferential direction of the lining unit.

D.4.2 Preparation

At least 20 coupons shall be prepared in accordance with the method described in B5.2.

D.5 Procedure

D.5.1 Cut coupons shall be submerged in water at 50 ± 1℃ for 180 days. The water shall be stirred and topped up as necessary with water already heated to 50 ± 5℃ to ensure the coupons are submerged at all times.

D.5.2 Allow the coupons to cool in air to room temperature after removal from the water bath.

D.5.3 Soak the coupons in potable water at room temperature for 24 hours.

D.5.4 The remainder of the test procedure is as described in B.6 with the exception of B6.6 and B6.7.

D.6 Calculation and expression of results

The modulus of rupture is calculated as described in B7.2.

D.7 Report

The test report shall include:

(a) Product identification.

(b) Details of specimen preparation.

(c) Radius of curvature of specimen,

(d) Date of the test.

(e) Number of sewer lining units tested and number of specimens tested from each unit.

(f) Individual values of MOR for each coupon tested.

(g) Arithmetic mean value of MOR for coupons tested with their mould face in contact with the minor span supports.

(h) Arithmetic mean value of MOR for coupons tested with their mould face in contact with the major span supports.

(i) Arithmetic mean value of MOR for all coupons.

(j) Top:bottom ratio of mean MOR values.

APPENDIX E- SAMPLING FREQUENCY FOR QUALITY CONTROL TESTS

E.1 Acceptable Quality Level (AQL)

Quality control tests shall be carried out to achieve an AQL of 10% defectives at an inspection level of S-3 as described in BS 6001 using the double sampling plan. This inspection level covers production batches up to and including 150 units of one size and classification, and specifies sampling requirements and acceptance/rejection levels as summarised in Table 4.

E.2 Defectives

A test unit failing a quality control test is defined as having a defect. A test unit having one or more defects is defined as a defective. All defective test units shall be rejected and the acceptability of the batch from which they were drawn shall be determined as follows:-

(a) If the number of defectives in a sample is less than or equal to the acceptance number corresponding to that sample then the batch is accepted.

(b) If the number of defectives in a sample is greater than or equal to the rejection number corresponding to that sample then the batch is rejected.

(c) If the number of defectives in a first sample from a batch is between the acceptance and rejection numbers corresponding to that sample, then a second sample is tested except in the case of reduced inspection.

(d) If the number of defectives in a sample at reduced inspection is between the acceptance and rejection numbers corresponding to that sample. then the batch is accepted, but the sampling level for further batches shall be at normal level.

E.3 Switching rules for sample frequency variation

The switching rules between the different inspection levels are described in BS 6001 and BS 6000 and may be summarised as follows:-

(a) Normal inspection shall be used at the start of inspection for any one size and classification of production unit.

(b) Tightened inspection shall be used if 2 out of 5 or less successive batches are rejected on normal inspection.

(c) Tightened inspection shall be continued until 5 successive batches have been accepted on

tightened inspection, when normal inspection shall be restored.

(d) Reduced inspection may be used at the discretion of the manufacturer provided that:-

i) The preceding 10 batches have been on normal inspection and none has been rejected (see Table VIII of BS 6001: 1972 for exceptions).

ii) The total number of defectives in all the sample tests from the preceding 10 batches (or such other number of batches as was used for condition (i) above) is equal to or less than the applicable number given in Table VIII of BS 6001: 1972.

iii) The production is at a steady rate.

iv) Reduced inspection is considered desirable by the independent inspector where a third party certification scheme acceptable to WRc Engineering is used, or reduced inspection is agreed to by the purchaser in writing.

(e) Any batch resubmitted for inspection shall be inspected at tightened inspection level and the result shall not be taken into consideration for the switching rules.

The manufacturer shall not knowingly supply any defective unit in any batch.

Table 4 – Summary of sampling plans for inspection level S-3 giving acceptance/rejection numbers

Batch size	Sample	Normal inspection				Tightened inspection				Reduced inspection			
		Sample size	Cumulative sample size	Ac	Re	Sample size	Cumulative sample size	Ac	Re	Sample size	Cumulative sample size	Ac	Re
Up to 150 units	First	3	3	0	2	5	5	0	2	2	2	0	2
	Second	3	6	1	2	5	10	1	2				

NOTE: Ac is the acceptance number and Re is the rejection number.

APPENDIX F-TYPICAL CERTIFICATE

CERTIFICATE

We ……..

hereby certify that the Glassfibre Reinforced Cement sewer linings manufactured on ……

and supplied to ……

on ……. have been manufactured and tested in accordance with the requirement of Information and Guidance Note 4-12-04, Issue 1 published by WRc Engineering to give:-

(a) a minimum structural wall thickness of …… mm

(b) a maximum overall wall thickness of ……mm

(c) Our company does/does not have third party certification acceptable to WRc in respect of this specification thus the lining units are/are not marked with the number 4-12-04

Signed: ……..

on behalf of: ……...

on: ……