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WAA Sewers and Water Mains Committee: Materials and Standards

Information and Guidance Note

BRICKS AND MORTAR

1. INTRODUCTION

Brick structures have been successfully used for a wide range of applications in the civil engineering field from manholes up to large bridges. Experience has shown that when the materials are correctly selected and carefully constructed the resulting structures are strong in compression and durable. In addition brickwork can provide considerable flexibility in plan including curves and other shapes without the use of formwork. It can offer an attractive and environmentally acceptable appearance and uses small elements which can be installed using skills that are widely available.

Since publication of the previous guidance note in 1982 there have been a number of important changes to British Standards and Codes of Practice which relate to the specification and design of bricks and brick structures. Important changes in relation to the 1982 note are: a revised (substantially altered) clay brick standard, BS 3921:1985, replaces the 1974 standard; concrete bricks are now specified in BS 6073: Parts 1 and 2:1981 (amended 1984) and BS 187 was amended in 1986. Pavers have increased in popularity, particularly for heavily used locations such as vehicle loading areas, and are covered (for clay and calcium silicate units) by BS 6677: Part 1 and for concrete units by BS 6717: Part 1.

The relevant Codes of Practice have all been updated as follows: the old Code of Practice for structural use of masonry, BS CP111, is now withdrawn and is replaced by BS 5628: Part 1:1978, revised 1985, for unreinforced brickwork and by BS 5628: Part 2:1985 for reinforced brickwork. The code for walling, CP121, which covered key areas such as durability, rain resistance, fire performance, detailing and workmanship has been replaced by BS 5628: Part 3:1985. Finally BS 8301:1985 supersedes CP301.

This revision has been prepared for the WAA Sewers and Water Mains Committee by the Building Research Establishment in consultation with WRc, users and manufacturers' organisations.

2. APPLICATIONS

The main value of brick structures is in areas which exploit their characteristics, inter alia:

- One-off or small run components such as manholes, inspection chambers, underground chambers, junction systems, balancing tanks and localised repairs to existing brick components.
- Works exposed to public view such as retaining walls, raised access chambers, gulleys, culverts and culverted watercourses. Bridges constructed using either arches or reinforced masonry.
- All types of repairs to existing structures particularly where appearance needs to be maintained, flexibility is required or access is restricted for large works or machinery, e.g. tunnel linings, arches, access facilities, etc.
- Drainage works in areas where high vertical loads are applied such as works near the surface of roads and vehicle loading bays.

3. REQUIRED PROPERTIES

The key requirement is for durability in persistently wet and abrasive conditions and, for sewer works, the ability to withstand either continuous or occasional inundation with foul water or groundwater containing dissolved salts, organic matter and acids or alkalis. The bricks also need to be reasonably strong especially where the works are associated with roads and need to withstand loads from heavy lorries. If used above ground in positions where the bricks will be repeatedly frozen whilst saturated with water, the brick should be frost resistant. Solid bricks (i.e. without perforations) are preferable for continually wet situations since they have no internal voids which might assist leakage and harbour liquid.

4. TYPES, CLASSIFICATION AND PERFORMANCE

Bricks for normal civil engineering applications which are available in the UK are produced by one of three processes using different raw materials. These bricks are not intended necessarily for particularly aggressive chemical effluents although some bricks are suitable for such duties. **If particularly aggressive effluents are involved, Table 3 of BS 8301:1985 should be consulted. If doubt still exists the manufacturer of the bricks or an independent expert should be consulted before specifying.**

The three categories are:

(a) **Clay bricks conforming to BS 3921:1985.** These bricks are manufactured by either moulding, pressing or extruding and cutting moist clay to size then drying and firing to form a ceramic body. Clay bricks are now characterised by strength, water absorption, frost resistance, soluble salt content and efflorescence. Engineering bricks and damp proof course bricks have minimum compressive strength and maximum water absorption requirements. **Although engineering bricks are normally very frost resistant and have low salt content this is not automatically implied by the new standard so they must be specified carefully.** Clay bricks tend to expand slightly after manufacture but this can be an

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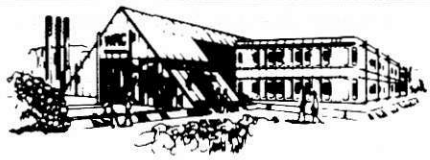

advantage in many civil engineering applications provided it is allowed for in the design. Clay bricks cover a very wide range of performance, particularly in respect of durability, and only some categories will be suitable for normal civil engineering bricks applications. Dense, smooth, low absorption fired clay engineering bricks will normally have the best resistance to chemical attack of all the types of brick available. This includes a wide range of normal and industrial effluents, acids, alkalis and hot effluents. These bricks are also very durable towards frost and abrasion. Bricks with higher levels of porosity will not be as durable but will be satisfactory for some applications.

Table 1 below summarises the specification choices. When ordering clay bricks the level of frost resistance and salts content may be specified using a combination of the durability designation code letters, e.g. moderately frost resistant brick with low salts content is ordered as ML.

Table 1 — Classification of clay bricks

Class	Minimum Strength N/mm² (MPa)	Maximum Water Absorption % by mass	Durability Designation				
			frost resistance			salts content	
			high	moderate	not	low	normal
Engineering A	70	4.5	F	M	★	L	N
Engineering B	50	7.0	F	M	★	L	N
Damp course 1	5	4.5	F	M	★	L	N
Damp course 2	5	7.0	F	M	★	L	N
Others	5	No limit	F	M	O	L	N

★ Bricks with an "O" (not frost resistant) designation in these classes would be unsuitable for the purpose.

The frost resistance classification of bricks must either be on the basis of satisfactory field performance or, optionally, by use of an accelerated test method for panels of brickwork as described below.

The panel freezing test for brickwork

The method is designed to test panels of brickwork consisting of 10 courses of three UK standard bricks laid in half-bond, i.e. panels 750mm high by 665mm wide. The standard apparatus will accommodate two 750mm × 665mm panels placed side by side or other sizes if provided with a masking plate.

The panel is first totally immersed in water for 7 days then one face is exposed to repeated cycles of freezing and thawing. The other face, the top and the sides of the panel are enclosed in a close fitting jacket of 25mm thick expanded polystyrene.

The apparatus automatically subjects the wall to a cycle of freezing and thawing, consisting of 132 minutes freezing at an air temperature of −15°C; 20 minutes thawing with radiant heaters to a maximum air temperature of 25°C; 2 minutes spraying with water to replace that lost by evaporation; and finally 3 minutes dwell to drain away the water in the system; the cycle then restarts.

The panels are examined daily at the end of the thaw part of the cycle for obvious signs of damage. After 50 cycles the test is halted and the panel allowed to thaw out completely before being removed from the apparatus for careful examination. If no damage has occurred the panel is replaced in position and tested for up to a further 50 cycles. After the completion of 100 cycles the panel is removed and dismantled. Each brick is carefully examined for surface damage and any incipient separation of the surface layers.

If the bricks, when tested by this method, show no signs of failure after 100 cycles they would be expected to be durable under all conditions of exposure normally found in practice. Bricks showing no signs of failure after 10 cycles, but having failed after 100 cycles, would be expected to be durable under most conditions of exposure but some failure could occur if they were used in a situation where repeated freeze/thaw cycling occurred when the bricks were saturated with water. Bricks which fail in less than 10 cycles are considered to be suitable for internal use only.

A fuller description of the test is given in a paper by West, Ford and Peake in J British Ceramic Society, *83*, p 112, 1984.

(b) **Concrete bricks conforming to BS 6073: Parts 1 and 2:1981.** These bricks are manufactured by pressing Portland cement concrete to shape and curing in moist air or steam to cause the cement to harden. They are classified by size, strength and drying shrinkage and are currently available in strengths ranging from 7 to 40N/mm². Manufacturers may be able to supply stronger bricks to special order. **Special purpose bricks,** intended for civil engineering applications, are made using a minimum content of 350kg/m³ of sulphate resisting Portland cement (SRPC), having a minimum 40N/mm² crushing strength and a maximum water absorption of 7%. Facing and common bricks, which are normally 20N/mm² minimum strength and made from ordinary Portland cement (OPC), are suitable for general constructions above and below ground where

particularly aggressive conditions do not occur.

A limited test has been carried out on samples of three different (SRPC) concrete bricks in current production using simulated industrial and commercial effluent solutions and reported in Concrete, April 1986. The solutions, containing inorganic and organic sulphates and adjusted at regular intervals to a pH of around 5, caused some erosion of the bricks giving weight losses of up to 1% over a period of 6 months. The best performance was given by engineering quality 40N/mm^2 limestone aggregate bricks which lost 0.5% (i.e. 1% per annum). The bricks were still at their specified strength at the end of the test. Reports numbers 143, 145 and 320 of the Cement and Concrete Association give data on the performance of SRPC concretes in contact with strong sulphate solutions, acid solutions and combinations of particular bacteria and high temperature effluents.

This data would indicate that the stronger bricks are likely to be very durable for duty in subsurface works where there is occasional inundation and moderately durable when in continuous contact with effluent. If the pH of the effluent is likely to be persistently below 5 or it is at an elevated temperature there is likely to be strength loss with time. Table 3 of BS 8301:1985 reflects these conclusions and places reservations on performance of concretes in some industrial effluents, particularly acids. In these cases the manufacturer or an independent specialist should be consulted before specifying.

(c) **Calcium silicate (sandlime, flintlime) bricks conforming to BS 187.** These bricks are manufactured by pressing mixtures of siliceous material, e.g. fine sand and/or crushed rock, and lime into bricks and autoclaving to cause the formation of a calcium silicate cementing phase. Classification, in the latest revision of the standard is by strength only and they are available in strengths ranging from 20N/mm^2 to 49N/mm^2. Calcium silicate bricks expand when wetted and shrink as they dry out and this must be allowed for in design but the test and classification of shrinkage have been removed in a recent amendment of the standard because of doubts about the reproducibility of the existing test.

There is no classification of durability as such but some information relating durability to strength for bricks produced in the period 1930-1939 is contained in BRE CP24/70. This work indicated that the stronger types tested (circa 30N/mm^2) were substantially frost resistant and that even the 20N/mm^2 bricks performed well in walling. There was, however, a loss of strength of up to 50% for bricks buried on contact with the ground on all faces, due apparently to carbonation. While this effect is probably exaggerated by the experimental conditions and would be less apparent in walling, the Code of Practice recommends that bricks of a higher strength class than would otherwise be deemed necessary should be used for this application. The products in current production, especially the high strength units, are likely to be more durable than those tested in the past and these bricks are likely to be suitable for a fair range of duties both above and below ground. The binder, however, is probably susceptible to attack by acids and some salt solutions and they should only be used for applications where direct contact with effluent or sewage is possible on the advice of the manufacturer and/or an independent specialist.

5. FORMS OF BRICKS

Bricks may be produced in a number of forms as follows:

- **Solid bricks** — bricks having no designed voids (holes, depressions or perforations).
- **Frogged bricks** — solid bricks with a depression (or frog) in one or both of the bed faces where the total volume of the frog(s) does not exceed 20% of the gross volume.
- **Cellular bricks** — bricks having one or more deep holes or depressions in from one bed face which do not penetrate through to the other side.
- **Perforated bricks** — bricks having one or more holes passing from one face to the opposite face (exclusively the bed faces in UK products). Other relevant definitions are contained in BS 6100: Part 5.3:1984.
- **Specials (special shapes)** — a range of standard bricks for curves, non right-angled corners, plinths, cappings, etc. are available (described in BS 4729 (which is under revision).

6. DIMENSIONS AND TOLERANCES

All of the main standards include dimensions for bricks of the traditional work size of 215 × 102.5 × 65mm (coordinating size 225 × 112.5 × 75mm). BS 6073: Part 2 shows additional sizes for concrete bricks and BS 6649 (dimensional only) gives an additional work size for clay and calcium silicate modular bricks of 190 × 90 × 65mm (coordinating size 200 × 100 × 75mm).

The methods of measurement and the allowable deviations from the basic dimensions vary between standards. These are summarised in Table 2.

The standards suggest that tighter tolerances should be agreed between manufacturer and purchaser when required.

7. SELECTION OF BRICKS AND MORTARS FOR DURABILITY

The main recommendations are given in Table 3.

7.1 Bricks

Where brickwork is in contact with the ground, clay bricks should be class F or M and concrete and calcium silicate bricks should be selected in the light of data on the amount of leachable salts

Table 2 — Permitted deviations from work size (mm)

Standard	Sample	Length	Width	Height
BS 187	Individual brick	±2	±2	±2
BS 3291	Row of 24 bricks (equivalent average for one brick — any individual deviations permitted).	±75 (±3.1)	±45 (±1.9)	±45 (±1.9)
BS 6073: Part 1	Individual brick	+4 −2	±2	±2
BS 6649 (Clay)	Row of 24 bricks (equivalent average for one brick). Upper limit for individual brick	±66 (±2.8) +10	±45 (±1.9) +10	±45 (±1.9) +10
(Calcium silicate)	Individual brick	+2 −3	±2	±2

present. Clay brickwork exposed at near ground level and above will normally require the use of bricks of the F classification for frost resistance but M classification units may be suitable for some subsurface works and some structures above damp proof course level which are neither exposed on two faces nor in direct contact with the ground. **Under no circumstances should second quality (e.g. underfired) clay bricks be used for exposed work!** For the purposes of judging frost resistance special purpose concrete bricks and calcium silicate bricks of class 4 and above should be regarded as frost resistant (F) and other products as moderately resistant (M). Exposure to soluble salts may reduce the frost resistance of calcium silicate bricks.

If earth retaining walls are drained at their base, waterproofed on their back face and have a backfill of free-draining material, bricks of lower frost resistance than would otherwise be required for a wall in contact with the ground may be used.

7.2 **Mortars**

The recommended mortars are generally standard OPC or SRPC mortars with the stronger mortars being preferred for aggressive conditions.

In all these service conditions the brickwork is likely to be in contact with moist ground or moisture derived from the ground. If sulphates are present in the ground and can be leached out then sulphate resisting Portland cement (SRPC) should be used in strong (designation (i) or (ii))

Table 3 — Selection of units and mortar for durability

Application	Quality of bricks and mortar		
	fired clay	calcium silicate	concrete
Earth retaining wall with back face waterproofed and back-filled and with coping	FL, FN, ML or MN in (i) or (ii)	Classes 3 to 7 in (ii) or (iii)	15N/mm² or greater in (ii)
Earth retaining wall with coping but no protection of back face and cappings and copings.	FL or FN in (i)	Classes 4 to 7 in (ii)	30N/mm² or greater in (i) or (ii)
Surface water drains and ancillary works.	Engineering bricks FL, FN, ML, MN in (i)	Classes 3 to 7 in (ii) or (iii)	20N/mm² or greater in (ii)
Foul water drains and ancillary works subject to occasional inundation.	Engineering bricks FL, FN, ML or MN in (i)	Classes 3 to 7 on advice of manufacturer in (i) or (ii)	40N/mm² or greater in (i) or (ii)
Foul water drains and ancillary works subject to continuous inundation.	Engineering bricks FL, FN, ML or MN in SRPC (i)	Class 7 in SRPC (i) but seek specialist advice	40N/mm² or greater in SRPC (i) but seek specialist advice
Structures carrying industrial effluents particularly when hot or acidic.	Engineering bricks FL, FN, ML or MN in special mortar	Not suitable	Seek specialist advice

Mortar designation: (i) 1:0-¼:3 cement:lime:sand,
(ii) 1:½:4-4.5 cement:lime:sand,
(iii) 1:1:5-6 cement:lime:sand or equivalent non-lime mortars where suitable.

mortars. SRPC mortar will also be required where clay brickwork with the NORMAL (N) salt content classification is likely to remain wet for extended periods.

To obtain the most durable and lowest permeability mortars, very well graded sand with a low fines content is necessary (e.g. a washed S grade sand from BS 1200). Generally lime plasticised mortars are denser and less porous than aerated mortars of equivalent strength. Where industrial effluents with low pH or other harmful compounds are involved special mortars such as polymer modified cement mortars or epoxy mortars may be preferable. If SBR or acrylic latex is used, the sand must be completely free of clay particles. These mortars can give high bond and low permeability if properly specified. If very hard mortars are used where there can be unrestrained movement, cracking is likely to occur and this should be borne in mind when specifying mortar.

Table 3 summarises the selection criteria.

8. WORKMANSHIP REQUIREMENTS

Workmanship should normally be in full accordance with the requirements of section 4 of BS 5628: Part 3 with the following particular requirements:

- All joints must be fully filled with mortar.
- The design width of mortar joints should be 10mm thick or less.
- Joints should always be struck flush to reduce drag and turbulence in liquid flow and to minimise the area exposed to aggressive fluids.
- Frogged or cellular bricks should be laid with the only or larger depression upwards and filled with mortar.
- Only whole bricks shall be used except where pieces are required to maintain bond. The pieces should preferably be saw cut not snapped.
- Clay bricks should be adjusted to an initial suction rate of less than 1.5kg/m^2/minute (determined in accordance with Appendix H of BS 3921:1985) by wetting (if necessary) but to avoid excessive shrinkage of the finished work, concrete and calcium silicate bricks should not be deliberately wetted.
- All work should be covered at the end of each day to protect it against ingress of rain and damage from night frost. In persistent sub-zero conditions work should normally be discontinued.
- Bricks should not be reused unless they have been thoroughly cleaned and conform to the relevant standards for similar new materials.

9. QUALITY ASSURANCE AND PURCHASING

It should not automatically be assumed that adequate quality control procedures are in operation and care is advised when ordering bricks to ensure that the appropriate quality of brick for the user's application is received. If a special category of manufacturing control is required this has to be additionally specified, e.g. see Appendix J of BS 3921:1985 or 6.5 of BS 6073: Part 2:1981.

For demanding applications all aspects discussed in this IGN need to be considered carefully and the order should reflect the choice made. In addition, handling requirements need to be specified e.g. strapped. Useful check lists are contained in Appendix G of BS 3921:1985 and Appendix A of BS 6073: Part 2:1981.

There is now a Kitemark scheme for BS 3291 bricks and there are also other quality assurance schemes for brickworks in operation which are in accordance with BS 5750: Parts 1 or 2. It is advisable to purchase bricks from manufacturers covered by quality assurance schemes.

10. LIST OF STANDARDS, CODES AND OTHER GUIDANCE FOR DESIGN AND CONSTRUCTION

10.1 **Standards**

BS 187: Specification for calcium silicate (sandlime and flintlime) bricks).

BS 1199 and BS 1200: Building sands from natural sources: BS 1200: Sands for mortar for plain and reinforced brickwork, blockwalling and masonry.

BS 3921: Specification for clay bricks.

BS 4729: Shapes and dimensions of special bricks (under revision).

BS 5750: Quality systems:
Part 1 Specification for design, manufacture and installation.
Part 2 Specification for manufacture and installation.

BS 6073: Precast masonry units:
Part 1 Specification for precast concrete masonry units.
Part 2 Method for specifying precast concrete masonry units.

BS 6649: Specification for clay and calcium silicate modular bricks.

BS 6677: Specification for clay and calcium silicate pavers for flexible pavements.
Part 1 Specification for pavers.

BS 6717: Precast concrete paving blocks:
Part 1 Specification for paving blocks.

10.2 **Codes**

BS 5400: Steel, concrete and composite bridges:
Part 2 Specification for loads — deals with loads for manholes, etc. built under roads allowing for the depth of earth above and any impact loading. Loadings in other situations should be the sum of all dead and imposed loads.

BS 5628: Code of practice for the structural use of masonry:
Part 1 Unreinforced masonry — covers normal unreinforced structural masonry such as walls, arches, tunnels, columns, etc. subject to compressive, lateral and shear loads.

Part 2 Structural use of reinforced and prestressed masonry — covers design of earth retaining walls, chamber covers, etc. and has a useful treatment for the use of corrosion resistant reinforcement for service in harsh conditions such as foul drains.
Part 3 Materials and components, design and workmanship — covers all non-structural aspects of brickwork design, particularly the specification of units and mortars for durability over a wide range of applications and also workmanship, detailing bonding patterns, fire resistance and resistance to weather conditions.

BS 6100: Glossary of building and civil engineering terms:
Part 5.3 Masonry. Bricks and blocks.

BS 8301: Code of practice for building drainage — covers dimensions, materials, pressure testing, leakage and broad aspects of design for standard surface water and foul drainage works.

10.3 **Building Research Establishment publications:**

Digest 89 Sulphate attack on brickwork.
Digest 151 Soakaways.
Digest 157 Calcium silicate (sandlime, flintlime) brickwork.
Digest 160 Mortars for bricklaying.
Digest 164 Clay brickwork: 1.
Digest 165 Clay brickwork: 2.
Digest 200 Repairing brickwork.
Digest 240 Low rise buildings on shrinkable clay soils: Part 1.
Digest 246 Strength of brickwork and blockwork walls: design for vertical load.
Digest 250 Concrete in sulphate bearing soils and groundwaters.
Digest 257 Installing wall ties in existing construction.
Digest 273 Perforated clay bricks.
Digest 298 The influence of trees on house foundations in clay soils.

Performance specifications for wall ties — BRE report.

BRE CP24/60 Some results of exposure tests on durability of calcium silicate bricks.

BRE CP23/77 Chemical resistance of concrete (Concrete, *11*, (5), pp 35-37. 1977).

HARRISON W. H. **Durability of concrete in acidic soils and groundwaters.** To be published in Concrete Journal 1986.

10.4 **Brick Development Association publications:**

The revision of BS 3921 Specification for clay bricks. Brief comparative notes re the 1974 and 1985 versions.

A new code of practice for the use of masonry — materials and components, design and workmanship. Brief comparative notes on BS 5628: Part 2 and CP121.

Brick diaphragm walls in tall single storey buildings (and earth retaining walls).

BDA Design note 3: Brickwork dimensions tables.
BDA Design note 7: Brickwork durability.
BDA Design note 8: Rigid paving with clay and calcium silicate pavers.
BDA Design note 9: Flexible paving with clay and calcium silicate pavers.

10.5 **British Ceramic Research Limited publications:**

Technical note 368: The performance of calcium silicate brickwork in high sulphate environments.
Technical note 373: Water testing brickwork manholes.
SP56: 1980 Model specification for clay and calcium silicate structural brickwork (in process of updating).
Supplement No. 1 to SP56 Glossary of terms relating to the interaction of bricks and brickwork with water.
SP108 Design guide for reinforced clay brickwork pocket-type retaining walls.
SP109 Achieving the functional requirements of mortar.

10.6 **Cement and Concrete Association publications:**

Concrete pipes and pipelines for sewerage and water supply. Data on durability, scour, protection, etc. of concrete products.
Technical report TRA/143 An investigation of the erosive effect on concrete of soft water of low pH value.
Technical report TRA/145 The effects of sulphates on Portland cement concretes and other products.
Technical report TRA/320 An unusual example of concrete corrosion induced by sulphur bacteria in a sewer.

10.7 **Concrete Brick Manufacturers Association publications:**

CBMA Information sheet 2 Concrete bricks — product information.
CBMA Information sheet 3 Concrete bricks — practice notes for bricklayers.
CBMA Information sheet 4 Concrete bricks — practice notes for designers.

10.8 **Miscellaneous publications.**

The concrete engineering quality brick. Concrete. April 1986.

HENDRY, SINHA and DAVIES. **An introduction to load bearing brickwork design.** Ellis Horwood Ltd. 1981.