BRITISH STANDARD

BS 8221-2:2000

Code of practice for cleaning and surface repair of buildings —

Part 2: Surface repair of natural stones, brick and terracotta

ICS 91.040.01

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by Technical Committee B/209, General building codes, to Technical Subcommittee B/209/7, Cleaning and surface repair of buildings, upon which the following bodies were represented:

Chartered Institute of Building
Construction Confederation
Department of the Environment, Transport and the Regions — Construction Directorate
National Council of Building Material Producers
National House-Building Council
Royal Institute of British Architects
Royal Institution of Chartered Surveyors

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Brick Development Association
British Ceramic Research Ltd.
Concrete Society
Council for Aluminium in Building
Council for the Care of Churches
Department of the Environment, Transport and the Regions — Represented by the Building Research Establishment
Ecclesiastical Architects and Surveyors Association
English Heritage
Historic Scotland
London Transport
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National Grp Construction and Engineering Federation
Society for Protection of Ancient Buildings
Stone Federation
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Contents

Foreword

This British Standard has been prepared by Subcommittee B/209/7. Together with Part 1, it supersedes BS 6270-1:1982 and BS 6270-2:1985, which are withdrawn.

This part of BS 8221 gives guidance on surface repair of external facades of buildings. It has been prepared in parallel with BS 8221-1, which provides guidance on cleaning.

This code of practice covers repointing and types of mortar, repair of stone masonry, brickwork, terracotta and faience, use of surface coverings, external render repair, and use of consolidants on weathered stone and other porous building materials.

This code of practice takes the form of guidance and recommendations. It should not be quoted as if it were a specification and care should be taken to ensure that claims of compliance are not misleading.

WARNING This British Standard calls for the use of materials that may be injurious to health or damaging to the environment if adequate precautions are not taken. The recommendations given in this standard refer only to technical suitability and do not absolve the user from legal obligations relating to health and safety.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

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Introduction

This code of practice is intended to provide building owners, architects, surveyors, engineers and contractors general information concerning surface repairs of buildings.

This code of practice recommends investigative procedures for selecting a suitable repair process. It describes a range of repair and conservation procedures and some problems that may be encountered.

Before carrying out surface repairs, it is essential to ascertain any factors causing decay, such as open joints allowing water ingress, migrating salts from a backing wall, run-off from limestone, or a corroding metal tie/armature.

1 Scope

This British Standard provides recommendations for surface repair of natural stones, clay brick, calcium silicate brick, glazed and unglazed terracotta, and faience masonry in buildings. It covers repointing and selection of mortars, and provides guidance on treatment for protection of surfaces.

Surface repairs of concrete and structural repairs are not covered by this code of practice. For guidance on structural repairs, reference should be made to BS 5390 and BS 5628-1.

2 Normative references

The following normative documents contain provisions that, through reference in this text, constitute provisions of this British Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 12:1996, *Specification for Portland cement.*

BS 63-2:1987, *Road aggregates — Specification for single-sized aggregate for surface dressing.*

BS 187:1978, *Specification for calcium silicate (sand-lime and flint-lime) bricks.*

BS 812-103-1, *Testing aggregates — Method for determination of particle size distribution — Sieve tests.*

BS 882:1992, *Specification for aggregates from natural sources for concrete.*

BS 890:1995, *Specification for building limes.*

BS 1014:1975, *Specification for pigments for and Portland cement products.*

BS 1139 (all parts), *Metal scaffolding.*

BS 1178:1982, *Specification for milled lead sheet for building purposes.*

BS 1199 and 1200:1976, *Specifications for building sands from natural sources.*

BS 1217:1986, *Specification for cast stone.*

BS 2482:1981, *Specification for timber scaffold boards.*

BS 2873:1969, *Specification for copper and copper alloys — Wire.*

BS 3148:1980, *Methods of test for water for making concrete.*

BS 3892-1, *Pulverized-fuel ash — Specification for pulverized-fuel ash for use with Portland cement.*

BS 3921:1985, *Specification for clay bricks.*

BS 4551 (all parts), *Methods of testing mortars, screeds and plasters.*

BS 4721:1981, *Specification for ready-mixed building mortars.*

BS 4729:1990, *Specification for dimensions of bricks of special shapes and sizes.*

BS 4887-1:1986, *Mortar admixtures — Specification for air-entraining (plasticizing) admixtures.*

BS 5224:1995, *Specification for masonry cement.*

BS 5262:1991, *Code of practice for external renderings.*

BS 5390:1976, *Code of practice for stone masonry.*

BS 5628-1:1992, *Code of practice for use of masonry — Structural use of unreinforced masonry.*

BS 5628-3:1985, *Code of practice for use of masonry — Materials and components, design and workmanship.*

BS 5838-2:1980, *Specification for dry packaged cementitious mixes — Prepackaged mortar mixes.*

BS 5973:1993, *Code of practice for access and working scaffolds and special scaffold structures in steel.*

BS 6037:1990, *Code of practice for permanently installed suspended access equipment.*

BS 6100 (all parts), *Glossary of building and civil engineering terms.*

BS 6213:1982, *Guide to selection of constructional sealants.*

BS 6431-17:1983, *Ceramic floor and wall tiles — Method for determination of crazing resistance — Glazed tiles.*

BS 6477:1992, *Specification for water repellents for masonry surfaces.*

BS 6649:1985, *Specification for clay and calcium silicate modular bricks.*

BS 6915:1988, *Specification for design and construction of fully supported lead sheet roof and wall coverings.*

BS 7913:1998, *Guide to the principles of the conservation of historic buildings.*

BS 8210:1986, *Guide to building maintenance management.*

DD ENV 459-1:1995, *Building lime — Definitions, specifications and conformity criteria.*

BS EN 10088-2:1995, *Stainless steels — Technical delivery condition for sheet, plate and strip for general purposes.*

BS EN 10088-3:1995, *Stainless steels — Technical delivery conditions for semi-finished products, bars, rods and sections for general purpose.*

BS EN ISO 3506-1:1998, *Mechanical properties of corrosion resistant stainless-steel fasteners — Bolts, screws and studs.*

BS EN ISO 3506-2:1998, *Mechanical properties of corrosion resistant stainless-steel fasteners — Nuts.*

PD 6472:1972, *Guide to specifying the quality of building mortars.*

Control of Pesticides Regulations, 1986.

The Lead Sheet Manual — A Guide to Good Building Practice.

3 Definitions

For the purposes of this British Standard, the terms and definitions in BS 6100 (some of which are repeated below for convenience) and the following apply.

3.1

armature

austenitic stainless steel, copper or copper based alloy rods, wires or mesh set within a mortar repair to secure it to the parent stone and reinforce its layers

3.2

brick slip

brick, either specially manufactured or cut, of the same height and length as a header or a stretcher, and usually with a thickness of between 20 mm and 50 mm

3.3

conservation

stabilizing and preventing or retarding further deterioration of masonry

3.4

crazing

fine, hair-line stress relief cracks caused by inability of a glazed surface and the underbody to accommodate thermal and moisture movement

NOTE Crazing is also known as poor glaze fit.

3.5

cramp

shaped piece of metal or slate, bedded into sinkings in stone units to tie them to each other or to their backing

3.6

Coade stone

proprietary off-white terracotta body produced from a kaolinitic clay, containing titanium dioxide, feldspar as flux and quartz as glass-forming agent, and a grog of powdered prefired clay

NOTE Coade stone was manufactured by the Coade family between 1769 and 1820.

3.7

dowel

short piece of material sunk or cast into adjacent hidden wall faces, to align or prevent movement of the faces

3.8

engobe

surface application by brush or spray of liquid clay, before firing, to provide an opaque, unglazed coloured finish on some forms of terracotta

3.9

faience

masonry, similar to terracotta, with one or more surfaces covered with a clear or coloured glaze

3.10

fired-clay unit

masonry unit formed from brick-earth, clay or shale, dried and burned

NOTE Fired-clay should not be confused with fireclay, which is used for making refractory bricks.

3.11

fireskin

thin, smooth, outer layer on unglazed terracotta, containing a high proportion of fines

NOTE In traditional firing processes, fireskin is vitrified to a greater degree than the body of clay beneath. Fireskin has a protective role and retention of it should be a priority in cleaning and repair works.

3.12

gauged brickwork

soft bricks cut to shape and abraded to the size required

3.13

glaze

mixed paste of fluxes and colouring ingredients that becomes a thin, vitreous, transparent or coloured surface finish of glassy, opaque or translucent consistency on firing

NOTE Glazes can be plain, mottled or textured and can range from high-gloss to egg-shell finish.

3.14

grog

inert filler added to a clay mixture before firing to control shrinkage

3.15

grout

flowing material that sets after application, used to fill fissures and cavities

3.16

hydraulic lime

binder of limestone, clay, and calcium and magnesium carbonates, that sets and hardens by chemical interaction with water, both in water and in air

NOTE Hydraulic limes are classified as eminently, moderately or feebly hydraulic limes.

3.17

non-hydraulic lime

binder consisting mainly of calcium hydroxide (high calcium lime) or magnesium carbonate (magnesian/dolomitic lime) that, when mixed with water, sets slowly by drying out and atmospheric carbonation

NOTE Non-hydraulic limes can be prepared and used as a putty or as a powder (hydrated lime).

3.18

piecing-in

cutting out a decayed or damaged section of masonry and inserting new

NOTE Piecing in is also known as indenting.

3.19

slip casting

method of manufacture of thin solid slabs, hollow blocks, or tiles, in which a suspension of clay particles in water, of liquid, creamy consistency, is poured into plaster moulds and allowed to dry solid before releasing, drying and firing

3.20

surface repair

renewal, by minor replacement, of damaged or heavily weathered masonry surfaces with similar or compatible material

3.21

terracotta

fired clay, fine textured and unglazed, usually yellow to brownish-red

4 Considerations affecting surface repair decisions

4.1 General

COMMENTARY Most surface repairs are concerned with prevention of moisture ingress or repair/replacement of decayed or damaged elements. Work to improve the weather resistance of buildings may relate to repair of surface defects likely to have a long-term detrimental effect on the whole or part of the structure, replacement of defective fixings, or reinstatement of the surface of a building after structural repairs. Work to improve the appearance of buildings may include repairs of decayed or damaged mouldings, surface decoration or sculpture, badly stained areas, and areas that have been badly repaired in the past. Repair work has many criteria to consider, including method of repair, materials of construction, and the condition of these. Previous experience with a building or similar buildings may be useful but should not be assumed to apply fully.

Distinction should be made between what is necessary and what is desirable before carrying out surface repair work. If funds are limited or if the building is of architectural or historic value, only essential repairs should be carried out.

Ease of access for future work, relative costs of hiring/erecting scaffolding and the probable frequency of maintenance, should be considered at the planning stage of repairs. If significant numbers of masonry units are defective or likely to become so within a few years, it may be more economical in the long term to replace rather than repair them, and this should be decided on considerations of structural, weathering and aesthetic assessments and any conservation requirements of the building.

For work on historic buildings, advice should be obtained from professionals experienced in historic masonry repairs, to determine the extent and nature of the work required. When this has been established, formal consent should be obtained through a procedure established by the relevant legislation. Guidance on conservation of historic buildings is given in BS 7913.

Repair work on historic buildings should be carried out by skilled and experienced masonry repairers, under the direction of a supervisor(s) with a full working knowledge of the repair process.

4.2 Procedure for selecting and undertaking surface repair

4.2.1 *Inspection and identification*

A comprehensive survey should be carried out, by advisors with expertise in the particular type of masonry repair, before carrying out any work. The nature and condition of masonry materials and the causes of deterioration should be assessed before the extent and nature of appropriate repairs are decided.

Masonry facades should be inspected closely using the following procedure.

a) Each material should be identified in sufficient detail to enable work to proceed without risk to the fabric of the building.

b) The condition of the masonry and its joints and associated materials should be assessed and recorded, as well as the effects of previous repairs.

c) Tests to identify stone types or causes of deterioration should be carried out where appropriate.

4.2.2 *Documentation*

Records should be kept of buildings and repair work, including:

a) photographs of the building showing its condition and appearance before repair work is carried out; and/or

b) non-destructive survey techniques (see annex A).

Drawings and work schedules should be used. If original drawings cannot be found, new ones should be prepared. The level of documentation should be appropriate to the nature and scale of the facades and the work proposed.

4.2.3 *Trial area of repair work*

Trial areas should be completed, where appropriate, to determine that proposed repairs are suitable for the masonry and its condition, and that acceptable standards can be achieved.

4.2.4 *Specification*

After an assessment has been carried out and documented, a detailed specification for the work should be prepared. Where applicable, the specifications for surface repair work should be integrated with the specification for cleaning the building.

NOTE Repair work to prevent water penetration may be required prior to cleaning.

4.2.5 *Selection of a masonry repair contractor*

The competency of the masonry repair contractor and the skilled operatives assigned to carry out proposed work should be established. It is important to establish that work supervisors have a full working knowledge of the repair processes.

4.2.6 *Records*

All work and treatment on masonry facades should be recorded as executed. Documents should be retained to provide background information prior to further assessments or work.

4.3 Use of scaffolding

Access to the facades of the building may be by fixed scaffolding or in some circumstances by permanently installed suspended access equipment. Guidance on fixed scaffolding is given in BS 5973, BS 1139-1 to -5 and BS 2482. Guidance on suspended access equipment is given in BS 6037.

NOTE Scaffold requirements can be extensive and complicated. Scaffolding is not considered in detail in this standard.

If repairs to masonry are to be undertaken, scaffolding should be appropriate to the repair work. Lifting tackle may be required and the scaffold may be used to support large weights. Particular attention should be paid to:

a) tying-in to avoid or reduce damage to the faces of masonry units;

b) avoiding physical damage during erection and striking;

c) use of base plates to isolate stones or other surfaces from scaffold standards;

d) avoiding rust staining of the building.

4.4 Services

Before choosing a surface repair method, the water supply, drainage, and electricity supply should be examined to ensure they are satisfactory.

4.5 Weather conditions

Wet methods of surface repair (including repointing) should be suspended, or suitable protection provided, if there is risk of freezing of the building fabric.

In hot, dry or windy conditions, sheeting, boarding or similar should be provided to prevent rapid moisture evaporation from repaired surfaces.

5 Procedures associated with surface repair

5.1 Replacement materials

New replacement masonry units should match the old units. Physical characteristics, visual appearance, weathering performance, and method of preparation of new materials should match the old ones.

The lead-in time necessary for procurement of replacement materials should be determined and accounted for in the repair programme.

NOTE 1 Sometimes and for some materials, determining replacement materials may require scaffolding.

If a particular stone is not available, the best petrographic match should be used.

Inspection and testing of replacement stone should be carried out in accordance with BS 5390:1976. Samples of new stone should be compared with existing masonry.

NOTE 2 Replacement units for historic brickwork, terracotta, and faience are available, but sometimes may have to be specially made.

NOTE 3 Use of alternative replacement materials for historic building work is not usually recommended or necessary. In exceptional cases, poor stone in the original construction may justify replacement by a more durable stone that is otherwise compatible.

5.2 Taking down and rebuilding

If it is necessary to rebuild localized areas of historic masonry, these should be recorded before taking down. Records should include photographs, measurements, and levels, and details such as bed and perpend joint widths.

Temporarily removed masonry units should be numbered, coded to a survey drawing, and stored to prevent accidental damage or contamination.

5.3 Metal fixings

5.3.1 *Corrosion*

Corroded iron or steel cramps or dowels that have fractured surrounding masonry by expansion should be removed, if necessary, and:

a) replaced with austenitic stainless steel fixings; or

b) thoroughly cleaned on all surfaces and treated to prevent further corrosion.

NOTE Structural iron, steel frames and embedded ferrous metal fixings can sometimes be protected from further corrosion by cathodic protection.

5.3.2 *Metal components in masonry*

5.3.2.1 *General*

New masonry fixings (anchor bolts, armatures, cramps, dovetail slots, dowels, wall ties, or other reinforcement) should be of austenitic stainless steel or phosphor bronze. Masonry fixings attached to other fixings should be of the same metal or isolated to avoid bimetallic corrosion.

5.3.2.2 *Stainless steel fixings*

Stainless steel for restraint and load bearing fixings should conform to the following:

— BS EN 10088-2 for fixings made from sheet, plate and strip;

— BS EN 10088-3 for fixings made from bar and rod.

Austenitic stainless steel grades and uses should conform to Table 1.

5.3.2.3 *Nuts and bolts*

Nuts and bolts should be of austenitic stainless steel conforming to BS EN ISO 3506-1 and -2.

5.3.2.4 *Copper wire*

Copper for wire should conform to BS 2873:1969.

5.3.2.5 *Fabrication*

Welding and brazing should be carried out by skilled craftsmen with proper facilities. Procedures for testing welds should be agreed at the design and specification stage.

5.4 Removal of soluble salts

5.4.1 *Identifying salt types and quantities*

Tests should be performed to determine the level of potentially damaging soluble salts within masonry. Salt types and quantities should be determined at several locations on the masonry, at a range of depths.

NOTE This should be done by drilling the masonry.

5.4.2 *Methods of removal*

Soluble salts should be removed by one of the following methods:

a) dry brushing with bristle brushes and collection of removed salts (a dry vacuum with soft brush attachments can also be used);

b) saturation and poulticing with an inert absorbent medium (e.g. clay, paper pulp or cotton wool);

c) treatment with a sacrificial render (which breaks down or is cut away after a period of months);

d) application of acidic proprietary chemicals that combine with and neutralize inherent or deposited salts.

5.4.3 *Verification of salt reducing measures*

Tests should be performed after a programme of work to verify the level of soluble salts within masonry.

NOTE This should include drilling the masonry.

Table 1 — Austenitic stainless steel grades and uses

Grade[a]	Formerly known as	Application
1.4301	304 S15, 304 S16	General fixings
1.4303	303 S31	If significant machining is required (e.g. threaded ferrules, couplers or sockets)[b]
1.4306	304 S11	Hot working or welding
1.4401	316 S31, 316 S33	For enhanced resistance to pitting corrosion (e.g. for use on coastal sites)
1.4404	316 S11	Hot working or welding on coastal sites
1.4541	321 S31	Stabilized welding if subsequent heat treatment not required

[a] The designation system used in BS EN 10088 is defined in BS EN 10027.
[b] Not suitable for welding or working on site.

5.5 Grout filling of voids

The final strength of grout should not exceed the strength of masonry units or mortar, and the permeability of grout and masonry should be similar. Grout should have good flow properties at gravity- or low-pressure and shrinkage should be minimal.

NOTE 1 Cement grouts are brittle and extremely hard when set, and so can differ from many traditional masonry constructions. Cement grouts can contain alkali salts that can cause staining and damage to masonry.

WARNING Commercially available grouts containing soluble salts, that set hard or inhibit moisture movement within the wall, should not be used on historic fabric.

Gravity grouting should be carried out gradually to prevent excessive saturation, bulging and bursting. Leaking grout should be removed from the wall face as soon as possible.

NOTE 2 Several non-destructive investigation systems to locate voids in walls are listed in annex A.

6 Pointing and bedding mortars

COMMENTARY Replacement of the outer zone of mortar between masonry units is known as repointing. Pointing mortars are not always of the same composition as bedding or core mortars, and make a distinctive contribution to the appearance of the wall. The primary functions of mortar in a wall are:

— to bond units together to resist lateral forces;

— to provide an even bed, so that the load on the wall is distributed evenly over the whole bearing area of the units;

— to inhibit wind and rain penetration, but also allowing drying out.

6.1 Mortar sampling and analysis

Sampling of mortar for analysis should be carried out as follows.

a) A coordinated sampling programme should be prepared by persons experienced with the masonry and involved in its repair.

b) The location of mortar samples should be recorded on a drawing. A photographic and written description should be prepared of each sample, showing the nature and condition of the masonry.

c) Clear differentiation should be made between original and repointed mortars. Render materials should be separated into individual layers.

d) Samples should be discreet lumps (not powder).

NOTE 1 About 40 g to 50 g is usually required for comparative analysis and for reference material.

e) At least three samples should be taken from different areas and analysed.

f) Samples should be clearly labelled.

g) The testing laboratory should be informed of the exact information required from analysis. The range and type of tests should be agreed prior to sampling.

Chemical analysis of mortars should be undertaken in accordance with BS 4551:1990. Interpretation of results should be closely linked with visual examinations.

The type, shape and colour of aggregate particles should be determined by acid-wash separation (for non-calcareous aggregates), sieve grading, and visual examination by hand lens or low-powered microscope.

NOTE 2 Thin section petrographic analysis may be required for determining binders and aggregates. In exceptional cases, additional tests may be required to ascertain natural organic substances.

6.2 Repointing mortar

6.2.1 *Selection criteria*

Repointing mortar should be chosen on the basis of the resistance of the masonry unit to weathering and should match the appearance, permeability and mechanical properties of the original mortar, including adhesion, ability to tolerate movement, strength, and durability (resistance to damage by frost and salts).

NOTE Guidance on specifying the quality of building mortars is given in PD 6472.

6.2.2 *Mortar groups and mixes for repair work*

Old mortars should be repaired with materials and mixes that match the original as closely as possible. Mortars for repair work, in a wide variety of conditions and exposures, should conform to Table 2.

Mortar mixes for groups A1 to D5 should conform to Table 3.

COMMENTARY There are no standard mixes for repair work, and adjustments should be made to match the appearance and composition of the original mortar, type and condition of stones or bricks, and the degree of exposure. Specialist advice should be sought on which mix should be used in each case.

6.2.3 *Compatibility with existing mortar*

Replacement mortar should be compatible with and should match the unweathered interior of the original mortar, in composition, strength, colour, and texture.

Pigments should be used if colour matching cannot be obtained from the aggregates. Pigments should be colourfast and should conform to BS 1014 if possible.

NOTE BS 1014 does not cover the full range of colours. Other pigments may be used if known to be satisfactory.

It is essential that pigments are stable, that they are not affected by lime or exposure to light, and that they are not easily leached out by water. Pigments should not have adverse effects on cement or other constituents. Accurate mixing and batching are essential for consistency of colour.

Table 2 — Mortar types and applications

Mortar mix group	Typical applications and exposure conditions	Characteristics of mortar mix groups
A	Use with dense, impermeable, durable materials (e.g. granite, basalt, flint, or well-vitrified brick), especially where there is severe exposure (sea and river walls, retaining walls, paving, plinths, and copings)	Decrease in strength and resistance to frost and salt damage ⇓
B	Use with durable, moderately permeable limestones and sandstones, semi-vitrified brick, and group B materials with less severe exposures. Suitable for all exposures and high demands (e.g. mortar fillets)	
C	Use with weathered materials from groups A and B that are tending to scale and powder, in all exposures and locations. Suitable for less durable limestones, sandstones and bricks in all locations	⇑ Decrease in workability and ability to accommodate movement
D[a]	Use with less durable material (e.g. some calcareous or argillaceous sandstones, fine-grained limestones, or soft gauged bricks)	

[a] Group D mortar mixes may be used as with materials in groups B and C in sheltered environments and locations other than paving and major weatherings.

Table 3 — Mortar mixes for groups A1 to D5

Mortar mix group	Binder[a]						Aggregate[a]	
	White cement or OPC[b]	Masonry cement[c]	Eminently hydraulic lime[d]	Moderately hydraulic lime[d]	Feebly hydraulic lime[d]	Non-hydraulic lime[e]	Brick dust pozzolan[f]	Sand or other fine aggregate[g]
A1[h]	1					½		4 to 4½
A2[h]		1						2½to 3½
A3[h]		1						4 to 5
A4	1					1		6
A5			1				½	2½
A6			1					3
B1	1					2		9
B2			1					4
B3				1			½	2½
B4				1				3
C1	1					3		12
C2					1		½	2
C3					1		½	2½
C4					1			3
D1						1	½	2½
D2						1	½	3½
D3						1		3
D4						1		4
D5[j]						1		1

[a] Proportions are by volume.
[b] White cement or ordinary Portland cement (OPC) conforming to BS 12 may be used. Cements should be slurried to a thin cream before blending with lime putty and aggregates, especially if small amounts of cement are used.
[c] Masonry cement should conform to strength class MC 12.5 of BS 5224:1995.
[d] Hydraulic limes are natural hydraulic limes classified in DD ENV 459-1:1995. The designations in this table are equivalent to NHL 5 (eminently hydraulic lime), NHL 3.5 (moderately hydraulic lime) and NHL 2 (feebly hydraulic lime) in DD ENV 459-1:1995.
[e] Non-hydraulic lime is high calcium or dolomitic lime conforming to BS 890:1995. It is available as putty or hydrated lime powder.
[f] Brick dust is fired, ground clay brick in the particle size range 38 μm to 75 μm. It is used primarily as a pozzolanic agent, reacting with lime and water to form a hydraulic set. Most reactive brick is fired at low temperatures (900 °C to 1 000 °C).
[g] In general, sand and other fine aggregate should conform to BS 1199 and BS 1200.
[h] A1, A2 and A3 mortar mixes should not be used on historic masonry.
[j] Group D5 mortar mix should be used for very fine joints in ashlar or gauged brick, using soft sand or stone dust as aggregate.

6.3 Matching old mortars

COMMENTARY Mortars consist of binder and aggregate materials and are designed so that the voids between the sand or other aggregate are filled with binder paste. The amount of binder used depends on the grading and particle shape of the aggregate. Until early in the 19th century, mortars were generally based on lime or clay binders. These could include a wide variety of aggregate materials, including sand, charcoal, crushed stones and shells, as well as various pozzolanic additives (e.g. volcanic ash, crushed brick). Old mortars may also include natural organic substances added to impart particular physical properties (e.g. animal hair and straw to improve binding qualities, urine or beer to aid carbonation, glucose to provide air entrainment, tallow and linseed to increase water repellency). In modern mortars, aggregate types are generally less varied. Lime is not widely used, and there is wider use of cements and other set-control and workability additives.

6.3.1 *Aggregates*

Aggregates should match the original as closely as possible. Sand for repair mortars should be clean and well graded with particles ranging from 2.36 mm to 150 μm mesh. Sand should conform to BS 1199 and BS 1200.

NOTE 1 Angular sand (sharp sand) can be mixed with sand of rounder particles (soft sand) to achieve both good cohesion and workability.

NOTE 2 Inclusion of porous particulates (e.g. crushed limestone) in an aggregate helps to entrain air in the mortar mix, promoting carbonation and enhancing frost and salt resistance. Colour, porosity and particle size should be considered carefully if choosing a porous particulate.

Natural aggregate other than sand should conform to BS 882 and BS 63-2. Guidance on methods of test to determine particle size distribution in aggregates is given in BS 812-103-1.

6.3.2 *Matching non-hydraulic mortars*

6.3.2.1 *Lime mortar*

COMMENTARY Old mortars often consist of non-hydraulic lime and sand, which carbonate with air for setting and hardening. These mortars strengthen very slowly; stiffen by losing water into the masonry and by evaporation, and harden by reaction with atmospheric carbon dioxide.

Non-hydraulic lime consists primarily of high calcium or dolomitic lime and should conform to BS 890.

NOTE 1 Traditionally, non-hydraulic limes were prepared and used in putty form. Modern limes, however, are usually slaked with just enough water to form a powder known as hydrated lime. Putty and hydrated lime powder are readily available.

Table 4 shows the range of mixes that can be made using non-hydraulic lime binders. The mortar mix should be compatible with and should match the original mortar. Specialist advice should be sought when choosing a mortar mix.

Table 4 — Non-hydraulic mortar mixes

Group	Binder		Aggregate[a]
	White cement or OPC	Non-hydraulic lime	
A1	1	2	4 to 4.5
A4	1	1	6
B1	1	2	9
C1	1	3	1.5
D3	—	1	3
D4	—	1	4
D5	—	1	1

[a] Sand or other fine aggregate.

Lime obtained as putty direct from the slaking process should be used for repair work to historic buildings. Lime putty should be matured for at least 2 months prior to use if possible.

Putty should be kept covered by water for at least two weeks for general use.

NOTE 2 For other work, or if putty lime is not available, dry hydrated lime (bagged lime) can be converted to putty by soaking under water for at least 24 h before use.

In order to achieve a good base for a mortar or plaster, slaked lime putty should be mixed with the sand and other aggregates. The combined constituents should be stored together as wet "coarse stuff" for as long as practicable (preferably in plastics bins with airtight lids).

Coarse stuff should be thoroughly final mixed or "knocked up", using a mortar mill or with thorough beating and ramming with a simply made wooden rammer or pickaxe handle, to increase the overall lime-aggregate contact and to remove surplus water, to create a highly plastic and workable material.

6.3.3 *Lime mortar with pozzolanic additives*

COMMENTARY Pozzolans are fine siliceous materials such as low-fired bricks ground to a powder, pulverized fuel ash (PFA), and high temperature insulation (HTI) powder that, when added to a lime-sand mortar, provide an additional chemical set and improve frost resistance. Pozzolans react with lime in a mix to form calcium silicate cementing compounds.

Table 5 shows mixes that can be made using a non-hydraulic lime binder with pozzolanic additives.

Table 5 — Lime mortar mixes with pozzolanic additives

Group	Non-hydraulic lime binder	Aggregate	
		Pozzolanic additives	Sand or other fine aggregate
D1	1	0.5	2.5
D2	1	0.5	3.5

Because pozzolans vary in reactivity, trial mortars should be prepared in order to assess their effects.

6.3.4 *Matching hydraulic lime mortars*

COMMENTARY Hydraulic limes set, at least in part, by chemical reaction with water. The raw material for hydraulic limes is limestone, which contains clay and calcium (and magnesium) carbonates. In general, the rate of setting in water and the ultimate compressive strength increase with higher hydraulicity. Properly prepared, hydraulic lime mixes should have relatively low shrinkage.

On-site trial mortar samples should be prepared to test that the chosen hydraulic lime produces a mortar of the desired characteristics.

Hydraulic limes should be classified by the constituent amount of active clay materials (see Table 6).

Table 6 — Classification of hydraulic limes

Classification	Active clay materials	Typical colours
Feebly hydraulic	<12 %	off-white or pale grey
Moderately hydraulic	12 % to 18 %	pale grey or pale buff
Eminently hydraulic	18 % to 25 %	grey or brown

COMMENTARY Feebly hydraulic limes set more slowly and have a lower compressive strength than eminently hydraulic limes. Some eminently hydraulic limes are pregauged with cement to ensure consistency of hydraulicity, which leads to variability in colour and salt content. These factors should be taken into account if choosing materials for work in which consistency of colour and/or sensitivity to salts are important.

NOTE 1 Several hydraulic limes are available and technical literature should be studied to determine whether other additives are present in proprietary products.

Moderately and eminently hydraulic limes should be mixed with selected aggregates and used like cements. These types of mortar are typically usable for up to 4 h, but eminently hydraulic types may begin to set after 2 h.

NOTE 2 Hydraulic lime mortars should not be knocked up again and reused after stiffening has begun.

6.3.5 *Matching cement-lime-sand mortar*

COMMENTARY Cement-lime-sand mortar is mortar in which part of the lime is replaced by cement, and so early strength is obtained without too high a mature strength, but good working properties, water retention, and bonding are retained. Recent research (Teutonico et al., 1994) has shown that addition of very small quantities of cement to lime mortars (less than ¼ part in a 1:3 lime-sand mix) can reduce the strength and durability of lime mortars, but substantial quantities of cement can create mortars that are too strong and impervious for use on historic masonry.

Cement-lime-sand mortars should be mixed and used as shown in Table 3.

6.3.6 *Matching cement-aggregate mortar*

COMMENTARY Portland cement is combined with aggregate to provide rapid development of strength in the early stages and in the fully hardened mortar. It may not be practical to adjust the strength simply by varying the ratio of cement to sand because lean mixes of cement and sand are harsh and unworkable. However, air entraining agents and/or inert fillers may be used for this. The good working properties of mortar mixes made with masonry cements are derived from the plasticizing effects of the fine material and entrained air.

Air entraining admixtures in cement-aggregate mortar, if used, should conform to BS 4887-1. Pulverized fuel ash for use with Portland cement should conform to BS 3892-1.

NOTE Plasticized Portland cement-based mortars should not be used in repair and maintenance work to older buildings.

COMMENTARY Masonry cement has been used since 1914 when it was developed to provide better workability and water retention than cement-sand mortars. Masonry cements are based on Portland cement but include fine mineral fillers and air entrainers.

6.4 Proprietary mortar materials

Proprietary mortar materials should be suitable for their intended purpose.

NOTE Traditional lime putty mortars to match original mortars may be available off-the-shelf.

Ready-mixed lime-sand for mortar and ready to use retarded cement-lime-sand and retarded cement-sand mortars should conform to BS 4721.

Dry packaged cementitious mixes should conform to BS 5838-2.

Gun-applied mortars may be used for repointing large areas of uniform sized facing material, e.g. brickwork, but are not generally recommended for historic work.

Proprietary mortar materials should be applied as recommended by the manufacturer, unless professional advice or on-site conditions indicate otherwise.

6.5 Construction sealants

COMMENTARY In the past, mastic pointing was used for window sills and their surrounds and engineering brickwork. Traditional mastic pointing was prepared from litharge (lead oxide), linseed oil, sand (sometimes with brick dust added for colouring), and whiting (crushed chalk). The irregularity of weathered masonry units makes neat application of sealants and their effective adhesion to joint surfaces difficult to achieve.

In historic masonry, consideration should be given to use of traditional fillers (e.g. sand, lime putty, hair).

Sealants should be selected in accordance with BS 6213.

NOTE Some sealants can cause staining of stone and manufacturer's confirmation of fitness for purpose should be sought. Many sealants also require a primer.

7 Repointing

7.1 General

7.1.1 *Localized repointing prior to cleaning*

Where joints are heavily weathered and can permit penetration of cleaning water or chemicals, localized repointing should be carried out before cleaning. Deteriorated or open joints should be temporarily sealed with removable non-staining materials.

7.1.2 *Water quality*

Water used in mortar mixes should be potable. If mains water is not available, it should otherwise be clean and should not contain material (in solution or suspension) in quantities sufficient to harm mortar or metals, or to impair durability of construction. If the water quality is not known, it should be sampled and tested in accordance with BS 3148.

7.2 Specification of work to be undertaken

The standard of work should be clearly specified at each stage [e.g. raking out of joints (cleaning of loose, weathered mortar with hand-held, non-mechanical tools), replacement of pinnings, placement of mortar (including cleanliness of the masonry face), joint finish, finishing procedures].

The wall should be assessed to establish which areas should be cut out and repointed. The assessment should take into account damage that could occur duing cutting out mortar, the degree of weathering to the masonry units and the visual effect of repointing.

NOTE Pointing that has become only moderately weathered over many decades should not require repointing.

7.3 Workmanship

7.3.1 *Skills*

Repointing should be carried out by experienced craftsmen as removal of existing material involves risk of damage to arrises. Skills selected for preparation and placement of mortar should be suitable for purpose.

7.3.2 *Samples of work*

Test panels should be prepared prior to repointing so that precise methods, mixes and appearance can be designed.

Samples of the following should be approved by the contract administrator/supervizing officer prior to repointing masonry:

a) cutting out of joints;

b) prepared mortar;

c) mortar placement, including surface finish, appearance on drying out, and cleanliness of surface of repointed unit.

7.3.3 *Cutting out*

Joints should be cleared of mortar prior to repointing without damaging the arrises or faces. Old mortar in joints should be cut out to a depth not less than 20 mm and not less than twice the thickness of the joint. (This depth should be increased in areas of high exposure.) Wide joints, especially if liable to extreme weathering, should be cut out to at least 38 mm to 50 mm.

NOTE 1 It may not be possible to achieve this in joints less than 3 mm wide, in which case the cutting out should be as near to 6 mm deep as achievable without damage.

NOTE 2 Techniques for cutting out joints of weathered masonry can vary depending on the joint thickness, the shape and susceptibility of the masonry unit to damage, and the condition of the original mortar. For brickwork with thick joints, cutting out may be carried out by hand with small masonry tools (e.g. hammer and chisel).

For stonework with narrow joints, hand-held saws and hacksaw blades should be used (purpose-made tools may be required for clearing out deeply weathered joints). Cutting out should not increase the thickness of joints and should leave a neat, square face at the back of the joint.

NOTE 3 Mechanical cutting tools can assist in removing hard, cementitious repointing mortars, with the work finished by hand. These tools should only be used where they cannot damage masonry units.

Dust and loose material should be cleared from joints by air or clean water.

7.3.4 *Mortar placement*

Joints should be thoroughly (but not excessively) cleaned and wetted before placement of new mortar.

Mortar for filling joints should be compacted in to ensure maximum penetration and bond to the original bed. Pointing tools should fit the joint thickness. When replacing stone inserts such as pinnings during repointing, the load-bearing purpose of these should be reinstated.

Where mortar in joints has disintegrated to a large depth, it should be deep tamped with replacement mortar, and, if necessary, hand grouted to fill the joint to the depth required for pointing. Mortars should be placed in layers. Each underlying layer should be initially set, not fully dried out, prior to placing the next layer.

Generally, mortar should not extend beyond the joint [mortar should not spread over the face of masonry unless this occurs in the original finish (e.g. Scottish slaister)]. For weathered masonry in which units have lost their arrises, mortar should be kept back from the worn arrises to avoid an apparent increase in the thickness of the joint, and creation of feathered edges.

Care should be taken not to spread or smudge mortar on the face of masonry units (it should not be necessary to use chemical mortar removers).

NOTE 1 Some masonry and pointing materials can be dissolved by chemical mortar removers.

Mixing and batching of mortars should be carried out in accordance with BS 5390. If weight batching is not practicable, volume batching should be specified, and accurately constructed gauge boxes used. Lime putty mortars should be mixed by hand or with a pan or roller mill.

NOTE 2 Lime putty mortars are generally firm and do not require additional water.

Non-hydraulic lime and inert aggregates may be combined well before use but should be kept in airtight containers. Pozzolanic constituents (including cement) should be added to mixes just before use.

7.3.5 *Joint finish and pointing profile*

COMMENTARY Masonry for repointing should itself be used as the main reference for selection of a pointing profile. If the original finish of a large proportion of joints is weathered, or the masonry units are heavily weathered, a flush-faced pointing slightly recessed to remain within the original joint width should be used. Press mortar flat into the joint with the back of a purpose-made pointing key that fits into the joint width. Excess fines should be removed from the mortar face after initial stiffening using a stick or coarse sacking. (Alternatively, the face should be stippled or brushed with a natural bristle brush.)

Repointed areas should match the original pointing profile where it is evident. Unless originally designed as a special feature, the appearance of joints should be subservient to the masonry material.

NOTE Narrow joints in stone, ornamental brickwork, or terracotta require special repointing procedures. It may be better to leave them untouched rather than to risk change.

8 Stone masonry repair

8.1 General

It is essential to understand the nature and condition of stonework prior to preparation of a repair programme. The following should be considered:

a) the type or types of stone;

b) the method of construction;

c) fractures due to loading or movement;

d) the extent, cause and nature of weathering;

e) the type of decay (e.g. surface crystallization, contour scaling, sulfate skins);

f) incorrect bedding;

g) weathering of soft beds, vents and shakes;

h) damage from rusting iron.

8.2 Repairs using natural stone

8.2.1 *Use of stone*

In most cases natural stone should be used for surface repairs. Before starting work, the original stone should be identified, and enquiries should be made to find out if it is still quarried. If available, the quality should be checked. If the original stone is not available, a matched alternative should be chosen. It is important to match block size, but stone should primarily be matched on colour, texture, porosity, strength, and durability.

Where a substitute stone is used, differences between it and the original should be understood. The two stones should be petrographically compatible.

Stones should be bedded in accordance with BS 5390. Generally, stones should be laid on their natural bed (edge or joint bedding can be used for projecting features and copings). Arch stones should be bedded at right angles to the thrust.

8.2.2 *Full stone replacement*

Defective stones should be carefully cut or sawn out, without overruns, to a depth sufficient to remove all decay and to give a good seating for replacements. The minimum depth for replacement ashlar units should be 100 mm.

NOTE 1 Greater bedding depths may be required for overhanging stones or where a stone is replaced to its full original depth.

Cavities should be cleared of stone and mortar residues and rinsed with clean water.

Replacement stones should match the size, profile and finish (surface tooling) of the original unweathered face and wall alignment, where these can be established.

Joints to the rear and sides of new ashlar blocks should be filled with mortar slurry of appropriate constituents and softness. The stone should be supported on shims to ensure the original joint widths are maintained. Supports should not impose excessive point loads on the stone.

Joints surrounding new stone should be repointed to match the original pointing.

Stones should be secured within the original opening using stainless steel dowel fixings where necessary.

NOTE 2 Replacement of larger stones (e.g. cornice units) may require more elaborate fixing procedures.

8.2.3 *Replacement of carved stone*

Carving of replacement stone should be carried out by a stone carver where appropriate. New pieces should match the features, size, nature, and quality of carving of the original work. Installation of new pieces should be undertaken by a mason experienced in fixing techniques.

8.2.4 *Piecing-in repairs*

COMMENTARY New stone for repair work may gradually tone in as it weathers, but is unlikely to appear exactly the same as the original stone. In the long term, the visual match achievable with new stone is usually better than with a mortar repair.

Repair of local damage to large stones (e.g. damage caused by rusting cramps or fixings) may be carried out by piecing in matching stone.

NOTE Piecing in repairs usually require a minimum depth related to the surface area and ranging between 50 mm and 100 mm. This may also vary depending on the stone, size and extent of the repair and the degree of decay.

The damaged area should be cut out to a rectilinear surface shape of appropriate depth. The new piece of stone should fit the prepared cavity exactly with no joint between the edges of the repair within the block. No jointing material should be visible at the interface of the stone with the stone indent. Natural stone indents should not cross over existing joints.

The rear of stone indents may be secured to the main block with non-ferrous or stainless steel dowels. Epoxy resin should be used only to secure dowels, not to fill the side or rear faces of the repaired area. A fine-grained modification of repair mortar should be used.

The finished face of the repair should exactly match the original masonry outline. The final profile or surface texture of the repair should be worked in situ to ensure this.

8.2.5 *Stone or brick tile repair*

Where appropriate (depending on location and materials), clay or stone tiles, usually bedded horizontally, can be used for surface repair. Tiles and mortar should be of lower strength and higher porosity than adjacent masonry, and repairs may be visible or covered.

8.2.6 *Synthetic adhesives*

Synthetic adhesives (e.g. thixotropic epoxide resin), to fix portions of stone that have become detached, or to secure fixing dowels, should only be used locally to the rear of a repair area. Remaining gaps should be grouted up and joints finished with normal bedding mortar. Care should be taken to avoid spillage of adhesive on face work. Adhesives should be mixed and applied by experienced applicators.

Resins should only be used in limited applications (e.g. to secure fixings).

8.3 Repairs with manufactured (cast) stone

COMMENTARY Manufactured (cast) stone is made from a mix of aggregate and cement, and any initial similarity in appearance between it and natural stone can soon diminish because of differences in weathering, soiling and organic growth promoted.

Manufactured (cast) stone should not be used in repairs to listed buildings, unless originally used, or else there is no petrographically matched alternative or source of reclaimed stone. Guidance on specification for cast stone is given in BS 1217.

8.4 Mortar repairs with special mortars

8.4.1 *General*

COMMENTARY Mortar repairs minimize disturbance of the original fabric but allow matching to worn surfaces, particularly in carved or moulded work. They can be used to remake previous mortar repairs undertaken in incompatible mortars. Special mortars are used instead of stone for repairs to areas of localized damage.

NOTE Mortar repairs using special mortars should only be carried out by skilled workers able to produce high quality results.

Mortar repairs should be limited to areas of low to moderate exposure, or, if required on areas of high to extreme exposure (e.g. on copings, cornices), a lead flashing covering should be provided.

8.4.2 *Special mortars*

Ingredients for special mortars for repairs should be carefully selected. Special mortars should be based principally on natural aggregates, of which a proportion may be the same as the stone to be repaired. Colour matching should be obtained with natural materials if possible. Pigments should be colourfast and should conform to BS 1014.

Special mortars for repairs should be compatible with the stone, should be permeable, and should not impose new stresses. Mortars should be of similar porosity and permeability as the host stone to enable uninterrupted flow of moisture between the repair and the stone. For repairs to limestones, mortars should generally be lime mortar based, with small amounts of cementitious or pozzolanic additives. For repairs to sandstones, consideration should be given to use of hydraulic limes with a low free lime content.

Samples of repairs should be carried out in situ, prior to final agreement of appropriate repair mortars.

8.4.3 *Preparation of repair area*

The repair area for mortar repairs should be neatly scribed to a rectangular shape. Decayed stone should be cut back to a sound and even base and the new surface well keyed. All edges should be as sharp as possible and slightly undercut to avoid feathered edges (except for the bottom edge, which should be straight cut). Edges of repairs should be parallel to the existing jointing.

Mortar repairs should not bridge original joints. If a repair is required in such a position, a joint should be cut through, following the line and thickness of the original joint. Stone should not be weakened by preparatory works. A balance should be made between producing a mortar repair of sufficient depth and removal of sound material.

8.4.4 *Placement and finish of repair*

Repair mortars should be applied to prewetted cavities. Repairs should be at least 20 mm in depth. For large areas, the recommendations of BS 5262 for application of external rendered finishes should be complied with. Joints surrounding the repair should be repointed. Repair mortars should be built up in layers of 9 mm to 12 mm. Each layer should be initially set before rewetting and placing the next layer. Lime and aggregate mortars should be compacted firmly, covered, and allowed to cure slowly.

The surface of each layer should be scratched or abraded to provide a mechanical key for subsequent layers.

The final finish of a repair mortar should be achieved to the appropriate profile using a wood or felt covered float, a coarse cloth, or a damp sponge. Steel trowels and dry, absorbent pads should not be used for this purpose. Alternatively, the final finish can be prepared by scraping back a small excess of mortar to a finished line, leaving a slightly textured finish. Mortar repairs should be protected from sun, frost, or other rapid drying conditions.

NOTE Rapid drying can be prevented by localized measures such as covering with damp cotton wool pads, sacks, or plastics sheeting, and intermittent hand spraying of covered areas with water.

8.4.5 *Armatures*

Repairs to projections should be reinforced with stainless steel or non-ferrous armatures. The reinforcement should be fixed to the sound stone with synthetic adhesives.

8.5 Repair of stone fractures

The reason for a fracture occurring through a stone should be established before an appropriate repair technique can be selected. With significant fracturing in masonry, structural engineering advice should be sought before carrying out surface repairs.

If movement is suspected and structural monitoring is carried out, the line of fracture should be filled with a soft mortar and the void grouted, with both filling materials softer than the stone.

Corroded ferrous cramps and other fixings that have caused fracturing in stonework should be removed and treated or replaced with non-ferrous fixings.

Where a fractured piece of stone can be reattached, the rear should be pinned with non-ferrous dowels in addition to mortar bedding.

NOTE For reattachment of very small pieces of fractured stone, an adhesive may be required.

Dowel holes should be drilled at angles across the fracture and thoroughly cleaned. A threaded stainless steel pin embedded in thixotropic epoxy resin should then be inserted. The end face of each pin should terminate 25 mm from the face of the stone. The remainder of the hole should be filled with a stone plug or, for special mortars, a repair.

8.6 Descaling

Superficial powdering and scaling should be treated by stiff bristle brushing or hand-held carborundum block rubbing.

8.7 Redressing stone

NOTE Redressing stone is removal of loose pieces from the face by tooling rather than brushing. The procedure is rarely used on historic masonry because it removes the face of the stone and therefore the original tooling or other finishes.

Redressing should be used in cases of severe surface deterioration within otherwise sound blocks. The work should be carried out by skilled stone masons using hand techniques.

8.8 Lime method of repair and treatment of limestone

Cleaning, stabilization, surface repair, and shelter coating of decayed limestone should be carried out using the lime method (see annex B).

9 Brickwork repair

9.1 Characteristics

Replacement brickwork should match the original bricks, mortar, joint profile, and bonding.

9.2 Replacement bricks

9.2.1 *General*

Replacement bricks should match the originals in material, size, colour, texture, density, hardness, and porosity.

9.2.2 *Reversed bricks*

In historic work, it may be possible to cut out deteriorating bricks, clean off the mortar, and reuse them with the face reversed.

9.2.3 *Salvaged bricks*

Bricks salvaged from other locations on a building should be confirmed by the contract administrator/supervising officer as suitable for repair work, as different brick types may have been used in the original construction.

9.2.4 *Secondhand bricks*

Bricks for repair work originating from other buildings should be sound and unspoiled on the external face. Secondhand bricks should not originate from a contaminated source (e.g. a chimney stack).

If old bricks are recycled for repairs, representative samples should be tested for quality and salt content (particularly for repairs exposed to high moisture and freeze/thaw cycles).

The original colour and unweathered texture and profiles should be matched.

9.2.5 *New bricks*

Replacement new bricks should match the original bricks in size, colour, and texture and samples should be compared with originals at each of the locations on site, for matching.

NOTE 1 New bricks are available for historical brick repairs.

Clay bricks should conform to BS 3921 and calcium silicate (sand-lime and flint-lime) bricks should conform to BS 187. Clay and calcium silicate modular bricks should conform to BS 6649.

NOTE 2 Guidance on specification of dimensions of bricks with special shapes and sizes is given in BS 4729.

9.3 Brick replacement

9.3.1 *Extent of replacement*

The extent of surface repairs to brickwork should be decided considering the condition of bricks and the ease with which cutting out can be performed. The brickwork bond, function of the wall, and strength of the bedding and pointing mortars should be considered prior to carrying out repairs.

If there is any structural risk, engineering advice should be sought regarding cutting out and rebuilding of areas of brickwork.

9.3.2 *Preparation*

Cutting out should be performed with minimal disturbance to adjacent sound brickwork.

NOTE Small scale mechanical cutting and drilling methods can be used to assist hand tools. Hand tools are normally used to finish off preparation of an opening.

Preparation should not damage adjacent bricks or brick arrises, or increase the width of joints.

Care should be taken that fragments do not drop into the cavity of cavity walls during cutting out.

Where whole bricks are replaced, bricks should be cut out to a minimum single brick depth.

For brickwork of historic value or where structurally necessary, header bricks should be replaced to full depth.

9.3.3 *Brick placement*

Replaced bricks should be fully bedded in mortar to ensure thorough rebonding into the wall.

Mortar for rebuilding should be compatible with the original mortar. Excessively strong mortars or grouts unable to accommodate building movement should not be used.

Dry packing to the top joint of a repair area should use a compatible mortar. (This should be placed with a purpose-made pointing key that fits into the joint width and that can be used to push the material to the rear of the joint and compact it.)

9.3.4 *Brick slips*

Where cutting out is likely to disturb adjacent sound brickwork, a brick slip should be inserted rather than a full-sized unit. Brick slips should also be used at points on a facade where, for structural reasons or cost, it is necessary to minimize the depth of brickwork to be cut out. Brick slips should be at least 30 mm thick, and should be specially manufactured or cut from whole bricks ("L" shaped slips for use on opening reveals can be cut from whole bricks).

Repairs using brick slips should be limited to individual bricks or to relatively small areas of up to six bricks. Slips should be solidly bedded on mortar that enables the original moisture circuitry of the wall to continue. Additional mechanical support should be provided by small-scale dowels if required.

Brick slips should only be used in unexposed areas.

9.3.5 *Non-ferrous ties and pins*

Where the repair area is extensive, new matching brickwork should be tied in with header bricks or non-ferrous or austenitic stainless steel ties or anchors to provide mechanical bonding. Ties should be inserted on a staggered grid of 450 mm.

9.4 Repairs to ornamental brickwork

9.4.1 *Gauged brickwork*

COMMENTARY In gauged brickwork soft bricks are cut to shape and rubbed to a high degree of accuracy. Gauged brickwork should only be undertaken by suitably skilled craftsmen. Sharpness and precision are vital to the effect of the finished work and joints should rarely exceed 3 mm in thickness.

Repairs and pointing to rubbed and gauged brickwork should only be carried out where essential (e.g. if there is water penetration, or if an arch is on the point of collapse).

Where possible, rubbed brickwork should be dismantled and rebuilt using the original bricks, and lime putty as the jointing medium. Construction should match the original exactly.

NOTE 1 Replacement of loose and decayed individual bricks is sometimes possible but complicated.

New bricks should be identical in shape and size and of similar colour and texture to the originals. Matching should be carried out on site.

NOTE 2 Soft rubbing bricks are available for replacement. Harder bricks can be cut to shape by diamond saw.

Joints should be even and should match the original width exactly. Special precautions (e.g. taping) should be taken to prevent bedding or pointing medium depositing on the face of finished work.

Carved or moulded work should be accurately reproduced.

NOTE 3 Existing carved or moulded work is often of sufficent value that it should be retained and stabilized, not replaced.

9.4.2 *Carvings and mouldings in ordinary brickwork*

Where ordinary bricks have been used for carvings and mouldings, repairs should be carried out without dismantling, wherever possible. New bricks and mortar should match the originals in dimensions, colour, and texture, and carved and moulded work should be carefully reproduced by skilled craftsmen.

9.4.3 *Patterned and polychrome brickwork*

Repairs to patterned and polychrome brickwork should be carried out by skilled craftsmen. Suitable replacement bricks should be obtained.

NOTE 1 Several types of replacement brick may be required.

NOTE 2 Original header bricks that have lost their glazing can be reglazed, or replacement glazed bricks can be made.

9.5 Patch repairs with mortar

Mortar should only be used for minor repairs to isolated bricks. The damaged area of the brick should be cut back to a sound face at a depth of at least 20 mm. Repair mortar may contain coloured sands and other crushed masonry aggregates, pozzolans and binders of cement, lime or resin.

Joints should be cut out and pointed separately.

10 Repair of terracotta and faience

10.1 General

COMMENTARY Terracotta and faience from different areas and geographic locations have characteristic differences and durability. Throughout the 19th and early 20th centuries when production was widespread, a variety of clay types were used to produce kiln-fired slabs or hollow blocks, to which special surface textures or finishes were applied. Terracotta and faience can range from facing slabs and ashlar blocks to decorative friezes or greater than life-size figures. Units may be individually made or mass produced. Surface textures and finishes include fireskin, slip, engobe, or glaze. Terracotta blocks are formed by building clay walls approximately 35 mm thick. Hollow cells formed in the back of the block by addition of strengthening webs may be designed to accommodate metal fixings. Voids generally require filling with a weak concrete mix.

Wherever possible, the original characteristics of terracotta and faience should be matched.

NOTE This standard does not cover repairs to glass or ceramics mosaics. Specialist advice should be sought concerning these.

10.2 Faults in terracotta and faience

COMMENTARY Faults in terracotta and faience can arise from manufacture, methods of construction, weathering and associated deterioration, inadequate maintenance (particularly of joints), damage, and inadequate previous repairs. Inherent faults include underburning (underfiring), incorrect packing of clay, poor glaze fit (crazing), staining, warping, and cracking. Construction faults can include excessively hard mortar in joints, incomplete void filling, incompatible fillers, rusting iron cramps/supports, stress cracking due to insufficient allowance for movement, and soluble salt crystallization from some mortars. External decay mechanisms can include effects of weathering, abrasion of surface coatings, effects of biological systems, and damage caused by fixings. Some faults may require immediate repair. Certain other defects (e.g. crazing) are not a serious problem.

Causes of defects to terracotta units and their facade should be determined before a repair programme is prepared. The method of construction of terracotta facades should be established at an early stage. Structural engineering advice should be sought if underlying structural defects are suspected.

10.3 Inspection

Terracotta and faience should be surveyed at close range. If necessary, inspections should be carried out from a platform to locate all defects.

NOTE 1 Open joints and small fractures can give significant clues to hidden trouble.

Non-destructive testing methods should be carried out to locate voids and ironwork within the structure (see annex A), or exploratory opening-up work where appropriate.

NOTE 2 Rusting iron, sulfate-rich concrete packing and excessively hard pointing mortar are the sort of items that can lead to more work than is at first determined. Embedded iron or steel may be in the form of structural members or armatures for items such as balusters, cornices and balconies.

A survey of a terracotta facade should identify each unit that should be replaced or repaired, and the category of repair required. Areas to be taken down and rebuilt should be identified. Methods for cleaning and treatment of exposed steel or ferrous fixings should be clearly stated.

10.4 Conservation of items of special value

The artistic quality of conservation terracotta and faience should be of the same standard as original work.

Conservation of items of special value (e.g. a Coade stone frieze) should be carried out by a specialist terracotta conservator.

10.5 Replacement materials

10.5.1 *Available materials*

Replacement terracotta and faience should be used to replace units that are beyond repair.

Contracts with replacement terracotta manufacturers should be planned to allow for investigative work and production times. A production and delivery schedule should be agreed.

10.5.2 *Matching*

Replacement units should match the originals in surface colour, texture, and finish as closely as possible.

Drawings of replacement units, including details of fixings, should be prepared in conjunction with a fixing contractor. At least three samples of replacement material, indicating the range of colours and textures in the body clay, and surface finishes of replacement material, should be provided to enable the specifier to make an informed choice.

Dimensional tolerances should be established in consultation with the manufacturer at the specification stage. The nature and extent of acceptable defects in replacement blocks should be specified. Tolerances should closely match those of the existing material in dimensions, squareness, colour, texture, and surface quality.

Terracotta blocks should fit tightly and should be very closely bonded to the backing structure. Fixing of replacement units should be carried out by skilled craftsmen.

10.6 Removal of deteriorated blocks

Removal of terracotta blocks or parts of terracotta blocks should be carried out without risk of levering up the arrises. Joints should be cut into with diamond-tipped circular saws before attempting to cut out a block.

WARNING Care should be taken not to damage adjacent blocks.

NOTE After careful removal, fractured blocks can be reassembled with non-ferrous pins and resin adhesive.

Openings should be cleaned of remains of blocks, filling and joint mortar.

Units to be reused should be indelibly marked on a side or rear face with a unique code relating to a master drawing.

Removal procedures should include all necessary temporary works and weather protection measures.

10.7 Refixing of units

Salvaged and/or replacement terracotta blocks should be reattached to both the backing structure and to adjacent blocks, using a combination of mortars, grouts, dowels and other fixings of non-ferrous metal, polyester or ceramics.

NOTE Proprietary anchoring systems may be used.

Voids within blocks should be filled with a relatively dry cement-aggregate mix of proportions 1:8 to 1:10 (by volume), and placed and compacted by hand.

Immediately prior to refixing, units should be thoroughly wetted. Each unit should be set in a solid bed of mortar with all joints filled to their full depth and width, with provision made for any grouting required.

Joint widths and finishes should match the original. Excess mortar should be cleaned off the faces of units while still wet.

10.8 Cleaning and treatment of exposed steel

Rust on steel exposed during opening up should be removed by grinding or grit blasting in situ. Adjacent terracotta should be protected. Exposed metal should be treated immediately with a corrosion-inhibiting coating system and allowed to cure prior to rebuilding work.

10.9 Repair of fractured or damaged units

10.9.1 *Fracture repairs*

Resin repair works to fractures should be carried out by experienced craftsmen.

Care should be taken not to splash or spill synthetic resins.

Cracked units or detached pieces should be refixed with repair mortar and dowels. Dowels through the face of a block should be positioned with the end face of the dowel recessed 25 mm from the outer face of the block.

10.9.2 *Filling of cracks*

Cracks in in situ units should be filled with colour-matched, thixotropic resin pastes, or grouted with liquid or thixotropic resins. Fractures wider than 6 mm should be filled in accordance with **8.5**.

10.9.3 *Mortar repairs*

Cavity preparation should be as for stone (see **8.4.3**).

A neat surface edge to the repair area should be prepared with a diamond-tipped circular saw. Repair areas should not be feather-edged.

Mortars should only be used for minor repairs.

Repair mortars should contain selected natural aggregates and non-fading natural pigments, bound with cement, lime or synthetic resins.

NOTE Synthetic resin-based mortars should not be used for long-term repairs, or repairs that require an acceptable appearance both wet and dry.

The surface texture of repairs should match the surrounding block.

10.9.4 *Reinstatement of surface finishes*

Glaze or fireskin should not be reinstated by application of paints or other coatings.

10.10 Cutting out and repointing joints

10.10.1 *Cutting out*

Cutting out of joints should be carried out with small diamond-tipped circular blades. Cutting out should be carried out by highly skilled craftsmen. No damage should be caused to the edges or faces of blocks.

NOTE Hand finishing may be required, especially at joint junctions.

10.10.2 *Compatible mortars*

Pointing mortars should be weaker than the terracotta units. They should match the colour and texture of the original mortar accurately.

Mixes should be in the following range of proportions (by volume).

— cement-lime-sand: 1:2:9 to 1:3:12;

— hydraulic lime-sand: 1:2.5 to 1:3; or

— lime-brick dust pozzolan-sand: 1:0.5:2.5.

Colourfast pigments may be used, where required, to match dark or strong colours. Aggregate should be well-graded from 1.18 mm down.

NOTE Waterproof caulking compounds such as mastics or silicon rubber should only be used as a temporary measure (e.g. for waterproofing when masonry with open cracks is to be cleaned prior to repair).

10.11 Test samples

Samples of the following work should be provided for each category of repair so that precise methods, mixes and appearance can be designed:

a) removal or replacement of defective units;

b) fixing, pointing and grouting in of replacement units;

c) refixing of detached fragments;

d) dowelling and/or resin injection of insecure units or pieces of units;

e) crack filling and crack injection;

f) cutting out for repointing;

g) repointing;

h) preparation for mortar repair;

i) mortar repair.

11 Surface coverings

11.1 Materials

Where there is evidence of water penetration or related masonry damage, upper surfaces of cornices, strings, and (sometimes) copings should be covered with lead, with the front edge dressed over to form a drip.

NOTE Existing coverings in slate or copper sheet can require repair or replacement.

11.2 Lead sheet

Lead sheet and leadwork should conform to BS 1178, BS 6915, and *The Lead Sheet Manual — A Guide to Good Building Practice*.

NOTE 1 It is not always possible to repair original lead on historic buildings with modern lead technology. Technical advice should be sought on the nature and condition of old lead, and appropriate methods of repair.

NOTE 2 Sand cast lead sheet is available for historic building repair work.

12 External render repairs

12.1 General

External render repair work should be carried out in accordance with BS 5262. On historic buildings, work should be based on information in technical references (see Bibliography).

12.2 Characteristics and condition

COMMENTARY Renders may be of a wide variety of materials, including sand-lime, clay loam and hydraulic lime mortars. These materials may have been applied in various combinations ranging from single coat slurries to three coat renders.

In conservation or repair of multiple layer renders, the characteristics of the original layers should be matched.

Constituents and proportions of the original mixes of renders should be determined together with the method of application.

A specification should be prepared for work, including:

a) preparation of surfaces;

b) consolidation of friable render surfaces;

c) removal of defective render;

d) preparation and filling of cracks;

e) dubbing out cavities;

f) mortar mixes, preparation and application;

g) curing of render layers.

13 Treatment and protection of surfaces

13.1 General

Surface treatments should only be used after careful consideration of the condition and exposure of the surface, and to future maintenance requirements.

13.2 Water repellency on porous masonry

13.2.1 *General characteristics and situations of use*

COMMENTARY Effective water repellency treatments should line rather than block the pores of stone, brick, or mortar, inhibiting capillary absorption of water but allowing water vapour to permeate. Penetration of water repellents varies with the moisture content and permeability of the masonry, but a depth of penetration from the outer surface of 3 mm is commonly achieved.

The cause of damp should be understood prior to application of a water repellent (water repellency treatments should not be required on historic masonry surfaces). All other repair procedures should be completed before application of a water repellent.

Water repellents should not be used to reduce efflorescence. They should not be used on decaying or friable masonry, masonry with rising damp, or where salts are likely to accumulate behind the treated surface.

COMMENTARY Cleaned surfaces treated with water repellents may develop an irregular appearance as rainwater is channelled down unevenly over the surface. Deposited dirt can adhere to surfaces protected by projecting features and in sheltered zones on the building. Application of water repellents on an upper part of a wall may result in a significant increase in flow of water down the wall, which may lead to water penetration problems at a lower level. As the effective life of water repellents is normally less than 10 years, the economic considerations of application should be considered. Water repellents may break down patchily. The cost of scaffolding every 3 years to 10 years to maintain the treatment may outweigh the benefits of application. Although water repellents may increase resistance to rain penetration, they may also reduce the rate of evaporation of water from the wall. Depending on the exposure conditions, this could lead to a build-up of trapped moisture in the wall with potential for salt crystallization and frost damage and resultant spalling of the masonry surface. Water repellents may also add complications to subsequent cleaning or surface treatments.

NOTE Treatment of lime stained brickwork with a water repellent, after cleaning, can reduce restaining.

13.2.2 *Selection of water repellents*

Care should be taken to select the appropriate type and class of water repellent for treating a particular material (see BS 6477).

Aqueous siliconate solutions should not be used on stones with a significant iron content.

13.2.3 *Method of application*

Surfaces should be prepared for treatment by repairing any cracks or fractures that allow ingress of water and by removing substantial accumulations of dirt and organic growth. Detergent residues should be removed. All mortar joints should be in good order and surfaces should be dry.

Water repellents should be applied to clearly defined areas, by brush flooding or low pressure spraying. The masonry face should be covered by slow horizontal passes, allowing a run down of 150 mm, that is covered again by the next pass. Work should proceed from top to bottom. Treatment should not be worked into the surface by agitation.

Care should be taken not to allow water repellent to come into contact with bituminous surfaces. Glass should be protected from spillage. Where spillage does occur, the water repellant should be cleaned off immediately with white spirit.

13.3 Treatments for controlling organic growth

Chemical treatments for controlling organic growth should conform to the Control of Pesticides Regulations, 1986, and should have an HSE approval number.

NOTE Many currently available materials are more environmentally friendly, with several being based on dodecylamine.

Prior to application of treatment, heavy growth, small plants and moss cushions should be removed with stiff fibre brushes and spatulas, or, where masonry surfaces are sound, a low pressure water lance. Cutting out of roots should be followed by repointing, and, where required, hand grouting of cavities previously filled with soil.

Treatment should be applied to kill off existing growth and then reapplied after cleaning off the dead growth. Periodic retreatments should be carried out if it is ascertained that the cumulative effect of the biocide is not damaging.

The treatment area should be as dry as possible, for maximum retention of treatment. Treatment should be applied with low pressure garden sprays with lances. The masonry face should be covered by slow horizontal passes, allowing a run down of 150 mm, that is covered again by the next pass.

NOTE An effective method of reducing organic growth is to ensure that weatherings, flashings, rain water gutters, etc., conduct water away from walls.

13.4 Consolidation of weathered masonry

COMMENTARY Weathering of building stone (and other porous masonry) often results in dissolution of the materials that cement the stone grains together. This creates a deteriorated, friable surface lacking in cohesion, of weakened mechanical strength. Consolidation is impregnation of the deteriorated material with a consolidating material ("the consolidant") that is usually applied as a liquid to the deteriorated surface. The consolidant penetrates to a certain depth and deposits material to re-establish a sound matrix.

Consolidants should not be used unless the cause of decay and the constituents and properties of the substrate are understood. Other repair options should be considered first.

In general, consolidants should only be used if:

a) masonry or sculpted surfaces are deteriorating in an unacceptable and readily quantifiable way;

b) use of the material is the only alternative to replacement;

c) the causes of deterioration are properly identified and understood;

d) there are no practical ways of protecting the stones by damp courses, flashings, humidity controls, stitching, dentistry and joint repairs, etc., without affecting their architectural character;

e) the properties of the consolidant, its constituents and the consolidation techniques are known and understood by the specifier and applicator;

f) pre-application laboratory analysis has confirmed that the effect on the physical properties of the masonry are within acceptable limits;

g) testing has enabled production of a detailed specification for application of the consolidant;

h) provision has been made to record all steps of the treatment and to establish any necessary periodic maintenance inspections (and treatments);

i) experienced conservators/applicators are available to carry out the work.

NOTE Other repair and conservation activities may be involved in consolidation treatment.

The effect of a chemical consolidant on the masonry of a particular project should be fully understood before it is applied (e.g. by taking samples of the masonry, treating with the consolidant, and measuring and assessing the porosity, permeability, depth of penetration, change of appearance, etc., before and after treatment).

Specialist advice should be sought prior to application of consolidants to masonry.

Consolidation should generally be carried out after cleaning and at the early stages of a repair programme. Application of consolidants should be integrated with other cleaning and surface repair procedures. Further guidance on selection and application of consolidants is given in annex B.

13.5 Anti-graffiti treatments

Non-removable anti-graffiti treatments and treatments that alter the appearance or physical characteristics (in particular, the porosity and permeability) of the surface of masonry should not be used. Treatments should be fully reversible. "Sacrificial graffiti barriers" should be periodically replaced to remain effective.

NOTE Anti-graffiti treatments are not fully effective against all markers.

14 Coatings

14.1 Limewash

COMMENTARY Limewash is a thin aqueous solution of calcium hydroxide, traditionally used on plaster and calcareous stones as an inexpensive decorative and protective treatment. It is suitable primarily for use on surfaces with poor weathering properties and does not significantly affect their permeability. Although limewash may be used on previously untreated surfaces other than external sandstone walls, it is most suitable for treating surfaces that have been limewashed previously.

Limewash formed by sieving and diluting slaked lime putty should be applied thinly in multiple applications over a period of several days.

NOTE 1 Traditional recipes can include tallow (introduced during lime slaking while hot), casein (as a binder or setting agent), formalin (as a biocide) and earth pigments (for colour).

NOTE 2 Limewash can also be used to consolidate friable limestone (see **B 4.1.1**).

14.2 Shelter coat

COMMENTARY Shelter coat is a thick solution of calcium hydroxide in water to which casein, pigments and stone dust (filler) can be added.

Shelter coating is a sacrificial layer for weather protection and should be applied in several thick coats.

14.3 Silicate paint

COMMENTARY Silicate paint is a solution of potassium silicate or other silicates in water, with pigments and fillers that chemically combine with alkali substrates to produce a resistant, decorative finish.

Silicate-based paints cannot be chemically removed and should be overpainted.

NOTE Only compatible paint systems adhere well to silicate paint surfaces.

15 Maintenance of the exteriors of buildings

Buildings should be inspected regularly to ensure that repair work is carried out as soon as required and before associated damage can occur (see BS 8210).

Defective downpipes and gutters, damaged flashings, defective lead coverings to cornices and defective jointing should be quickly repaired.

Obsolete cables and fixings (particularly old iron brackets, nail heads, and other fixings that can cause permanent staining and fracturing) should be removed.

Creepers that insert roots into masonry (e.g. ivy) should be removed. Where possible, this should be carried out by cutting through the roots one year or more before removal of the creeper.

Maintenance and repair of renders should be carried out in accordance with BS 5262.

Annex A (informative)
Non-destructive and "key-hole" survey methods

A.1 General

This annex gives some methods of making a preliminary survey of the construction and condition of buildings without opening up the fabric. These surveys should be complemented by reference to original drawings where available. Detailed subsequent studies can include exploratory opening-up to confirm hypotheses and to calibrate non-destructive survey methods.

Surveys can require the interpretative skills of a specialist technician (who is not necessarily an expert in building construction). A close working relationship with a specialist technician is essential.

NOTE Survey methods overlap. Some systems help to locate buried elements of construction that can be subsequently assessed using other equipment. It should be recognized that some tools do not provide information on the condition of the fabric.

A.2 Pulse radar

Long wave, modulated energy is transmitted through the structure from antennae and the partially-absorbed reflected signal collected and compared. Voids, steelwork and metal armatures can be located with this technique.

A.3 Magnetometry

Magnetic metal objects can be located precisely when defined electromagnetic fields are passed over them. Cover meters and metal detectors of various types and sensitivities are available, but the depth of penetration can be limited to 150 mm and the efficacies of sensitive systems are affected by surface roughness, temperature, and moisture content.

A.4 Endoscopy

Fibre-optic borescopes or endoscope probes can be introduced into voids or cavities through 4 mm to 6 mm diameter drill holes, to enable visual assessment of the condition of underlying fabric, including oxidization of buried metal cramps and other fixings.

Equipment can be connected to a 35 mm or video camera.

Annex B (informative)
Use of consolidants on weathered stone and other porous materials

B.1 General

Testing should be carried out prior to full application of a consolidant to confirm that the consolidant is deposited throughout the outer zone of the masonry, not just the surface layer.

Consolidants should not be used as grouts or void fillers, or to reattach flaking, exfoliating or spalling surface layers. Most consolidants are not reversible and should not be used unless the constituents of the stone and cause of decay are understood.

B.2 Performance criteria

B.2.1 *General*

The following criteria should be taken into account prior to selecting a consolidant:

a) the objective of treatment;

b) characteristics and condition of the masonry;

c) the type and extent of decay;

d) any statutory constraints applicable to the building;

e) performance characteristics of available consolidants on the masonry;

f) the method of application;

g) expertise available;

h) environmental and health and safety regulations;

i) the effect on the light-reflecting properties of the surface (including changes in the colour of the consolidant).

NOTE 1 Application of most consolidants is not reversible.

NOTE 2 It should be ascertained, by reference to previous treatments in the same conditions, that the consolidant selected and the chosen method of treatment are not damaging.

B.2.2 *Performance requirement checklist*

All consolidating material should conform to a number of requirements. These include:

a) *Consolidation value*

The consolidant should re-establish cohesion of the stone particles. This process should significantly improve measurable mechanical properties such as compressive strength, modulus of rupture, and abrasion resistance.

b) *Penetration of treatment*

The consolidant should penetrate to a depth so that all incoherent materials are bonded together and attached to a sound core behind the deteriorated zone of frost and salt activity.

NOTE Treatment is more successful with greater penetration.

c) *Porosity/water vapour permeability*

The pore structure and the ability of the material to transfer moisture should not be adversely affected by the consolidant.

d) *Thermal characteristics*

The consolidant should not significantly alter the thermal expansion characteristics of the material.

e) *Chemical stability*

The consolidant should not form by-products harmful to the original material.

f) *Appearance*

The consolidant should not change the colour, texture, or surface reflectance characteristics of the material.

g) *Biological resistance*

The consolidated fabric should not encourage or support organic growth.

h) *Durability*

The consolidated fabric should retain improved properties for an agreed time period.

i) *Retreatability*

The consolidant should allow retreatment as part of medium and long term maintenance.

j) *Application requirements*

A trained applicator should be able to apply the consolidant quickly and at reasonable cost, without significant loss of surface or hazard to health and safety.

NOTE None of the consolidants commonly available conforms to all of a) to j). For each repair, it is essential to determine the most important properties for the consolidant prior to making a selection.

B.2.3 *Pre-application analysis*

Testing should be carried out prior to application of a consolidant to masonry.

Untreated samples should be tested for moisture and soluble salt content, porosity, and permeability. After a cure period of 2 weeks, treated samples should be assessed for changes in porosity and permeability, depth of penetration of the consolidant, and changes in appearance.

Where the masonry is suitable for consolidation treatment, the following should be ascertained:

a) the volume of material required;

b) the method of application.

B.3 Specification

A specification should be prepared for each application of a chemical consolidant, identifying:

a) preapplication inspection and analysis (see **B.2.3**);

b) choice of consolidation treatment;

c) area of application;

d) application conditions, i.e.:

1) cleanliness and dryness of the masonry;

2) environmental conditions;

e) preparation of the treatment area, including:

1) removal of small, loose and flaking particles (not large flakes);

2) preparation of joints;

3) protection of items such as glass;

4) phasing of any masonry cleaning;

f) on-site testing;

g) method of application (including quantity of treatment);

h) post-application inspection and analysis.

B.4 Categories of consolidants

B.4.1 *Alkaline earth hydroxides*

B.4.1.1 *Limewater*

Limewater is the best known alkaline earth hydroxide consolidant. It is a saturated solution of calcium hydroxide (water that forms over lime putty after slaking quick lime).

Limewater should be used to consolidate friable limestone (and other calcareous materials) by spraying multiple applications onto the surface over a period of several days. Between 40 and 50 applications should be made.

If required, limewater consolidation should be accompanied by lime mortar grouting, application of support fillings and a shelter coat.

Limewater should not be used on sandstones, brick or terracotta.

B.4.1.2 *Barium hydroxide*

There are two methods for employing barium hydroxide as a consolidant for calcareous materials such as limestone, marble and renders.

The Lewin Method (US Patent 1971) employs solutions of barium hydroxide and urea resulting in deposition of barium carbonate.

The second method involves use of barium hydroxide in conjunction with ammonium carbonate poultices on sulfated limestones and marbles. The result is both consolidation and conversion of calcium sulfate into barium sulfate, which is nearly insoluble in water.

NOTE These methods have given inconsistent results on architectural stone in situ.

Barium hydroxide methods are difficult on buildings because they attack aluminium, zinc, and glass materials. Application is difficult and highly sensitive to environmental factors, and there are health and safety risks to applicators.

Barium hydroxide should not be used on sandstones, brick or terracotta.

B.4.2 *Alkoxysilanes*

COMMENTARY Alkoxysilanes are monomeric organo-silicon compounds that contain oxygen, hydrogen, carbon, and silicon atoms. Most of these compounds are colourless, low viscosity liquids that react with water and cure to form a three dimensional polymer network. The molecular weight of alkoxysilanes allows deep penetration (up to 80 mm). Subsequent curing is a two stage process of hydrolysis and condensation to form a silica lattice that, in the correct conditions, forms a molecular bond to the substrate.

NOTE 1 If a large number of alkoxysilanes are joined together, the resulting material is known as a "siloxane"; and when several siloxanes are chemically connected, a "silicone" is formed. These larger molecules are unable to achieve deep penetration and should not be used as consolidants.

Alkoxysilanes (alkylalkoxysilanes or "silanes") can be used to consolidate stone (especially sandstone), brick, earth, and renders. Properly applied by an experienced applicator, alkoxysilanes should consolidate friable surfaces without blocking pore spaces.

Alkoxysilanes in use in the UK fall into three main groups:

a) tetraethoxysilane and derivitaves (TEOS group);

b) triethoxymethylsilanes (methyltriethoxysilanes, MTEOS group);

c) trimethoxymethylsilanes (methyltrimethoxysilanes, MTMOS group).

COMMENTARY Tetraethoxysilane compounds (tetraethylorthosilicate, TEOS) have very good penetration in porous materials, but large quantities are required. Effective consolidation requires up to one month and the treated surface should be protected from liquid water during the cure period. The setting reaction is very sensitive to thermohygrometrical changes in the microclimate and conditions should be carefully controlled to prevent excessive evaporation before consolidation.

NOTE 2 MTEOS compounds are chemically similar to the TEOS group of silanes, except for substitution of a methyl group for one ethoxy group.

NOTE 3 MTMOS compounds are chemically similar to the MTEOS group of silanes, except for substitution of methoxy groups for the ethoxy groups.

COMMENTARY The main difference in the properties of the three types of consolidants is that the methyl groups b) and c) also provide water repellency, which can be an important consideration if cleaning and grouting or filling are carried out.

When selecting an alkoxysilane as a consolidant, in addition to performance criteria given in **B.2.2**, guidance should be sought from manufacturers on how surface/air temperature, relative humidity, wind and sun exposure could adversely affect performance.

Alkoxysilanes should be applied to a clean, dry surface to ensure penetration.

NOTE 4 This may entail provision of a protective covering for some weeks before treatment.

Alkoxysilanes should be sprayed or brushed onto the substrate in repeated applications, in accordance with the manufacturers' recommendations. Application should be continued until a sufficient depth of penetration is achieved, as determined by preapplication analysis.

NOTE 5 In cases of extreme deterioration, alkoxysilanes can be applied by percolation or through a poultice with a continuous supply of consolidant.

Alkoxysilane consolidation treatment should be carried out by trained applicators. Health and safety precautions should be adhered to. Care should be taken to ensure that no excess consolidant is left on the surface.

Records should be kept of the condition of the substrate before and after treatment. Regular inspection and maintenance should be carried out.

B.4.3 *Synthetic organic polymers*

COMMENTARY Because the relatively large size of the molecules in synthetic organic polymers make deep penetration difficult, these compounds are generally only used for superficial consolidation (e.g. for reattachment of stone and paint flakes). Some organic polymers are unstable with UV light and oxygen, resulting in discolouration and loss of effectiveness.

Synthetic polymer consolidants fall into two categories.

a) *Acrylics (acrylic co-polymers)*

Acrylics should be dissolved in organic solvents and applied by brush or spray. Local environmental control may be required during application.

Acrylics can be used to reattach stone flakes and fragments of paint layers, and for "surface consolidation". Methylmethacrylate can be used to consolidate concrete and stone.

NOTE Although techniques have been developed to achieve deep penetration of methylmethacrylate to small objects, they are difficult to apply to buildings.

b) *Epoxies*

Epoxies should not be used as consolidants.

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