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PRECAST CONCRETE PIPES – UNREINFORCED AND REINFORCED, WITH FLEXIBLE JOINTS

CONTENTS

1. INTRODUCTION

This note gives general information and guidance on precast unreinforced and reinforced concrete pipes with flexible joints as currently specified in BS 5911: Part 100. For clarity, references to bends and junctions have been omitted. Pipes with rebated (including ogee) joints, prestressed pipes, precast pipes of composite construction and porous pipes are not covered but Appendix A shows the range of products covered by the BS 5911 series and the logical part numbering systems which is being applied to new or revised standards. Information on imported granular and selected as-dug bedding and sidefill materials is given in IGN No. 4-08-01.

As with many other products covered by British Standards, a harmonised European one specifying precast concrete pipes and fittings with flexible joints is being drafted for use throughout the Single Market post-1992. Pending confirmation of the European Standard's (EN) final form, this note refers in general terms only to the CEN proposals.

2. APPLICATIONS

Unreinforced and reinforced pipes with flexible joints are intended to be used for drainage and sewerage. No distinction should be made in the application of the two types, nor when using their "maximum" or "proof" test strengths in the structural design of pipelines comprising them. See "A guide to design loadings for buried rigid pipes" and "Simplified tables of external loads on buried pipelines" published by TRRL in 1983 and 1986 respectively.

In the past, concern at the dramatic failure of unreinforced pipes tested to their ultimate strength led some to consider that, for safety reasons, they ought not to be used for man-entry sized pipelines. This ignored the load-carrying capacity of cracked rigid pipes in the ground (see TRRL Supplementary Report 534) - a phenomenon from which all rigid pipes benefit.

3. SIZES

BS 5911: Part 100 currently specifies pipes in the range DN150 to DN3000, though there are proposals in Europe for the upper limit to be raised to DN4000. Between DN 150 and DN1200 pipes are currently specified in increments of 75; above DN1200 the increment doubles to 150, though median sizes may be ordered.

In theory, both unreinforced and reinforced pipes are available throughout the full range of nominal sizes, though in practice those smaller than DN675 will usually be unreinforced. The larger size range (especially those of higher strength classification) are normally reinforced, this being the cheaper form of

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manufacture for such sizes. Below DN45- unreinforced pipes are significantly cheaper to produce than reinforced ones.

4. PROPERTIES

Concrete pipes must exhibit adequate crushing strength, chemical resistance, impermeability, smooth internal walls and sufficient durability to withstand persistently wet, abrasive and aggressive soil or groundwater conditions. BS 5911: Part 100 specifies criteria relevant to each of the properties.

5. CRUSHING STRENGTH

Three crushing strength classes are specified in BS 5911: Part 100 for pipes with flexible joints: "L", "M: and "H" denoting "light", "medium" and "heavy", and provision is made for stronger pipes on request. Design information and recommendations on the use of the three crushing strength classifications are given in the TRRL guide and tables referred to in clause 2 of this note.

Crushing strengths are defined in two ways:

"works proof load" An unreinforced pipe must withstand the appropriate works proof load for at least 1 minute without showing signs of distress. A similar reinforced pipe must withstand the same load for the same time without developing a crack greater than 0.25mm wide.

"maximum load" The appropriate maximum load must be withstood by an unreinforced pipe without showing signs of distress and by a reinforced pipe with no limit on crack but without collapse. Maximum loads are 25% greater than works proof loads.

The proposed European Standard will specify crushing strengths in accordance with a harmonised system for all types of pipe.

6. BEAM STRENGTH

BS 5911: Part 100 includes a bending moment resistance test to assess the beam strength of pipes up to and including DN300 with effective lengths of greater than 1.25m. Within the range covered by BS65 (up to and including DN225) the resistance criteria are consistent with those for "normal" type vitrified clay pipes, though not identical size-for-size, because of differing crushing strength values.

7. DURABILITY

(a) Cement content

The requirements of BS 5911: Part 100 for minimum cement content and maximum water/cement ratio will ensure that any of the permitted cements or standard combinations of BS12 cement and ground granulated blast furnace slag (ggbs) or pulverized-fuel ash (pfa) will facilitate resistance to sulphate attack equivalent to Classes 1 or 2 of Table 6.1 of BS 8110: Part 1: 1985.

Higher classifications of exposure conditions can be resited by additional measures, for which BS 5911: Part 100 provides. Class 3 resistance will be provided by the use of a special combination of BS12 cement and ggbs or pfa, or by BS 4027 cement alone; the latter will also facilitate Class 4 resistance if the minimum cement content is increased from 360kg/m^3 to 370kg/m^3. The advice of the pipe manufacturer should be sought where Class 5 conditions exist, or where unreinforced or reinforced pipes are intended to convey sea water, industrial effluent, etc.

(b) Impermeability

The permeability of concrete is such that, in service, the surface of a pipe may be expected to be cold and damp to the touch, but there should be no sign of water passing through the wall. BS 5911: Part 100 specifies tests to measure impermeability by the hydrostatic test and the water absorption test.

(i) Hydrostatic test
In this test an internal water pressure of 0.14N/mm^2 (1.4 atmospheres) is applied for 1 minute, during which time the pipe must not crack, sweat or show other signs of distress such as leaking or dripping. (A "sweat" would be the appearance of a damp patch on the outside of a pipe under test, due to internal hydrostatic pressure). Pipes cannot be treated with any coating or lining before testing.

(ii) Water absorption
Both unreinforced and reinforced pipes are subject to this test. Absorption must not exceed 3.6% after 30 minutes, nor 6.5% after 24 hours.

(c) Concrete cover to steel

Reinforce pipes are required to have a minimum concrete cover of 12mm over all steel, other than stainless steel, cast in them. This is relevant to the provisions of BS 8110 in two ways:

(i) Being an actual minimum value, the 12mm cover is equivalent to a "nominal cover" of 17mm for the purposes of BS 8110: Part 1 (see clause 3.3.1.1).

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(ii) Given the inspection procedures specified for reinforced pipes and the minimum 12mm cover required for pipes not exposed to particularly aggressive environments, the permissible crack width of 0.25mm under works proof load is consistent with the crack control provisions in BS 8110: Parts 1 and 2.

The actual cover to steel in pipes is routinely checked by cutting channels or by taking cores or cut sections. Other checks may be carried out using an electromagnetic covermeter.

(d) Compaction

BS 5911: Part 100 requires that all pipes must be compacted so that when hardened they are free from honey-combing and from any individual void greater than 6mm. This criterion is linked to the description in sub-clause 4.4.1 of BS 1881: Part 120.

Additionally, voids which are shown by the surface void test to accommodate up to a 10mm diameter hemisphere are permissible and larger voids up to 12mm deep can be made good. Other voids are not permissible.

8. ABSOLUTE REQUIREMENTS

In addition to these in BS 5911: Part 100 for compaction and surface voids, unreinforced and reinforced pipes are subject to two other absolute requirements. That is, compliance can be tested and must be provide at any time. These tests are for straightness and internal surface evenness, with appropriate criteria being specified in the Standard.

9. JOINTS

Pipes manufactured to BS 5911: Part 100 must have flexible joints of the spigot and socket or rebated (in-wall) type. The former type is usually employed.

Joints must be designed to incorporate an elastomeric ring complying with type D of BS 2494: 1990. Various designs of ring are used, though typically of the rolling or sliding type. It is essential that the former type is not lubricated during installation.

The performance of each type of flexible joint is subject to tests for deflection, straight draw and shear, carried out whilst the joint assembly is subjected to an internal hydrostatic pressure of 0.07 MPa N/mm². For pipes over DN180 this pressure is halved, for safety reasons and to avoid excessive end thrusts.

10. REINFORCEMENT

Reinforcement in pipes to BS 5911: Part 100 is normally in the form of a cylindrical cage. Socket reinforcement is usually separate but is often tied back to the main cage, though this is not demanded by the Standard, which relies instead on the performance requirements of the shear test. Continuous flow automatic welding machines are, however, available which can be programmed to manufacture a cage shaped at one end to produce integral socket reinforcement.

BS 5911: Part 100 permits main reinforcement to be in an elliptical arrangement, rather than the conventional circular. Under external loading, maximum tensile stresses are developed on the inside surface of the pipe at the crown and invert, and on the outside of the pipe on the line of the horizontal diameter. These stresses are normally resisted by two cages of reinforcement, which is structurally inefficient, especially in the larger sizes of pipe. A single elliptically-shaped cage can perform the same task, providing it is positioned and laid correctly, for the load-carrying capacity of a pipe reinforced in this way will be significantly reduced if the cage is over 5° out of alignment.

In order to guard against the possibility of mis-alignment, BS 5911: Part 100 requires a lifting facility to be cast into the crown of elliptically reinforced pipes, also that they be marked "LIFT HERE - TOP" and "INVERT" at the top and bottom of the pipe respectively. This has two aims:

(1) The former, for casting in a lifting hole or galvanised steel anchorage, will be tied to the elliptically-shaped cage, thus fixing it to a point on its minor axis and accurately positioning the cage during manufacture. For this reason, the drilling of lifting holes is not permitted for elliptically reinforced pipes.

(2) The presence of a marked lifting facility should ensure that pipes are laid in the correct alignment.

Lifting facilities must be plugged and sealed during construction of the pipeline and are permissible in pipes not elliptically reinforced. A pull-out test is specified for lifting anchorages.

11. METHODS OF MANUFACTURE

British Standard Specifications for unreinforced and reinforced concrete pipes draw no distinction between the various methods by which they are manufactured. The aim is to specify the requirements of the product and in recent years considerable improvements have been made in this respect. The WAA "Civil Engineering Specification for the Water Industry" follows this pattern and again does not limit the means by which the required product is made.

Various methods of production are used which, in broad terms, may be divided into four categories, viz: centrifugal spinning, roller suspension, pressed and vibration.

(a) Centrifugal spinning

Several manufacturers use this method to produce pipes, normally in the range DN675 to DN1800. However, pipes as small as DN150 are made and some manufacturers have moulds available for pipes up to DN3000. Some pipes in the smaller sizes may be unreinforced, but pipes of DN675 and above are usually reinforced. The reinforcement normally consists of one or more helical cages or hoops of cold reduced steel wire which are automatically machine formed and spot-welded. Reinforcement cages are also formed by manually spot welding individual rings to longitudinal wires. There are two recognised methods of producing centrifugally spun pipes:

(i) Wet spin process

This process is used by the majority of manufacturers. A reinforcement cage is positioned into a steel mould which is then placed horizontally onto two sets of drive wheels. The concrete mix, which is relatively wet (up to a maximum water/cement ratio of 0.45), is then fed and distributed into the slowly rotating mould. The speed of rotation is then increased to the high speed necessary to compact the concrete fully by centrifugal action (25-35g). The spinning time varies according to pipe size, but is of the order of 15 to 20 minutes.

Excess water and cement used in the concrete mix are expelled during the spin and this can result in laitance being brought to the bore of the pipe. A technique often used to remove excess water, and to improve the size distribution of aggregate within the pipe walls, is to form the pipe in two separate spins. Each spin has to be carefully controlled to ensure that a lower of laitance is not formed at the reinforcement.

The first stage of curing takes place in controlled steam ovens for about five hours, after which the mould is removed and the pipe further cured in the open.

(ii) Dry spin process

This is similar to the wet spin process, except that additional compaction of the concrete is achieved by applying vibration to one pair of drive wheels. This vibration may be of low frequency and high amplitude or vice versa. Alternatively, high frequency vibration may be applied directly to the rotating mould. A free moving roller acting on the bore of the pipe is sometimes used to aid compaction. The spinning time and method of curing are similar to the wet spin process, but the speed of rotation may be greater, giving a radial acceleration of 35-50g.

The advantage of this method over the wet spin process is that by using a dry concrete mix, less water has to be expelled during the spin, thereby reducing laitance formation on the bore of the pipe. The pipe is formed in one continuous spin and a slightly higher output is obtained. However, maintenance costs on plant and machinery are generally higher.

(b) Roller suspension

Within the United Kingdom this process is now only used in Northern Ireland. In it, the mould is suspended from a horizontal drive shaft and the pipe is formed by a combination of rolling, vibration and limited centrifugal action (3-5g). The drive shaft spins the mould, at the same time vibrating the roller thus compacting the concrete. The spinning time and method of curing are similar to the methods in (a) above, although the rate of spin is slower.

(c) Pressed

Radial compaction is no longer used in the United Kingdom but axial compaction is still used in Northern Ireland to manufacture pipes with ogee joints. The concrete mix is fed in from the top of the mould onto a rotating mandrel fitted with shaped shoes which compress the concrete in a downward direction and cause the mandrel to rise as the concrete becomes compacted. A reinforcement cage cannot be used with this process.

(d) Vibration

Most manufacturers produced concrete pipes using this method. There are many forms utilising various degrees of automation:

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(i) Vertical casting
This is the simplest form using inner and outer moulds, usually with "Wacker" type vibrators attached.

The mould is assembled around the reinforcing cage and concrete is fed between the inner and outer sections. Initially only the lower vibrators are used but as the pour rises the vibrators attached to the upper sections are gradually introduced. It is normal for the socket section to be formed by the base ring and the spigot by a shaped section attached to the outer mould with the extreme end being screened and hand finished to the top of the inner and outer moulds.

This method is usually restricted to large diameter units where high outputs are not required.

(ii) Vibration machines
These range from simple hand operated machines using "Wacker" type vibrators fixed to the outer mould, through to fully automated computer controlled machines which can not only control the feed to suit the pipe diameter but also vary the amplitude and frequently of the vibrators during the manufacturing cycle.

Whilst all machines utilise a low water/cement ratio concrete mix fed into a vertical mould which is then vibrated, the output rate, diameter range and quality differ considerably.

The earlier external vibrator machines are not suitable for the manufacture of reinforced pipes and are generally now confined to the manufacture of small bore ogee and porous pipes.

The more modern machines use an internal vibrator fitted inside the core which may also move either vertically or radially to improve the surface of the bore. Some machines also incorporate a revolving head on top of the core to distribute the concrete evenly around the wall of the pipe whilst others use a distributor in the hopper above the mould. In some instances the load on the distributor is monitored and fed to the computer to control the rate at which the core rises during manufacture and/or the concrete is fed into the mould.

The size range of the machines and number of pipes per cycle vary between manufacturers but most supply machines which fall into one or more of the following groups:

Group	Nominal Size (DN)	Max. Length (m)	No. of Pipes Cast per Cycle
A	150 – 225 or 300 or 375 – 600	1.25 1.25 1.25	3 2 1
B	300 – 600	2.5	1 or 2
C	300 – 600 or 675 – 750 or 825 – 1200	2.5 2.5 2.5	2 or 3 1 or 2 1
D	675 – 3000	2.5	1

Fully automatic machines are in operation to produce pipes, including demoulding, up to 1200mm diameter but above this size it is usual for the pipe to be removed from the machine in the mould by overhead crane. The pipe and mould are then positioned in the curing area where the mould is removed, cleaned and returned to the machine for the next cycle.

The cycle time for the various machines varies from about 3 minutes for group "A" machines and up to 10 to 15 minutes for group "D". It is usual for the pipes to be stored for 24 hours indoors before final curing in the open.

12. GENERAL APPRAISAL OF MANUFACTURING METHODS

Whilst a general description of current manufacturing methods has been given, it has no relevance to the design and specification of sewerage and drainage schemes.

Spinning methods rely upon skilled operators who must produce the quality of finish required in a pipe bore by means of a blade attached to the end of a hand-held pole approximately 3 metres long. They are often required to work in a wet, humid and noisy environment. Steam curing is applied to spun pipes to maximise the use of costly moulds and end rings.

The vertical casting method utilises fixed moulds rather than sophisticated machines, it is relatively labour intensive and is generally confined to large heavy units. Output is very dependent upon the number of people employed in the gang.

Modern vibration machines are usually automated, have high production rates and, with the advent of developments over recent years, are capable of producing pipes to the required standard. That is not to say, however, that all vibration machines could produce pipes that complied with BS 5911: Part 100.

Before the advent of modern vibration machines there was a widespread preference in the UK for spun pipes. This helps to explain why pipes with an asymmetrical cross-section, for example vertically cast ones having an integral flat base ("pre-bed") or an egg-shape, are more commonly found on the mainland of Europe. The hydraulic advantages of an egg-shaped pipeline over a circular one, especially where used as a combined sewer, have long been appreciated and it is proposed that the European Standard should cover pipes with an asymmetrical cross-section, subject to similar requirements as circular ones.

13. THIRD PARTY CERTIFICATION

Third party certification is available to support claims by manufacturers that pipes have been manufactured to BS 5911: Part 100. The "Civil Engineering Specification for the Water Industry" demands such support by requiring that:

"Wherever, in respect of any British Standard, a BSI Kitemark Certification Scheme is available, all material required to comply with that Standard (BS), or the containers of such materials, shall be marked with the BSI Certification Trade Mark (The Kitemark)". In order to comply with European and UK Law, it goes on to add that: "The mark of conformity of any other third party certification body accredited by the National Accreditation Council for Certification Bodies or equivalent shall be an acceptable alternative to this requirement". Kitemarked pipes are readily available in the UK.

14. SUMMARY AND CONCLUSIONS

No distinction should be drawn between unreinforced and reinforced pipes in the structural design of pipelines. BS 5911: Part 100 and national design recommendations are framed with this in mind.

Vibration machines are less labour intensive than vertical casting or spinning methods and the latter also involves steam curing to speed up mould recovery.

The British Standard for unreinforced and reinforced concrete pipes with flexible joints does not prescribe the method of manufacture and WAA/WSA Specifications draw no distinction. The philosophy of both BSI and WSA is that a concrete pipe complying with BS 5911: Part 100 and bearing the "Kitemark" or equivalent will be entirely satisfactory for its purpose, provided that the method of installation and the general conditions under which the pipeline is operating are suited to the original design concept.

15. REFERENCE

This IGN makes reference to the following publications.

BS 12 Specification for Portland cements.

BS 65 Specification for vitrified clay pipes, fittings, joints and ducts.

BS 1881 Testing concrete.
Part 120: Method for determination of the compressive strength of concrete cores.

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

BS 4027 Specification for sulphate-resisting Portland cement.

BS 5911 Precast concrete pipes, fittings and ancillary concrete products.
Part 100: Specification for unreinforced and reinforced pipes and fittings with flexible joints.

BS 8110 Structural use of concrete.
Part 1: Code of practice for design and construction.
Part 2: Code of practice for special circumstances.

Transport and Road Research Laboratory. A guide to design loadings for buried rigid pipes.

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Transport and Road Research Laboratory. Supplementary Report 534. Load carrying capacity of cracked rigid pipes - Preliminary Study.

Water Authorities Association. Civil Engineering Specification for the Water Industry - third edition.

Water Services Association, Sewers and Water Mains Committee. Information and Guidance Note No. 4-08-01: Imported granular and selected as-dug bedding and sidefill materials for buried pipelines.