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Water Industry Specification

SPECIFICATION FOR PRECAST AND IN SITU FERROCEMENT

FOREWORD

This specification is one of a number of specifications which have been prepared by the Water Research Centre (WRc) in consultation with the Water Industry in order to assist engineers responsible for repair and maintenance of sewers. It covers precast and in situ ferrocement sewer linings suitable for Type I designs as defined in the Sewerage Rehabilitation Manual (published by WRc).

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. Reference to a British Standard, Water Industry Specification or any other specification applies equally to any equivalent specification.

Purchasers are reminded that this specification requires that the manufacturer shall operate a quality system relating to the manufacture of fittings to this specification in compliance with BS 5750: Part 2 (EN 29002) which ensures that products claimed to comply with this specification consistently meet the required level of quality. Enquiries regarding the availability of third party certification should be addressed to an appropriate NACCB or equivalent accredited third party certification scheme or to WRc.

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 at 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.

Information contained in this specification is given in good faith but neither the Foundation for Water Research nor the Water Research Centre can accept any responsibility for actions taken as a result.

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

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

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1. SCOPE

This specification defines the requirements for quality assurance, construction materials, dimensional tolerance, jointing, testing, marking and workmanship of ferrocement linings intended for the renovation of gravity sewers where the lining is designed to act together with the existing sewer fabric and annulus grout to form a composite structure; Type I design, as defined in the Sewerage Rehabilitation Manual.

2. DEFINITIONS

For the purpose of this specification the following definitions apply:

Ferrocement A type of thin walled reinforced concrete construction where a hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh reinforcement, normally steel.

Effective length (applicable to precast only) The distance between planes normal to the unit axis and passing through the real end points of the lining unit (see Figure 1).

In situ Ferrocement lining A ferrocement lining manufactured within the sewer being renovated.

Major axis length (applicable to precast only) The distance between the crown and invert of a lining section.

Out-of-squareness (applicable to precast only) 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 (applicable to precast only) 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).

Pipe lining Circular or non-circular sewer lining that has no longitudinal joints.

Precast Ferrocement lining unit A ferrocement lining unit manufactured and cured at a factory.

Real corner points (applicable to precast only) 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 (applicable to precast only) The extreme point on the real end surface (see Figure 1).

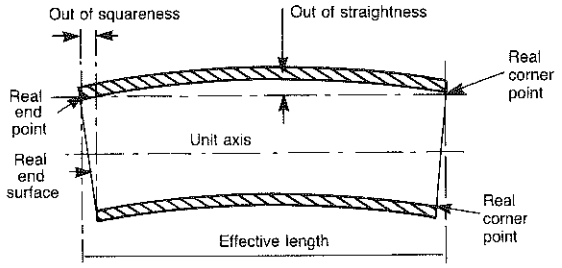

Figure 1. Section through nominally straight lining unit

Real end surface (applicable to precast only) 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).

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

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.

Unit axis (applicable to precast only) For a pipe lining section, the unit axis is a line passing through the centroids of the two real end surfaces. For a segment, 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).

3. QUALITY ASSURANCE

Manufacturers shall operate a quality system relating to this specification in compliance with BS 5750: Part 2 (EN 29002).

4. MATERIALS

4.1 Cement

The Portland cement shall be either ordinary or sulphate-resisting 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.

Sulphate-resisting cement shall not be used with pulverized-fuel ash.

Each consignment of cement shall be identified, stored in dry conditions, protected against deterioration, and used in its order of manufacture.

4.2 Aggregates

Aggregates shall consist of materials complying with the requirements of BS 882, and shall be obtained from a source approved by the purchaser.

The aggregate size shall not exceed 2mm and shall comply with the fine aggregate grading in Table 5 of BS 882: 1983.
The chloride ion content of the aggregate when determined in accordance with BS 812: Part 4 shall not exceed 0.06% by mass of the aggregate for 95% of the test results, with no individual result greater than 0.08%.

The sulphate ion content shall not exceed 0.4% by mass when tested in accordance with BS 3681: Part 2: 1973, clause 9.

Aggregates shall be handled and stored in a manner to minimise segregation and avoid contamination.

4.3 Water

The water used in the mix shall be of a potable quality and be free from harmful matter.

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

4.4 Pulverized-fuel ash

PFA when used as a pozzolanic material to replace cement shall meet the requirements of BS 3892: Part 1.

PFA when used to replace aggregate only, shall meet BS 3892: Part 2.

4.5 Steel reinforcement

Individual layers of steel mesh shall be fabricated from an assemblage of continuous single strand filaments. These may be woven or welded together and shall be galvanised. Reinforcement of dissimilar metals or with differing surface treatment shall not be used in the same construction.

Mesh size shall not be greater than 25mm × 25mm.

Woven reinforcement shall be fabricated from galvanised mild steel wire and comply with BS 1485 and BS 443.

Welded mesh reinforcement shall be manufactured from mild steel wire and welded at the intersections. Galvanising shall be undertaken after fabrication of the mesh and comply with BS 729.

The ultimate tensile strength of the steel wire for both woven and welded reinforcement shall not be less than 370 MPa when tested in accordance with BS 4545.

4.6 Reinforcement planks

Where reinforcement planks are used, the steel in their fabrication shall comply with the requirements of 4.5. They shall be factory manufactured from welded steel meshes or a combination of woven and welded steel meshes. Their actual dimensions shall be decided by agreement between purchaser and manufacturer. However they shall not be longer than 3m or have a width less than 0.275m or greater than 0.6m. Suitable provision shall be made to provide adequate steel laps between adjacent planks.

4.7 Chromium trioxide

Chromium trioxide shall be added to the mortar at a level sufficient to inhibit hydrogen gas evolution during cure. The actual concentration shall be determined by the manufacturer, but shall not be less than 200ppm of the weight of water.

The purity of the chromium trioxide used shall not be less than 99.5%.

WARNING Adequate precautions must be taken in the handling of this substance. Skin contact should be avoided otherwise severe burns can result. Contact with combustible materials may cause fire.

4.8 Admixtures

Admixtures complying with the requirements of BS 5075: Part 1 may only be incorporated into ferrocement to aid the manufacturing process. Any used must not affect the strength or durability of the ferrocement. Furthermore their use must not affect the efficiency of the chromium trioxide.

Combinations of admixtures in one mix shall not be undertaken without consultation with their respective manufacturers.

The manufacturer shall provide for approval by the purchaser, the amount of the admixture to be added to the mix, the method of use together with the chemical names of the main active ingredients and the reason why the use of the additive is being proposed. The detrimental effects, if any, of under or over dosage shall be established, particularly in relation to the durability of the lining material.

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.

No admixture containing calcium chloride shall be used.

5. CONSTRUCTION

5.1 General

Ferrocement linings may either be manufactured in the sewer or precast in a factory.

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 all the raw material batches used, and the products made each work shift or day.

Manufacture shall be carried out under environmental conditions suitable for the production of satisfactory linings. All raw materials shall be stored and used in compliance with the recommendations of their manufacturers.

Prior to commencement of placing the mortar, the manufacturer shall certify to the purchaser that the foreman, nozzleman and delivery equipment operatives have completed satisfactory work in similar capacities elsewhere.

Where required by the purchaser, the operators shall complete preconstruction test panels which shall be approved by the purchaser before the operators are employed on the works. Such panels may be used by the purchaser to assess the competence of operators or trainees.

5.2 Mix design

5.2.1 Aggregate content

The aggregate:cement ratio should not be less than 1.5:1 or greater than 2.5:1.

5.2.2 Water content

The water:cement ratio of the mix shall not exceed 0.4:1.

5.2.3 Chloride ion content

The total chloride ion content of the mix expressed as a percentage of chloride ion by weight of cement shall not exceed 0.35% for 95% of the test results with no result greater than 0.5%.

5.3 Mortar production

5.3.1 Batching

Weight batching shall be employed unless volume batching is approved by the purchaser. Batch weights of aggregate shall, where necessary, be adjusted to allow for moisture content. The use of prebagged material will be acceptable provided the individual constituents and the final mix meet the requirements of this specification.

5.3.2 Mixing

All constituents shall be uniformly dispersed throughout the mix. No frozen materials shall be used.

Ordinary Portland cement shall not be mixed with sulphate-resisting Portland cement.

Pulverized-fuel ash shall not be used with sulphate-resisting Portland cement.

5.3.3 Mortar flow value

The range of flow values over which the mortar is workable shall be determined to BS 1881: Part 105 and declared by the manufacturer.

5.3.4 Mortar application

No mortar shall be mixed or applied in air temperatures less than 5°C.

No mortar shall be applied to frozen surfaces.

The mortar shall be applied so that it neither sags nor slumps.

Reinforcement shall be completely surrounded by mortar except that which protrudes from the edges of precast lining units for jointing purposes.

Rebound material shall not be worked into the construction or reused.

6. MANUFACTURE

6.1 In situ manufacture

6.1.1 Fixing the steel reinforcement

The steel reinforcement, whether in the form of planks or separate meshes, shall be affixed to the sewer wall using galvanised or non-metallic fixings. Overlapping of the reinforcement shall be a minimum of 100mm. Spacers shall be inserted where necessary to ensure that the separation between the reinforcement and the sewer wall, and between the individual layers of reinforcement, complies with that specified in the contract. Spacers shall be constructed from a non-metallic material and be a maximum of 15mm in diameter.

Any fixing of the reinforcement remote from a spacer must not reduce the separation between the sewer wall and the reinforcement below the minimum specified in the contract.

6.1.2 Mortar application

The mortar shall be applied in one or two coats. It shall completely penetrate the steel reinforcement leaving no voids either within or behind the reinforcement. It shall be capable of obtaining a good bond to the existing sewer wall.

6.1.3 Depth of cover

The thickness of mortar covering the reinforcement shall not be less than 5mm or greater than 10mm unless otherwise agreed with the purchaser.

6.1.4 Two-coat systems

The time between separate applications of mortar shall not exceed 24 hours. If between applications the sewer is subject to flow it will be necessary to clean the sewer before the application of the finishing coat, unless agreed otherwise with the purchaser.

6.1.5 Surface finish

The surface shall be smooth and free from defects such as air bubbles or extraneous matter.

The finish may be applied using a trowel or by means of a brush.

No reinforcement shall be exposed, although it is acceptable for the surface to exhibit a pattern mirroring the subsurface reinforcement.

6.1.6 Preconstruction test panels

Preconstruction testing, where required, shall be carried out using plant identical to that proposed for the works, and shall be undertaken in such time before commencement of the works to allow approval by the purchaser.

6.2 Precast

6.2.1 Formers

Formers shall be constructed using timber, steel or ferrocement, and shall be evenly coated using an approved release agent.

Contact between the release agent and the reinforcement shall be avoided.

6.2.2 Fixing the steel reinforcement

The steel reinforcement shall be formed to conform to the geometry of the former and fixed in position using galvanised wire. The meshes shall be in the correct order and at the separations as specified in the contract.

For precast invert units intended for use with in-situ-manufactured material, reinforcement shall be left protruding from the longitudinal edge a minimum of 100mm and not more than 200mm to allow jointing to in-situ-manufactured material.

6.2.3 Mortar application

The mortar shall be applied in a manner that ensures complete penetration of the steel reinforcement. The method of application shall be capable of uniformly covering the reinforcement leaving no voids either within or behind the steel reinforcement.

6.2.4 Depth of cover

The thickness of the mortar covering the reinforcement shall not be less than 5mm or greater than 10mm unless otherwise agreed by the purchaser.

6.2.5 Internal surface finish

The surface shall be smooth and free from defects such as air bubbles or extraneous matter.

No reinforcement shall be exposed, although it is acceptable for the surface to exhibit a pattern mirroring the subsurface reinforcement.

6.2.6 External surface finish

The external surface shall be of sufficient roughness to allow the bond between the precast unit and the grout to pass the shear bond requirements of 8.8.

6.2.7 Curing

Precast units shall be protected from direct sunlight and kept in a humid, frost-free environment for a minimum of 7 days or until they have developed two-thirds of their 28-day strength.

Membrane curing shall not be used.

Units may be stripped from their moulds in accordance with 6.9.2.3 of BS 8110: Part 1: 1985.

7. DIMENSIONS OF PRECAST UNITS

7.1 Section length

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

7.2 Effective length

The difference in effective length of a pair of segments intended to fit together to form a lining section shall not exceed 10mm.

7.3 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.

7.4 Wall thickness

The wall thickness of the lining (excluding any rough backing) shall be at least the minimum specified by or agreed with the purchaser, and not greater than 10mm above.

7.5 Out-of-squareness

The out-of-squareness at each end shall be compatible with the jointing system employed and shall be not more than 2mm + 0.002W or 5mm, whichever is the lesser, where W is the average width between the real end corner points at each end of the segment measured in mm.

7.6 Out-of-straightness

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

7.7 Joints

The joints used between precast units shall be designed so that they cause no obstruction to the flow. Furthermore they must be sufficiently grout tight so that during grouting they preclude any infiltration of the grout into the sewer.

8. TYPE TESTS

8.1 General

The requirements given in this section shall be met before compliance to this specification can be claimed. Whenever a change in process technique or introduction of a new or modified material has occurred, it may be necessary to repeat some or all of these tests. Also, the Quality Assurance Schedule of the quality system (see clause 9) may require type tests to be repeated at specified intervals.

The test samples shall be fabricated from materials representative of those used in normal production, and model the production material in method of fabrication, as closely as possible.

All tests are the responsibility of the manufacturer. Details and results for type tests relevant to each material composition and manufacturing process shall be made available to the purchaser or his representative on request.

8.2 Preparation of test samples

Test panels intended to provide samples for the determination of short and long term mechanical properties, or preshaped tensile samples shall be fabricated so that they model the production material as closely as possible.

The materials and method of manufacture used shall be identical to those used in manufacture.

The composition of the mortar shall be identical with that used in manufacture.

NOTE Care must be taken to ensure that the water:cement ratio is identical and that all admixtures used in manufacture are included.

The alignment, number of layers and type of steel reinforcement shall be that used in practice, except where the test specifies otherwise.

The depth of cover shall be representative of that used in practice. The mortar shall be applied to the test sample in the same way as the normal fabrication process.

Before use, the test panels shall be cured for a minimum of 28 days in moist conditions, protected both from direct sunlight and frost.

8.3 Tensile properties

The cracking behaviour of the material together with the tensile strength shall be determined as specified in Appendix B. The tensile properties shall not be less than those specified in Table 1.

Table 1 – Tensile properties

20μm crack stress	2.0 MPa
Tensile strength	4.0 MPa

The predicted steel stress for a maximum crack width of 40μm shall not be greater than 200 MPa, unless it can be demonstrated that with a particular steel configuration maximum crack widths less than 40μm can be achieved at a higher working stress.

8.4 Flexural properties

The flexural strength when determined in accordance with Appendix C, shall be not less than 15.0 MPa.

8.5 Compressive strength of the mortar

The compressive strength of 100mm or 70.7mm cubes shall be at least 40.0 MPa at 28 days when tested in accordance with BS 1881: Part 116.

8.6 Long term mechanical properties

The long term mechanical properties, determined by means of the test procedure detailed in Appendix D shall be equal to or exceed the 28-day strength of the material. Also they shall exceed that of gunite meeting WIS No.4-12-05 requirements when tested in a similar manner.

8.7 Abrasion resistance

The abrasion resistance shall be determined by the method given in Appendix E.

The sample weight loss shall be less than 10g. Also the abrasion resistance shall be equal or better than a sample of gunite, which conforms to the requirements of WIS No. 4-12-05 "Specification for precast gunite sewer linings".

8.8 Shear bond strength

Samples from a precast unit shall be tested in accordance with the method described in Appendix F and shear bond strength values shall attain or exceed 1.0 MPa.

9. QUALITY CONTROL TESTS

The test requirements in this section are necessary in order to demonstrate a continuing satisfactory level of quality in day-to-day production.

9.1 Precast units

The required sampling frequency unless otherwise indicated for quality control tests is given in Appendix G.

9.1.1 Dimensions

The overall effective length of each test sample shall be determined to the nearest millimetre and shall comply with 7.2.

Wall thickness shall be determined at a minimum of five locations on each test sample using a method of measurement accurate to the nearest 0.1mm. Each measurement shall comply with the requirements of 7.4. Generally the locations shall include:

(1) A point of minimum internal surface curvature.

(2) A point near the centre of the test sample.

(3) Points near each end of the test sample.

NOTE It may be necessary to cut through the lining wall to satisfy this clause.

9.1.2 Compressive strength of the mortar

For each day's work six 100mm or 70.7mm cubes shall be cast, three cubes shall be cast from the first batch and three from the last batch used in the day. The 7-day compressive strength determined in accordance with BS 1881: Part 116 shall be equal to or greater than that declared in the contract.

9.1.3 Flexural strength

The flexural strength of samples removed from the hoop direction and having a radius of curvature greater than 250mm shall be tested in accordance with Appendix C. The measured value shall be not less than that given in 8.4.

9.1.4 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 test.

If it is equivalent in respect of surface roughness, it shall be deemed to have adequate shear bond strength. If it differs appreciably it shall be rejected.

9.1.5 Appearance

Lining units shall have the general physical appearance of a dense, well-compacted mortar. There shall be no significant air voids, foreign matter or cracks.

The internal finish shall be smooth and comply with 6.2.5.

9.2 In situ manufacture

9.2.1 Compressive strength of the mortar

For each day's work six 100mm or 70.7mm cubes shall be cast, three cubes shall be cast from the first batch and three from the last batch used in the day. The 7-day compressive strength determined in accordance with BS 1881: Part 116 shall be equal to or greater than that declared in the contract.

9.2.2 Slump test

For each of the batches where cubes have been taken, the slump shall be a maximum of 50mm when determined according to BS 1881: Part 102.

9.2.3 Core samples

Using a suitable coring machine, 3 cores shall be taken every 15m along the length of the lining.

Cores shall not be taken until the lining has cured for 7 days.

One core shall be removed from the crown of the sewer, the position of the other two cores shall be determined by the purchaser. It is not necessary for the position of these two cores to remain constant for each of the positions where coring is to be carried out.

Examination of the core allows the following properties of the lining to be assessed.

(1) Penetration of the reinforcement by the mortar.

(2) Bonding between the ferrocement lining and the existing sewer wall.

(3) Type, order and spacings of reinforcement to check compliance with the contract.

(4) The depth of cover.

If considered necessary these cores can be used to assess the compressive strength.

9.2.4 Appearance

The lining shall have the general physical appearance of a dense, well-compacted mortar. There shall be no exposed steel reinforcement, and the surface shall contain no voids or extraneous matter.

10. INSPECTION AND CERTIFICATION

10.1 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 areas used for manufacture and testing and to all relevant test records.

10.2 Certification

The manufacturer shall, upon request, furnish the purchaser or purchaser's representative with copies of a signed certificate stating that the construction and testing of the lining supplied comply with the requirements of this specification and giving details of minimum performance 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 H.

11. MARKING OF PRECAST UNITS

All precast lining units shall be marked on the inside face.

No method of marking shall prejudice the performance of the lining when in service.

The marking shall give the following information:

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

(b) WIS 4-12-06. (The use of this mark is a claim by the manufacturer that the product has been manufactured in accordance with the requirements of this specification and the claim is solely his responsibility.)

(c) The letters "OPC" or "SRPC" to indicate the type of cement used.

(d) The batch and date of manufacture. Coding of this information is permitted provided that the meaning of the code is available on request.

12. REFERENCES

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

BS 12 Specification for Portland cements.

BS 443 Specification for testing zinc coatings on steel wire and for quality requirements.

BS 729 Specification for hot dip galvanized coatings on iron and steel articles.

BS 812 Testing aggregates.
Part 4 Methods for determination of chemical properties.

BS 882 Specification for aggregates from natural sources for concrete.

BS 1485 Specification for zinc coated hexagonal steel wire netting.

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 Testing concrete.
Part 102 Method for determination of slump.
Part 105 Method for determination of flow.
Part 115 Specification for compression testing machines for concrete.
Part 116 Method for the determination of compressive strength of concrete cubes.

BS 3148 Methods of test for water for making concrete (including notes on the suitability of the water).

BS 3681 Methods for sampling and testing of lightweight aggregates for concrete.
Part 2 Metric units.

BS 3892 Pulverized-fuel ash.
Part 1 Specification for pulverized-fuel ash for use as a cementitious component in structural concrete.
Part 2 Specification for pulverized-fuel ash for use in grouts and for miscellaneous uses in concrete.

BS 4027 Specification for sulphate-resisting Portland cement.

BS 4545 Methods for mechanical testing of steel wire.

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 production and installation.

BS 6000 Guide to the use of BS 6001, sampling procedures and tables for inspection by attributes.

BS 6001 Sampling procedures for inspection by attributes.
Part 1 Specification for sampling plans indexed by acceptable quality level (AQL) for lot-by-lot inspection.

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

EN 29002 (European Standard) Quality systems – model for quality assurance in production and installation.

WIS No 4-12-05 Specification for precast gunite sewer linings.
WRc Sewerage Rehabilitation Manual.

APPENDIX A – CONTRACT INFORMATION

A.1 GENERAL

This Appendix 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. It does not form a mandatory requirement of this specification.

A.2 INFORMATION TO BE PROVIDED BY PURCHASER

(a) Details of sewer environment (for selection of appropriate materials).

(b) Size and shape of sewer to be lined.

(c) Compressive strength of ferrocement (if greater than 40.0 MPa (N/mm^2) required).

(d) Proposed grouting pressure and method if applicable.

A.3 DETAILS TO BE AGREED BETWEEN PURCHASER AND MANUFACTURER

(a) Shape and cross-section dimensions.

(b) Wall thickness (maximum overall and minimum structural).

(c) Lengths of segments (if precast).

(d) Joint details.

(e) Reinforcement spacing (if in situ).

A.4 INFORMATION TO BE PROVIDED BY MANUFACTURER

(a) Method of manufacture: precast or in situ.

(b) Constituent materials and proportions.

(c) Whether products will be covered by a third party certification scheme.

A.5 SAMPLES

A representative sample having identical composition and thickness as the lining units under consideration should be submitted to the purchaser upon request.

APPENDIX B – METHOD FOR THE DETERMINATION OF TENSILE PROPERTIES

B.1 APPARATUS

(a) Tensile testing machine accurate to Grade 1.0 of BS 1610: Part 1: 1985.

(b) Strain or deflection measuring system capable of 1% accuracy over the gauge length given in Figure 2.

(c) Portable microscope with measuring graticule capable of measurement down to 20μm.

B.2 TEST SPECIMENS

Three specimens of dimensions and geometry shown in Figure 2 shall be tested. Fabrication shall be carried out in accordance with 8.2.

B.3 PROCEDURE

B3.1 Measure the mean width and thickness of each specimen. At least three evenly spaced measurements along the gauge length shall be made.

B3.2 Place the first specimen in the tensile testing machine and load at a rate of 1.5 kN.min^{-1} ± 0.5 kN. min^{-1} until tensile failure occurs. The maximum force sustained shall be recorded.

B3.3 Providing the cross-sectional areas of the three specimens agree within 5%, the incremental force to be used in the next part of the test may be derived by dividing the failure force by 10.

B3.4 If the cross-sectional areas differ by more than 5%, it is necessary to convert the failure force into an apparent failure stress. Divide the apparent failure stress by 10 to determine the incremental stress, convert this to an incremental force for a particular specimen by using the cross-sectional area.

B3.5 Place the second specimen in the tensile testing machine and apply a load equal to the incremental force, as determined in B3.3 or B3.4, at a rate of 1.5 kN.min^{-1} ± 0.5 kN.min^{-1}.

B3.6 Measure the elongation of the gauge length.

B3.7 For each side of the specimen count the number of cracks and record their position using graph paper divided into 1mm squares.

B3.8 Measure the crack width according to the following criteria:

When there are 10 or less cracks, measure the width of each of them.

When there are more than 10 cracks, the number to be measured is equal to 10 + 10% of the number, e.g. if there were 20 cracks then 10 + 2 = 12 cracks to be measured. The measured cracks should be uniformly distributed along the gauge length.

B3.9 The specimen shall not be held at the incremental force for longer than 5 minutes whilst measurements are being taken.

B3.10 Increase the force by an amount equal to the incremental force and repeat the operations from B3.6 above.

B3.11 Continue the test by repeating from B3.6 until the specimen fails, record the maximum force sustained.

B3.12 Repeat from B3.5 with the third specimen.

B3.13 From the failed specimens determine the depth of cover to the nearest 0.5mm.

B.4 CALCULATION AND EXPRESSION OF RESULTS

B4.1 Convert all measured force values to apparent stress.

B4.2 Convert all measured displacement values to strain.

B4.3 For Specimens 2 and 3 plot average crack width and number of cracks against apparent stress and determine the applied stress at which cracks of 20μm will be present.

B4.4 For specimens 2 and 3 plot maximum crack width against apparent stress. The graph shall clearly indicate the specimen number and steel configuration. Results from similar tests using the same mesh but a different number of layers may be plotted on the same graph. From these results predict the steel stress for a maximum crack width of 40 μm.

NOTE It is permissible to plot crack width and crack number against stress on the stress/strain graph.

B4.5 Mark any of the plots clearly to show if the cover depth differed from that specified in 6.2.4.

NOTE Apparent stress is obtained by using the cross-sectional area of the specimen in the calculation of stress from the applied force. Similarly the apparent steel stress is obtained by using the the cross sectional area of the steel in the direction of the applied force.

B.5 REPORT

The report shall include the following information:

(i) The identification of the samples tested.

(ii) Details of specimen preparation.

(iii) The 20μm crack stress and tensile strength of the material.

(iv) The predicted steel stress for a maximum crack width of 40μm.

(v) The depth of cover recorded.

(vi) The loading rate.

(vii) The date of the test.

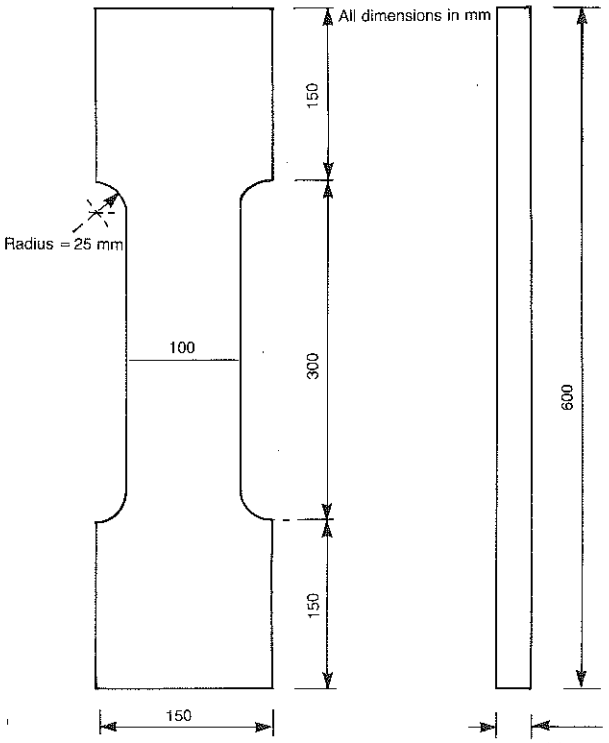

Figure 2. Geometry of tensile test specimens

Thickness varies from 12–40 mm to suit reinforcement

APPENDIX C – METHOD FOR THE DETERMINATION OF FLEXURAL PROPERTIES

C.1 APPARATUS

(a) Testing machine accurate to Grade 1.0 of BS 1610: Part 1: 1985.

(b) 4-point bend jig, with minimum deflection measurement resolution of at least 0.1mm (see Figure 3).

C.2 TEST SPECIMENS

At least three rectangular specimens of dimensions shown in Figure 3 shall be tested. These may be cut from plates of ferrocement, fabricated and cured as detailed in 8.2 or for quality control purposes removed from precast units.

C.3 TYPE TEST PROCEDURE

C3.1 Measure the mean width and thickness of each specimen. At least three evenly spaced measurements along the specimen length shall be made.

C3.2 Place the first specimen in the flexural testing machine and load until flexural failure occurs. The maximum force sustained shall be recorded.

C3.3 A record of force versus deflection shall be taken.

C3.4 Repeat from C3.2 for each of the remaining specimens.

C3.5 From the failed specimens determine the depth of cover to the nearest 0.5mm.

C.4 CALCULATION AND EXPRESSION OF RESULTS-TYPE TEST PROCEDURE

C4.1 Plot force versus deflection for each of the specimens.

C4.2 Calculate the apparent failure stress in the outermost fibre assuming a homogenous section.

C4.3 Calculate the theoretical stress in the outermost layer of the reinforcement and plot this against deflection. The method used must be given.

C4.4 Mark any of the plots clearly to show if the cover depth differed by more than ±2mm from that declared.

C.5 QUALITY CONTROL PROCEDURE

C5.1 Measure the mean width and thickness of each specimen. At least three evenly spaced measurements along the specimen length shall be made.

C5.2 Place the first specimen in the flexural testing machine and load until failure occurs. The maximum force sustained shall be recorded.

C5.3 Repeat C5.2 with the remaining specimens.

C.6 CALCULATION AND EXPRESSION OF RESULTS-QUALITY CONTROL PROCEDURE

C6.1 Calculate the theoretical stress in the outermost layer of reinforcement. The method used must be given.

C.7 REPORT

The report shall include the following information.

(i) The identification of the samples tested.

(ii) Details of specimen preparation.

(iii) The test procedure followed, i.e. whether Type Test, or Quality Control.

(iv) Graph of theoretical stress (in outermost layer of the reinforcement) versus deflection (Type Test).

(v) The apparent failure stress (Type Test).

(vi) The depth of cover (Type Test).

(vii) The theoretical failure stress (in outermost layer of the reinforcement) (Quality Control).

(viii) The date of the test.

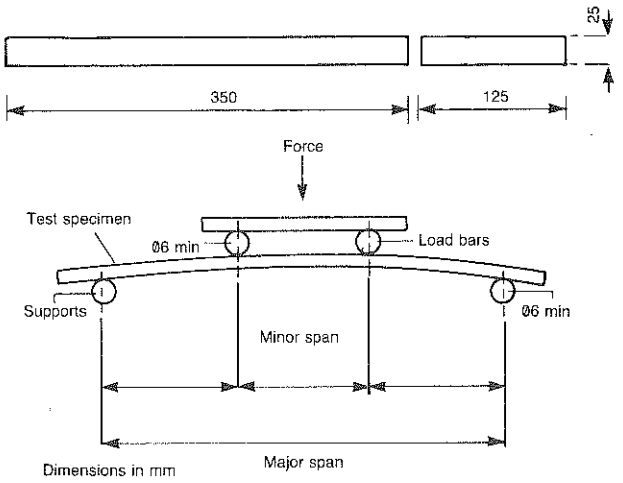

Figure 3. Geometry of flexural test specimen and its position in bending test rig

APPENDIX D – ACCELERATED DURABILITY TEST

D.1 APPARATUS

D1.1 Twenty five 4-point bend rigs of geometry similar to that used in Appendix C are required. These rigs must be capable of maintaining a constant deflection on the specimen, and shall be fabricated from materials suitable for at least 6 months immersion in hot (60°C) sodium chloride solution (6%).

D1.2 Testing facility that meets the following criteria:

(a) To include an immersion chamber large enough to contain all 25 rigs and allow circulation of the sodium chloride solution.

(b) To enable draining and refilling of the immersion chamber under automatic control.

(c) To maintain the aqueous salt solution and air temperature in the immersion chamber at 60 ± 2.5°C.

(d) To provide cycle times of 1 hour immersion followed by 1 hour drying. Emptying and refilling times shall not be longer than 6 minutes each.

D.2 TEST SPECIMENS

D2.1 Test specimens shall be cured in water or damp conditions for 28 days.

D2.2 Twenty specimens of ferrocement of similar dimensions to those given in Appendix C shall be tested.

D2.3 Five specimens of gunite of the same width and breadth dimensions as the ferrocement specimens shall be tested concurrently. (The thickness of these may differ from that of the ferrocement.) These gunite specimens shall meet the requirements of WIS No. 4-12-05.

NOTE Advice relating to a suitable supplier may be obtained from WRc.

D2.4 For each specimen measure and record the width and thickness to 0.5mm, at 3 positions spaced evenly along its length.

D.3 PROCEDURE

D3.1 Load 20 of the 4-point bend rigs with ferrocement specimens. Set the initial deflection of each rig such that the tensile steel stress in the outermost layer of reinforcement is equal to 200 MPa.

D3.2 Measure and record the width and position of all the cracks that form on loading. Use the method given in B3.8. If no cracks are formed then increase the force to the stress necessary to initiate cracking as determined from the short term flexural tests.

D3.3 Load the remaining five 4-point bend rigs with gunite specimens. Set the initial deflection such that the force applied expressed as a percentage of the ultimate strength is the same as that applied to the ferrocement samples.

D3.4 Place all the 4-point bend rigs into the immersion chamber. Allow the sodium chloride solution to attain 60°C and start the wet/dry cycling.

D3.5 Check the temperature and concentration of the sodium chloride solution regularly. The temperature shall be maintained at 60 ± 2.5°C. The concentration of the sodium chloride shall be 6% ±0.5%. If the conditions fall outside of these limits, then this fact shall be recorded.

D3.6 After 28 days remove the first set of 5 ferrocement specimens. Specimens shall be removed from various parts of the immersion chamber.

D3.7 Before unloading examine each specimen for visible damage such as spalling of the cover, rusting of the reinforcement, etc. Any such damage observed shall be recorded using colour photography. Unload the specimens.

D3.8 Using 4-point bend loading, determine the flexural strength of each specimen as per C.3.

D3.9 From the mechanically failed specimens determine the depth of cover to the nearest 0.5mm.

D3.10 Repeat from D3.6 with sets of ferrocement specimens removed after 2 and 4 months.

D3.11 After 6 months repeat from D3.6 using the remaining 5 ferrocement and 5 gunite specimens.

D.4 EXPRESSION OF RESULTS

D 4.1 Plot the individual together with the mean values of the failure force against time for the ferrocement and gunite specimens. Indicate the average cover depth for each group of ferrocement specimens.

D4.2 Plot the individual failure force against cover depth for the ferrocement specimens only.

D.5 REPORT

The report shall include the following information:

(i) The identification of the samples tested.

(ii) Details of specimen preparation.

(iii) Evidence of any damage to exposed specimens.

(iv) Graphs of individual and mean values of failure force against time for ferrocement and gunite specimens.

(v) Graph of failure force against cover depth for ferrocement samples.

(vi) The dates of the test.

APPENDIX E – ABRASION TEST

E.1 APPARATUS

The apparatus consists of a drill press, an agitation paddle, a cylindrical steel container housing a steel plate which holds the square specimen, and an abrasive charge of 1.5kg consisting of steel grinding balls with the following size distribution:

(i) 14 balls of 19.0mm diameter
(ii) 37 balls of 12.7mm diameter
(iii) 89 balls of 9.5mm diameter
(iv) 250 balls of 6.3mm diameter
(v) 1,000 balls of 3.9mm diameter.

The test arrangement is shown schematically in Figure 4. The water in the container is circulated by an agitation paddle powered by the drill press rotating at 510 ± 5rpm.

E.2 TEST SPECIMENS

Two samples of the lining material and two samples of gunite shall be tested as described in E.3

E.3 PROCEDURE

The test procedure for this method is as follows:

E3.1 Cut a 200mm × 200mm square specimen from lining material.

E3.2 Soak the specimen in water for 48 hours at 20°C.

E3.3 Surface dry the specimen and record its weight to the nearest 0.5 g.

E3.4 Place the specimen in the steel holding plate (with the surface to be tested facing upwards) and place this arrangement in the steel container (see Figure 4).

E3.5 Position the specimen so that its surface is normal to the drill shaft and the centre of the specimen coincides with the drill shaft.

E3.6 Mount the agitation paddle in the drill press so that the bottom of the agitation paddle is 40 ± 5mm above the surface of the specimen.

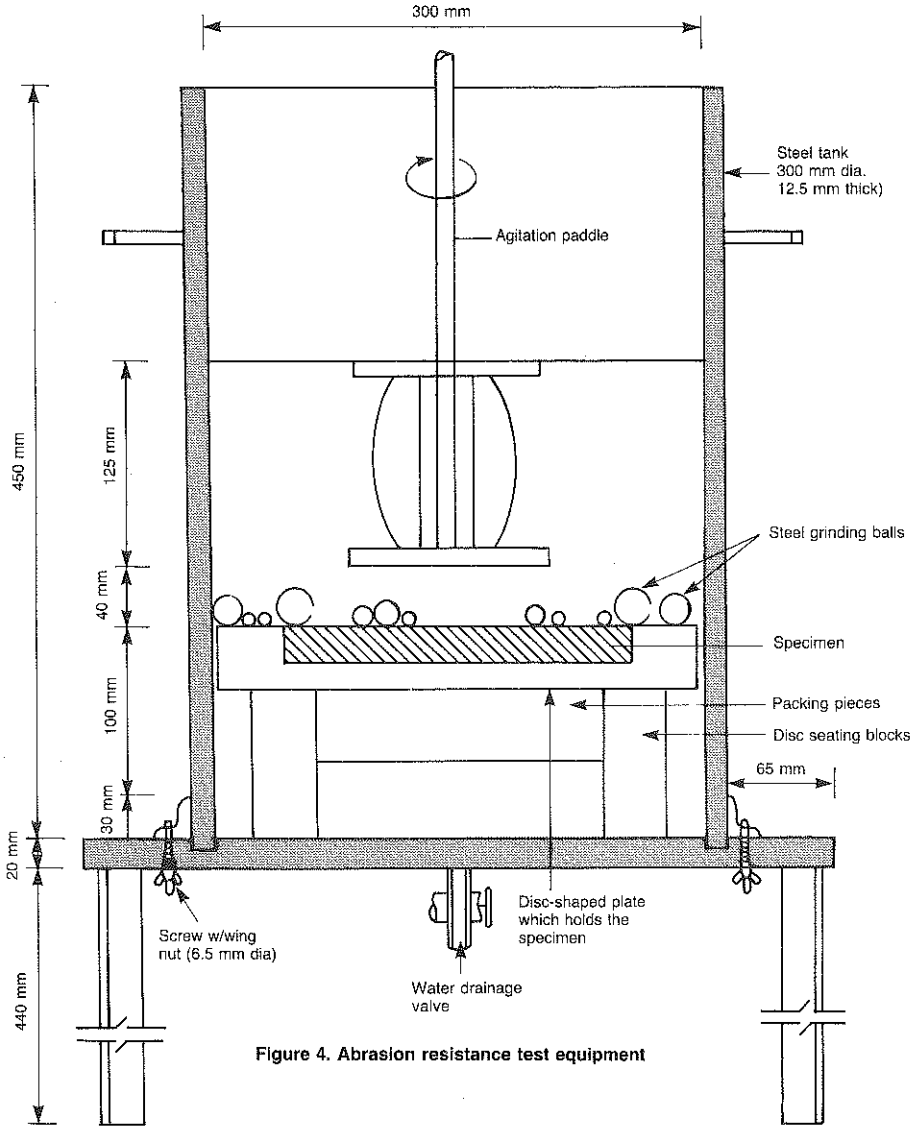

Figure 4. Abrasion resistance test equipment

E3.7 Place the abrasive charges on the surface of the specimen and add water to 165 ± 5mm above the surface of the specimen.

E3.8 Start the machine and check that the drill press is rotating at 510 ± 5rpm when the paddle is immersed.

E3.9 Remove the specimen from the container every 24 hours and record the clean surface-dry weight of the specimen to within 0.5 g.

E3.10 At the end of the test (after 96 hours), record the surface-dry weight.

E.4 CALCULATION AND EXPRESSION OF RESULTS

The type of damage caused to each specimen shall be documented. Especially if any reinforcing steel has been exposed. The loss of weight of each specimen shall be recorded together with the depth of abrasion, measured to the nearest 0.5mm.

E.5 REPORT

The report shall include the following information:

(i) The identification of the samples tested
(ii) Details of specimen preparation
(iii) The specimen weight losses and abrasion depths
(iv) The dates of the test.

APPENDIX F – METHOD FOR THE DETERMINATION OF SHEAR BOND STRENGTH (FOR PRECAST MATERIAL ONLY)

F.1 APPARATUS

(a) Compression testing machine accurate to Grade 1.0 of BS 1610: Part 1: 1985 (see BS 1881: Part 115).
(b) Shear testing rig of the form shown in Figures 5, 6 and 7.
(c) Load spreading bar of the form shown in Figure 8.

F.2 TEST SPECIMENS

F2.1 Cementitious grout of the same composition as that to be used during the renovation contract and 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.

F2.2 At least two specimens approximately 150mm × 150mm shall be cut from the full thickness of the lining unit. (Care shall be taken that the sample dimensions do not exceed 150mm.) The radius of curvature of each sample shall 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.

F.3 PREPARATION AND CONDITIONING

F3.1 The cut lining samples shall be immersed in water for at least 24 hours prior to testing.

F3.2 The lining sample shall be placed in a 150mm cube mould with roughened "outside" surface facing upwards.

F3.3 The grout shall be mixed in a suitable grout mixer (neither hand mixing or the use of freefall concrete mixers shall be permitted).

F3.4 Grout shall be poured onto the linings in the moulds to a depth of 100 ± 5mm.

F3.5 From each batch of grout used, 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 bond strength.

F3.6 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.

F3.7 The shear bond samples shall be removed from their moulds with care and immersed in water at 20 ± 2°C until tested at 28 days after casting.

F.4 PROCEDURE AFTER PREPARATION

F4.1 The test specimen shall be clamped in the shear testing rig as shown in Figures 5, 6 and 7 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 force in the longitudinal and not transverse direction.

F4.2 Force shall be applied without shock and increased continuously at a rate of approximately 0.5MPa (N/mm^2) per minute until failure. The maximum force applied to the lining shall be recorded.

F4.3 A note shall be made of the failure mode, usually either grout or bond failure.

F.5 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).

F.6 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.

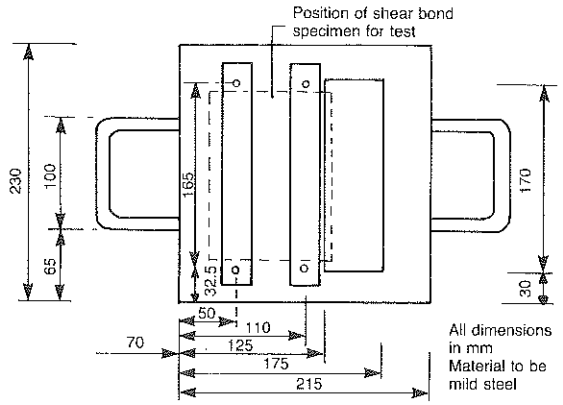

Figure 5. Plan: shear bond rig

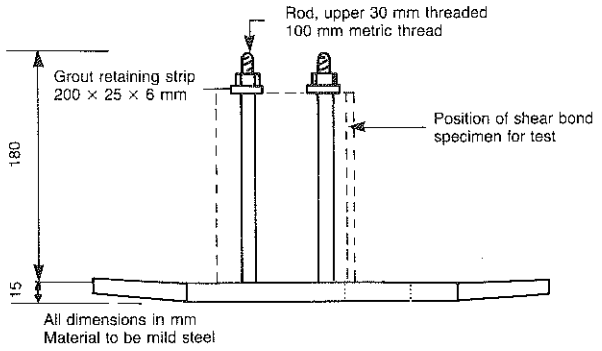

Figure 6. Elevation: shear bond rig

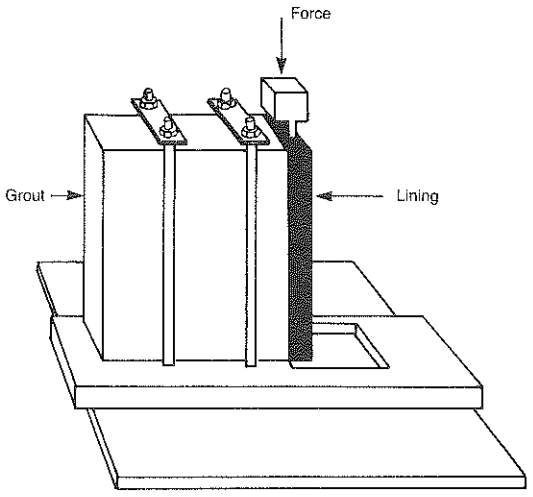

Figure 7. Assembled shear bond apparatus

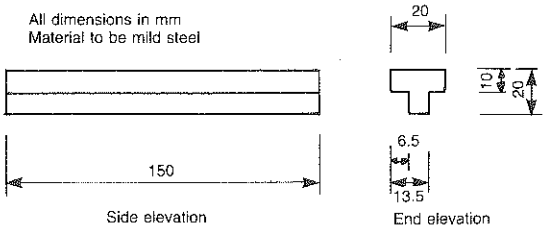

Figure 8. Load spreading bar

APPENDIX G – SAMPLING FREQUENCY FOR QUALITY CONTROL TESTS ON PRECAST FERROCEMENT UNITS

G.1 ACCEPTABLE QUALITY LEVEL (AQL)

Quality control tests shall be carried out to achieve an AQL of 6.5 defectives at an inspection level of S-3 as described in BS 6001: Part 1 using the double sampling plan (except where 100% testing is specified in this specification).

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 2.

G.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:

G2.1 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.

G2.2 If the number of defectives in a sample is equal to or greater than the rejection number corresponding to that sample then the batch is rejected.

G2.3 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.

G2.4 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.

G.3 SWITCHING RULES FOR SAMPLING FREQUENCY VARIATION

The switching rules between the different inspection levels are described in BS 6000 and BS 6001: Part 1 and may be summarised as follows:

G3.1 Normal inspection shall be used at the start of inspection for any one size and classification of production unit.

G3.2 Tightened inspection shall be used if 2 out of 5 or less successive batches are rejected using normal inspection.

G3.3 Tightened inspection shall be continued until five successive batches have been accepted on tightened inspection, when normal inspection shall be restored.

G3.4 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 BS 6001: Part 1: 1972, Table VIII 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 BS 6001: Part 1: 1972, Table VIII.

(iii) The production is at a steady rate.

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

G3.5 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 a defective unit in any batch.

Table 2 – 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 H – TYPICAL CERTIFICATE

We ..... hereby certify that the ferrocement linings supplied/installed* to/for*

....

at .....

on/between the* ..... and* ..... have been manufactured and tested in accordance with the requirements of WIS No. 4-12-06:Issue 1 Specification for precast and in situ ferrocement linings, published by FWR/WRc.

The lining units are/are not* marked with the number 4-12-06.

Our company has/does not have* third party certification in respect of this specification.

* Delete as applicable.

Signed: .....

On behalf of: .....

On: .....