CHAPTER 9

GROUND SUPPORT IN TUNNELS AND SHAFTS

1.REV.B of this document was expanded to cover all aspects of ground support in tunnels and shafts and incorporated MdO comments on Sections 9.100, 9.500, 9.600 and 9.700.

2.REV.C was issued at VLO status for general application.

3.REV.C was reviewed and revised to incorporate ILF/MHA and TML comments.

4.REV.E was issued at APT status, Approved for Construction by Tunnel Engineering Manager, for general application. Section 9.200 was issued for construction for Shakespeare Underground Development only at EXN status as document MHAT 8076 REV.1. It has been withdrawn (CAN status) and its contents included in this document since REV.E.

5.REV.F was issued at VLO status to incorporate comments by ILF/MHA and ET.

6.REV.G was issued at VLO status to incorporate comments by TML and ILF/MHA.

7.REV.H was issued at APT status, Approved for Construction by Tunnel Engineering, for general application.

8. Section 9.800 specifies the requirements for Shotcrete Class P1. Section 9.800 was issued as a separate document MHAT 8090.

9.MHAT 8039 Rev 1 was issued for construction for general application at EXN status.

10. MHAT 8039 Rev.2 incorporates Section 9.800 Shotcrete Class P1 and is issued for construction for general application at EXN status. Document MHAT 8090 is now cancelled.

11. MHAT 8039 EXN status REV.3 incorporates minor changes and modification to requirements for lattice girders and MHAT 8107 Shotcrete Class P2, with renumbering of Sections 9.900 and 9.1000. Changes from Rev.2 are marked in the margins. Document MHAT 8107 is now cancelled.

CHAPTER 9

GROUND SUPPORT IN TUNNELS AND SHAFTS

CHAPTER 9

GROUND SUPPORT IN TUNNELS AND SHAFTS

9.100 GENERAL

1. This Chapter refers to support which is installed in tunnels and shafts at or after the time of excavation but which will be supplemented by the later addition of additional lining which will alone or in combination with the ground support carry the external loadings. Where specified, the materials and techniques described may also be used for other purposes.

2. For requirements relating to monitoring of movements, loads and stresses in tunnels and shafts supported by ground support, see Chapter 19 - Instrumentation and Monitoring.

3. Section 9.200 specifies the requirements for Shotcrete Class T. Shotcrete Class T shall be used where shown on the Drawings for initial ground support only.

4. Section 9.800 specifies the requirements for shotcrete Class P1. Shotcrete Class P1 shall be used where shown on the Drawings for initial and permanent ground support.

5. Section 9.900 specifies the requirements for shotcrete Class P2. Shotcrete Class P2 shall be used where shown on the Drawings for permanent ground support.

9.110 Definitions

Sprayed Concrete	A mixture of cement, aggregate and water and which may contain admixtures, projected at high velocity from a nozzle into place to produce a dense homogeneous mass.
Shotcrete	A term used for sprayed concrete where the maximum aggregate size is 10 mm.
Shotcrete Class T	Shotcrete which is applied as primary ground support but is not designed to carry permanent loads.
Shotcrete Class P1	Shotcrete which is applied as primary ground support and is designed to carry permanent loads.
Shotcrete Class P2	Shotcrete with steel fibres, added during batching, mixing or during the application process as appropriate depending on the application, which is applied as a secondary lining and is designed to carry permanent loads.
Dry Method	A method of producing shotcrete in which a mixture of cement, aggregate, and admixtures when required, are weigh batched, thoroughly mixed in a dry condition and fed into a purpose made machine wherein the mixture is pressurised, metered into a dry air stream and conveyed through hoses or pipes to a nozzle immediately before which water as a spray is introduced into the mix which is projected without interruption into place.
Wet Method	A method of producing shotcrete in which cement and aggregate are weigh batched and mixed with water at the shotcreting

	location or in mixer trucks prior to being pumped through a pipeline to a nozzle where air, and admixtures if necessary, are injected and the mix projected into place without interruption.
Wet Method with Fibres	As the Wet Method but with fibres added during batching, mixing or during the application process as appropriate.
Layer	A term used for a discrete thickness of shotcrete built up from a number of passes of the nozzle and allowed to set.
Rebound	A term used for all material having passed through the nozzle which does not adhere to the surface on which shotcrete is being applied.
Base Concrete	A term used for all concrete of a design intended for use in shotcrete but which is produced without admixtures.
Cement and Latent Hydraulic Binder (LHB)	(a) Hydraulic cement that is an active hydraulic binder formed by grinding clinker and complying with BS 12, BS 1370 or BS 4027;
	(b) Hydraulic binder, manufactured by a controlled process in which Portland cement clinker or Portland cement is combined in specified proportions with a latent hydraulic binder consisting of pulverized-fuel ash (pfa), the product to comply with BS 6588;
	(c) Hydraulic binder, manufactured in the concrete mixer by combining Portland

	cement complying with BS 12 or BS 4027, with a latent hydraulic binder consisting of pulverized-fuel ash complying with BS 3892: Part 1, and/or silica fume.
Admixtures	A term used for materials which are added to the base concrete such as accelerators, plasticisers and retarders.

9.200 SHOTCRETE CLASS T

9.210 Cement and Aggregates

9.211 Cement

1. It is of particular importance to use cement of uniform chemical composition and uniform fineness. The required characteristic values shall be agreed by the Construction Manager or his delegated personnel with the cement manufacturer before commencement of delivery. For all cement delivered the manufacturer shall make the cement analyses and the results of standard tests available.

2. Cement shall comply with BS 12:1978, BS 4027:1980 or BS 1370:1979 and with the following additional requirements:

(a) Initial setting time: not less than two hours and not more than three hours. (BS 4550:Part 3 1978,: Section 3.6)

(b) Fineness: Not less than 340 m^2/kg. (BS 4550:Part 3, 1978: Section 3.3).

(c) Bleeding: not more than 20 cm^3. (See Section 9.291 for test procedure)

(d) Compressive strength after 3 days (72 ± 1h) on concrete cubes: not less that 18 N/mm^2 (BS 4550:Part 3:1978: Section 3.4)

Cement that does not meet with all the above requirements may be used for shotcrete, subject to the approval of the Engineering Manager or his delegated personnel, provided the shotcrete complies with the Specification.

9.212 Aggregates

1. Aggregates shall comply with the requirements of BS 882:1983 unless otherwise specified.

2. The following requirements refer to a nominal particle size of 10 mm.

3. Single size aggregates shall be combined in the proportions determined during the site trials.

4. Fine and coarse aggregates shall be clean. The grading shall remain within the acceptable range and wherever possible within the desired range according to the grading curve - Figure 9.1.

5. The coarse fraction of the aggregate shall not exhibit excessive fragmentation during delivery. The percentage of particles smaller than 0.075 mm as determined in accordance with the decantation method specified in BS 812: Part 103: 1975 shall not exceed 3%.

6. Frozen aggregates shall not be used.

7. For the dry method, at the time of mixing, the moisture content of the combined aggregates shall not exceed the saturated surface dry value by more than 5% unless otherwise approved by the Senior Engineer New Austrian Tunneling Method (NATM).

Figure 9.1 - Aggregates for Shotcrete Class T - Grading Curve.

9.213 Water

1. Water shall comply with BS 5328: 1981.

9.220 Admixtures

9.221 General

1. The Engineering Manager shall consider any potential for admixtures contaminating ground water in giving or withholding approval for their use.

2. Retarding and plasticising admixtures shall comply with BS 5075:1982.

3. Compatibility of all admixtures with each other and with all other shotcrete constituents shall be verified during the site trials.

9.222 Accelerators

1. Only the minimum quantity of accelerator necessary shall be permitted in normal shotcreting operations, and this quantity shall be determined by trials as specified herein.

2. Testing of accelerators, with regard to setting time and strength decrease at a later age (28 days), shall take place in due time before commencement of shotcreting. For this purpose the method specified in Section 9.292 - Testing of Accelerators shall be used. All components unless otherwise specified in the test method shall be fully representative of those which will be used in the Works.

3. The testing of setting time for the selected type(s) of powdered accelerator shall be carried out in accordance with section 9.292 Paragraph A(1). The setting time of the selected type(s) of powdered accelerator is appropriate for shotcrete applications, if measured setting times are within the range determined in Section 9.292 Paragraph A(1)(g) and dosage of accelerator used for this test is less than 7% by weight of cement.

4. The testing of the strength decrease for the selected type(s) of powdered accelerator shall be carried out in accordance with Section 9.292 Paragraph A(2) at the following dosages to establish the variability with dosage:

(a) Dry Method

- accelerators in powder form: 3.0, 5.0, 7.0%
- accelerators in liquid form: 2.0, 4.0, 6.0%

(b) Wet Method

- water glass: 8.0, 12.0, 15.0%

The above percentages are by weight of cement.

At the dosage chosen for use in the Works, the decrease in strength at an age of 28 days, as determined in Section 9.292 -Testing of Accelerators, shall not exceed the following:

- accelerators in powder form: maximum 45%
- accelerators in liquid form and water glass: maximum 30%

The performance of liquid accelerators shall be determined in accordance with Section 9.292 (B) Liquid Accelerators.

5. If the sulphate (SO_4) content of the ground water is more than 600 mg/l, the water-soluble aluminate in the accelerator shall not be greater than 0.6% by weight of the cement content.

6. The accelerators delivered to the Site shall be tested in accordance with this specification not less than once every two months for their reaction with the cement used (setting behaviour and strength decrease). In the case of accelerators in liquid form, their stability during storage shall be visually inspected and checked for crystallisation at similar intervals. Storage times and

working temperature ranges shall be in accordance with the manufacturers recommendations. The manufacturer's safety instructions shall be observed.

7. The required characteristic values and regularity of delivery shall be agreed with the manufacturer of accelerator before commencement of shotcreting.

8. Provided the characteristic strength requirements are met, the dosage of accelerators can be up to a maximum of:

10% by weight of cement for accelerators in powdered form
9% by weight of cement for accelerators in liquid form
15% by weight of cement for water glass

9.223 Plasticisers and Retarders

1. With the wet method, plasticisers and retarders may be used to reduce the quantity of the mixing water and to improve the pumpability of the concrete. The effects of the plasticizer shall be determined in the site trials (see Section 9.240 - Site Trials). Shotcrete made by using plasticisers and retarders shall be checked regularly for the setting time, water reduction and the development of strength as compared with the base concrete in accordance with BS 5075.

9.230 Shotcrete Requirements

1. Shotcrete shall be capable of being applied in layers up to 150 mm in thickness with good adhesion to the ground or previous layers of shotcrete, with good embedment of reinforcement and without sagging.

2. The characteristic strength shall be as follows :

Trial Type	Time of Test	Characteristic Strength N/mm^2
Site Trials	After 24 hours	8

	After 28 days	25
Works Tests	After 24 hours	6
	After 28 days	22

Strength requirements shall be based on cores sampled in both directions from test panels for the site trials and in the direction of spraying from shotcrete placed in the works.

3. Shotcrete shall be dense and homogeneous without segregation of aggregates or other visible imperfections.

4. The requirements specified in Section 9.240 shall be met prior to the use of shotcrete in the Works.

9.240Site Trials

9.241General

1. This section shall be read in conjunction with Section 9.244 - Proficiency of Operatives.

2. Site trials shall be started sufficiently early to ensure that the required shotcrete mix is developed and all trials completed satisfactorily by the time shotcreting Class T commences in the Works. Shotcreting shall not commence until the trials and results of laboratory tests have been completed satisfactorily.

3. The site trials shall employ the equipment which will be used in the Works and constituent materials shall be fully representative of those to be used in the Works.

9.242Development of Mix Design

1. The design of the shotcrete mix shall be developed in two stages:

(a) Production of a suitable base concrete.

(b) Production of shotcrete from the base concrete.

The target mean strength for the base concrete shall be such as to ensure that the strength reduction specified in Clause 9.222 is not exceeded for shotcrete with accelerator and to ensure that the specified strengths are achieved.

9.243 Shotcreting Trials

1. A trial mix shall be designed and prepared with the constituent materials in the proportions proposed for use in the Works. Sampling and testing procedures shall be in accordance with BS 1881. A clean dry mixer shall be used and the first batch discarded.

2. From the trial mix an experienced nozzleman shall prepare sufficient test panels. Each panel shall be at least 600 x 400 mm in size and shall be 200 mm thick. The panels shall be prepared by shotcreting into vertical rigid plywood boxes. The shotcrete in the panels shall adhere well to the backform, be properly compacted and exhibit no sagging.

3. Cylindrical test specimens shall be cored from each test panel and tested as listed below. Drilling and dimensions of test specimens shall be in accordance with BS 1881:Part 120. Drilling of cores shall be located to avoid areas of possible rebound. Cores to be tested at different ages (i.e. 1 and 28 days) may come from the same panel. For each test at least one spare specimen shall be provided.

(a) Compressive strength in spray direction after 1 and 28 days on 4 cores each. The test cores shall be 100 mm diameter and 100 mm long.

(b) Compressive strength perpendicular to spray direction after 1 and 28 days on 4 cores each. The test cores shall be 100 mm diameter and 100 mm long.

4. Target workability values shall be determined for the wet method.

5. Each cored cylinder shall be marked with a reference mark and the date and time of shotcreting.

6. The panels shall be stored without disturbance at a temperature between 10°C and 25°C covered by polythene sheet until the time of coring. Cores for 1 and 28 day compressive strength tests shall be obtained from the panels at 1 day. The cores for 28 day strength test shall be stored in water in accordance with BS 1881:Part 111.

7. Testing for compressive strength shall be in accordance with BS 1881:Part 120.

8. Additional test panels shall be prepared as necessary to calibrate indirect test methods approved by the Engineering Manager or his delegated personnel. For the purpose of calibration a minimum of four tests shall be carried out at each age for each indirect test method and shotcrete mix.

9. The strength of shotcrete cores from test panels shall be acceptable if both the compressive strength results for samples with their axes parallel to the direction of spraying and the compressive strength results for samples with their axes perpendicular to the direction of spraying, comply with the following requirements.

(a) The average strength determined from the 4 cores from a particular trial shall exceed the specified characteristic strength by at least:

2.0 N/mm^2 for 1 day strength

3.0 N/mm^2 for 28 day strength

(b) Any individual core strength result shall not be lower than the specified characteristic strength by more than:

2.0 N/mm^2 for 1 day strength

3.0 N/mm^2 for 28 day strength

10. The test results shall be passed to the Engineering Manager or his delegated personnel responsible for design of shotcrete structures.

11. The site trials shall be repeated if the source or quality of any of the materials or the mix proportions are changed.

9.244 Proficiency of Operatives

1. Nozzlemen shall have had previous experience in the application of shotcrete, or shall work under the immediate supervision of the foreman or instructor with such experience. Production shotcrete shall be applied only by nozzlemen who have successfully demonstrated their competence and their ability to produce shotcrete complying in all respects with this Specification. Nozzlemen shall hold certificates of competence issued by the Senior Engineer NATM or written evidence of previous satisfactory work. The Senior Engineer NATM shall be responsible for ensuring compliance with this section.

9.250 Works Tests

9.251 Strength Tests

1. The tests for strength specified in this section replace the equivalent strength tests in Chapter 12 - Concrete, Section 12.100 - Concrete General.

2. Compressive strength tests shall be carried out on cores taken from shotcrete in the Works in accordance with BS 1881:Part 120:1983. The time of coring shall be as close as possible to 24

hours after placing. Cores required for 28 day strength tests may be obtained at the same time as those for 1 day tests and stored in the laboratory in accordance with BS 1881:Part 111:1983. The frequency of coring shall be such as to obtain 3 cores each for 1 and 28 day tests for every 100 m^3 of shotcrete used in the Works. Depending on the compliance of test results with this Specification, circumstances of application and importance of construction, the frequency of work tests may be reduced (to every 200 m^3) or increased (to every 50 m^3) subject to previous approval of the Engineering Manager or his delegated personnel. The cores shall be drilled through the whole thickness of the shotcrete and visually inspected to verify that the shotcrete is dense and homogeneous without segregation of aggregate or other visible imperfections. The distribution of the cores for each test shall be as approved by the Senior Engineer NATM.

3. Instead of testing cores taken from shotcrete placed in the Works indirect penetration and pull out test methods may be used to determine the 1 day strength of shotcrete as approved by the Engineering Manager or his delegated personnel. Tests for 1 day strength shall be carried out between 22 and 48 hours preferably at 24 hours ± 2 hours. Results of tests shall be related to the characteristic strength of one day. Mechanical rebound hammers shall not be used to obtain indirect compressive strength of shotcrete.

4. Where the nominal required shotcrete thickness is less than 100 mm the cores for compressive strength testing shall be taken from areas where the actual thickness is greater than 100 mm. Alternatively additional shotcrete thickness shall be applied in selected areas for subsequent test coring as directed by the Senior Engineer NATM.

5. The strength of shotcrete measured by cores taken from the Works (or by indirect test methods as specified in Paragraph 3 above) shall be acceptable if the compressive strength results comply with the following requirements:

(a) The average strength for any group of four consecutive test results shall exceed the specified characteristic strength by at least:

$2.0\ N/mm^2$ for 1 day strength
$3.0\ N/mm^2$ for 28 day strength

(b) Any test result shall not be lower than the specified characteristic strength by more than:

$2.0\ N/mm^2$ for 1 day strength
$3.0\ N/mm^2$ for 28 day strength

where one test result shall consist of the mean of 3 core strengths.

6. If the shotcrete fails to meet the compliance requirements specified herein, the validity of the test results shall be checked prior to implementing one of the following courses of action:

a) confirm the requirements for remedial action by assessing the results of geotechnical measurements and/or back analysis.

b) make good deficiencies by the application of additional thickness of shotcrete.

c) remove the defective shotcrete and replace by new shotcrete.

The course of action to be adopted shall be approved by the Senior Engineer NATM.

9.252 Stability Tests

1. Tests shall be carried out to assess the load bearing capability of shotcrete in the Works under site conditions. These tests may be carried out on cores taken from panels.

2. One set of tests shall be conducted for each mix type.

3. These panels shall be produced in the works under site conditions. The panels shall be stored underground in the works (with the same climatic conditions as the shotcrete placed in situ). Core samples shall be taken from the panels just before testing, or at least on the same day as testing.

4. Cylindrical test specimens shall be cored and tested as listed below. Dimensions of test specimens and testing shall be in accordance with Section 9.243 - Shotcreting Trials.

(a) Compressive strength in the spray direction after 1, 3, 7 and 28 days on 3 cores each.

(b) Modulus of elasticity in the spray direction after 1, 3, 7, 28 days on 3 cores each. The core shall be 100 mm in diameter and 200 mm long. The strain shall be measured on the central part of the sample, the upper test limit being 1/3 and the lower test limit being 1/30 of the compressive strength. The modulus of elasticity at different ages shall be determined on the same sample, the compressive strength being measured after 28 days.

5. If the stability of the tunnel is endangered because shotcrete does not meet the specified strength requirements, the affected shotcrete shall be replaced carefully or where practicable the deficiencies made good by application of additional shotcrete as approved by the Senior Engineer NATM.

9.253 Workability Tests

1. The workability of shotcrete produced by the wet method shall be measured by slump tests in accordance with BS 1881 : Part 102: 1983 after the addition of plasticiser. Samples shall be tested for every 50 m^3 produced.

2. Target workability values shall be determined during the site trials.

3. The workability of wet method shotcrete shall be within ± 25 mm or ± one third of the target value, whichever is the greater.

9.254 Thickness Tests

1. The thickness of placed shotcrete shall be checked by drilling small uncored holes in such a manner that the rock/shotcrete interface can be recognised. The number and positions of holes shall be in accordance with the Procedure for Application of NATM or as directed by the Senior Engineer NATM. Alternative methods of determining shotcrete thickness may be used subject to the Approval of the Senior Engineer NATM.

9.260 Production and Transport

9.261 Batching and Mixing

1. The individual components for the production of shotcrete shall be measured by weight with an automatic batching device, except that liquid admixtures may be measured by volume. The batching accuracy shall be within ± 3% for cement, water and aggregates and within ± 5% for admixtures. The method of batching used shall ensure that the accuracy can be easily checked. The accuracy shall be checked at least once a month.

2. Mixing shall be carried out in a mixer suitable for the efficient mixing and discharge of dry or wet batched materials as appropriate.

3. Regular checks shall be made to ensure that complete mixing is consistently achieved.

4. The mixing time for the dry method shall be sufficient to produce complete mixing and shall be at least 1 minute. The mixture shall be

delivered by means of appropriate equipment and segregation shall be avoided.

5. Mixed materials for the dry method may be used up to 3 hours after the addition of cement provided that the shotcrete can be applied satisfactorily. Any unused material after this time shall be discarded.

6. Accelerators for the dry method shall not be added until immediately prior to depositing the materials in the placing equipment, or, if in liquid form shall be accurately proportioned into the water supply at the shotcreting equipment. Accelerator for the wet method shall be added immediately prior to the application of shotcrete at the application nozzle.

7. The mixed base concrete for the wet method shall be applied, depending on the type of cement used and the temperature of the base concrete and atmosphere, within three hours. Retarders may be used to extend the time for placing.

9.262 Transport

1. For shotcrete produced by the dry method, the dry mixture may be transported by truck mixers or non-agitating containers. The dry mixture shall be effectively protected against any influence of the weather.

2. For shotcrete produced by the wet method, the base concrete including any admixtures except accelerator shall be transported by any suitable means which provides complete mixing during transportation such that segregation of the mix components is prevented. The mixture shall be effectively protected against any influence of the weather.

9.270 Shotcreting Equipment

9.271 General

1. All transport pipes consisting of hoses or pipes of uniform diameter that carry shotcrete ingredients shall be laid straight or in gentle curves and protected so that the flow of ingredients through them is not restricted.

2. The shotcrete machine shall be adjusted to suit the length of the pipe that carries the shotcrete mix. Equipment shall be leak-proof. Residual deposits of materials shall be removed after each usage.

3. The air and water supply system shall be capable of supplying the delivery machine and hose at the pressures and volumes recommended by the manufacturer of the machine. No air supply system shall be used that delivers air contaminated by oil.

4. Shotcreting equipment shall be capable of feeding materials at a regular rate and ejecting shotcrete from the nozzle at velocities that will allow adherence of the materials to the surface being shotcreted with a minimum of rebound and maximum adhesion and density.

5. The placing equipment shall be so arranged that the nozzleman may use air and water in any combination to prepare raw surfaces as specified in Section 9.281 or to clean completed work.

6. Equipment shall be provided to allow application of shotcrete to all surfaces with the nozzle at the distances from the work specified in Section 9.280 - Shotcreting.

7. A boom mounting or similar device shall be provided for the spray nozzle for use in conditions where manual spraying is unsafe or otherwise unsuitable or undesirable.

9.272 Equipment for the Dry Method

1. The nozzle shall be capable of controlling the quantity of water to be added as well as ensuring effective mixing of all shotcrete ingredients.

2. Admixtures in powder form shall be added by means of mechanical batching devices located at the shotcrete machine. The batching device shall be capable of ensuring continuous accurate batching of the admixture. If necessary, it shall be possible to adjust the batches mechanically or manually for a larger or smaller quantity of admixture. The batching devices shall be protected against water, dust and weather and shall be cleaned at regular intervals.

3. Liquid accelerators shall be metered uniformly into the water. If this is carried out by pumps adding a specified quantity of accelerator to the water, special screens shall be incorporated to eliminate foreign substances.

9.273 Equipment for the Wet Method

1. The equipment for the wet method shall be set up according to the recommendations of the manufacturer.

2. Pumping shall ensure a continuous conveyance of base concrete including any admixture except accelerator. The equipment shall incorporate a suitable metering device for liquid admixtures.

9.280 Shotcreting

9.281 Shotcrete Application

1. Before the application of shotcrete, the excavated surfaces shall be cleaned with compressed air and, as far as the local conditions permit, with an air-water mixture as necessary to remove all material which may prevent proper adhesion of the shotcrete to the rock surface. Loose rock shall be cleared from behind the steel mesh. The surface to receive shotcrete shall be damp and where possible without free water prior to application of shotcrete.

2. Action shall be taken where necessary to control ground water and prevent it adversely affecting the shotcrete lining. Water inflows which might cause deterioration of the shotcrete, or prevent adherence, shall be diverted as detailed on the Drawings by channels, chases, pipes or other appropriate means to the invert or to the ground water drainage system.

3. Where necessary pressure relief holes shall be provided through the lining to ensure that no hydrostatic pressure develops behind the lining.

4. Shotcrete shall only be applied by nozzlemen certified in accordance with Section 9.244. The distance between the nozzle and the surface being shotcreted shall not exceed 2.0 m with the dry method and 1.5 m with the wet method. The nozzle shall, as a general rule, be held perpendicular to the application surface. However, when shooting through reinforcing bars the nozzle shall be held closer and at a slight angle in order to permit encasement and minimise rebound.

5. No rebound material is to be covered with shotcrete. To facilitate this, and depending on ground conditions and the excavation cycle, the shotcrete shall preferably be applied from the shoulder to the

crown. The rebound material shall be removed from the tunnel and shall not be used in the Works.

6. Each layer of shotcrete shall be built up by making several passes of the nozzle over the working area. The shotcrete shall emerge from the nozzle in a steady uninterrupted flow. Should the flow become intermittent for any cause the nozzleman shall direct it away from the work until it again becomes constant.

7. Where a layer of shotcrete is to be covered by succeeding layers, it shall first be allowed to set and loose material and rebound shall be removed. The surface shall be finally cleaned and wetted using a blast of air and water.

8. For vertical and near vertical surfaces application shall commence at the bottom. Layer thickness shall be governed mainly by the requirement that the material shall not sag. Where thick layers are applied the top surface shall be maintained at a slope of approximately 45 degrees.

9.282 Shotcrete Thickness

1. The inner surface of shotcrete may follow the contours of the rock surface, with the necessary rounding of the edges and corners, provided that protruding, sound blocks of rock still firmly linked to the rock mass have a minimum shotcrete cover of 2/3 of the specified thickness.

2. Steel arches, steel mesh and the like shall be free of loose rust and they shall be surrounded with at least 30 mm of shotcrete unless otherwise shown on the Drawings.

3. Excavated surfaces of intermediate stages of construction (face, invert, etc.) shall be secured by a temporary lining consisting of a thin layer of shotcrete, generally at least 20 mm thick, or as otherwise shown on the Drawings or directed on Site by the Senior Engineer NATM.

9.283 Reinforcement

1. Reinforcement shall comply with Chapter 14 and the following paragraphs.

2. Reinforcement mesh shall be securely fixed in place. The reinforcement shall be cleaned of any previously deposited material which might prevent a proper bond.

3. Ties, anchors and supports for the mesh shall be of steel and suitable spacers shall be provided where necessary. Timber packing shall not be used. The method of fixing the mesh shall be such that shotcrete can be compacted soundly behind the reinforcement at all points. Except where otherwise shown on the Drawings laps shall be a minimum of one pitch. Additional fixings shall be installed as necessary to fit the mesh snugly into any depressions.

9.284 Application of Shotcrete in Cold Weather

1. When shotcrete is placed at air temperatures of less than 5°C measures shall be taken to maintain shotcrete temperature above 3°C for at least 1 day after application.

2. No frozen materials, ice or snow shall by allowed to enter the mixer.

3. Cement shall not be heated. If water is introduced at the nozzle, it shall not be heated above 20°C.

9.285 Curing

1. Measures shall be taken to ensure that shotcrete exhibits proper strength gain and a minimum of cracking. Curing measures shall be applied as necessary to achieve these requirements.

9.290 Test Methods

9.291 Test Procedure for Bleeding of Cement

1. Pour exactly 98 g of water with a temperature of 20°C into a 250 ml glass beaker with a small magnetic stirring rod. At medium stirring rate add 115 g of cement little by little within 20 seconds. Combine the mixture for 2 minutes until an homogeneous, relatively thin cement paste (water/cement ratio = 0.85) has been achieved.

2. Fill the homogenized mass into a 100 ml measuring cylinder up to the 100 ml index mark by means of a glass rod (do not pour directly into cylinder). It is absolutely necessary that the measuring cylinder be kept in a high glass beaker filled with water of 20°C during the entire period of testing. Fluctuations in temperature shall not exceed ± 2°C.

3. After 120 minutes the amount of cement that has settled can be read from the scale, i.e. the amount of supernatant water may be determined. The reading is in ml corresponding to % by volume of repelled water.

9.292 Testing of Accelerators

A. Powdered Accelerators

1. Setting Time

The dosage of accelerator, as % by weight of cement required to provide an initial setting of 60 sec $\pm$ 20 sec and a final setting of max 150 sec shall be determined in accordance with the following procedure.

(a) The temperature of the cement and water shall be 20°C ±1°C.

(b) 1200 g of cement shall be placed in the mixing bowl of a mortar mixer (Hobart 5 litre mixer).

(c) The powder shall be weighed and then added to the cement in the mixing bowl and mixed on speed No.1 for 2 minutes to ensure even distribution.

(d) 420 ml of water shall be added to the mixture in the bowl within approximately 2 sec with the mixer on speed No.1. After 5 sec the mixing speed shall be changed to No.2 for a further 15 sec.

(e) The cement paste shall be taken from the mixing bowl by means of a spatula and placed in a vicat mould (BS 4550:Part 3:Section 3.6:1978) and lightly tamped to ensure no entrapped air is present in the sample. The top surface shall be struck off level and the mould placed on the vicat apparatus within 20 sec of completion of mixing (i.e. 40 sec from addition of water).

(f) The determination of initial set shall be in accordance with BS 4550:Part 3:Section 3.6:1978 and final set shall be determined by continuing the use of the initial set method and recording the time at which the needle penetrates the top surface by less than 1 mm. Times shall be measured from the moment of water addition.

(g) If the initial setting is less than 40 sec or more than 80 sec or the final setting more than 150 sec, the test shall be repeated using a smaller or higher dosage of the accelerator.

2. Strength Decrease

The decrease in strength shall be determined according to the following procedure:

(a) Mortar cubes shall be used in accordance with BS 4550:Part 3:Section 3.4:Item 2.3.1.

(b) A comparison of the 7-day and 28-day strengths of mortar shall be carried out as follows:

- Strength shall be determined without the accelerator (A)

- Strength shall be determined with the accelerator with dosage used for the setting time tests (B)

(c) Strength decrease is (A - B) x 100 / A

3. Mortar Tests - With Accelerator

The strength of mortar with accelerator shall be determined in accordance with the following procedure:

(a) The temperature of the mortar constituents (ie. cement standard sand to BS 4550:Part 6:1978 and water) shall be: 20° ± 1°C.

(b) 370 g of mix water shall be poured into the dry mortar mixer bowl.

(c) Accelerator shall be added to and blended with the mix water at the dosage determined in accordance with 9.292 (A), Item 1 - Setting Times.

(d) 1,710 g of standard sand (in accordance with BS 4550:Part 6:1978) shall be added to the water in the mixing bowl with the mixer running at low rotation speed.

(e) 570 g cement shall be poured into the bowl within 5 sec and the mortar mixer switched immediately to high speed and mixed for 30 sec.

(f) The moulds shall be filled with mortar as quickly as possible in accordance with BS 4550:Part 3:Section 3.4 Item 2. The mortar shall be compacted by vibration for a period of 15 seconds only, notwithstanding Clause 2.5.5 of BS 4550:Part 3:Section 3.4.

(g) The bulk-density of the compacted mortar cubes shall be determined and compared with the bulk-density of mortar cubes prepared without accelerator in order to check that appropriate compaction has been achieved. (Maximum admissible difference of bulk-density to cubes prepared without accelerator shall not exceed ± 5%).

(h) The cubes shall be removed from the moulds at an age of 4.5 hours and stored in the moist curing chamber at 20°C.

(i) Compressive strength testing of the specimens in accordance with BS 4550:Part 3:Section 3.4, Item 2.7 shall be undertaken after 7 and/or 28 days.

4. Mortar Tests - Without Accelerator (Basic Mortar Mix)

The compressive strength of mortar cubes without accelerator shall be determined in accordance with BS 4550:Part 3:Section 3.4:1978, Item 2. Departing from this standard the following altered mix ratio shall be used:

370 g water
570 g cement
1,710 g sand according to requirements of Part 6 of BS 4550.

B. Liquid Accelerators

1. Shotcrete produced by using liquid accelerators shall be checked at least once per month for development of strength as compared with the base concrete. The test procedure and acceptance criteria for monthly checking shall be as follows:

a) 5 Cylindrical test specimens shall be cored from test panels made from shotcrete without liquid accelerator (base concrete) at least

once per month. Compressive strength in spray direction after 28 days shall be determined. Procedure of panel-preparation and determination of compressive strength shall be according to Paragraph 9.243 - Shotcreting Trials.

b) The average strength (S_O) of these 5 base concrete specimens shall be compared with the average strength (S_W) of five consecutive test results of compressive strength of cores taken from shotcrete in the Works being shotcreted during the same time period as the 5 panel-specimens (same cores as prepared for Strength Tests according to Section 9.251).

c) The comparison of average strength S_O and S_W shall fulfil the following criteria:

$S_w/S_0 \geq 0.7$

2. The maximum dosage of liquid accelerator used shall be 4% by weight of cement.

9.300 ROCK DOWELS

9.310 Definitions

1. Rock Dowel - Cemented or Resin Grouted:

This type of rock dowel is an untensioned rod inserted into a drilled hole and grouted along its entire length using cement grout or resin capsules. The rock dowel consists of a high yield steel deformed ribbed bar with cut or rolled threads at one end, a face plate, shim plates and nut.

2. Rock Dowel - Swellex Type or Similar:

This type of rock dowel is manufactured from a mechanically reshaped steel tube. Bushings are pressed onto the ends, which are sealed through welding. The lower bushing has a flange to hold a face plate in place. High pressure water (300 bars) is injected into the steel tube through a hole in the lower bushing. This causes the steel tube to expand and to form it to the irregularities in the drilled hole. A 200 mm long sleeve tube made of steel prevents the dowel from swelling at the drillhole mount. As the swelling process occurs, the lower part of the steel tube shortens, pulling the face plate firmly against the rock face. The water pressure is released after installation and the water allowed to drain out of the expanded steel tube. The drillhole diameter has to be adjusted to suit the size of rock dowel.

3. Fibreglass Rock Dowel:

This type of rock dowel is an untensioned rod made from fibreglass bonded together by resin. One end of the rod is cut at 45° angle to provide a bevelled end and the other end is threaded to receive a nut. A fibreglass face plate and a fibre/resin nut of proprietary manufacture completes the assembly. The surface of the bonded fibres is left to provide a rough surface to improve bond with grout.

Fibreglass dowels are used to strengthen excavated faces where subsequent tunnelling work is to be carried out or to provide temporary support to an excavation face during stoppages. The dowels are installed in a manner similar to that for steel dowels. Steel face plates and nuts may be used with fibreglass dowels but these shall be removed before excavation is resumed.

9.320 Materials

1. A detailed statement of the types and sources of rock dowels proposed for use in the Works, shall be prepared.

2. The constituent materials for cement grout shall be in accordance with Chapter 12 - Concrete except as specified below.

3. Cement shall be Ordinary Portland or Rapid Hardening Portland cement to BS 12.

4. Aggregate for cement grout shall contain high quality quartz sand up to 1 mm particle size.

5. Cement grout shall achieve a characteristic strength of at least 5 N/mm^2 at 1 day and 30 N/mm^2 at 28 days when tested on mortar cubes in accordance with BS 4550:1978. Rock dowels grouted with cement grout shall be demonstrated during Site trials to be capable of sustaining a pullout force of 60 percent of the working load 12 hours after grouting.

6. Cement grout for fast acting dowels shall achieve a characteristic strength of at least 10 N/mm^2 at 1 day and 30 N/mm^2 at 28 days when tested on mortar cubes in accordance with BS 4550:1978. Fast acting rock dowels grouted with cement grout shall be demonstrated during Site trials to be capable of sustaining a pullout force of 60 percent of the working load 6 hours after grouting.

7. Rock dowels grouted with resin grouts shall be demonstrated during Site trials to be capable of sustaining a pullout force of 60 percent of the working load one hour after installation.

8. Admixtures shall be plasticisers and expanding agents to BS 5075:1982. The admixtures used shall have no detrimental effect on the performance of the rock dowels. Admixtures containing chlorides shall not be used.

9. Face plates shall be of dished shape in steel to BS 4360:1986 Grade 43A and shall have a hemispherical seating and a centralised slot to suit the dimensions of the different rock dowels. The dimensions of the face plates shall be as follows:

Face Plate Type	Dimensions (mm)
I	200 x 200 x 10
II	150 x 150 x 8

10. Bolts, nuts and seatings shall comply with the requirements of BS 4190:1967.

11. Fibreglass rock dowels shall be made from polyester resin reinforced with glass fibres in continuous strands. The glass strands shall form 65% to 75% of the weight of the dowel with the balance being resin.

12. Face plates made from fibre glass shall have a minimum diameter of 130 mm. Alternatively type II steel face plates may be used.

13. The characteristic load, defined as the product of the cross-sectional area of the bars and the characteristic yield (or proof) strength, f_y, shall not be less than shown in Table 9.1. The cross-sectional area shall be as defined in BS 4449:1978. In any case, the minimum cross-sectional area of bars and the minimum cross-sectional area at the root of the threads shall not be less than the values given in Table 9.1.

TABLE 9.1 - REQUIREMENTS FOR DEFORMED RIBBED STEEL BARS

Type of Dowel	Minimum Characteristic Load (kN)	Minimum Cross-Sectional Area (mm^2)	Minimum Characteristic Load at Threads (kN)
Type I	200	420	170
Type II	120	250	100

TABLE 9.2 - REQUIREMENTS FOR FIBREGLASS BARS

Type of Dowel	Minimum Characteristic Load (kN)	Minimum Cross-Sectional Area (mm^2)	Minimum Characteristic Load of Dowel Head (kN)
Type I	200	380	100
Type II	120	250	100

Fibreglass rock dowels shall comply with the requirements of Table 9.2.

9.330 Drilling and Installation

1. Rock dowels shall be installed in the positions, sequence and at the spacings shown on the Drawings. The exact locations of dowels shall be adapted to suit the prevailing geological conditions. When necessary to ensure the safety of the Works, rock dowels shall be installed immediately behind the face. The detailed procedures to be adopted for the installation of the dowels shall be in accordance with the Works Procedures.

2. Holes for the installation of rock dowels shall be drilled into the rock to the lengths indicated or stated on the Drawings and shall be inclined such that dowels are generally installed normal to the designed surface of the excavation. The inclination, length and number of holes shall be adapted to suit the geological conditions

and the results of geotechnical measurements. Holes shall be drilled with an accuracy of ± 15°.

3. Drillhole diameter shall be within the range recommended by the rock dowel and resin capsule manufacturers to match the particular rock dowel diameter and any couplers required for extending the dowels.

4. Holes shall be drilled using sharp bits to produce straight holes of the required length. On completion of each drillhole and prior to the installation of each dowel, drillholes shall be cleaned to remove debris.

5. Installation shall be made in accordance with the rock dowel and resin capsule manufacturers' recommendations and generally as follows:

(a) A regular surface, normal to the drillhole, shall be provided to seat the face plate. Some preparation of the rock or shotcrete surface local to the drillhole/ dowel location may be necessary, involving trimming local surface irregularities or forming pads of quick-setting mortar. Where mortar pads are required they shall be larger than the face plates and the edges shall be chamfered at 45°. Care shall be taken to ensure that the mortar does not interfere with the installed dowel.

(b) The dowels shall be installed in accordance with the drawings and Site instructions given by the Senior Engineer NATM. Face plates shall be tightly screwed against the surface using hand wrenches.

(c) The grouting material shall be injected starting from the furthest end of the drilled hole such that the dowel rod is completely encased in grout Tremie and vent pipes shall be provided as necessary for grouting and the open ends of holes sealed to prevent grout loss. Any grout on the exposed threads of the dowels shall be cleaned off.

(d) Dowels installed in overhead positions shall be supported where necessary until the grout has set.

9.340 Testing of Materials

9.341 Testing of Cement Grout

1. Sets of six cubes of cement grout shall be taken once every month when installation of grouted rock dowels is in progress. Sampling, preparation, curing and testing shall be in accordance with BS 4550:1978.

2. Half of the cubes shall be tested at 1 day and the remainder at 28 days. The average compressive strength determined from any group of four tests shall exceed the specified characteristic strength by:

1 N/mm^2 for cement grout tested after 1 day
3 N/mm^2 for cement grout tested after 28 days

The strength determined from any single test result shall be not less than the specified characteristic strength minus:

1 N/mm^2 for cement grout tested after 1 day
3 N/mm^2 for cement grout tested after 28 days

9.342 Testing of Threaded Bars

1. Tensile tests shall be carried out on portions of steel dowel bars containing the threaded length from each batch of bars generally in accordance with BS 4449:1978 and BS 18:1987. At least three bars in every 1000 shall be tested to destruction. Tests may be carried out at the manufacturer's works or on Site. Test certificates shall be provided. Batches of bars which do not comply with Table 9.1 shall be rejected.

2. At least one in every 100 fibreglass dowels with a minimum of 3 from every batch delivered to Site shall be tested to destruction. Batches of fibreglass rods which fail at loads less than 1.5 times the working load shall be rejected.

9.350 Trials and Testing of Dowels

9.351 Site Trials

1. Prior to commencement of installation of dowels, 5 trial rock dowels of each type of dowel to be used in the Works shall be installed and tested. Two of the trial dowels shall be tested at 60% of the working load after 12 hours (1 hour for resin grouted bolts or 6 hours for fast acting grouted bolts) and the remaining tested at working load between 3 and 21 days after installation.

2. Trial dowels shall be installed in similar rock conditions to those which are likely to be encountered during installation in the Works and shall be in accordance with this Specification.

3. Additional rock dowel tests shall be carried out if the procedures for installation of working dowels do not match those adopted for the preconstruction Site trials. If the test results on dowels used in the Works when compared with the results of the original trial tests show inadequacies in load carrying capacity, a detailed investigation and further tests to identify and rectify the inadequacies shall be carried out.

9.352 Works Tests

1. Two percent of the dowels installed in the Works shall be load tested to 60% of the working load, 12 hours after grouting for cement grouted dowels, 1 hour after installation for resin grouted dowels and 6 hours after grouting for fast acting grouted bolts. Five percent of the installed dowels shall be tested to working load between 3 and 21 days after installation. The proportion of the dowels tested at working load may be varied if consistent test results are obtained for the previous 50 dowels tested, subject to approval by the Engineering Manager or his delegated personnel. Dowels which fail the tests shall be replaced.

2. The in situ tests shall be carried out generally in accordance with the suggested method for determining the strength of a rockbolt anchor given in Rock Characterisation Testing and Monitoring: ISRM Suggested Methods edited by E.T. Brown (Pergamon Press 1981). The specified test loads shall be applied and then released at the end of the tests.

3. The in situ load tests shall be carried out at the following working loads:

Dowel Type	Working Load for In-Situ Load Tests (kN)
I	150
II	90

The rock dowels shall be deemed to be acceptable provided the working load is sustained for at least 10 minutes. Fibreglass dowels shall be tested to loads for type II dowels.

9.353 Testing of Installed SWELLEX Dowels

1. Five percent of the installed dowels shall be tested by renewed application of the high water pressure (300 bars) and two percent of the dowels shall be tested by means of pull out tests.

9.360 Records

1. Records shall be kept for each dowel installed in accordance with the NATM procedures and copies of all records shall be maintained on site after installation of the dowel or completion of testing, as appropriate.

9.400 FOREPOLING

9.410 General

1. Forepoling is a general term for the treatment of ground outside and ahead of the excavated tunnel face by the installation of linear type ground reinforcement at intervals around the crown, usually at an angle of 10° to 15° with the tunnel direction. Treatment may include the following:

- Ungrouted rock dowels (spiles)

- Grouted rock dowels (spiles) inserted into a drilled hole and grouted along their entire length using cement grout

-Injected steel pipes driven into the rock and grouted by injection

-Interlocking steel sheets driven to form an arch ahead of the tunnel face

9.420 Materials

1. Rock dowels (spiles) shall consist of high yield steel deformed bars in accordance with BS 4449 (1978) or BS 4461 (1978).

2. Injected Steel Pipes

Injected steel pipes shall consist of weldable steel pipes with an internal diameter of 32 to 42 mm and a minimum wall thickness of 4.5 mm, with thread cut at one end and a strong pointed steel tip at the other end. Perforations with a diameter of 8 mm at 200 mm longitudinal spacing are provided along two thirds of the total length of the pipe starting from the tip. If necessary, the injected steel pipes are provided with face plates which are tightly screwed at the rock face or shotcrete.

3. Where interlocking steel sheets are required for forepoling, they shall be of grade 43 steel to BS 4360.

4. Grout used for grouting spiles as injected steel pipes shall be in accordance with Section 9.320 Materials.

9.430 Application

1. Forepoling shall be used wherever ground conditions require support to allow excavation to proceed in a safe environment. Forepoling shall be carried out as shown on the Drawings and approved by the Senior Engineer NATM.

2. Forepoling for NATM construction shall be used in conjunction with lattice girders. The forepoling shall be driven above or through the lattice girder closest to the excavation face.

3. The length and type of forepoling shall be selected to suit the ground conditions and the expected length of advance. Typically the length of forepoling shall be at least twice the excavation advance.

4. The spacing of forepoling rock dowels shall be between 250 and 500 mm around the crown and that of injected steel pipes between 500 and 1000 mm. The actual spacing used shall be selected to suit the ground conditions, as approved by the Senior Engineer NATM.

5. Forepoling using rock dowels and injected steel pipes shall be installed by driving in soft ground or by drilling and grouting. Injected grout shall be set before advancing the excavation.

6. Forepoling for ground support methods other than NATM shall be used in conjunction with steel ribs to BS 227:1970, the forepoling being driven above the steel rib closest to the face.

7. The sheet piles shall be driven ahead of the face by a method approved by the Engineering Manager or his delegated personnel.

9.500 STEEL RIBS - NATM

9.510 General

1. Tunnels, junctions, adits and other underground cavities to be constructed in accordance with the New Austrian Tunnelling Method (NATM) shall be supported by steel ribs incorporated within the primary linings as shown on the Drawings.

2. Excavation shall not be commenced until adequate stocks of steel ribs and all other requisite accessories are available on Site.

9.511 Purpose

1. Steel ribs shall be installed as a means of immediate support at the working face over the length of the last excavation advance to prevent spalling, to improve the load distribution and to improve the effectiveness of the rock dowels.

9.512 Materials

1. Materials for the steel ribs shall be in accordance with BS 4449:1978 or BS 4461:1978. All steel shall have a minimum characteristic strength of 460 N/mm^2 and shall be of "weldable classification".

2. Alternatively materials for lattice girders shall comply with DIN 488 to Class B St 500S as modified by (a) to (h) below:

(a) Nominal size, nominal cross-sectional area and mass.

COMPONENT	NOMINAL SIZE (mm)	NOMINAL CROSS-SECTIONAL AREA (mm^2)	NOMINAL MASS PER METER RUN (kg)
Chords	18	254.46	1.998
	20	314.15	2.466
	22	380.12	2.984
	26	530.91	4.168
	28	615.78	4.833
	30	706.84	5.549
	32	804.22	6.313
	34	907.89	7.127
Stiffeners	10	78.54	0.616
	12	113.09	0.888
	14	153.03	1.208

(b) Process of manufacture : Steel shall be made by a self tempering process.

(c) Chemical composition of steel (with tolerances).

ELEMENT	STEEL FOR CHORDS	STEEL FOR STIFFENERS	ALLOWABLE TOLERANCES
Carbon	0.25	0.22	+ 0.03
Sulphur	0.050	0.005	+ 0.008
Phosphorus	0.050	0.005	+ 0.008

(d) Quality : All bars shall be free from harmful defects which can be shown to adversely affect the mechanical properties of the steel specified herein.

(e) Weldability : Steels specified herein shall be considered weldable only if the cast analysis gives a carbon equivalent not greater than 0.50% when derived from the following formula:

$$CARBON\ \ EQUIVALENT\ \ VALUE = C + \frac{Mn}{6} + \frac{Cr + V + Mo}{5} + \frac{Cu + Ni}{15}$$

(f) Shape of surface of bars : The surface shall be smooth and uniform.

(g) Tolerances on mass and cross-sectional dimensions : The mass shall be within the range of 0% to +8% and the cross sectional area shall be within the range of -4% to 0% of the respective nominal value stated in (a) above.

(h) Specified characteristic strength: The characteristic values for the yield strength, the tensile strength and the minimum elongation shall be as follows, where the characteristic value is the value below which there is a statistical probability of W = 0.9 that not more than 5% of the values of units of components will fall.

COMPONENT	SPECIFIED CHARACTERISTIC YIELD STRENGTH R_e (N/mm^2)	SPECIFIED CHARACTERISTIC TENSILE STRENGTH R_m (N/mm^2)	MINIMUM ELONGATION AT RUPTURE (%)
Chords	510	560	14
Stiffeners	500	550	10

3. Test certificates shall be obtained from the supplier confirming compliance with the appropriate Standards.

4. Steel ribs shall be fixed to soleplates or support beams which shall be supported by steel shims and wedges. Timber foot plates, blocks or wedges shall not be used to support steel ribs.

9.520Design

9.521Rib Types

1. The steel ribs shall be rolled sections or fabricated lattice girders. Steel ribs fabricated from rolled sections shall be as specified in Section 9.600 - Steel Ribs-Other than NATM. Lattice girders shall have three or four circumferential bars. When using lattice girders with three bars, two bars shall be positioned adjacent to the excavated surface as shown on the Drawings.

9.522Strength Requirements

1. The strength of steel ribs and lattice girders shall be demonstrated by calculation or by load tests. If the manufacturer has appropriate previous experience of testing lattice girders of a design similar to those intended for the Works the test results from previous testing may be accepted as a basis for calculation.

2. Where tests are necessary they shall be performed in accordance with test procedures approved by the Engineering Manager or his delegated personnel.

3. Tests shall conform with the following:

(a) The test piece shall consist of a straight length of steel rib with a length of 4.5 m restrained by a pinned support at one end, and a pinned roller support at the other end.

(b) A uniformly distributed vertical loading of 5.0 kN/m shall be applied over the entire length of the girder. At the same time a horizontal compressive load of 125 kN shall be applied at the roller support. The rib shall not collapse under the combined loading.

4. Where the strength of the ribs is demonstrated by calculation, an ultimate limit state check shall be carried out using the loads

specified in Paragraph 3 above with a partial safety factor for loads of 1.0. The partial safety factor for material strength shall be 1.15.

9.530 Fabrication and Erection

9.531 Drawings

1. Fully detailed fabrication drawings and specifications for all components of the steel ribs shall be prepared before commencement of manufacture. Manufacture shall be in accordance with these drawings and specifications.

9.532 Welding

1. Welding shall be carried out in accordance with BS 5135 except that in the case of materials supplied in accordance with Clause 9.512 Paragraph 2, welding may be carried out in accordance with a prodedure provided by the Engineering Manager based on the fabricator's own specification.

9.533 Connections

1. All connections shall be rigid unless otherwise shown on the Drawings.

2. Hinged connections shall be capable of transferring the full section axial compressive force and shear forces. The adequacy of connections shall be demonstrated by calculation or by load test.

3. Rigid connections shall be capable of resisting the full sectional bending moments, axial forces (tension and compression) and shear forces. These and other more complex connections shall be proved by testing as specified in Section 9.522.

4. The connections shall be designed to allow complete covering with shotcrete, so that no voided areas are created behind the connections.

5. Connections for latice girders supplied in accordance with Clause 9.512 Paragraph 2 shall comply with DIN 267.

9.534 Surface Condition

1. At the time when the steel ribs are encased in shotcrete, they shall be free from mud, oil, paint, concrete retarders, loose rust, loose mill scale, grease or any other substance which could adversely affect the steel or concrete chemically, or reduce the bond.

9.535 Tolerances

1. The ribs shall be supplied and erected as shown on the Drawings.

2. Ribs shall not deviate from the above shape by more than ± 50 mm.

3. The length of a complete rib shall not deviate from the required length by more than ± 50 mm.

4. The ribs shall be erected within ± 100 mm of positions shown on the Drawings unless otherwise approved by the Senior Engineer NATM. The erected profile shall not deviate by more than 0.6% of the internal dimensions shown on the Drawings.

9.600 STEEL RIBS - OTHER THAN NATM

9.601 Rolled Steel Ribs

1. Rolled steel ribs shall comply with the requirements of Chapter 20 - Steelwork except as specified herein.

2. Rolled steel ribs and attachments thereto, ties, spreaders and collar braces shall be Grade 43A weldable structural steel in accordance with BS 4360. All bolts and nuts for steel ribs shall be black bolts Grade 4.6 except where otherwise shown on the Drawings. Lagging shall be of steel or timber or shotcrete as specified in Section 9.700 - Laggings. Blocking shall be hardwood unless otherwise specified. Soleplates shall have adequate bearing capacity.

3. Steel ribs shall be cold worked to the required radii. The sections as rolled shall comply with the required dimensions and masses shown on the Drawings and shall be within a tolerance of 22% of the mass per unit length and within + 3 mm and - 1 mm of the required depth. The shape of the rib shall conform to true design template at the ends of segments, while intermediate points may depart by up to 10 mm from the true templates provided that no point shall depart more than 3 mm from a template section 1 m long. Each rib set, when assembled with the connections fully and tightly bolted, shall lie within ± 25 mm of a true plane.

4. Ribs shall be free from cracks and flaws and shall be well finished, without rough or jagged edges or other imperfections. The ends shall be clean, smooth and, where necessary, dressed before despatch.

5. The type, size and spacing of rolled steel ribs shall be as shown on the Drawings. Steel ribs shall be erected within the specified tolerances and shall be firmly blocked off the rock or shotcrete

at spacings around the periphery of the rib as shown on the Drawings. Adjacent ribs shall be tied and braced as necessary for stability. Steel rib supports shall be fixed to soleplates which shall be supported by steel shims and wedges on concrete foot blocks as shown on the Drawings, bearing on sound undisturbed rock base. Timber footplates or blocks shall not be used.

9.610 Not Used

9.620 Not Used

9.630 Fabrication and Erection

9.631 Drawings

1. Fully detailed fabrication drawings and specifications for all components of the steel ribs shall be prepared before commencement of manufacture. Manufacture shall be in accordance with these drawings and specifications.

9.632 Welding

1. All welding shall be carried out in accordance with BS 5135.

9.633 Connections

1. Hinged connections shall be capable of transferring the full section axial compressive forces and shear forces. The adequacy of connections may be demonstrated by calculation or by load test.

2. Stiff connections shall be capable of resisting the full sectional bending moments, axial forces (tension and compression) and shear forces. Adequacy of these and other more complex connections shall be proved by testing as specified in Section 9.522.

3. The connections shall be designed to allow complete covering with shotcrete or surrounding by concrete, so that no voided areas are created behind the connections.

9.634 Surface Condition

1. At the time the steel ribs are encased in shotcrete or concrete, they shall be free from mud, oil, paint, concrete retarders, loose rust, loose mill scale, grease or any other substance which could adversely affect the steel or concrete chemically, or reduce the bond.

9.635 Tolerances

1. The ribs shall be erected within ± 100 mm of the positions shown on the Drawings unless otherwise approved by the Construction Manager and shall not deviate by more than ± 50 mm from the profiles shown on the Drawings.

9.700 LAGGINGS

9.710 Materials

1. Laggings shall be of steel, treated hardwood or shotcrete as shown on the Drawings and shall be installed as soon as practicable after erection of steel ribs.

9.720 Strength Requirements

1. The strength and/or thicknesses and material types of laggings shall be as shown on the Drawings.

9.730 Fixing

1. Steel and timber laggings shall be firmly fixed in place with hardwood blocks and wedges.

9.740 Fire Resistance

1. Timber laggings shall be pressure-impregnated with fire retardant preservative to provide at least 2 hour fire resistance. The preservative shall have no deleterious effect upon any of the Permanent Work in contact with it or in close proximity to it.

9.800 SHOTCRETE CLASS P1

9.810 Base Concrete

9.811 Cement

1. It is of particular importance to use cement of uniform chemical composition and uniform fineness. The required characteristic values shall be agreed by the Construction Manager or his delegated personnel with the cement manufacturer before commencement of delivery. For all cement delivered the manufacturer shall make the cement analyses and the results of standard tests available.

2. Cement shall comply with BS 12:1978, BS 4027:1980 or BS 1370 1979 and with the following additional requirements:

(a) Initial setting time: not less than two hours and not more than three hours. (BS 4550:Part 3:1978:Section 3.6)

(b) Fineness: The specific surface shall not be less than 350 m^2/kg. (BS 4550:Part 3:1978:Section 3.3). The range of results of individual samples tested shall be less than 40 m^2/kg.

(c) Bleeding: Not more than 20 cm^3 (see Section 9.891 for test procedure).

(d) Compressive strength of concrete cubes (BS 4550:Part 3 1978:Section 3.4):

- after 1 day (24 hours ± 0.5 hours): ≥ 9 N/mm^2
- after 3 days (72 hours ± 1 hour): ≥ 18 N/mm^2
- after 28 days (28 days ± 4 hours): ≥ 40 N/mm^2

(e) The temperature of the cement at the time of use in the mixing plant shall not be higher than 50°C.

9.812 Latent Hydraulic Binders (Pulverised-Fuel Ash and Silica Fume)

1. Pulverised-Fuel Ash (pfa)

Pfa shall comply with the requirements of BS 3892:Part 1:1982. In addition the pfa shall comply with the following:

(a) Tests shall be carried out monthly on samples of pfa (in accordance with BS 3892:Part 1) and test results provided for:

Loss on ignition
Moisture content
Fineness
Relative density

(b) Pfa shall only be supplied from one source, (i.e. power station). If material is to be supplied from a new source it shall be fully tested.

(c) Fineness: The specific surface (as defined in BS 4550: Part 3:Section 3.3) shall not be less than 450 m^2/kg. The range of results of individual samples tested shall be less than 50 m^2/kg.

For the purpose of applying BS 4550: Section 3.3 to pfa, the following shall apply:

(i) The value of 0.540 shall be used as the porosity of pfa (instead of 0.475 for cement)

(ii) Instead of using tables 1 or 2, the following formula shall be used to determine the required weight of pfa:

$$W = V d (1-P)$$

where W = weight of sample required (g)

V = volume of bed (cm^3)

d = density of pfa (g/cm^3)

P = porosity of pfa = 0.540 (no units)

(d) When pfa is added in the mixing plant it shall be separately weigh batched.

(e) The dry cement and pfa shall be thoroughly blended in a mixer.

2. Silica Fume (SF)

Silica fume shall comply with the following requirements:

(a) Dry Powder

- Silica content shall be not less than 85%
- Particle size shall be between 0.1 and 0.2 microns
- Fineness - Specific surface area shall not be less than 15000 m^2/kg
- Total alkali oxide content shall not exceed 2%
- Activity index >85%
- Moisture content <3%
- SO_3 (water soluble) <1%

(b) Silica Fume Slurry

- pH shall be 5.5 ± 1.0
- Water content shall be 50% ± 2%
- Viscosity shall be 20 seconds with a 4 mm viscosity cup in accordance with British Board of Agrément Certificate 85/1568
- Relative density shall be between 1.3 and 1.4

(c) Testing to establish compliance with the above shall be carried out on a monthly basis, or more frequently as may be determined by the Engineering Manager or his delegated personnel.

(d) Storage and Handling

The slurry shall be regularly agitated by circulation pumps prior to use. Heating facilities shall be incorporated into storage tanks to prevent the slurry freezing during cold weather. The maximum temperature of the slurry during heating shall be 20°c.

(e) The compatibility of silica fume and liquid admixtures shall be established by either:

- verification of existing test data or experience
- carrying out appropriate accelerated testing procedures

(f) The optimum content of silica fume shall be determined during site trials.

9.813 Aggregates

1. In addition to the requirements of this section, aggregate shall comply with BS 882 and Chapter 12 - In Situ Concrete.

2. The following requirements refer to a nominal particle size of 10 mm.

3. The ten per cent fines value shall be not less than 100 kN as determined by the method specified in BS 812 : Part 3 1975.

4. Single size aggregate shall be combined in the proportions determined during the site trials. The individual fractions shall be stored separately.

5. Coarse and fine aggregates shall be clean. The grading shall be within the acceptable range and wherever possible within the target range according to the grading curve - Figure 9.2.

6. The coarse aggregate shall not exhibit excessive fragmentation after delivery. The percentage of particles smaller than 0.075 mm as determined in accordance with the decantation method specified in BS 812: Part 103 :1975 shall not exceed 3%.

7. The aggregate used shall be checked for chemical reactions (AAR) with latent hydraulic binders and admixtures, especially accelerators, that are not covered in Chapter 12.

8. Frozen aggregates shall not be used. The minimum permissible temperature of the aggregate shall be +3°C. If the aggregates are to be warmed by the use of steam, special attention shall be paid to control of moisture content, particularly in the sand fraction.

9. For the dry method, at the time of mixing, the moisture content shall be between 3% and 8% for the fine aggregate and shall not exceed 5% for the combined aggregate. In each case the percentages are by weight of the saturated surface dry material.

10. The grading of the aggregate for use in shotcrete shall be checked weekly in relation to the grading curve shown in Figure 9.2, and the moisture content of the same shall be checked daily in relation to 9.813 Clause 9.

Figure 9.2 - Aggregates for Shotcrete Class P1 - Grading Curve

9.814 Water

1. Water shall comply with BS 5328: 1981.

9.820 Admixtures

9.821 General

1. Where conditions allow, the use of accelerators shall be avoided. Only accelerators in liquid form shall be used.

2. Retarding and plasticising admixtures shall comply with BS 5075:1982.

3. The Engineering Manager shall consider any potential for admixtures contaminating groundwater in giving or withholding approval for their use.

4. The admixtures shall be free of chlorides, i.e. the percentage of chlorides shall not exceed 0.001% by weight.

5. The required characteristic values and consistency of delivery to Site shall be agreed with the manufacturer of each admixture before commencement of shotcreting.

6. Storage conditions and usage of admixtures shall comply with the manufacturer's recommendations.

7. Details of the stability of the admixtures with the mix water shall be obtained from the manufacturer.

8. Compatibility of all admixtures with each other and with all other shotcrete constituents shall be verified during the site trials.

9.822 Accelerators

1. Shotcrete produced by using accelerators shall be checked at least once per month for development of strength as compared with the base concrete. The test procedure and acceptance criteria for monthly checking shall be as follows:

a) 5 Cylindrical test specimens shall be cored from test panels made from shotcrete without accelerator (base concrete) at least once per month. Compressive strength in spray direction after 28 days shall be determined. Procedure of panel-preparation and determination of compressive strength shall be according to Paragraph 9.843 - Shotcrete Trials.

b) The average strength (S_O) of these 5 base concrete specimens shall be compared with the average strength (S_W) of five consecutive test results of compressive strength of cores taken from shotcrete in the Works being shotcreted during the same time period as the 5 panel-specimens (same cores as prepared for Strength Tests according to 9.852).

c) The comparison of average strength S_O and S_W shall fulfil the following criteria:

$S_w/S_0 \geq 0.7$

2. The maximum dosage of accelerator used in the mix on Site shall not exceed 9% by weight of cement:

9.823 Plasticisers and Retarders

1. With the wet method, plasticisers and retarders may be used to reduce the quantity of the mixing water and to improve the pumpability of the concrete. The effects of the plasticiser shall be determined in the site trials (see Section 9.840 - Site Trials). Shotcrete made by using plasticisers and retarders shall be checked regularly for setting time, water reduction and development of strength as compared with the base concrete in accordance with BS 5075.

9.830 Shotcrete Requirements

1. Shotcrete shall be capable of being applied in layers up to 150 mm in thickness with good adhesion to the ground or previous layers of shotcrete, with good embedment of reinforcement and without sagging.

2. The characteristic strength shall be as follows :

Trial Type	Time of Test	Characteristic Strength N/mm^2
Site Trials	After 24 hours	8
	After 28 days	25
Works Tests	After 24 hours	6
	After 28 days	22

Strength requirements shall be based on cores sampled in both directions from test panels for the site trials and in the direction of spraying from shotcrete placed in the works.

3. In order to enhance resistance to chemical attack, shotcrete should be dense, homogenous and without segregation of aggregate or other visible imperfections.

4. Pfa or Silica Fume shall be used.

5. The maximum permeability of shotcrete measured by depth of water penetration, for varying sulphate attack conditions, is defined in Section 9.831 Table 9.3.

6. The permeability test shall be carried out in accordance with Section 9.892 - Permeability Test. The chloride penetration shall be determined in accordance with Section 9.894 - Profile Grinding.

7. The requirements specified in Section 9.840 shall be met prior to the use of shotcrete in the Works.

9.831 Shotcrete Exposed to Sulphate Attack

1. The sulphate resistance of the shotcrete shall be demonstrated by testing in accordance with Section 9.893 and Table 9.3.

2. The increase in sulphate concentration above the background level as defined in Section 9.893 shall be less than 3%.

3. At the completion of each test, the trend of the increase with time shall indicate that sulphate concentrations will remain below 3.0%.

TABLE 9.3 SHOTCRETE EXPOSED TO SULPHATE ATTACK

Class	Sulphate SO_3 Concentration in Groundwater (g/l)	Cement Type	Latent Hydraulic Binder (LHB) (% by weight of total [cement+LHB])	Minimum [Cement + LHB] Quantity (kg/m^3)	Maximum W/[C+LHB] ratio	Permeability test-maximum penetration depth (mm)
I	< 0.3	OPC	15 % pfa	370	-	45
II	0.3-1.2	OPC	15-20% pfa or 5-10% SF	390	0.50	30
III	1.2-2.5	SRPC $C_3A \leq 3.5\%$	20-25% pfa or 5-10% SF	410	0.47	30

Shotcrete Class P1 shall not be used as a permanent lining where the concentration of SO_3 in the ground water is in excess of 2.5 g/l.

The frequency of testing in accordance with Clause 9.853 shall be as follows:

1 Permeability Test per month
1 Sulphate Resistance Test for Classes II and III every 3 months.

9.840 Site Trials

9.841 General

1. This section shall be read in conjunction with Section 9.844 - Proficiency of Operatives.

2. Site trials shall be started sufficiently early to ensure that the required shotcrete mix is developed and all trials completed satisfactorily by the time shotcreting Class P1 commences in the Works. Shotcreting shall not commence until the trials and results of laboratory tests have been completed satisfactorily.

3. The site trials shall employ the equipment which will be used in the Works and the constituent materials shall be fully representative of those to be used in the Works.

9.842 Development of Mix Design

1. The design of the shotcrete mix shall be developed in two stages:

(a) Production of a suitable base concrete.
(b) Production of shotcrete from the base concrete.

The target mean strength for the base concrete shall be 1.4 times the characteristic strength for the shotcrete.

9.843 Shotcreting Trials

1. A trial mix shall be designed and prepared with the constituent materials in the proportions proposed for use in the Works. Sampling and testing procedures shall be in accordance with BS 1881. A clean dry mixer shall be used and the first batch discarded.

2. From the trial mix an experienced nozzleman shall prepare sufficient test panels. Each panel shall be at least 600 x 400 mm in size and shall be 200 mm thick. The panels shall be prepared by shotcreting into vertical rigid plywood boxes. The shotcrete in the panels shall adhere well to the backform, be properly compacted and exhibit no sagging.

3. Target workability values shall be determined for the wet method.

4. The panels shall be stored without disturbance at a temperature between 10°C and 25°C covered by polythene sheet until the time of coring. Cores for 1 and 28 day compressive strength tests shall be obtained from the panels at 1 day. The cores for 28

day strength test shall be stored in water in accordance with BS 1881: Part 111.

Cores for Permeability and Sulphate Resistance Tests shall be obtained at 1 day and shall be wrapped in plastic sheeting that is impermeable to water and water vapour for storage until time of testing at 28 days.

5. Cylindrical test specimens shall be cored from each test panel and tested as listed below. Drilling and dimensions of test specimens shall be in accordance with BS 1881:Part 120. Drilling of cores shall be located to avoid areas of possible rebound. No two cores to be tested at any given age shall come from the same panel. Cores to be tested at different ages (i.e. 1 and 28 days) may come from the same panel. For each test at least one spare specimen shall be provided.

(a) Compressive strength in spray direction after 1 and 28 days on 4 cores each. The test cores shall be 100 mm diameter and 100 mm long.

(b) Compressive strength perpendicular to spray direction after 1 and 28 days on 4 cores each. The test cores shall be 100 mm diameter and 100 mm long.

(c) The water permeability in the spray direction on 3 cores taken after 28 days in accordance with Section 9.830. The test cores shall be 100 mm diameter and 200 mm long.

(d) The sulphate resistance in the spray direction after 28, 42 and 56 days on 4 cores. The test cores shall be 100 mm in diameter and at least 100 mm long.

6. Each cored cylinder shall be marked with a reference mark and the date and time of shotcreting.

7. Testing shall be in accordance with the following test methods:

TEST	**TEST METHOD**
Compressive Strength	BS 1881: Part 120
Water Penetration depth	Permeability Test (see Section 9.892)
Sulphate Resistance	Sulphate Resistance Test (see Section 9.893)

8. Additional test panels shall be prepared as necessary to calibrate indirect test methods approved by the Engineering Manager or his delegated personnel. For the purpose of calibration a minimum of four tests shall be carried out at each age for each indirect test method and shotcrete mix.

9. The strength of shotcrete cores from test panels shall be acceptable if both the compressive strength results for samples with their axes parallel to the direction of spraying and the compressive strength results for samples with their axes perpendicular to the direction of spraying, comply with the following requirements.

(a) The average strength determined from the 4 cores from a particular trial shall exceed the specified characteristic strength by at least:

2.0 N/mm^2 for 1 day strength
3.0 N/mm^2 for 28 day strength

(b) Any individual core strength result shall not be lower than the specified characteristic strength by more than:

2.0 N/mm^2 for 1 day strength
3.0 N/mm^2 for 28 day strength

10. The test results shall be passed to the Engineering Manager or his delegated personnel responsible for design of shotcrete structures.

11. The site trials shall be repeated if the source or quality of any of the materials or the mix proportions are changed.

9.844 Proficiency of Operatives

1. Nozzlemen shall have had previous experience in the application of shotcrete, or shall work under the immediate supervision of the foreman or instructor with such experience. Production shotcrete shall be applied only by nozzlemen who have successfully demonstrated their competence and their ability to produce shotcrete complying in all respects with this Specification. Nozzlemen shall hold certificates of competence issued by the Senior Engineer NATM or written evidence of previous satisfactory work. The Senior Engineer NATM shall be responsible for ensuring compliance with this section.

9.850 Works Tests

9.851 General

1. Tests shall be carried out on cores taken from shotcrete placed in the Works. Cores are to be taken to avoid mesh or other embedded metal.

2. Cylindrical test specimens shall be cored and tested in accordance with the following test methods as listed in Section 9.852 to 9.856.

TEST	TEST METHOD
Compressive Strength	BS 1881: Part 120
Modulus of Elasticity	BS 1881: Part 121
Water Penetration depth	Permeability Test (see Section 9.892)
Sulphate Resistance	Sulphate Resistance Test (see Section 9.893)
Thickness Test	Thickness Tests (see Section 9.856)

Dimensions of test specimens shall be in accordance with Section 9.843 - Shotcreting Trials.

3. Test areas shall be as selected by the Senior Engineer NATM with regard to checking areas of difficult operations, i.e. water ingress, poor ground etc.

4. Where the nominal required shotcrete thickness is less than 100 mm the cores for compressive strength testing shall be taken from areas where the actual thickness is greater than 100 mm. Alternatively additional shotcrete thickness shall be applied in selected areas for subsequent test coring as directed by the Senior Engineer NATM.

9.852 Strength Tests

1. Compressive strength tests shall be carried out on cores taken from shotcrete in the Works in accordance with BS 1881 : Part 120 : 1983. The time of coring shall be as close as possible to 24 hours after placing. Cores required for 28 day strength tests may be obtained at the same time as those for 1 day tests and stored in the laboratory in accordance with BS 1881 : Part 111 : 1983. The frequency shall be such as to obtain 3 cores each for 1 day, 7 day and 28 day strength for every 100 m^3 of shotcrete used in the Works. Depending on the compliance of test results with this specification, circumstances of application and importance of construction, the frequency of work tests may be reduced (to every 200 m^3) or increased (to every 50 m^3) subject to previous approval of the Engineering Manager or his delegated personnel. The cores shall be drilled through the whole thickness of the shotcrete and visually inspected to verify that the shotcrete is dense and homogeneous without segregation of aggregate or other visible imperfections. The distribution of the cores for each test shall be as approved by the Senior Engineer NATM.

2. Density of shotcrete samples saturated with water, shall be measured by using the cores for 28 day strength tests at the same frequency of testing.

3. Instead of testing cores taken from shotcrete placed in the Works, indirect test methods may be used to determine the 1 day strength of shotcrete as approved by the Engineering Manager or his delegated personnel. The use of mechanical rebound hammers is not permitted. Tests for 1 day strength shall be carried out at 24 hours ± 2 hours. Results of tests shall be related to the characteristic strength of one day.

4. The strength of shotcrete measured by cores taken from the Works (or by indirect test methods) shall be acceptable if the compressive strength results comply with the following requirements:

(a) The average strength for any group of four consecutive test results shall exceed the specified characteristic strength by at least:

$2.0\ N/mm^2$ for 1 day strength
$3.0\ N/mm^2$ for 28 day strength

(b) Any test result shall not be lower than the specified characteristic strength by more than:

$2.0\ N/mm^2$ for 1 day strength
$3.0\ N/mm^2$ for 28 day strength

Where one test result shall consist of the mean of 3 core strengths.

7 day results shall be used for indicative purposes only.

5. If the shotcrete fails to meet the compliance requirements specified herein, the validity of the test results shall be checked prior to implementing one of the following courses of action:

(a) confirm the requirements for remedial action by assessing the results of geotechnical measurements and/or back analysis.

(b) make good deficiencies by the application of additional thickness of shotcrete.

(c) remove the defective shotcrete and replace by new shotcrete.

The course of action to be adopted shall be approved by the Senior Engineer NATM.

9.853 Durability Tests

1. Permeability shall be tested on a monthly basis on 3 cores in accordance with Section 9.892 - Permeability Test. Sulphate resistance shall be tested on a 3 monthly basis (in accordance with Section 9.831) by the Sulphate Resistance Test, Section 9.893. Cores shall be obtained at 1 day and shall be immediately wrapped in plastic sheeting that is impermeable to water and water vapour for storage until time of testing at 28 days.

2. If the shotcrete fails to meet the criteria specified herein, then the validity of the test results shall be checked in consultation with the Senior Engineer NATM who will if necessary determine further action.

9.854 Stability Tests

1. Tests shall be carried out to assess the load bearing capability of shotcrete in the Works under site conditions. These tests may be carried out on cores taken from panels.

2. One set of tests shall be conducted for each mix type.

3. These panels shall be produced in the works under site conditions. The panels shall be stored underground in the works (with the same climatic conditions as the shotcrete placed in situ). Core samples shall be taken from the panels just before testing, or at least on the same day as testing.

4. Cylindrical test specimens shall be cored and tested as listed below. Dimensions of test specimens and testing shall be in accordance with Section 9.843 - Shotcreting Trials.

(a) Compressive strength in the spray direction after 1, 3, 7 and 28 days on 3 cores each.

(b) Modulus of elasticity in the spray direction after 1, 3, 7, 28 days on 3 cores each. The core shall be 100 mm in diameter and 200 mm long. The strain shall be measured on the central part of the sample, the upper test limit being 1/3 and the lower test limit being 1/30 of the compressive strength. The modulus of elasticity at different ages shall be determined on the same sample, the compressive strength being measured after 28 days.

5. If the stability of the tunnel is endangered because shotcrete does not meet the specified strength requirements, the affected shotcrete shall be replaced carefully or where practicable the deficiencies made good by application of additional shotcrete as approved by the Senior Engineer NATM.

9.855 Workability Tests

1. The workability of shotcrete produced by the wet method shall be measured by slump tests in accordance with BS 1881 : Part 102 after the addition of plasticiser. Samples shall be tested for every 50 m^3 produced.

2. The workability of wet method shotcrete shall be within ± 25 mm or ± one third of the target value as determined by trials, whichever is the greater.

9.856 Thickness Tests

1. The thickness of placed shotcrete shall be checked by drilling small cored holes at 50 m intervals or at intervals directed by the Senior Engineer NATM in such a manner that the rock/shotcrete interface can be recognised. The number and position of holes shall be in accordance with "TML Tunnel Engineering Procedure for Application of NATM (011/0002/PR). Form F" or as directed by the Senior Engineer NATM.

2. Alternative proven methods of determining shotcrete thickness may be used after shotcreting subject to the approval of the Senior Engineer NATM.

9.860 Production and Transport

9.861 Batching and Mixing

1. The individual components for the production of shotcrete shall be measured by weight with an automatic batching device, except that liquid admixtures may be measured by volume. The batching accuracy shall be within $\pm$ 3% for each constituent. Silica fume shall be weighed separately. The method of batching used shall ensure that the accuracy can be easily checked. All measuring equipment shall be maintained in a clean, serviceable condition and shall be zeroed daily and calibrated monthly.

2. Mixing shall be carried out in a mixer suitable for the efficient mixing and discharge of dry or wet batched materials as appropriate.

3. Regular checks shall be made to ensure that complete mixing is consistently achieved.

4. The mixing time for the dry method shall be sufficient to produce complete mixing and shall be at least 1 minute. The mixture shall be delivered by means of appropriate equipment and segregation shall be avoided.

5. Mixed materials for the dry method may be used up to 3 hours after the addition of cement provided that the shotcrete can be applied satisfactorily. Any unused material after this time shall be discarded.

6. Accelerators for the dry method shall be accurately proportioned into the water supply at the shotcreting equipment. Accelerator for the wet method shall be added immediately prior to the application of shotcrete at the application nozzle.

7. The mixed base concrete for the wet method shall be applied within one and a half hours depending on cement and LHB type used and the temperature of the base concrete and atmosphere. Retarders may be used to extend the time of placing.

9.862 Transport

1. For shotcrete produced by the dry method, the dry mixture may be transported by truck mixers or non-agitating containers. The dry mixture shall be effectively protected against any influence of the weather.

2. For shotcrete produced by the wet method, the base concrete including any admixtures except accelerator shall be transported with any suitable means which provides complete mixing during transportation such that segregation of the mix components is prevented. The mixture shall be effectively protected against any influence of the weather.

9.870 Shotcreting Equipment

9.871 General

1. All transport pipes consisting of hoses or pipes of uniform diameter that carry shotcrete ingredients shall be laid straight or in gentle curves and protected so that the flow of ingredients through them is not restricted.

2. The shotcrete machine shall be adjusted to suit the length of the pipe that carries the shotcrete mix. Equipment shall be leak-proof. Residual deposits of materials shall be removed after each usage.

3. The air and water supply system shall be capable of supplying the delivery machine and hose at the pressures and volumes recommended by the manufacturer of the machine. No air supply system shall be used that delivers air contaminated by oil.

4. Shotcreting equipment shall be capable of feeding materials at a regular rate and ejecting shotcrete from the nozzle at velocities that will ensure adherence of the materials to the surface being shotcreted with a minimum of rebound and maximum adhesion and density.

5. The placing equipment shall be so arranged that the nozzleman may use air and water in any combination to prepare raw surfaces as specified in Section 9.881 or to clean completed work.

6. Equipment shall be provided to allow application of shotcrete to all surfaces with the nozzle at the distances from the work specified in Section 9.880 - Shotcreting.

7. A boom mounting or similar device shall be provided for the spray nozzle for use in conditions where manual spraying is unsafe or otherwise unsuitable or undesirable.

9.872 Equipment for the Dry Method

1. The nozzle shall be capable of controlling the quantity of water to be added as well as ensuring effective mixing of all shotcrete ingredients.

2. Accelerators shall be metered uniformly into the water. This can be carried out by pumps adding a specified quantity of accelerator to the water. Special screens shall be incorporated to eliminate foreign substances.

9.873 Equipment for the Wet Method

1. The equipment for the wet method shall be set up according to the recommendations of the manufacturer.

2. Pumping shall ensure a continuous conveyance of base concrete including any admixtures except accelerators. The equipment shall incorporate a suitable metering device for liquid accelerators.

9.880 Shotcreting

9.881 Shotcrete Application

1. Before the application of shotcrete, the excavated surfaces shall be cleaned with compressed air and, as far as the local conditions permit, with an air-water mixture as necessary to remove all material which may prevent proper adhesion of the shotcrete to the rock surface. Loose rock shall be cleared from behind the steel mesh. The surface to receive shotcrete shall be damp and where possible without free water prior to application of shotcrete.

2. Action shall be taken where necessary to control ground water and prevent it adversely affecting the shotcrete lining. Water inflows which might cause deterioration of the shotcrete, or prevent adherence, shall be diverted as detailed on the Drawings by channels, chases, pipes or other appropriate means to the invert or to the ground water drainage system.

3. Where necessary pressure relief holes shall be provided through the lining to ensure that no hydrostatic pressure develops behind the lining.

4. Shotcrete shall only be applied by a nozzleman certified in accordance with Section 9.844. The distance between the nozzle and the surface being shotcreted shall not exceed 2.0 m with the dry method and 1.5 m with the wet method. The nozzle shall, as a general rule, be held perpendicular to the application surface. However, when shooting through reinforcing bars the nozzle shall be held closer and at a slight angle in order to ensure encasement and minimise rebound.

5. With respect to adequate cover to the wire mesh, and steel ribs or lattice girders, the following shall apply:

(a) To ensure adequate cover to the wire mesh, and steel ribs or lattice girders, a 30 mm thick shotcrete layer shall be first applied to the rock surface. Wire mesh and steel ribs or lattice girders shall be fixed onto this layer.

(b) If it can be shown that adequate cover is achieved by compliance with Section 9.882 Paragraph 2, then the Senior Engineer NATM shall review the need for a 30 mm thick initial shotcrete layer.

6. No rebound material shall be covered with shotcrete. To ensure this, and depending on ground conditions and the excavation cycle, the shotcrete shall preferably be applied from the shoulder to the crown. The rebound material shall be removed from the tunnel and shall not be used in the Works.

7. Each layer of shotcrete shall be built up by making several passes of the nozzle over the working area. The shotcrete shall emerge from the nozzle in a steady uninterrupted flow. Should the flow become intermittent for any cause the nozzleman shall direct it away from the work until it again becomes constant.

8. Where a layer of shotcrete is to be covered by succeeding layers, it shall first be allowed to set and loose material and rebound shall be removed. The surface shall be finally cleaned and wetted using a blast of air and water.

9. For vertical and near vertical surfaces application shall commence at the bottom. Layer thickness shall be governed mainly by the requirement that the material shall not sag. Where thick layers are applied the top surface shall be maintained at a slope of approximately 45 degrees.

10. Pockets, sags or other defects shall be cut out and resprayed. The area of respraying shall not be less than 300 mm x 300 mm.

9.882 Shotcrete Thickness

1. The inner surface of shotcrete may follow the contours of the rock surface, with the necessary rounding of the edges and corners, provided that protruding, sound blocks of rock still firmly linked to the rock mass have a minimum shotcrete cover of 2/3 of the specified thickness.

2. Steel arches, steel mesh and the like shall be free of loose rust and they shall be surrounded with at least 30 mm of shotcrete unless otherwise shown on the Drawings.

3. Excavated surfaces of intermediate stages of construction (face, invert, etc.) shall be secured by a temporary lining consisting of a thin layer of shotcrete, generally at least 20 mm thick or as otherwise shown on the Drawings or directed on site by the Senior Engineer NATM.

9.883 Reinforcement

1. Reinforcement shall comply with Chapter 14 and the following paragraphs.

2. Reinforcement mesh shall be securely fixed in place. The reinforcement shall be cleaned of any previously deposited material which might prevent a proper bond.

3. Ties, anchors and supports for the mesh shall be of steel and suitable spacers shall be provided where necessary. Timber packing shall not be used. The method of fixing the mesh shall be such that shotcrete can be compacted soundly behind the reinforcement at all points. Except where otherwise shown on the Drawings laps shall be a minimum of one pitch. Additional fixings shall be installed as necessary to fit the mesh snugly into any depressions.

9.884 Application of Shotcrete in Cold Weather

1. When shotcrete is placed at air temperatures of less than 5°C measures shall be taken to maintain shotcrete temperature above 3°C for at least 1 day after application.

2. No frozen materials, ice or snow shall by allowed to enter the mixer.

3. Cement shall not be heated. If water is introduced at the nozzle, it shall not be heated above 20°C.

9.885 Curing

1. Measures shall be taken to ensure that shotcrete exhibits proper strength gain and a minimum of cracking. Curing measures shall be applied as necessary to achieve these requirements.

9.890 Test Methods

9.891 Test Procedure for Bleeding of Cement

1. Pour exactly 98 g of water with a temperature of 20°C into a 250 ml glass beaker with a small magnetic stirring rod. At medium stirring rate add 115 g of cement little by little within 20 seconds. Combine the mixture for 2 minutes until an homogeneous, relatively thin cement paste (water/cement ratio = 0.85) has been achieved.

2. Fill the homogenized mass into a 100 ml measuring cylinder up to the 100 ml index mark by means of a glass rod (do not pour directly into cylinder). It is absolutely necessary that the measuring cylinder be kept in a high glass beaker filled with water of 20°C during the entire period of testing. Fluctuations in temperature shall not exceed ± 2°C.

3. After 120 minutes the amount of cement that has settled can be read from the scale, i.e. the amount of supernatant water may be determined. The reading is in ml corresponding to % by volume of repelled water.

9.892 Permeability Test

1. Three 100 mm diameter cores shall be obtained by rotary diamond drill from each trial in accordance with Section 9.840 or 9.940, and from the works tests in accordance with Section 9.853 or 9.953 - Durability Tests. The ends of cores shall be trimmed to provide flat surfaces and four 45 mm thick slices shall be cut, one slice from each end and the other two from the remaining central part of each core. For each slice, the following information shall be recorded:

Date of Coring

Core Number

Slice Number

Direction of Spray

Special precautions shall be taken when slicing the cores to minimise micro-cracking and other potential damage to the cut surfaces.

2. One end slice and one slice from the central part of each core shall be tested. If testing is to take place within 24 hours the slices shall be stored wrapped in waterproof and vapour-proof plastic until testing commences. If testing is not to take place for a period in excess of 24 hours, the slices shall be stored in a desiccator at a relative humidity (RH) > 85% where the equilibrium relative humidity is recorded. The remaining

slices shall be wrapped in waterproof and vapour-proof plastic in case further testing is required.

3. The top and bottom faces of the slices shall be clearly marked, and then placed in a tapered brass sleeve of identical design to that of the test rig (except for the absence of the neoprene O-ring seal and recess). The void between the shotcrete slice and the sleeve shall then be filled with a suitable epoxy resin (the sides of the sleeve shall first be greased to facilitate removal of the specimen after curing).

4. The epoxy resin shall be allowed to cure in accordance with the manufacturer's recommendations before the specimen is removed from the sleeve.

5. The specimen then shall be vacuum saturated in distilled water until the change in weight is less than 0.5 g per kg of sample weight over a 24 hour period.

6. The specimen shall be reweighed and then placed in the test sleeve with sufficient pressure to ensure retention by the O-ring.

7. The sleeve and specimen shall then be placed in the permeability rig and all the bolts tightened.

8. The test shall be conducted at 20°C. Sodium chloride (NaCl) solution at 19,000 parts per million Cl^- in distilled water shall be used as a marker for the water front. The pressure regime which shall be applied through the rig to the bottom face of the sample shall be as follows:

1 bar for 48 hours
3 bars for 24 hours
7 bars for 10 days

(Sealing of the side of the specimen shall be achieved by means of a 5 mm diameter neoprene O-ring housed in a recess in the brass sleeve. This sealing is aided by the tapered nature of the sleeve and sample, in that as the pressure is applied to the base it forces the sample into the sleeve thereby sealing the side).

9. The chloride profile in the specimen shall be determined by profile grinding (see Section 9.894), and the water penetration measured.

9.893 Sulphate Resistance Test

1. The test of sulphate resistance shall be carried out as follows:

(a) Four 100 mm diameter cores shall be obtained from each trial in accordance with Section 9.840 or 9.940, and from works tests in accordance with Section 9.853 or 9.953 - Durability Tests. Four 10 mm thick slices shall be cut from each core when the shotcrete is 28 days old.

(b) One slice from each core (4 slices in total) shall be immediately crushed and the sulphate (SO_3) concentration shall be determined in accordance with BS 1881:Part 124:1988. This concentration is the Background Level for the core from which the slice is taken.

(c) The remaining slices (12 in total) shall be placed in 2000 mg/l $CaSO_4$ solution (made up using anhydrous $CaSO_4$ and distilled water) at a temperature of 20°C for the durations detailed in clause (d).

(d) The requirements for the slices are as follows:

For Trial Tests

4 for analysis at 28 days (one from each core)

4 for analysis at 42 days (one from each core)

4 for analysis at 56 days (one from each core)

For Works Tests

4 for analysis at 28 days (one from each core)

4 for analysis at 56 days (one from each core)

4 for analysis at 84 days (one from each core)

(e) The sulphate concentration at each age shall be determined at 1 mm intervals to a depth of 5 mm (60 increments in total) using profile grinding techniques (Section 9.894).

(f) For each core, the background level shall be deducted from each incremental sulphate concentration to give the incremental residual concentration.

(g) Analyses of the powdered shotcrete for SO_3 concentration shall be undertaken in accordance with BS 1881: Part 124:1988.

(h) The maximum residual concentration of SO_3 from any 1 mm increment from any of the cores at each age shall be plotted on Figure 9.3.

Figure 9.3 - Graph to show the variation of sulphate concentration with time, for Shotcrete Class P1 or P2.

9.894 Profile Grinding

1. Profile grinding shall be used in conjunction with permeability tests (9.892) and sulphate tests (9.893).

2. The sample shall be cut in half, along the direction of chloride or sulphate ingress during the test. Half of the sample shall be used for immediate analysis. The other half of the sample shall be wrapped in waterproof and vapour-proof plastic for possible further analysis.

3. The sample for analysis shall be trimmed to remove any excess shotcrete (e.g. edge shotcrete), such that sufficient surface area remains so a 1 mm thick layer provides a large enough quantity of shotcrete dust for the chloride or sulphate ion concentration to be determined in accordance with BS 1881 : Part 124 : 1988.

4. Layers of the sample shall be progressively dry ground by tracking across the surface with a diamond coated grinding wheel. The dust shall be collected by vacuum suction in a clearly labelled disposable filter bag and dried to constant weight at 105°C.

5. The procedure for collection and analysis of samples for chloride analysis shall be as follows,

(a) The sample shall be ground in 1 mm layers to a depth of 10 mm.

(b) The final layer shall be analyzed for Cl^- in accordance with BS 1881:Part 124:1988 and calibrated against standard concrete blocks of known chloride ion concentration as detailed in Section 9.894 (7).

(c) If the value obtained from the analysis is less than 0.01% Cl^- by weight of sample, the dust samples obtained from the layers shall be analyzed to produce a chloride profile.

(d) If the value is greater than 0.01% chloride then (a), (b) and (c) shall be repeated for the next 10 mm.

(e) For samples which have undergone permeability tests and satisfied condition (c), the sample shall be reversed in the specimen holder and two 1 mm layers shall be ground from the reverse side. The ground dust samples shall be combined and analyzed to determine the background concentration of chloride in the shotcrete.

6. The procedure for collection and analysis of samples for sulphate analysis shall be as follows:

(a) The sample shall be ground in 1 mm layers to a depth of 5 mm.

(b) All the layers shall be analyzed for SO_3 in accordance with BS 1881: Part 124: 1988 and calibrated against standard concrete blocks of known sulphate ion concentration as detailed in Section 9.894 (8).

7. Calibration of Chloride ion concentration against standard blocks shall be as follows:

(a) Ten standard concrete cubes of size 100x100x100 mm with the base concrete composition and of known chloride ion concentration (added as Sodium Chloride dissolved in the mix water) shall be cast and cured according to BS 1881: Part 108: 1983. the chloride ion concentration added to pairs of cubes shall be 0%, 0.3%, 0.6%, 1.0% and 2.0% by mass of cementitious material (i.e.- cement + LHB).

(b) The Chloride ion concentration shall be determined for at least ten random points on each cube in accordance with BS 1881: Part 124: 1988.

(c) Results from the analysis of BS 1881: Part 124: 1988 for the chloride ion concentration of non-standard samples (those with an unknown percentage of chloride ions) shall be compared with the plotted test results for the standard cubes (of known chloride ion concentration) to obtain the calibration by way of correction factors. The correction factors may be found by curve fitting if required.

8. Calibration of Sulphate ion concentration against standard blocks shall be as follows:

(a) Ten standard concrete cubes of size 100x100x100 mm with the base concrete composition and of known Sulphate ion concentration (added as calcium sulphate dissolved in the mix water) shall be cast and cured according to BS 1881: Part 108: 1983. the sulphate ion concentration added to pairs of cubes shall be 0%, 2.0%, 3.0%, 5.0% and 8.0% by mass of cement.

(b) The sulphate ion concentration shall be determined for at least ten random points on each cube in accordance with BS 1881: Part 124: 1988.

(c) Results from the analysis of BS 1881: Part 124: 1988 for the sulphate ion concentration of non-standard samples (those with an unknown percentage of sulphate ions) shall be compared with the plotted test results for the standard cubes (of known sulphate ion concentration) to obtain the calibration by way of correction factors. The correction factors may be found by curve fitting if required.

9.900 SHOTCRETE CLASS P2

9.910 Base Concrete

9.911 Cement and Latent Hydraulic Binders (LHB)

9.912 Cement

1. It is of particular importance to use cement of uniform chemical composition and uniform fineness. The required characteristic values shall be agreed by the Construction Manager or his delegated personnel with the cement manufacturer before commencement of delivery. For all cement delivered the manufacturer shall make the cement analyses and the results of standard tests available.

2. Cement shall comply with BS 12:1978, BS 4027:1980 or BS 1370 and with the following additional requirements:

(a) Initial setting time: not less than two hours and not more than three hours. (BS 4550:Part 3:1978:Section 3.6)

(b) Fineness: The specific surface shall not be less than 350 m^2/kg. (BS 4550:Part 3:1978:Section 3.3). The range of results of individual test samples tested shall be less than 40 m^2/kg.

(c) Bleeding: Not more than 20 cm^3 (see Section 9.991 for test procedure).

(d) Compressive strength of concrete cubes (BS 4550:Part 3 1978:Section 3.4):

- after 1 day (24 hours ± 0.5 hours): ≥ 9 N/mm^2
- after 3 days (72 hours ± 1 hour): ≥ 18 N/mm^2
- after 28 days (28 days ± 4 hours): ≥ 40 N/mm^2

(e) The temperature of the cement at the time of use in the mixing plant shall not be higher than 50°C.

9.913 Latent Hydraulic Binders (Silica Fume)

1. Silica Fume (SF)

Silica fume shall comply with the following requirements:

(a) Dry Powder

- Silica content shall be not less than 85%

- Particle size shall be between 0.1 and 0.2 microns

- Fineness - Specific surface area shall not be less than 15000 m^2/kg

-Total alkali oxide content shall not exceed 2%

-Activity index >85%

-Moisture content <3%

-SO_3 (water soluble) <1%

(b) Silica Fume/Water Slurry

-pH shall be 5.5 ± 1.0

-Water content shall be 50% ± 2%

-Viscosity shall be 20 seconds with a 4 mm viscosity cup in accordance with British Board of Agrément Certificate 85/1568

-Relative density shall be between 1.3 and 1.4

(c) Testing to establish compliance with the above shall be carried out on a monthly basis, or more frequently as may be determined by the Engineering Manager or his delegated personnel.

(d) Storage and Handling

The slurry shall be regularly agitated by circulation pumps prior to use. Heating facilities shall be incorporated into storage tanks to prevent the slurry freezing during cold weather. The maximum temperature of the slurry during heating shall be 20°C.

(e) The compatibility of silica fume and liquid admixtures shall be established by either:

- verification of existing test data or experience
- carrying out appropriate accelerated testing procedures

(f) The optimum content of silica fume shall be determined during site trials.

9.914 Aggregates

1. In addition to the requirements of this section, aggregate shall comply with BS 882 and Chapter 12 - In Situ Concrete.

2. The following requirements refer to a nominal particle size of 10 mm.

3. The ten per cent fines value shall be not less than 100 kN as determined by the method specified in BS 812:1975.

4. Single size aggregates shall be combined in the proportions determined during the site trials. The individual fractions shall be stored separately.

5. Coarse and fine aggregates shall be clean. The grading shall be within the acceptable range and wherever possible within the target range according to the grading curve - Figure 9.4.

6. The gravel fraction of the aggregate shall not exhibit excessive fragmentation during delivery. The percentage of particles smaller than 0.075 mm as determined in accordance with the decantation method specified in BS 812:Part 103:1975 shall not exceed 3%.

7. The aggregate used shall be checked for chemical reactions (AAR) with latent hydraulic binders and admixtures, especially accelerators, that are not covered in Chapter 12.

8. Frozen aggregates shall not be used. The minimum permissible temperature of the aggregate shall be +3°C. If the aggregates are to be warmed by the use of steam, special attention shall be paid to control of moisture content, particularly in the sand fraction.

Figure 9.4 - Aggregate for Shotcrete Class P2 - Grading Curve.

9. The grading and the moisture content, of the individual fractions of the aggregate shall be recorded daily. If the grading is found to be consistently within the Target Range of figure 9.4 then the grading shall be checked twice weekly at the discretion of the Senior Engineer NATM.

9.915 Water

1. Water shall comply with BS 5328.

9.916 Steel Fibre Reinforcement

1. Fibres shall be made of mild steel and shall be crimped, twisted or deformed, in accordance with ASTM A820:85, Standard Specification for Steel Fibres for Fibre Reinforced Concrete. Fibres may be collated with a fast-acting water-soluble glue, or may be un-collated, individual fibres.

2. Steel fibres shall be stored in dry sealed containers until ready for use and shall be free from corrosion, oil, grease, chlorides and deleterious materials which may reduce the efficiency of mixing or spray processes, or which may reduce the bond between the fibres and the shotcrete.

3. Seams and surface irregularities shall not be cause for rejection provided that tensile properties are not less than requirements of this Specification and mixing performance in concrete is not adversely affected.

4. Steel fibres shall have an aspect ratio, i.e. fibre length divided by diameter, (or equivalent diameter, in the case of non-round fibres) in the range of 30 to 150 for lengths of 12.7 to 63.5 mm (0.5 to 2.5 ins), where

(a) The length shall not vary from its specified value by more than ±10%

(b) The diameter or equivalent diameter shall not vary from its specified value by more than ±10%

(c) The aspect ratio shall not vary from its specified value by more than 15%

5. The fibres shall comply with the following requirements:

(a) Bend Test

Fibres shall withstand bending around a 3.18 mm (0.125 in) inside diameter to an angle of 90° at temperatures not less than 16°C without breaking. The test shall be done by hand. At least one test consisting of 10 randomly selected specimens of fibres shall be made for each 4.5 tonnes or for each batch if less than 4.5 tonnes. At least 90% of the specimens shall pass the test.

(b) Tensile Strength

The average tensile strength shall not be less than 345 N/mm^2 when tested in accordance with Section 9.996.

6. Fibre type shall be selected on the basis of compliance with this Specification and on suitability and ease of use in the batching, mixing and shotcreting processes proposed, as demonstrated by site trials.

7. Fibres which tend to form fibre balls during batching, mixing and placing shall not be used.

9.920 Admixtures

9.921 General

1. Where conditions allow, the use of accelerators shall be avoided. Only accelerators in liquid form shall be used.

2. Retarding and plasticising admixtures shall comply with BS 5075:1982.

3. The Engineering Manager shall consider any potential for admixtures contaminating groundwater in giving or withholding approval for their use.

4. The admixtures shall be free of chlorides, i.e. the percentage of chlorides shall not exceed 0.001% by weight.

5. The required characteristic values and consistency of delivery to Site shall be agreed with the manufacturer of each admixture before commencement of shotcreting.

6. Storage conditions and usage of admixtures shall comply with the manufacturer's recommendations.

7. Details of the stability of the admixtures with the mix water shall be obtained from the manufacturer.

8. Waterglass shall not be used.

9. Water soluble glue or other additives to steel fibres shall be compatible with other shotcrete components. Compatibility shall be shown to exist by reference to manufacturer's test data.

9.922 Accelerators

1. Shotcrete produced by using accelerators shall be checked at least once per month for development of strength as compared with the base concrete. The test procedure and acceptance criteria for monthly checking shall be as follows:

a) 5 Cylindrical test specimens shall be cored from test panels made from shotcrete without accelerator (base concrete) at least once per month. Compressive strength in spray direction after 28 days shall be determined. Procedure of panel-preparation and determination of compressive strength shall be according to Paragraph 9.943 - Shotcrete Trials.

b) The average strength (S_O) of these 5 base concrete specimens shall be compared with the average strength (S_W) of five consecutive test results of compressive strength of cores taken from shotcrete in the Works being shotcreted during the same time period as the 5 panel-specimens (same cores as prepared for Strength Tests according to 9.952).

c) The comparison of average strength S_O and S_W shall fulfil the following criteria:

$S_w/S_O \geq 0.7$

2. The maximum dosage of accelerator used shall be 4% by weight of cement.

9.923 Plasticisers and Retarders

1. Plasticisers and retarders may be used to reduce the quantity of the mixing water and to improve the pumpability of the concrete. The effects of the plasticiser shall be determined in the Site Trials (see Section 9.940 - Site Trials). Shotcrete made by

using plasticisers and retarders shall be checked regularly for setting time, water reduction and development of strength as compared with the base concrete in accordance with BS 5075.

9.930 Fibre Reinforced Shotcrete Requirements

1. Shotcrete Class P2 shall be applied by the wet method and shall be capable of being applied in layers up to 150 mm in thickness with good adhesion to previous layers of shotcrete without sagging.

2. Two strength values of Shotcrete Class P2 are defined and they shall be referred to as the 40 N/mm^2 mix and the 25 N/mm^2 mix. The characteristic strength of the two mixes after 28 days shall be as follows :-

		40 N/mm^2 Mix	25 N/mm^2 Mix
a)	**In Site Trial**	40 N/mm^2	25 N/mm^2
b)	**In Works Tests**	35 N/mm^2	22 N/mm^2

Strength requirements shall be based on cores sampled in directions parallel and perpendicular to the direction of spray from test panels for the site trials and in the direction of spraying from shotcrete placed in the works.

The proportion of silica fume in the mix shall be between 10 and 15% by weight of cement in the 40 N/mm^2 mix and between 8 and 12% in the 25 N/mm^2 mix.

3. Shotcrete class P2 shall not develop plastic shrinkage or drying shrinkage cracks of a width greater than 0.05 mm. This shall be determined from Site Trials in accordance with Section 9.940

and from works tests, in accordance with Section 9.950, for shotcreting areas greater than 10 m x 10 m.

4. In order to enhance resistance to chemical attack, Shotcrete Class P2 shall be dense and homogeneous without segregation of aggregate or other visible imperfections.

5. The maximum permeability of Shotcrete Class P2 measured by depth of water penetration, for varying sulphate attack conditions, is defined in Section 9.931 Table 9.4.

6. The permeability test shall be carried out in accordance with Section 9.992 - Permeability Test. The chloride penetration shall be determined in accordance with Section 9.994 - Profile Grinding.

7. The requirements specified in Section 9.940 shall be met prior to the use of shotcrete in the Works.

9.931 Fibre Reinforced Shotcrete Exposed to Sulphate Attack

1. In order to enhance the resistance of Shotcrete Class P2 to chemical attack the density of the Shotcrete Class P2 shall be as high as possible and silica fume shall be used.

2. Shotcrete Class P2 Shotcrete shall comply with the requirements of Table 9.4. The increase in sulphate concentration above the background level, as measured in accordance with Section 9.993 shall be less than 3.0% and the trend of the increase in sulphate concentration with time shall indicate that sulphate concentration will remain below 3%.

3. Durability tests shall be carried out in accordance with Section 9.953.

TABLE 9.4 SHOTCRETE CLASS P2 EXPOSED TO SULPHATE ATTACK

Class	Sulphate SO_3 Concentration in Groundwater (g/l)	Cement Type	Silica Fume (SF)	Minimum [Cement+ SF] Quantity (kg/m^3)	Maximum W/[C+SF] ratio	Permeability Test-maximum penetration depth (mm)
I	< 0.3	OPC	8-15 %	370	0.50	45
II	0.3-1.2	OPC	8-15 %	390	0.50	30
III	1.2-2.5	SRPC $C_3A \leq 3.5\%$	8-15 %	410	0.47	30

Shotcrete Class P2 shall not be used as a permanent lining where the concentration of SO_3 in the groundwater is in excess of 2.5 g/l.

The frequency of testing in accordance with Section 9.953 shall be as follows:

1 Permeability Test per month
1Sulphate Resistance Test for Classes II and III every 3 months.

9.940 Site Trials

9.941 General

1. This section shall be read in conjunction with Section 9.944 - Proficiency of Operatives.

2. Site trials shall be started sufficiently early to ensure that the required Shotcrete Class P2 mix is developed and all trials completed satisfactorily by the time shotcreting Class P2 commences in the Works. Shotcreting shall not commence until the trials and results of laboratory tests have been completed satisfactorily.

3. The site trials shall employ the equipment which will be used in the Works and the constituent materials shall be fully representative of those to be used in the Works.

9.942 Development of Mix Design

1. The design of the Shotcrete Class P2 mix shall be developed in two stages:

   (a) Production of a suitable base concrete.
   (b) Production of Shotcrete Class P2 from the base concrete.

The target mean strength for the base concrete shall be 1.3 times the characteristic strength for the Shotcrete Class P2.

9.943 Shotcreting Trials

1. A trial mix shall be designed and prepared with the constituent materials in the proportions proposed for use in the Works. Sampling and testing procedures shall be in accordance with BS 1881. A clean dry mixer shall be used and the first batch discarded.

2. From the trial mix an experienced nozzleman shall prepare sufficient test panels. Each panel shall be at least 600 x 400 mm in size and shall be 200 mm thick. The panels shall be prepared by shotcreting into vertical rigid plywood boxes. The shotcrete in the panels shall adhere well to the backform, be properly compacted and exhibit no sagging.

3. Target workability values shall be determined.

4. The panels shall be stored without disturbance at a temperature between 10°C and 25°C covered by polythene sheet until the time

of coring. Cores for strength tests shall be obtained from the panels at 28 days.

5. Cylindrical test specimens shall be cored from each test panel and tested as listed below. Drilling and dimensions of test specimens shall be in accordance with BS 1881:Part 120. Drilling of cores shall be located to avoid areas of possible rebound. For each test at least one spare specimen shall be provided.

(a) Compressive strength in spray direction after 28 days on 4 cores each. The test cores, to be taken from different panels, shall be 100 mm diameter and 100 mm long.

(b) Compressive strength perpendicular to spray direction after 28 days on 4 cores each. The test cores, to be taken from different panels, shall be 100 mm diameter and 100 mm long.

(c) The water permeability in the spray direction on 3 cores taken after 28 days in accordance with Section 9.930. The test cores, to be taken from different panels, shall be 100 mm diameter and 200 mm long.

(d) The sulphate resistance in the spray direction after 28, 42 and 56 days on 4 cores. The test cores, to be taken from different panels, shall be 100 mm in diameter and at least 100 mm long.

6. Each cored cylinder shall be marked with a reference mark and the date and time of shotcreting.

7. Testing shall be in accordance with the following Methods:

TEST	TEST METHOD
Compressive Strength	BS 1881: Part 120
Water Penetration depth	Permeability Test (see Section 9.992)
Sulphate Resistance	Sulphate Resistance Test (see Section 9.993)

8. Additional test panels shall be prepared as necessary to calibrate indirect test methods approved by the Engineering Manager or his delegated personnel. For the purpose of calibration a minimum of four tests shall be carried out at each age for each indirect test method and shotcrete mix.

9. Optimum fibre content shall be determined dependent on ease of use in the batching, mixing and shotcreting processes proposed and from the results of Section 9.997-Toughness Test.

10. The strength of shotcrete cores from test panels shall be acceptable if both the compressive strength results for samples with their axes parallel to the direction of spraying and the compressive strength results for samples with their axes perpendicular to the direction of spraying, comply with the following requirements.

(a) The average strength determined from the 4 cores from a particular trial shall exceed the specified characteristic strength of 25 N/mm^2 by at least:

3.0 N/mm^2 for 28 day strength

(b) Any individual core strength result shall not be lower by more than 5 N/mm^2 for the specified strength of 40 N/mm^2 and not be

lower by more than 3 N/mm^2 for the specified strength of 25 N/mm^2

11. In addition, from each trial mix an experienced nozzleman shall prepare samples for Toughness Test - 9.997.

Threshold values for works tests shall be determined during site trials.

12. The test results shall be passed to the Engineering Manager or his delegated personnel responsible for design of shotcrete structures.

13. The site trials shall be repeated if the source or quality of any of the materials or the mix proportions are changed.

9.944 Proficiency of Operatives

1. Nozzlemen shall have had previous experience in the application of shotcrete, or shall work under the immediate supervision of the foreman or instructor with such experience. Production shotcrete shall be applied only by nozzlemen who have successfully demonstrated their competence and their ability to produce Shotcrete Class P2 complying in all respects with this Specification. Nozzlemen shall hold certificates of competence issued by the Senior Engineer NATM or written evidence of previous satisfactory work. The Senior Engineer NATM shall be responsible for ensuring compliance with this section.

9.950 Works Tests

9.951 General

1. Tests shall be carried out on shotcrete placed in the Works.

2. Specimens shall be tested in accordance with the following test methods as listed in Section 9.952 to 9.956.

TEST	TEST METHOD
Compressive Strength	BS 1881: Part 120
Modulus of Elasticity	BS 1881: Part 121
Workability	BS 1881: Parts 101 & 102
Water Penetration depth	Permeability Test (see Section 9.892)
Sulphate Resistance	Sulphate Resistance Test (see Section 9.893)
Thickness Test	Thickness Tests (see Section 9.856)
Fibre Strength	Fibre Strength Test (see Section 9.996)

Dimensions of test specimens shall be in accordance with Section 9.943 - Shotcreting Trials.

3. Test areas shall be as selected by the Senior Engineer NATM with regard to checking areas of difficult operations, i.e. water ingress.

4. Where the nominal required shotcrete thickness is less than 100 mm the cores for compressive strength testing shall be taken from areas where the actual thickness is greater than 100 mm. Alternatively additional shotcrete thickness shall be applied

in selected areas for subsequent test coring as directed by the Senior Engineer NATM.

9.952 Strength Tests

1. 28-Day compressive strength tests shall be carried out on cores taken from shotcrete in the Works. The time of coring shall be 25±2 days. The frequency shall be such as to obtain 3 cores each for every 100 m^3 of shotcrete used in the Works. For sections of work using less than 100 m^3 of Shotcrete, at least one set of 3 cores shall be taken. Depending on the compliance of test results with this Specification, circumstances of application and importance of construction, the frequency of works tests may be reduced (to every 200 m^3) or increased (to every 50 m^3) subject to previous approval of the Engineering Manager or his delegated personnel. The cores shall be drilled through the whole thickness of the shotcrete and visually inspected to verify that the shotcrete is dense and homogeneous without segregation of aggregate or other visible imperfections. The distribution of the cores for each test shall be as approved by the Senior Engineer NATM.

2. Density of shotcrete samples saturated with water, shall be measured by using the cores for strength tests at the same frequency of testing.

3. The strength of shotcrete measured by cores taken from the works shall be acceptable if the compressive strength results comply with the following requirements:

(a) The average strength for any group of four consecutive test results shall exceed the specified characteristic strength by at least:

$3.0\ N/mm^2$ for 28 day strength

(b) Any test result shall not be lower than the specified characteristic strength by more than:

$3.0\ N/mm^2$ for 28 day strength

where one test result shall consist of the mean of 3 core strengths.

4. If the shotcrete fails to meet the compliance requirements specified herein, the validity of the test results shall be checked prior to implementing one of the following courses of action:

(a) confirm the requirements for remedial action by assessing the results of geotechnical measurements and/or back analysis.

(b) make good deficiencies by the application of additional thickness of shotcrete.

(c) remove the defective shotcrete and replace by new shotcrete.

The course of action to be adopted shall be approved by the Senior Engineer NATM.

9.953 Durability Tests

1. Permeability shall be tested on a monthly basis on 3 cores taken from 28 days old shotcrete in accordance with Section 9.992 - Permeability Test. Sulphate resistance shall be tested on a 3 monthly basis (in accordance with Section 9.931) by the Sulphate Resistance Test, Section 9.993.

2. If the shotcrete fails to meet the criteria specified herein, then the validity of the test results shall be checked in

consultation with the Senior Engineer NATM who will if necessary determine further action.

9.954 Stability Tests

1. Tests shall be carried out to assess the load bearing capability of shotcrete in the Works under site conditions. These tests may be carried out on cores taken from panels.

2. One set of tests shall be conducted for each mix type.

3. These panels shall be produced in the works under site conditions. The panels shall be stored underground in the works (with the same climatic conditions as the shotcrete placed in situ). Core samples shall be taken from the panels just before testing, or at least on the same day of testing.

4. Cylindrical test specimens shall be cored and tested as listed below. Dimensions of test specimens and testing shall be in accordance with Section 9.943 - Shotcreting Trials.

(a) Compressive strength in the spray direction after 7 and 28 days on 3 cores each.

(b) Modulus of elasticity in the spray direction after 7, 28 days on 3 cores each. The core diameter shall be 100 mm and the core height shall be 200 mm. The strain shall be measured on the central part of the sample, the upper test limit being 1/3 and the lower test limit being 1/30 of the compressive strength. The modulus of elasticity at different ages shall be determined on the same sample, the compressive strength being measured after 28 days.

9.955 Workability Tests

1. The workability of Shotcrete Class P2 shall be measured by slump tests after the addition of plasticiser. Samples shall be tested for every 50 m^3 produced.

2. The workability of shotcrete shall be within ± 25 mm or ± one third of the target value as determined by trials, whichever is the greater.

9.956 Thickness Tests

1. The thickness of placed Shotcrete Class P2 shall be checked at 10 m intervals. Thickness indicators shall be evenly distributed over the cross-section according to "TML Tunnel Engineering Procedure for Application of NATM (011/0002/PR), Form F". These thickness indicators shall be placed at uniform distances along the tunnel or shaft as defined by the Senior Engineer NATM. Each test shall consist of 5 to 15 indicators depending on the size of the opening. Indicator type shall be selected to avoid drilling into the primary lining.

9.957 Fibre Content

1. The fibre content of the mix shall be established by site trials and shall be greater than 1% by weight of total mix. An evaluation of the fibre content shall be carried out on a 5 litre specimen of fresh Shotcrete Class P2. After the washing out, the steel fibres shall be collected, dried and weighed. The weight shall be compared to the weight of the specimen.

9.960 Production and Transport

9.961 Batching and Mixing

1. The individual components for the production of Shotcrete Class P2 shall be measured by weight with an automatic batching device, except that liquid admixtures may be measured by volume. The batching accuracy shall be within ± 3% for all constituents. Silica fume shall be weighed separately. The method of batching used shall ensure that the accuracy can be easily checked. All measuring equipment shall be maintained in a clean serviceable condition and shall be zeroed daily and calibrated monthly.

2. Mixing shall be carried out in a mixer suitable for the efficient mixing and discharge of batched materials.

3. Regular checks shall be made to ensure that complete mixing is consistently achieved.

4. The addition of the fibres shall be at a stage in the mixing suitable for the shotcreting equipment. The procedure for addition of fibres shall be determined during pre-production trials.

5. Fibres shall be added and mixed in a manner to avoid clumping and bending of the fibres. Any fibre clumps in the mix shall be diverted by means of a screen placed over the shotcrete hopper. Fibres shall be uniformly distributed throughout the mortar matrix without isolated concentrations. Fibres shall not be added to the mix at a rate faster than that at which they can be blended with the other ingredients without forming balls or clumps.

6. The mixed base concrete shall be applied within one and a half hours from the time of adding water. This time may be extended by the use of retarders or plasticisers as approved by the Engineering Manager or his delegated personnel.

9.962 Transport

1. The base concrete including any admixtures except accelerator shall be transported with any suitable means which provides complete mixing during transportation such that segregation of the mix components is prevented. The mixture shall be effectively protected against any influence of the weather.

9.970 Shotcreting Equipment

9.971 General

1. All transport pipes consisting of hoses or pipes of uniform diameter that carry shotcrete ingredients shall be laid straight or in gentle curves and protected so that the flow of ingredients through them is not restricted.

2. The Shotcrete Class P2 Shotcreting machine shall be adjusted to suit the length of the pipe that carries the shotcrete mix. Equipment shall be leak-proof. Residual deposits of materials shall be removed after each usage.

3. The air and water supply system shall be capable of supplying the delivery machine and hose at the pressures and volumes recommended by the manufacturer of the machine. No air supply system shall be used that delivers air contaminated by oil.

4. Shotcreting equipment shall be capable of feeding materials at a regular rate and ejecting Shotcrete Class P2 from the nozzle at velocities that will allow adherence of the materials to the surface being shotcreted with a minimum of rebound and maximum adhesion and density.

5. The placing equipment shall be so arranged that the nozzleman may use air and water in any combination to clean existing shotcrete in accordance with Section 9.981 or to clean completed work.

6. Equipment shall be provided to allow application of Shotcrete Class P2 to all surfaces with the nozzle at the distances from the work specified in Section 9.980 - Shotcreting.

7. A boom mounting or similar device shall be provided for the spray nozzle for use in conditions where manual spraying is unsafe or otherwise unsuitable or undesirable.

8. The diameter of the shotcrete conveying-pipe shall be at least 1.5 times the length of the steel fibres.

9. Shotcreting equipment shall be set up according to the recommendations of the manufacturer.

10. Pumping shall ensure a continuous conveyance of base concrete including any admixtures except accelerators. The equipment shall incorporate a suitable metering device for accelerators.

9.980 Shotcreting

9.981 Fibre Reinforced Shotcrete Application

1. Before the application of shotcrete, the existing shotcrete shall be cleaned with compressed air and, as far as the local conditions permit, with an air-water mixture as necessary to remove all

material which may prevent proper adhesion of the shotcrete to the surface. The surface to receive Shotcrete Class P2 shall be damp but without free water prior to application of Shotcrete Class P2. Treatment with air-water mixture shall be done shortly before application of Shotcrete Class P2.

2. Action shall be taken to control ground water and prevent it adversely affecting the Shotcrete Class P2 lining. Adopted measures shall remain effective for at least 28 days. Water inflows which might cause deterioration of the Shotcrete Class P2, or prevent adherence, shall be diverted as detailed on the Drawings by channels, chases, pipes or other appropriate means to the invert or to the ground water drainage system.

3. Shotcrete Class P2 shall only be applied by a nozzleman certified in accordance with Section 9.944. The distance between the nozzle and the surface being shotcreted shall not exceed 1.5 m. The nozzle shall, as a general rule, be held perpendicular to the application surface.

4. Shotcrete Class P2 application may, with the approval of the Senior Engineer NATM, be undertaken in two phases to minimise rebound. The first phase being a 50 mm layer with slightly adjusted application procedures at the nozzle than for subsequent layers.

5. No rebound material shall be covered with shotcrete. The Shotcrete Class P2 shall preferably be applied from the shoulder to the crown. The rebound material shall be removed from the tunnel and shall not be used in the Works.

6. Each layer of Shotcrete Class P2 shall be built up by making several passes of the nozzle over the working area. The shotcrete shall emerge from the nozzle in a steady uninterrupted flow. Should the flow become intermittent for any cause the nozzleman

shall direct it away from the work until it again becomes constant.

7. Where a layer of Shotcrete Class P2 is to be covered by succeeding layers, it shall first be allowed to set and loose material and rebound shall be removed. The surface shall be finally cleaned and wetted using a blast of air and water.

8. For vertical and near vertical surfaces application shall commence at the bottom. Layer thickness shall be governed mainly by the requirement that the material shall not sag. Where thick layers are applied the top surface shall be maintained at a slope of approximately 45 degrees.

9. Pockets, sags or other defects shall be cut out and resprayed. The area of respraying shall not be less than 300 mm x 300 mm.

10. Finishing actions, such as trowelling or premature screeding, shall be avoided.

9.982 Fibre Reinforced Shotcrete Thickness

1. The constructed profile of the intrados shall satisfy the requirements of Chapter 2[1]. Maximum single layer application shall be 150 mm. If total Shotcrete Class P2 thickness exceeds 150 mm, shotcrete shall be placed in more than one layer. Subsequent layers shall not exceed 150 mm in thickness and shall not be placed earlier than 24 hours nor later than 60 hours after finishing the previous layer. This period may be increased to 72 hours provided this increase does not result in additional shrinkage cracking. If this period of 72 hours is exceeded, the Engineering Manager shall direct what additional measures are required.

[1] NOTE: Chapter 2 will have to be revised to include special requirements for class P2 lining

The time between successive layers shall be selected within these limits to suit the ambient conditions.

2. Embedded steel, other than fibres,shall be surrounded with at least 30 mm of shotcrete.

9.983 Application of Fibre Reinforced Shotcrete in Cold Weather

1. When Shotcrete Class P2 is placed at air temperatures of less than 5°C measures shall be taken to maintain Shotcrete Class P2 temperature above 3°C for at least 1 day after application.

2. No frozen materials, ice or snow shall be allowed to enter the mixer.

3. Cement shall not be heated. If water is introduced at the nozzle, it shall not be heated above 20°C.

9.984 Curing

1. A proper curing method shall be applied in order to limit plastic shrinkage cracks, early thermal contraction cracks and long term drying shrinkage cracks.

2. The final layer of placed Shotcrete Class P2 shall be cured by keeping exposed surfaces wet continuously for 7 days, or by an alternative method which has been approved by the Engineering Manager or his delegated personnel.

9.990 Test Methods

9.991 Test Procedure for Bleeding of Cement

This procedure shall be in accordance with Clause 9.891.

9.992 Permeability Test

The test for permeability shall be in accordance with Section 9.892.

9.993 Sulphate Resistance Test

The sulphate resistance test shall be in accordance with Section 9.893

9.994 Profile Grinding

Profile grinding shall be used in accordance with Section 9.894

9.995 Not used

9.996 Test for Tensile Strength of Fibres

1. At least one tensile test, consisting of 10 randomly selected finished fibres, shall be performed for each 4.5 tonnes of material or each batch of less than 4.5 tonnes. The average value of tensile strength in these tests shall not be less than 345 N/mm^2. The tensile strength of any one of the ten specimens shall not be less than 310 N/mm^2.

2. The cross-sectional area used to compute the tensile strength shall be carried out to four decimal places, in units of square millimetres, and shall be:

(a) for drawn wire fibres, the area calculated from the actual diameter of the parent source material or finished fibres;

(b) for cut sheet fibres, the area calculated from the actual thickness and width of the parent source specimen, or if fibres are tested, the area of each individual fibre calculated from the measured length and weight of the fibre, weighed to the nearest 0.0001 g, based on a density of 7850 kg/m^3;

(c) for melt-extraction fibres, the area calculated from the equivalent diameter of the fibres, computed from measured average

length and the weight of a known quantity of fibres, based on 7850 kg/m^3.

3. The breaking load for individual fibres shall be measured to at least three significant figures in accordance with ASTM A820:85, Standard Specification for Steel Fibres for Fibre Reinforced Concrete.

9.997 Toughness Test for Class P2 Shotcrete

The testing for toughness shall be in accordance with ASTM C 1018 - 85 Standard Test Method for Flexural Toughness and First - Crack Strength of Fibre-Reinforced Concrete (using beam with Third-Point loading)

9.1000 REFERENCES

9.1001 Reference Standards

1. The following standards are referred to in this Chapter:

BS 12:1978	Ordinary and rapid-hardening Portland cement
BS 18:1987	Tensile testing of metals
BS 227:1970	H-Section Steel Arches for use in Mines
BS 812:Part 1:1975	Methods for Sampling and testing of mineral aggregates,sands and fillers
BS 882:1983	Specification for Aggregates from Natural sources for concrete
BS 1370:1979	Low heat Portland cement
BS 1881:Part 101:1983	Method for sampling fresh concrete on site
BS 1881: Part 102:1983	Method for determination of slump
BS 1881:Part 108:1983	Method for making test tubes from fresh concrete
BS 1881:Part 111:1983	Testing concrete - Method for normal curing of test specimens (20°C method)
BS 1881:Part 120:1983	Testing concrete - Method for determination of compressive strength of concrete cores
BS 1881:Part 124:1988	Testing concrete - methods for analysis of hardened concrete
BS 3892:Part 1:1982	Specification for pulverized-fuel ash for use as a cementitious component in structural concrete
BS 4027:1980	Sulphate resisting Portland cement
BS 4190:1967	Specification for Isometric black hexagon bolts screws and nuts
BS 4360:1986	Specification for weldable structural steels
BS 4449:1978 (1984)	Specification for hot rolled steel bars for the reinforcement of concrete
BS 4461:1978 (1984)	Specification for cold worked steel bars for the reinforcement of concrete
BS 4550:Part 3:1978	Test for heat of hydration
BS 4550:Part 6:1978	Standard sand for mortar cubes

BS 5075:Part 1:1982 Specification for accelerating admixtures, retarding admixtures and water reducing admixtures

BS 5135:1984 Specification for arc welding of carbon and carbon manganese steels

BS 5328:1981 Methods for specifying concrete, including ready-mixed concrete

BS 6588:1985 Specification for Portland pulverised-fuel ash cement

BBA Certificate 85/1568

DIN 267 Fasteners and similar parts technical specifications generalities

DIN 488 Reinforcing steel, definitions, quality requirements, identification marks

DIN 1164 Portland - blastfurnace - pozzolanic cement, definitions components, requirements, delivery

DIN 4100 Welded steel structures with predominantly static loads; proof of competence to weld structural steel work

DIN 18200 Control (quality control) of construction materials, construction components, and construction designs; general principles

9.1002 Other References

1. The following published reference has been referred to in the production of Chapter 9:

-TML Tunnel Engineering Procedure for Application of NATM (011/0002/PR), Form F

-Rock Characterisation Testing and Monitoring:
International Society for Rock Mechanics - Suggested Methods, Editor: E.T. Brown (Pergamon Press 1981)