British Standard

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BS EN 642:1995

Prestressed concrete pressure pipes, cylinder and non-cylinder, including joints, fittings and specific requirement for prestressing steel for pipes

Committees responsible for this British Standard

The preparation of this British Standard was entrusted to Technical Committee B/504, Water supply, upon which the following bodies were represented:

Association of Consulting Engineers
Association of Manufacturers of Domestic Unvented Supply Systems Equipment (MODUSSE)
British Bathroom Council
British Foundry Association
British Non-Ferrous Metals Federation
British Plastics Federation
British Plumbing Fittings Manufacturers' Association
Department of the Environment
Department of the Environment (Drinking Water Inspectorate)
Fibre Cement Manufacturers' Association Limited
Institute of Plumbing
Institution of Water and Environmental Management
Local Authority Organizations
Scottish Association of Directors of Water and Sewerage Services
Water Companies Association
Water Research Centre
Water Services Association of England and Wales

The following bodies were also represented in the drafting of the standards, through subcommittees and panels:

Association of Metropolitan Authorities
British Precast Concrete Federation Ltd.
Concrete Pipe Association
Concrete Society
Department of Transport
Federation of Civil Engineering Contractors
Institution of Civil Engineers
Institution of Highways and Transportation

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Contents

National foreword

This British Standard has been prepared by Technical Committee B/504 and is the English language version of EN 642:1994 *Prestressed concrete pressure pipes, cylinder and non-cylinder, including joints, fittings and specific requirement for prestressing steel for pipes*, published by the European Committee for Standardization (CEN).

EN 642 was published as a result of international discussion in which the UK took an active part.

This standard should be read in conjunction with BS 4625.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 22 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 642

October 1994

ICS 23.040.30; 23.040.50

Descriptors: Water pipelines, pressure pipes, potable water, water pipes, concrete tubes, prestressed concrete, metal plates, specifications, computation, equipment specifications, dimensions, tests

English version

Prestressed concrete pressure pipes, cylinder and non-cylinder, including joints, fittings and specific requirement for prestressing steel for pipes

Tuyaux pression en béton précontraint, avec ou sans âme en tôle, y compris joints et pièces spéciales et prescriptions particulières relatives au fil de précontrainte pour tuyaux

Spannbetondruckrohre, mit und ohne Blechmantel, einschließlich Rohreverbindungen, Formstücke und besonderen Anforderungen an Spannstahl für Rohre

This European Standard was approved by CEN on 1994-10-26. CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Ref. No. EN 642:1994 E

Foreword

This European Standard for concrete pipes is a standard which was prepared by WG5, Concrete pipes, of the Technical Committee CEN/TC 164, Water supply, Secretariat of which is held by AFNOR.

During preparation of this standard the provisional results already available of CEN/TC 164/WG 1, General requirements for external systems and components, and of CEN/TC 164/165/JWG 1, Structural design, were considered.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 1995, and conflicting national standards shall be withdrawn at the latest by April 1995.

In accordance with the CEN/CENELEC Internal Regulations, the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

Contents

0 Introduction

The product[1)] in permanent or temporary contact with water, intended for human consumption, shall not adversely affect the quality of the drinking water and shall not contravene the CE Directives and EFTA Regulations on the quality of drinking water.

This standard is to be used together with the common requirements standard (EN 639).

When the relevant EN dealing with general requirements, such as General requirements for external systems and components (CEN/TC 164/WG 1), Materials in contact with water (CEN/TC 164/WG 3), and Structural design (CEN/TC 164/165/JWG 1) are adopted, the current standards shall be revised, where appropriate, in order to ensure that these requirements comply with these relevant ENs.

To the present standard are attached:

— Annex A (normative): Specific technical requirements for high tensile steel wire used for prestressing concrete pipe with or without steel cylinder;

— Annex B (informative): Typical joints;

— Annex C (informative): Design guidance for prestressed concrete cylinder pipes;

— Annex D (informative): Design guidance for prestressed concrete non-cylinder pipes.

1 Scope

This standard covers the requirements and the manufacture of prestressed concrete cylinder and non-cylinder pressure pipes and fittings in sizes from DN/ID 500 to DN/ID 4000 inclusive. Larger sizes could be manufactured based on the concepts of this standard. These types of pipes are designed for the internal pressure, external loads and bedding conditions designated by the purchaser.

2 Materials

Materials are specified in clause **5** of EN 639 (common requirements). Additional requirement is specified as follows:

The maximum size of aggregate shall not exceed the least of the following:

— the concrete cover;

— or 0,33 times the thickness of the non-cylinder core pipe wall;

— or 0,33 times the concrete wall thickness on either side of the steel cylinder.

3 Design and fabrication of pipe

3.1 General requirements

3.1.1 *General*

Prestressed concrete cylinder pipe shall have the following principal features:

— a welded steel cylinder with steel joint rings welded to its ends;

— for lined-cylinder pipe, a core consisting of a lining of concrete within the steel cylinder, or for embedded-cylinder pipe, a core consisting of the steel cylinder encased in concrete;

— circumferential prestressing with high-tensile wire wound around the outside of the core in one or more layers at a predetermined stress and fastened securely at its ends;

— a coating of dense mortar or concrete, covering and protecting the core and wire, except for the necessarily exposed surfaces of the joint rings;

— a self-centring joint so designed that the joint shall be watertight under all conditions of service.

Prestressed concrete non-cylinder pipe shall have the following principal features:

— a concrete core pipe either steel reinforced or longitudinally prestressed with pretensioned high tensile steel wire embedded in the concrete;

— circumferential prestressing with high-tensile wire wound around the outside of the core in one or more layers at a predetermined stress and fastened securely at its ends;

— a coating of dense mortar or concrete, covering and protecting the wire;

[1)] Should be considered as any product used for the conveyance and distribution of water intended for human consumption.

— a self-centring joint so designed that the joint shall be watertight under all conditions of service.

Or for monolithic type:

— a concrete pipe longitudinally prestressed with pretensioned high tensile steel wire embedded in the pipe wall which is cast in one operation;

— circumferential prestressing by means of a reinforcement cage of high tensile steel wire also embedded in the pipe wall and prestressed to a predetermined stress by means of hydraulic expansion while the concrete is still fresh;

— a self-centring joint so designed that the joint shall be watertight under all conditions of service.

3.1.2 *Wall thickness*

Table 1 shows the minimum design wall thickness for each type of pipe.

Table 1 — Minimum design wall thickness

Pipe DN/ID	Cylinder pipe	Non-cylinder pipe	
	t_1 min	t_2 min	t_3 min monolithic
mm	mm	mm	mm
500	50	40	45
600	50	40	45
700	50	40	50
800	50	45	55
900	55	45	60
1 000	65	50	65
1 100	70	50	70
1 200	75	60	75
1 250	75	60	80
1 400	85	70	85
1 500	90	70	90
1 600	100	75	95
1 800	115	75	105
2 000	125	80	115
2 200	135	90	125
2 400	145	100	135
2 500	150	100	140
2 600	160	110	145
2 800	170	120	155
3 000	180	130	165
3 200	190	140	—
3 500	210	160	—
4 000	240	180	—

NOTES
t_1 min minimum design thickness of the core wall including the thickness of the cylinder.
t_2 min minimum design thickness of the core wall.
t_3 min minimum design thickness of the pipe wall.

3.2 Design of pipes

3.2.1 *General*

The reinforcement of the cylinder pipe shall consist of a welded steel cylinder in the core and high-tensile wire helically wound around the core under measured and controlled tension after the concrete in the core has been placed and cured. The minimum design thickness of the cylinder shall be 1,5 mm for all diameters.

For both cylinder and non-cylinder pipe the size of the high-tensile wire and the spacing and tension under which it is wound shall be such that the requirements specified for the design conditions stated in clause **3.2.2** are met. The design shall fully recognize all losses due to elastic and inelastic deformations. The initial tension in the high-tensile wire shall not exceed 75 % of the characteristic strength of the wire.

The wire shall not be less than 4 mm in diameter. The minimum clear spacing between wires shall be the wire diameter up to a maximum of 6 mm in the same layer of reinforcement.

The maximum centreline spacing of the wire shall be 50 mm. For lined-cylinder pipe with wire 6 mm and larger, the maximum centreline spacing of the wire shall be 25 mm.

3.2.2 *Design requirements*

The pipes shall be designed to resist the flexural and hoop stresses resulting from each of the following conditions:

— design pressure + dead load:

there shall be no tension in the core;

— maximum design pressure + 100 kPa + dead load:

tension in the core shall not exceed 0,38 $\sqrt[3]{f_{ck}^2}$ for cylinder pipe or 0,13 $\sqrt[3]{f_{ck}^2}$ for non-cylinder pipe;

— design pressure + dead load + live load:

tension in the core shall not exceed 0,38 $\sqrt[3]{f_{ck}^2}$ for cylinder pipe or 0,13 $\sqrt[3]{f_{ck}^2}$ for non-cylinder pipe;

— maximum design pressure:

there shall be no tension in the core;

where f_{ck} is the 28-day compressive strength of the concrete in MPa.

The total tensile stress in the core shall be considered as the sum of the hoop and flexural stresses without the application of any reduction factors.

When submitted to hydrostatic test (see **4.2**) the mortar or concrete coated pipe shall not have cracks in the coating wider than 0,1 mm for 300 mm length as measured in accordance with **6.3.10** of EN 639 (common requirements).

3.3 Reinforcement

Non-tensioned reinforcement is permitted.

3.4 Concrete and mortar

3.4.1 *Mix design*

3.4.1.1 *Core*

The concrete shall contain a minimum cement content of 350 kg per cubic metre. The water cement ratio of the concrete shall be suitable for the method of placement and shall not exceed 0,45 after compaction. For steel cylinder cores of less than 1000 DN/ID a maximum water cement ratio of 0,5 is allowed provided that the minimum cement content is 385 kg per cubic metre of concrete.

3.4.1.2 *Coating*

After the core has been wrapped with prestressing wire, an external coating either of concrete or mortar shall be applied to provide the minimum cover as specified in **3.5.2**. For multiple layers see **3.5.3**. There shall be no rust scale or pitting on the prestressing wire at the time of coating.

3.4.1.3 *Mortar coating*

Mortar for coating shall consist of one part cement by weight to not more than three parts fine aggregate. The water/cement ratio shall not exceed 0,35. The mortar shall be compacted by impact using high velocity projection on to the core or on to a first mortar coating.

Concurrently with the mortar coating a cement slurry shall be projected on to the core at a rate of not less than 1 l per 2 square metres just ahead of the mortar coating. The slurry shall consist of 1,2 kg of cement to 1 l of water.

3.4.1.4 *Concrete coating*

The concrete shall contain a minimum cement content of 400 kg per cubic metre. The proportions of cement, fine aggregate, coarse aggregate and water shall be determined and controlled as the work proceeds to obtain homogenous and workable concrete. The water/cement ratio shall not exceed 0,45. The concrete shall be deposited under high frequency vibration or by other approved method so that a dense, durable encasement is obtained.

3.4.2 ***Concrete strength***

At the time of applying the circumferential prestressing the concrete shall have a minimum compressive strength of 27 MPa.

At 28 days the concrete shall have a minimum compressive strength of 35 MPa.

3.5 Prestressing

3.5.1 ***Longitudinal prestressing***

For non-cylinder pipes the core or pipe shall be longitudinally prestressed throughout its length, including the socket, by means of high tensile wires which shall be indented or provided with permanent anchorages, embedded in the concrete within the joint portion of each end. The longitudinal prestress shall be sufficient to prevent excessive tensile stresses developing in the core due to the effects of the circumferential prestressing and bending due to beam loading during transporting, lifting and handling. The longitudinal wires shall be stressed to design tension, taking into account all losses due to elastic and inelastic deformations

Alternatively, the core shall be suitably reinforced with non-tensioned steel in order to take into consideration excessive tensile stresses developing in the core due to the effects of the circumferential prestressing and bending due to beam loading during transporting, lifting and handling.

The minimum cover to steel embedded in the core shall be 15 mm except to end faces.

3.5.2 ***Circumferential prestressing***

In addition to the requirements of **3.4.2** the compressive stress induced in the concrete core during prestressing shall not exceed 55 % of the compressive strength of the concrete in the pipe at that time. The method and equipment for applying the wire shall be such that the wire is wound around the core in a helical form at the predetermined design spacing and tension and capable of indicating, controlling and recording the tension.

The mean tension shall be at least the design tension. Normal fluctuations in tension shall not deviate from the mean by more than 10 % nor shall more than 5 % of the windings have instantaneous fluctuations exceeding the 10 % deviation.

Splicing shall be permitted and where splicing is carried out the splice shall develop the full strength of the wire.

For lined cylinder pipes circumferential prestressing wire shall be coated with a cement slurry. Immediately prior to placement of the cement slurry, all loose mill scale, excessive rust, oil, grease, and other foreign substances shall be removed from all surfaces to receive the slurry.

For monolithic pipes the circumferential cage shall be manufactured in helical form to the design spacing and placed in the pipe mould. The clear distance between successive turns of the wire shall be not less than 14 mm. The monolithic pipe wall in which the reinforcement is embedded shall be cast in one operation and prestressing shall be achieved through hydraulic expansion whilst the concrete is still fresh. The hydraulic prestressing pressure shall be controlled in order to achieve the correct tension in the wire. The hydraulic pressure shall not be released until the concrete has attained a minimum compressive strength of 32 MPa. The compressive stress induced in the concrete shall not exceed 55 % of the compressive strength of the concrete at that time.

The minimum thickness of the mortar or concrete cover over the circumferential prestressing wire shall either be 20 mm or alternatively 15 mm in which case a permeability test on the coating is required on one in every hundred pipes (see **4.3**).

Circumferential cracks in the core, due to discontinuity of prestress at the spigot end are allowed provided they do not affect watertightness.

3.5.3 ***Multiple layers***

If multiple layers of circumferential prestressing wire are used, each layer except the final layer shall be coated in accordance with **3.4.1** to provide a minimum cover over the reinforcement at least equal to the diameter of the wire and cured in accordance with **3.6** for a period of not less than eight hours. The first layer of reinforcement shall be wound on the surface of the core, and subsequent layers shall be wound over the previous layers of coating as specified in this section.

The final coating shall provide the minimum cover to the steel (see **3.5.2**).

3.6 Curing

Accelerated curing shall be permitted and shall be in accordance with procedures fixed by the manufacturer on the ground of experience in relation to the temperature and the time of the curing and the chamber humidity.

4 Factory testing

4.1 Concrete test

A minimum quantity of two cylinders or cubes per day of manufacture and per mix type of core concrete shall be tested for the compressive strength.

4.2 Hydrostatic test

4.2.1 ***General***

The hydrostatic test shall be applied to the whole prestressed core or pipe, including the portions of socket and spigot which are to be subjected to pressure in the as-laid condition. Care shall be taken to remove all air from the pipe before the pressure is applied. Internal pressure shall be applied at a rate not exceeding 200 kPa in five seconds.

4.2.2 ***Cylinder pipe***

One in 250 pipes shall be subjected to the hydrostatic test after coating. Full pressure shall be maintained for at least three minutes during which time there shall be no leakage or cracking (see **3.3.2**).

Should a pipe fail the test then a further two pipes from the batch of 250 shall be tested. If both pipes pass then the batch shall be accepted. If one or both pipes fail then the batch shall be rejected or each pipe in the batch shall be tested for individual approval.

For hydrostatic testing of steel cylinders before circumferential prestressing see **6.3.7** of EN 639 (common requirements).

4.2.3 ***Non-cylinder pipe***

All non-cylinder pipes shall be subjected to the hydrostatic test before or after coating. Full pressure shall be maintained for at least three minutes during which time there shall be no leakage or cracking (if tested after coating see **3.2.2**). Moisture which may appear on the surface of the pipe without dripping shall not be considered as a leakage. Pipes that fail may be retested at the option of the manufacturer.

If each pipe has been subjected to the hydrostatic test before coating then one in 250 pipes shall be subjected to the test after coating. Should a pipe fail this test then a further two pipes from the batch of 250 shall be tested after coating. If both these pipes pass then the batch shall be accepted. If one or both pipes fail then the batch shall be rejected or each pipe in the batch shall be hydrostatically tested after coating for individual approval.

4.2.4 ***Test pressure***

The hydrostatic test pressure to be applied shall stress the pipe wall to zero tension taking into consideration the losses in prestress at time of testing.

4.3 Permeability test on coating

4.3.1 ***Test purpose***

The test is to determine the permeability of the concrete or mortar cover coat on the finished product by non-destructive means. It is based on using standard style of equipment designed to measure the quantity of water absorbed under a constant pressure.

4.3.2 ***Test frequency on products***

The test shall be applied to one pipe in a batch of every 100 pipes.

Should the pipe fail the test then a further two pipes from the batch of 100 pipes shall be tested. If both pipes pass then the batch shall be accepted. If one or both pipes fail then the batch shall be rejected or each pipe in the batch shall be tested for individual approval.

4.3.3 ***Testing equipment***

A sketch of the required equipment is shown in Figure 1. The accuracy of the equipment shall be verified by certification.

The equipment shall consist of:

— a chamber with resilient seating to be clamped to the external surface of the pipe. This chamber shall have an orifice to create a known contact area immediately on the pipe surface;

— a calibrated sight glass attached to the chamber and with a suitable pressure gauge at its upper end;

— a source of compressed air to give a regulated constant pressure of 300 kPa (± 20 kPa) at the upper end of the sight glass;

— a suitable quantity of water based dye at a colour density sufficient to ensure observation within the sight glass and on the free surface of the pipe;

— six hour at least stop watch calibrated in minutes.

4.3.4 ***Test method***

The cover coat shall be fully saturated with water prior to testing.

The test shall be continuous for six hours.

The equipment shall be clamped to the pipe and the sight glass filled with dye. The compressed air source shall then be fitted and the whole assembly checked for leaks under the required pressure of 300 kPa (± 20 kPa).

The quantity of dye in the sight glass shall then be recorded at 30 min intervals for a period of at least six hours under the sustained pressure of 300 kPa (± 20 kPa) and under conditions of full hydraulic continuity of the dye to the pipe surface.

4.3.5 ***Test results***

The test results shall be expressed as the quantity of dye expelled from the sight glass within the time interval relative to the area of the orifice of the chamber being the dye contact area to the pipe surface.

Quantities in the sight glass shall be expressed in cubic centimetres and the area of the orifice in square centimetres. A measurement of the quantity of dye expelled from the sight glass (cm^3) per unit area of the chamber orifice at pipe surface (cm^2) is made every 30 min.

The slope of the relevant diagram (see Figure 2) is the following ratio:

$$\frac{\text{Qty of dye expelled from the sight glass (cm}^3\text{) per hour}}{\text{Area of the chamber orifice at pipe surface (cm}^2\text{)}}$$

4.3.6 ***Test acceptance criteria***

A successful test shall satisfy the following:

The ratio given in **4.3.5** above shall not exceed 0,15 per hour for the period between 121 min and 180 min into the test.

If this requirement has not been attained in this period, then the ratio shall be determined for the periods from 121 min to either 240, 300, 360, 420 or 480 until the requirement is met. If the requirement has not been met at 480 min the pipe has failed the test.

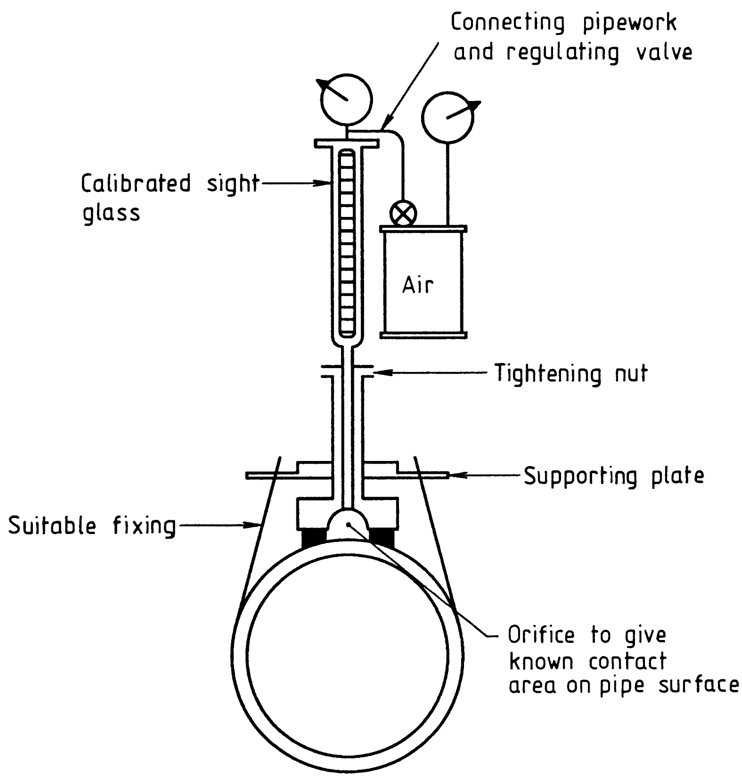

Figure 1 — Typical permeability test equipment

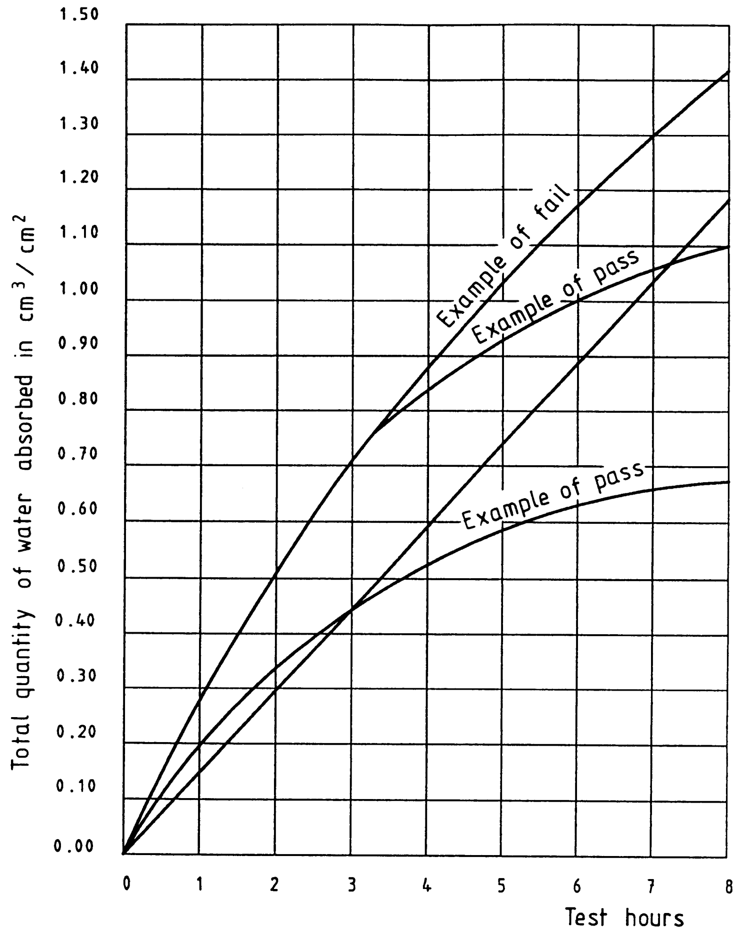

Figure 2 — Permeability test results and examples

Annex A (normative)
Specific requirements for high tensile steel wire used for prestressing concrete pipe with or without steel cylinder

Prestressing steel shall comply with the national standards, transposing EN as available. In addition, steel shall comply with the specific requirements hereunder listed by December 31st, 1995.

A.1 Mechanical properties

A.1.1 *Elongation*

For the acceptance test of one lot per consignment and per cast, three samples shall be taken from three different spools and coils and tested.

At least one of the following requirements shall be met:

— Elongation at maximum load (basic test length of 200 mm).

The elongation on a test length of 200 mm is the sum of the plastic elongation at maximum load (after rising to maximum load and returning to zero load) and the elastic elongation, which is a statistical value based on supplier's certified tests.

The minimum elongation at maximum load shall be 3 % of the original length.

— Permanent elongation excluding necking for a basic test length of 100 mm.

The minimum permanent elongation measured after breaking, excluding necking, shall be 2 % of the original length.

A.1.2 *Reverse torsion tests*

For the acceptance test of one lot per consignment and per cast three samples shall be taken from three different spools and coils and tested.

The test shall be made according to the cycle 1 – 2 – 1 on a wire held between two jaws at a distance from each other equal to 50 times the nominal diameter. The number of cycles made at the time the first crack appears shall be equal to 3 or above.

A.1.3 *Resistance to hydrogen embrittlement*

For the acceptance test of one lot per consignment and per cast, six cylinders are wound from at least three different spools or coils (see **A.3.2**):

— if the six cylinders have breaking times over 90 minutes, the lot is accepted;

— if one or more cylinders have breaking times below 90 minutes, a retest is made on six other cylinders:

— if the mean of the breaking times of the three worst cylinders in each of the two series is over 90 min, the lot is accepted. Nevertheless, if in each of the two series there is one or more cylinders, the breaking times of which are under one hour, the lot is refused;

— if the mean of the breaking times of the three worst cylinders in each of the two series is under 90 min, the lot is refused.

The test is stopped after three hours. If, in one series of tests, only one or two cylinders break, the three hours are taken into account for calculating the mean, for all the other cylinders.

A.2 Operating methods

A.2.1 *Elongations*

Plastic elongation at maximum load

The plastic elongation is determined by marking a basic test length of 200 mm on the wire and by plotting the results on a load extension graph up to the maximum load. The load is then reduced to zero, and the elongation of the 200 mm basic test length is measured.

This elongation shall be measured before any necking.

Permanent elongation excluding necking

Marks shall be drawn every 50 mm on a wire length of at least 500 mm before loading. After breaking the test piece, the new length shall be measured between marks of an original length of 100 mm, chosen as being the farthest from the necking zone.

A.2.2 ***Reverse torsions***

The test shall be carried out on a wire length of at least 70 times the diameter (Dw) of the wire.

The wire shall be secured between two jaws, 50 Dw apart and twisted one complete turn to the right, then two turns to the left and another turn to the right back to the initial position. These four turns make up a full cycle of torsion said "1 – 2 – 1". The maximum speed of rotation shall be one turn per 10 seconds.

The test shall be stopped when the first visual crack occurs.

A.2.3 ***Resistance to hydrogen embrittlement***

A.2.3.1 *Test principle*

The method consists of winding the wire at a constant tension close to the value under working conditions, on to small diameter cylinders, which are then immersed in an aggressive solution whilst under cathodic polarization. This causes hydrogen to be generated and available for absorption by the steel wire.

A.2.3.2 *Preparation of specimens and test procedure*

Preparation of the test pieces

The cylinders consist of a cold drawn mild steel tube placed into a suitable, hard isolating plastic sleeve of outer diameter = 172 mm ± 1 mm and thickness = 11 mm.

This system is equipped with:

— a catch plate for applying a rotative movement during wire wrapping;

— a device to anchor wire at the beginning of wrapping;

— an anchorage to secure the wire after wrapping.

Figure A.1 gives the dimensions of the cylinder and of its accessories.

The extremity of the wire to be tested is equipped with an anchor to hook it on to the cylinder. One spiral wound up without tension protects this anchor. The wire is then brought under the testing tension defined below, and its winding under tension proceeds at the constant pitch of 7 helixes per cylinder. The linear speed of winding is fixed at 40 mm ± 5 mm per second. When the winding is completed the wire is clamped with the bolts of the jaw to avoid any loss of tension, then, after relaxing this tension of the loose part of the wire, the latter is cut off. Marks are made on both wire and cylinders so as to make sure that no slipping will occur later on. The steel wire shall have an overall twist of at least 0,75 turns and not greater than 1,5 turns.

The electrical connection to the steel wire is fixed at one end of the wire at its anchorage.

Figure A.2 shows such a wire wrapped cylinder and Figure A.3 shows the principle of the system used to wind wire around the cylinders. After wire winding, the bolts stopping the wire are protected with a mastic compound, in order to isolate the steel part from the aggressive solution.

Within 24 hours of winding, the cylinder shall be partially immersed in a corrosive solution kept at a temperature of (18 ± 2) °C (see Figure A.4).

Winding tension

The winding tension shall be 75 % of the ultimate tensile strength guaranteed by the supplier. When the guaranteed ultimate tensile strength is not known, the winding tension shall be 70 % of the actual ultimate tensile strength of the wire.

The winding tension tolerance shall be ± 10 % of the ultimate tensile strength.

Test solution

The solution is placed in a non-conducting and acid resistant tank.

This solution is prepared with a 1/2 normal solution of hydrochloric acid (containing 1/2 mole of HCl per litre) called "pure for analysis" characterized by the following maximum contents of foreign elements:

— non volatile residue	below 0,0010 %;
— heavy metals (in lead)	below 0,0002 %;
— Fe	below 0,0005 %;
— As	below 0,0001 %;
— Br	below 0,0010 %;
— SO_4	below 0,0002 %;

— oxidizing agents (in Cl) below 0,0002 %;

— reducing agents (in SO_2) below 0,0010 %.

The normality of the solution shall remain between 0,48 and 0,52. The solution shall contain 20 l of distilled water having a resistivity between 500 and 800 Ωm and the quantity of hydrochloric acid necessary to get a 1/2 normal solution shall be added.

The solution is replaced for each test.

Figure A.4 gives the size of the tank and the layout of the cylinder in the acid solution. The anode shall be attached to the internal circumference of the tank, at half height of the cylinder. The cylinder is adjusted in the tank by means of an appropriate device and rests on the bottom on a rubber seating.

Cathodic polarization

Polarization is achieved by a direct rectified electric current running through the solution between the platinum anode and the cathode of the wire under test. The current is applied immediately on immersion of the cylinder.

The rectified current shall be such that the intensity does not vary from the specified value by more than ± 10 %. Anode and cathode shall be linked to an electric panel supplying rectified current and equipped with potentiometers in order to regulate the delivered current.

The anode shall be connected at three equidistant points so that its potential shall be the same at any point on the circumference. The intensity of the cathodic polarization current shall be 1 mA per cm^2 area of immersed wire.

Test duration

The duration of the test shall be three hours. The breaking times shall be recorded.

A.2.3.3 *Test results*

Results are expressed as the breaking time, measured from the moment of immersion of the test pieces in the solution to the breaking of the prestressing wire.

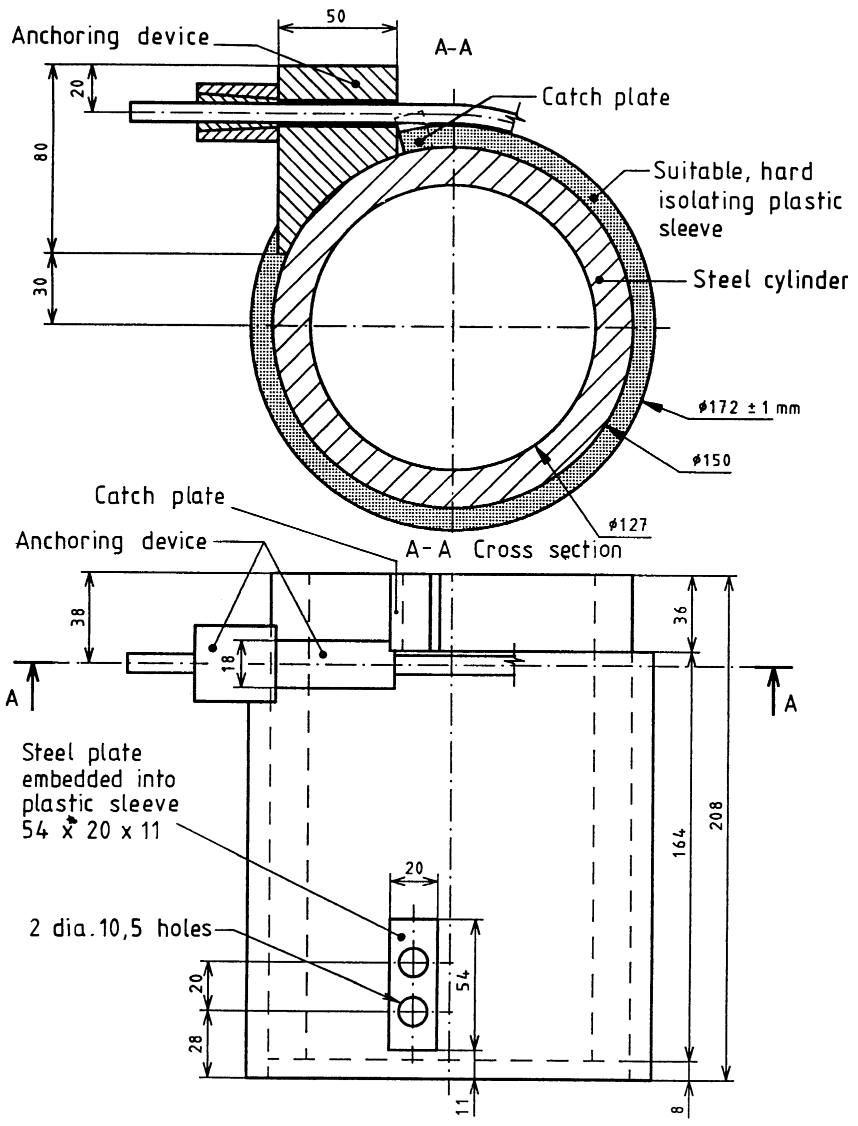

Figure A.1 — Details of test cylinder

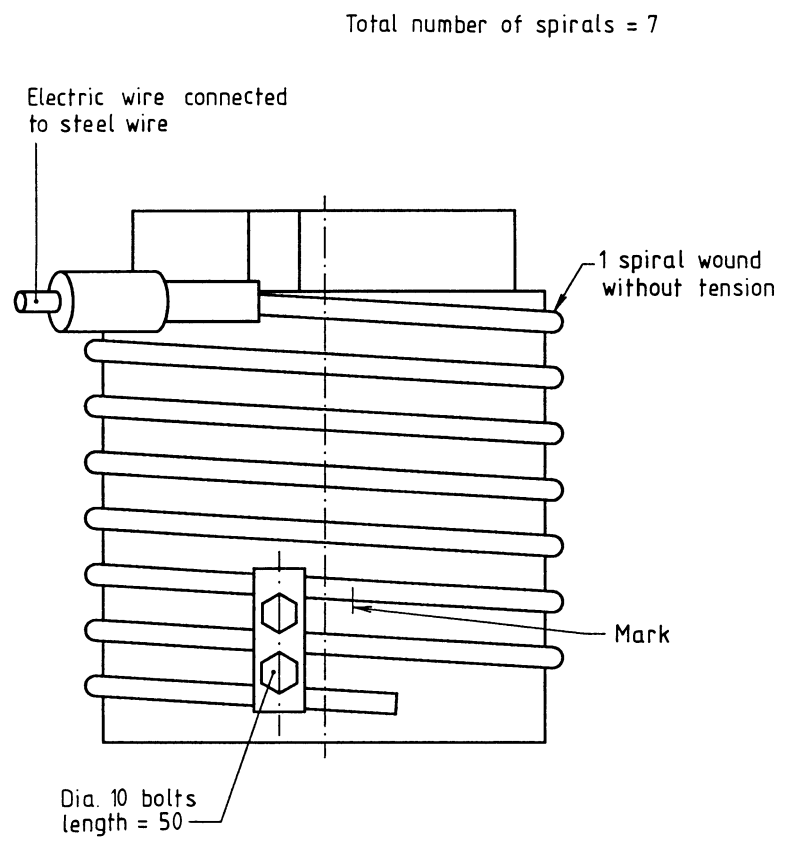

Figure A.2 — Wound test cylinder

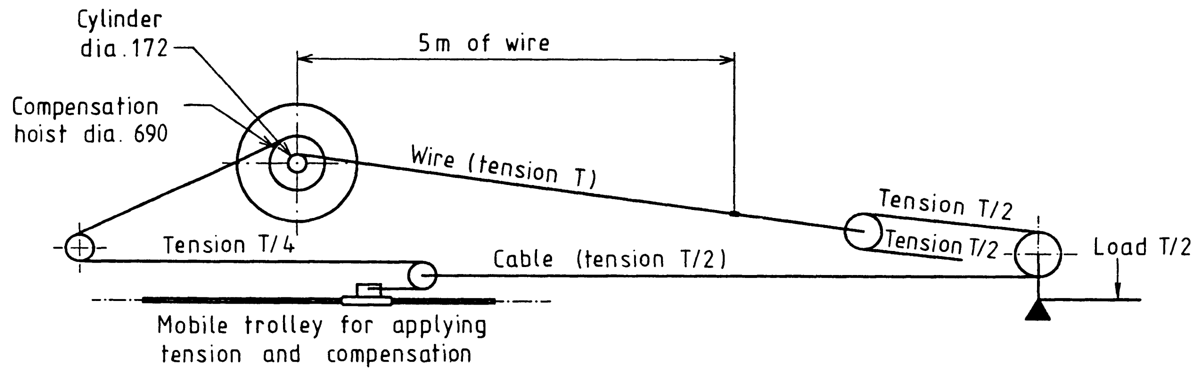

Figure A.3 — Typical arrangement for winding the test cylinders

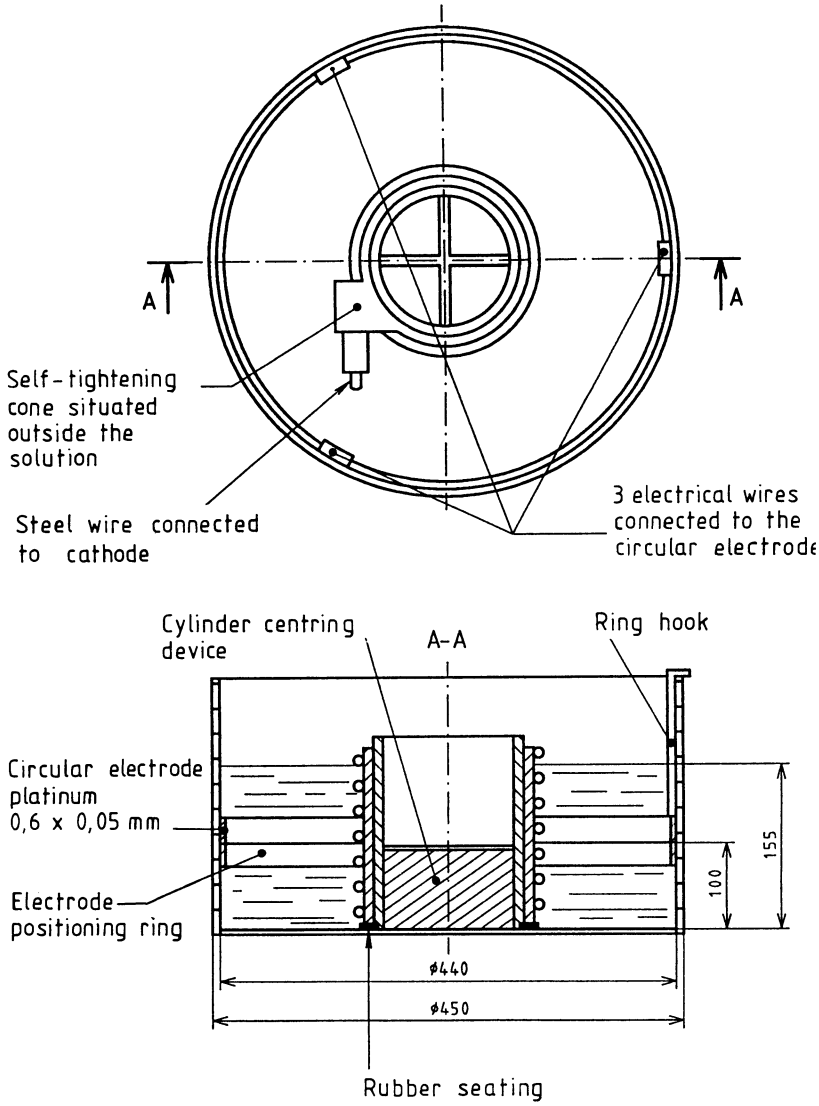

Figure A.4 — Arrangement of test cylinder in acid solution

Annex B (informative)
Typical joints

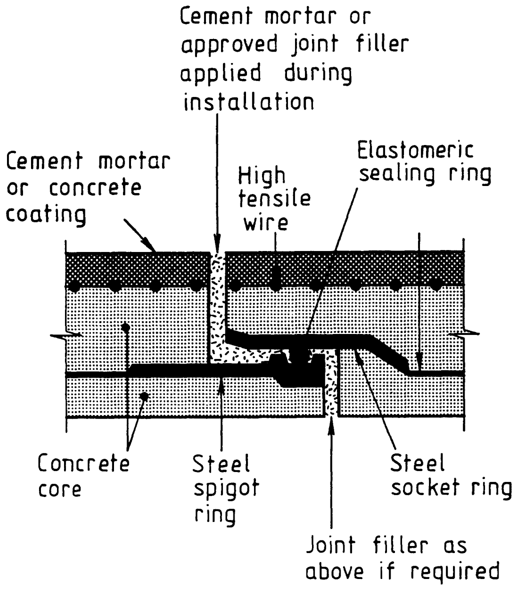

Figure B.1A — Typical embedded cyclinder pipe joint

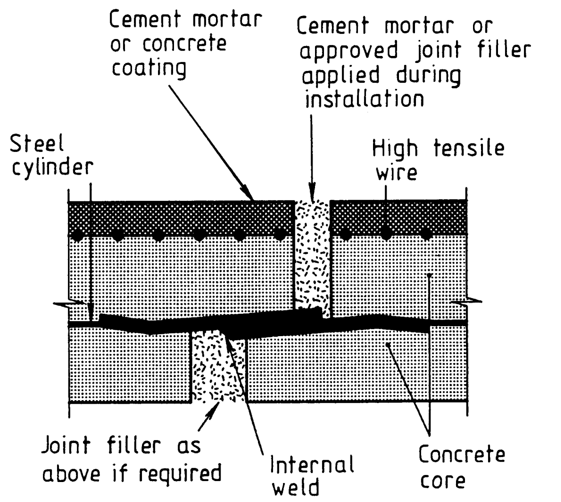

Figure B.1B — Typical internal weld joint

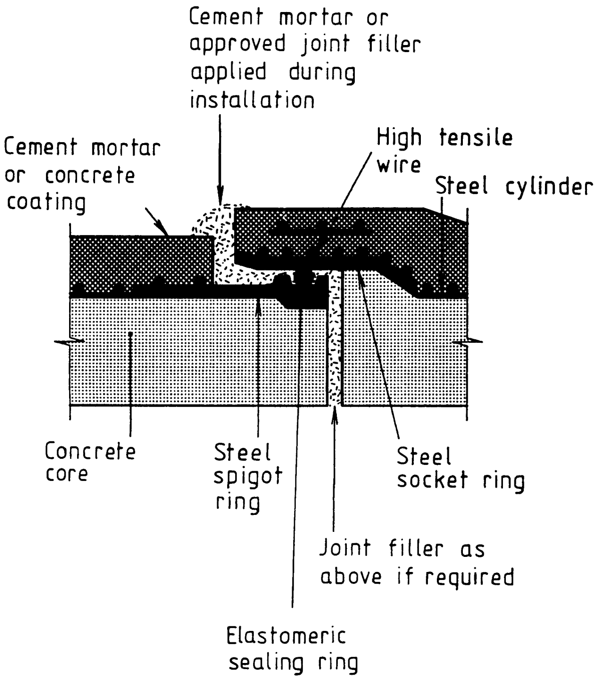

Figure B.1C — Typical lined cyclinder pipe joint

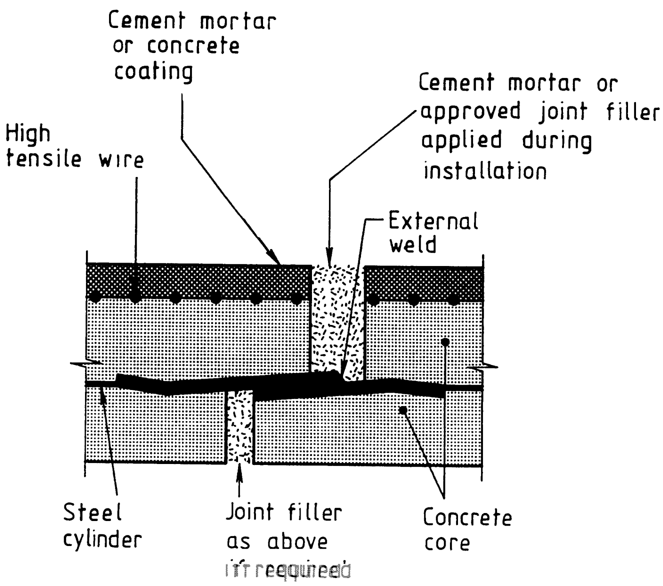

Figure B.1D — Typical external weld joint

Figure B.1 — Typical steel joints

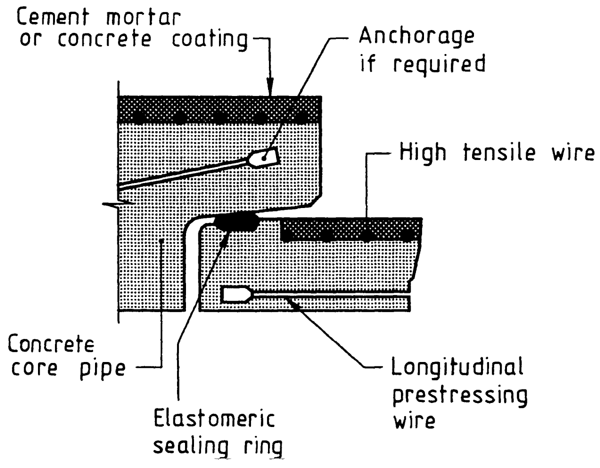

Figure B.2A — Typical sliding ring joint

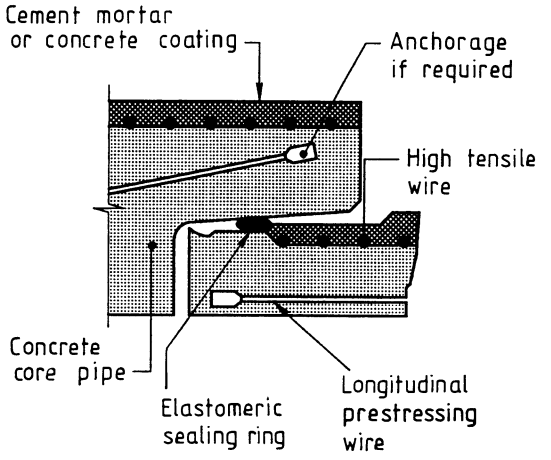

Figure B.2B — Typical rolling ring joint

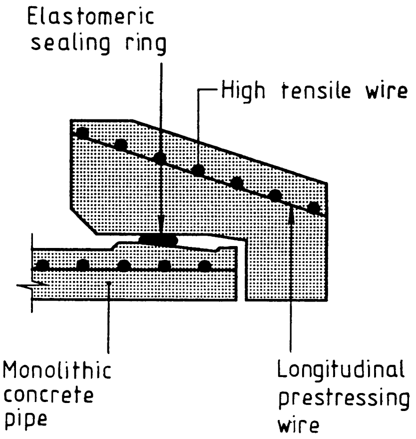

Figure B.2C — Typical monolithic pipe rolling ring joint

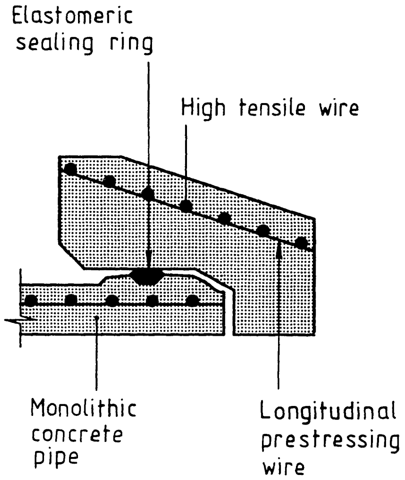

Figure B.2D — Typical monolithic pipe sliding ring joint

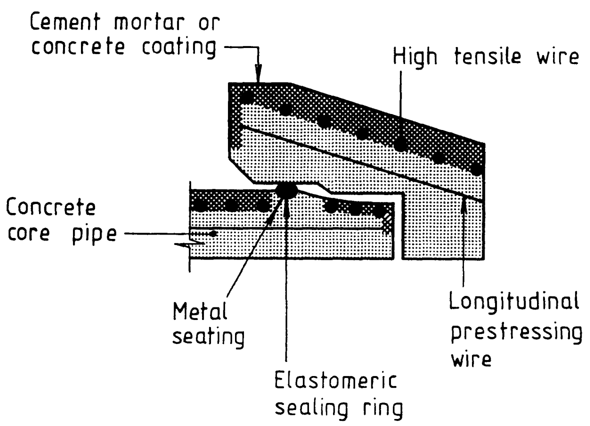

Figure B.2E — Typical sliding ring joint with metal seating for sealing ring

Figure B.2 — Typical concrete joints

Annex C (informative)
Design guidance for prestressed concrete cylinder pipes

Notation

A_c	Pipe cross section
A_s	Cross-sectional area of prestressing wire per unit length
E_c	Core concrete modulus of elasticity
E_{ci}	Initial modulus of elasticity for core concrete
E_r	Modulus of elasticity of the coating
E_s	Modulus of elasticity of prestressing wire and steel cylinder
f_s	Initial stress in the prestressing wire
N_{ov}	Normal force caused by the external loads, pipe weight and water weight
r_c	External core radius
r_i	Internal pipe radius
r_r	External coating radius
r_{sc}	Internal radius of steel cylinder
t_{sc}	Steel cylinder thickness
ϵ_c	Core concrete shrinkage strain
ϵ_r	Coating concrete shrinkage strain
φ_c	Core concrete creep coefficient
φ_r	Cover concrete creep coefficient

This calculation process starts from a prefixed cross section of tensioning wire and from the geometric and material characteristics of the pipe which, together with the appropriate ovalization and pretensioning stresses, permit finding the maximum working pressure.

Coefficients of equivalence

$$n_i = \frac{E_s}{E_{ci}}\, n = \frac{E_s}{E_c}\ ,\ n_1 = \frac{E_s}{E_r}\ ;\ n_2 = \frac{E_r}{E_c}$$

Lamé's coefficients

$$A = \frac{2r_i^2}{r_{co}^2 - r_i^2}\ ;\ B = A + 1;\ C = A + 2$$

$$A_r = \frac{2r_{co}^2}{r_{ro}^2 - r_{co}^2}\ ;\ B_r = A_r + 1;\ B_s = \frac{r_c}{A_s}$$

$$k = \frac{B}{B_r}$$

$$D = n_2 \times B\,(B_s + n_1 \times B_r) + B_r \times B_s$$

Geometric characteristics

$$t_{ro} = (r_c + r_i) + (n - 1)\,t_{sc} + (n - n_2)\,A_s + n_2\,(r_r - r_c) = \text{total equivalent thickness of pipe wall}$$

$$y_i = \frac{(r_c - r_i)^2}{2t_{ro}} + \frac{(n - 1)\,t_{sc}\,(r_{sc} - r_i)}{t_{ro}} + \frac{(n - n_2)\,A_s\,(r_c - r_i)}{t_{ro}} + \frac{n_2\,(r_r - r_c)\,(r_r + r_c - 2r_i)}{2t_{ro}}$$

= distance from neutral axis to core inner face

$$y_e = r_c - r_i - y_i$$

$$y_r = r_r - r_c + y_e$$

$$i_o = \frac{1}{12}(r_c - r_i)^3 + (r_c - r_i)\left(y_i \frac{r_c - r_i}{2}\right)^2$$

$$+ (n - 1)\,t_{sc}\,(r_i + y_i - r_{sc})^2 + (n - n_2)\,A_s\,y_e^2 + \frac{1}{12}\,n_2\,(r_r - r_c)^3 + n_2\,(r_r - r_c)\left(\frac{r_r - r_c}{2}\right)^2$$

= moment of inertia of equivalent total cross section

$r_{co} = r_c + (n - 1)\, t_{sc}$ = equivalent external core radius

$r_{ro} = r_r + (n - 1)\, t_{sc}$ = equivalent external coating radius

Calculation of circumferential stresses

Tensile stresses occurring immediately after winding:

$\Delta' f_s = \dfrac{n_i f_s}{4B_s} \times \dfrac{r_c + r_i}{r_c - r_i}$ = initial tension decrease in prestressing due to elastic deformation of concrete

$f'_s = f_s - \Delta' f_s$

$f'_{ci} = -\dfrac{CA_s f'_s}{r_c}$ = tensile stress at the inner core face

$f'_{ce} = -\dfrac{BA_s f'_s}{r_c}$ = tensile stress at the outer core face

Final tension due to prestressing

$\Delta''_o f_s$ = final relaxation loss in steel

$f''_s = f'_s - \Delta''_o f_s$

$\Delta''' f_s = 2\dfrac{n\varphi_c A_s B f''_s (1 - \varphi_r) - E_s \epsilon_r (1 + \varphi_r)\, r_c - E_r\, \epsilon_r n_2 k r_c}{2r_c (1 + \varphi_r + n_2 k) + n\, A_s B (1 + \varphi_r)(2 + \varphi_c)}$ loss in steel due to shrinkage and creep of concrete

$f_1 = \dfrac{E_s \epsilon_r + \Delta''' f_s}{n_1 B_r (1 + \varphi_r)}$ = induced compressive stress in the coating

$\Delta'' f_s = \Delta''_o f_s \left(1 - 2\dfrac{\Delta''' f_s}{f_s}\right)$ = total final loss in steel

$f'''_s = f_s - (\Delta' f_s + \Delta'' f_s + \Delta''' f_s)$

$f'''_{ci} = -C\left(\dfrac{A_s f'''_s}{r_c} - f_1\right)$ = final tension at inner core face

$f'''_{ce} = -B\left(\dfrac{A_s f'''_s}{r_c} - f_1\right)$ = final tension at outer core face

Tensile stresses caused by external loads, pipe weight and water weight =

$f_{ci.ov} = \dfrac{N_{ov}}{t_{ro}} + \dfrac{M_{yi}}{l_o}$ at the inner core face

$f_{ce.ov} = \dfrac{N_{ov}}{t_{ro}} - \dfrac{M_{yr}}{l_o}$ at the outer core face

Tensile stresses caused by the internal pressure =

$f_{ci.p} = BP - \dfrac{C\, n_2 A}{D}\,(B_s + n_1 \times B_r)\, P$ at the inner core face

$f_{ce.p} = AP - \dfrac{B\, n_2 A}{D}\,(B_s + n_1 \times B_r)\, P$ at the outer core face

The total tensile stress is the sum of the hoop and flexural stresses. The combination of hoop and flexural stresses, permitting tension in the core in accordance with **3.2.2** should be calculated for each condition in **3.2.2**.

The wire area, tension and spacing of the circumferential prestressing wire should be such that the requirements of **3.2.2** are met.

NOTE When calculating hoop stress, the wall thickness is taken as the core only. When calculating flexural stress, the wall thickness is taken as the sum of the core and coat thickness. For calculation of external loads, bending moments and axial stresses, see subclause **4.4** of EN 639 (common requirements)

Annex D (informative) Design guidance for prestressed concrete non-cylinder pipe

D.1 General

Prestressed concrete non-cylinder pipe should be designed to resist the internal pressures (hoop) and external (flexural) designated by the customer and should meet design requirements of clause **3.2.2** of this standard.

D.2 Calculation of circumferential prestress requirement

The hoop stress should be determined by the following equation for each condition:

$$f_{tp} = \frac{PD_i}{2(A_c + nA_s)}$$

where

f_{tp}: Tensile stress in pipe wall

P: Pressure (design pressure or maximum design pressure or site test pressure as appropriate)

D_i: Inside diameter of pipe

A_c: Cross-sectional area of single core wall per unit length

A_s: Cross-sectional area of steel per unit length

n: 5 (modular ratio)

The flexural stress should be determined by the following equation for each condition:

$$f_{tf} = \frac{6\ M}{t^2}$$

where

f_{tf}: Flexural tensile stress in pipe wall

M: Maximum bending moment per unit length according to recognized formulae e.g. Olander formulae, to include for weight of pipe, weight of water, dead and live loads as appropriate, assuming the appropriate design bedding conditions.

t: Total wall thickness

The total tensile stress is the sum of the hoop and flexural stresses. The combination of hoop and flexural stresses, permitting tension in the core in accordance with **3.2.2**, should be calculated for each design condition in **3.2.2**.

The wire area, tension (after losses, see **D.4**) and spacing of the circumferential prestressing wire should be such that the requirements of **3.2.2** are met.

NOTE When calculating hoop stress, the wall thickness should be taken as the core only. When calculating ovalization flexural stress, the wall thickness should be taken as the sum of the core and coating thickness. For calculation of external loads, see **4.4** of EN 639 (common requirements)

D.3 Calculation of longitudinal prestress requirement

The longitudinal prestress ($f_{c\ long}$) required should be the maximum value of the following considerations

D.3.1 The pipe should be designed to resist the secondary bending stresses due to wire winding without cracking.

$$f_{c\ long} \text{ (after losses — see } \mathbf{D.4}) = \frac{f_c}{3} - 2{,}4 \text{ MPa}$$

where

f_c: circumferential prestress (see **D.2**)

D.3.2 The prestress in the concrete (after losses — see **D.4**) should not be less than 0,7 MPa.

D.4 Loss of prestress

The total loss of prestress in the prestressing steel should be assumed to the sum, where appropriate, of the following components.

D.4.1 *Immediate losses*

Immediate losses (at transfer) due to elastic deformation of the concrete = 3,2 f_{ci}

Where

f_{ci}; Initial stress in concrete

For longitudinal steel, allowance should also be made, where appropriate, for immediate losses (before transfer) due to bedding in of the wire heads, mould shortening, wire stretch due to concrete placement and compaction.

$$\text{Loss} = 2\frac{E_{steel}}{L}$$

where

E_{steel}: 2×10^5 MPa (stress relieved)

E_{steel}: $1{,}93 \times 10^5$ MPa (as drawn)

and assume

L: effective length + 80 millimetres.

D.5 Deferred losses

In the absence of certified test data, the following values should be assumed for concrete:

Loss due to shrinkage of concrete = 0,0001 E_{steel}

Loss due to creep of concrete = 2,5 f_{ci}

Loss due to steel relaxation should be assumed to be twice the percentage relaxation after 1 000 hours obtained from suitable test data. In the absence of test data loss of stress due to relaxation should be assumed to be 16 % of the stress before losses for normal-relaxation stress relieved wire, 6 % for low-relaxation stress relieved wire, and 14 % for as-drawn wire.

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