The use of lime-based mortars in new build

NHBC Foundation
Housing research & development in partnership with BRE Trust

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December 2008

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Acknowledgements

This guide was produced as part of a project undertaken at BRE in conjunction with the Building Limes Forum and which was funded by the NHBC Foundation. The help of the STI LINK Project Team led by Geoff Allen, Brick Development Association, Jim Allen (Ellis and Moore Civil and Structural Engineers), Michael Beare (AKS Ward Lister Beare), Neil Beningfield (Neil Beningfield and Associates), Steve Foster (Singleton Birch), Mike Haynes (Lhoist UK Ltd), Stafford Holmes (Rodney Melville and Partners), Paul Livesey (formerly of Castle Cement Ltd), Christopher Mills (NHBC), Ian Pritchett (Lime Technology Ltd) and Peter Walker (University of Bath) is gratefully acknowledged.

We express our thanks to Lime Technology Ltd for photographs used in this review (© 2000-2008 Lime Technology Limited)

NF12
Published by IHS BRE Press on behalf of the NHBC Foundation
December 2008
ISBN 978-1-84806-066-1

FOREWORD

A key function of the NHBC Foundation is to provide best practice to the industry. Our latest guide aims to enhance the knowledge of designers and builders regarding lime-based mortars. Such mortars have been used for centuries, right back to the time of the Romans, and this guide highlights the many benefits in the areas of sustainability and design for the 21st century.

The use of lime-based mortars declined during the 20th century due to changing market demands and the availability of materials. The move was very much towards cement-based mortars. The question is 'why consider returning to lime-based mortars'?

The advantages of lime-based mortars over cement-based mortars are explored in this guide. In terms of sustainability the lime-based mortars excel as their manufacture consumes less energy and produces less greenhouse gases than their cement-based counterparts. The consistency of the set lime-based mortar also makes it far easier for bricks to be cleaned and re-used after demolition.

Research has also shown that lime-based mortars absorb in the course of their life most or all of the carbon dioxide that is driven off during the high temperature manufacturing process. In terms of design, walls built with this type of mortar have been shown to have an increased tolerance to movement caused by thermal and moisture action.

To allow a renaissance of these mortars, further information and guidance is required. Extensive research has helped establish the best uses of lime-based mortars and also their limitations. The final section of this guide identifies other sources of information on their use in new build, refurbishment and conservation.

The NHBC Foundation is very much about promoting good practice within the house building industry. This guidance highlights the different approach that lime-based mortars need when compared to current practice – but much can be learned from their traditional use and our experience with cement-based mortars. The unique aspects of lime mortars contribute to achieving the objectives of our sustainability agenda.

I hope you find this guide of relevance – I believe it provides a valuable resource for the industry.

Rt. Hon. Nick Raynsford MP

Chairman, NHBC Foundation

CONTENTS

DEFINITIONS

Additives	Materials added to high calcium limes or a natural hydraulic lime to improve the development of strength and durability (see pozzolans).
Air limes (ALs)	One of the main group of limes included in BS EN 459-1. It includes calcium limes (CLs) and dolomitic limes (DLs).
Calcium limes (CLs)	Limes mainly consisting of calcium oxide or calcium hydroxide without any additions of hydraulic or pozzolanic materials.
Dolomitic limes (DLs)	Limes mainly consisting of calcium oxide and magnesium oxide or calcium hydroxide and magnesium hydroxide without any additions of hydraulic or pozzolanic materials.
Formulated limes (FLs)	Blends of controlled materials which will result in mortars which have consistent and appropriate compressive strength while retaining some of the properties of lime-based mortars.
Hybrid mixes	Mortars and renders in which the binder is a mixture of calcium limes and hydraulic limes selected to provide a particular set of properties.
Hydraulic limes (HLs)	Binders consisting of limes and other materials such as cement, ground granulated blastfurnace slag, fly ash, limestone filler and other suitable materials.
Limes with hydraulic properties	The second main group of limes included in BS EN 459-1. It includes: natural hydraulic limes, formulated limes and hydraulic limes.
Natural hydraulic limes (NHLs)	Limes produced by the burning of argillaceous or siliceous limestones and reducing them to powder by slaking with water – with or without grinding. All natural hydraulic limes have the property of setting and hardening under water. Atmospheric carbon dioxide contributes to the hardening process.
Pozzolans	Materials containing constituents which will combine with hydrated limes at normal temperatures in the presence of moisture to form stable insoluble compounds having binding properties.

1 Introduction

The purpose of this guide is to provide a general introduction to using lime-based mortars. It is aimed at designers and builders who may have little knowledge of lime-based mortars but who want to apply best practice when they use these materials in new build construction projects. The guidance emphasises the fact that lime-based mortars need a different approach from cement-based mortars – although one that builds on a strong tradition of past use and lessons that can be learned from experience with cement-based mortars.

This guide describes a range of mortars that are often loosely grouped together under the name 'lime mortar' but concentrates on natural hydraulic limes (NHLs). It also includes a description of formulated limes (FLs); at present, there is insufficient published data on the performance of this group of materials to justify their inclusion in the tables of the characteristic properties of lime-based masonry (Tables B and C). However, it is recognised that more information will become available shortly, and it is expected that the information in this guide will be updated and revised accordingly.

This guide is linked directly with two other documents:

- BS EN 459-1:2001. *Building lime. Part 1: Definitions, specifications and conformity criteria*. This is the British and European Standard for building limes.
- Draft for Development Standard, 2008. *The structural use of unreinforced masonry made with natural hydraulic lime mortars – technical annex for use with BS 5628-1:2005* (published as an Appendix at the end of this guide).

The Draft for Development Standard was drafted at the same time as this guide and provides replacement and new clauses for incorporation into BS 5628-1:2005. *Code of practice for the use of masonry – Part 1: Structural use of unreinforced masonry*, based on up-to-date information on the properties of lime-based mortars. The Draft for Development Standard is included as an Appendix to this guide.

The final section of this guide identifies other sources of information on the use of lime mortars in new build, refurbishment and conservation.

2 Why use lime-based mortars?

In an industry which has developed considerable expertise in the use of cement-based mortars, and is notoriously conservative and averse to innovation, it is essential to address the question: why use lime-based mortars?

The best way to answer this question is to look at the advantages lime-based mortars have over cement-based mortars, advantages which have become apparent from experience and research. These can be considered under two broad headings: sustainability and design (based on De Vekey, 2005).

2.1 Sustainability

Bricks and blocks contain the majority of the embodied energy in a unit of wall. Cement-based mortars have higher bond strengths than lime-based mortars and masonry laid using cement-based mortars cannot readily be separated, cleaned and reused at the end of its life. By contrast, masonry laid using lime-based mortar has a lower bond strength, so the mortar can be cleaned off the bricks easily, allowing them to be reused.

The manufacture of limes or hydraulic limes (HLs) consumes less energy and produces less greenhouse gases than that of Portland cement per unit weight. Binders can be produced from limestone only by high-energy inputs. Significant efforts are continually being made by binder producers to reduce their energy consumption – and, more recently, their carbon dioxide emissions – by switching from hydrocarbons to other fuels and by improving their production processes. The total energy content per tonne of lime-based mortar has the potential to be between 75 and 90 % of that for cement-based mortars.

Over a period of years of exposure to the atmosphere, lime-based mortars absorb most or all of the carbon dioxide that was driven off during their high temperature manufacturing process – known as calcination ie recarbonate; by contrast, cement-based mortars do not normally fully re-carbonate.

Some calcium limes (CLs) are now being produced using alternative fuels, including biomass, and this process has the potential to deliver near carbon-neutral lime-based mortars – with the exclusion of the emissions from the fuels used in the kilns.

2.2 Design

- Walls built with lime-based mortars have more tolerance to movement caused by thermal and moisture action.
- Movement within masonry walls built with lime-based mortars can be accommodated in the individual bedjoints between the masonry units, reducing the need for vertical movement joints.
- Walls have improved 'breathability' to water and water vapour which reduces the likelihood of frost failure of the unit materials and improves the internal environment.
- Lime-based mortars are capable of self-healing microscopic cracks by plastic flow and diffusion.
- Lime-based mortars are less susceptible to sulfate attack.

3 When should lime-based mortars be used?

It is possible to use lime-based mortars and lime-based renders in many applications but it is important that the decision is made early in the design and planning process so all involved in the design and construction can make adjustments to the design and to the programme of work.

3.1 New build

Lime-based mortars can be used in all aspects of new build construction but have gained most acceptance in the construction of masonry walls.

3.2 Refurbishment

Some aspects of refurbishment can be considered as conservation, for example the matching of repair and replacement mortars to those already in the building, but they may also provide opportunities for using lime-based mortars in the construction of extensions or rebuilding of structures as part of the refurbishment.

3.3 Conservation and repair

This is the area of construction with the longest history of use as it includes the conservation and restoration of historic buildings. In this application it is important to establish the composition of the original mortar – both the binder and the aggregate – and to attempt to match the new mortar to the original provided that there is no evidence that the original mortar has been detrimental to the masonry.

3.4 Other applications

It is possible to use limes and HLs in a range of uses that go beyond the construction of masonry walls, for example in the construction of walls using limes and hemp, limecrete floor slabs, external render and internal plastering.

3.5 Constraints

When considering the use of lime-based mortars, it is important to be realistic and accept that there are some constraints, as well as areas where the properties of lime-based mortars are perceived as being limiting, and to address these issues.

- Speed of construction: The build rate with lime-based mortar is perceived as being very slow compared with cement-based mortars or thin bed mortars. Lime-based mortars do develop strength more slowly (see next bullet point) but it is still possible to achieve acceptable build rates, particularly as brick-laying teams gain confidence and experience in the use of the mortars.
- Rate of gain of strength: Compressive strength develops more slowly in lime-based mortars than in cement-based mortars. As a result, the compressive strengths of lime-based mortars are usually quoted at 91 days rather than 28 days. However, the data we have shows that a lime-based mortar will typically have reached half its 91-day strength by 28 days.

  The data available indicates that single skin brickwork or blockwork masonry constructed with lime-based mortars quickly develops sufficient resistance to vertical loads, but that it has less resistance to lateral loads (see under 4 Background, history and tradition) at an early age and so consideration needs to be given to this at the design stage.
- Cold weather working: Masonry walls constructed from all of types of mortars are susceptible to frost damage immediately after construction (Appendix A.4.2.3.8 in BS 5628-3 provides guidance on working at temperatures less than 5°C). The development of the strength and durability of lime-based mortars is highly dependent on temperature, with little or no hardening taking place below about 5°C, so protection from frost becomes even more important until the day and night temperature has been above 5°C for three months.

4 Background, history and tradition

Lime-based mortars have been used in building and construction for at least 2000 years. Many limes were produced locally to their point of use, being burnt from the nearest source of calcium carbonate, and so they would have been very variable – and probably ranged from reasonably pure limes to eminently hydraulic limes (discussed further in this section). The Romans were familiar with lime mortars and with the use of additives, generally termed pozzolans, to improve the speed of setting, durability and strength of mortars. That the mixes were successful can be seen from the fact that Roman masonry at exposed locations such as Hadrian's Wall in northern England has survived and remained effective for more than 1800 years. Some mortars contained ground or crushed stone dust as part of the aggregate, which improves the properties of the mortar (Lawrence et al, 2006) without the need for pozzolanic additives. Architectural styles and construction techniques developed within the constraints of the performance of lime-based mortars. In particular, the mortar was used to keep uneven surfaces apart or bind together rubble and other angular material, rather than acting as an adhesive to bond the units together.

The situation continued largely unchanged through the medieval period with a revival of interest in the use of additives in the 15th and 16th centuries. The Industrial Revolution in the 18th and 19th centuries created a desire to construct increasingly complex structures in demanding locations which required ever more sophisticated mortars. During the 1750s, John Smeaton began his investigations in connection with the building of the Eddystone lighthouse, undertaking, in the process, a systematic review of British limes in order to identify the characteristics that resulted in an HL. He concluded that a mortar that combined lime made from Blue Lias limestone and imported Italian pozzolanic earth resulted in a hydraulic binder of great strength (Cowper, 1927; 1998).

In the years after Smeaton's work a number of other 'natural cements', as they were termed, were developed. The best known of these were Roman cements, which were produced by burning argillaceous (clay-containing) limestone nodules found in London clay. Binders were also produced from other limestone deposits that were particularly rich in clays. These produced very fast setting mortars, but it was found to be difficult to achieve consistency. In 1824 the first Portland cement was patented and over the succeeding 100 years the use of natural hydraulic binders (cements or limes) declined substantially. By 1988, the Brick Development Association could write that "lime: sand mortars are obsolete, although suitable lime can be obtained in small quantities for the restoration of historic structures." (Hammett, 1988 [Brick Development Association]).

The rise in awareness of the need for sustainability (see section 2.1) in construction in recent years has led practitioners to re-consider the use of lime-based mortars. For guidance they turned to experience in building restoration and conservation, where lime-based mortars had continued to be used.

Most of the limes used in conservation were pure calcium hydroxide limes, obtained from large-scale lime producers, although there were also a number of smaller producers making CLs and NHLs using local kilns. There were also a number of larger producers in Europe, where the tradition of using NHLs had remained much stronger.

As the use of lime-based mortars declined during the 20th century, architectural styles and construction processes adapted to changing market demands and the availability of materials. In particular, buildings were designed with taller, thinner masonry walls, which were built much more quickly. This favoured the use of Portland cement-based mortars. Traditional lime-based mortars were more suited to the slower construction of thick masonry walls, which were required to resist only very low vertical stresses, and where the resistance to lateral loading depended more on the interlocking of the masonry units and gravity than on the adhesion between the units.

Revival in the use of lime-based mortars requires the re-assessment of the construction of walls built of stone, brick or block to take into account all the qualities of a modern lime-based mortar, allowing it to become competitive in the new build construction sector.

5 What are lime-based mortars?

5.1 Introduction

Mortars are a mixture of an aggregate, a binder, and, in many cases, an additive – such as a plasticizer. In a lime-based mortar, the binder is largely a hydrated lime with more or less hydraulic properties (see definitions); in a cement-based mortar, the binder is a cement. Over the past 100 years, mortars with cement as the binder have largely replaced lime-based mortars.

The European Standard for building lime (BS EN 459-1) defines and classifies different types of building lime.

The two main groups defined are:

- Limes with hydraulic properties, including NHLs, FLs and HLs
- Air limes, including CLs and dolomitic limes (DLs).

5.2 Limes with hydraulic properties

Natural hydraulic limes

NHLs include three commonly used grades: NHL2, NHL3.5 and NHL5. A new, lower strength, lime is also becoming available: NHL1. These limes are classified on the basis of the compressive strength, measured at 28 days, of a specially prescribed 'test' mortar made with them under controlled laboratory conditions. For example, an NHL3.5 lime derives its suffix '3.5' from the fact that the measured compressive strength of this 'test' mortar is at least 3.5 N/mm^2. This 'test' mortar comprises a specified clean 'test' sand, specified mix proportions, and a lower water : binder ratio than would be specified for normal use. As a result, the number associated with the designation of the NHLs should not be regarded as limiting the maximum strength that can be attained in practice with a given NHL-based mortar mix.

The nomenclature of the NHLs has largely replaced the traditional names for limes with hydraulic properties and Table A shows the approximate relationship between the traditional grades and the three now commonly used grades.

TABLE A

Traditional and current nomenclature for limes with hydraulic properties

Traditional nomenclature	Current nomenclature	Strength range*
Feebly hydraulic	NHL2	2–5 MPa
Moderately hydraulic	NHL3.5	3.5–10 MPa
Eminently hydraulic	NHL5	5–15 MPa

* The compressive strengths are measured in laboratory tests at 28 days.

It is important to note that different NHL products that are the same grade may give different strengths when used in different mortar mixes. The supplier should be asked to provide typical strength data in order to ensure that the correct grade is being used.

NHLs are manufactured using an argillaceous or siliceous limestone or chalk (containing clays or silica) to produce a dry hydroxide containing some hydraulic components. NHLs are produced by heating the limestone or chalk ($CaCO_3$) to temperatures in excess of 800°C to drive off the carbon dioxide and produce calcium oxide (quicklime), CaO, which then partially reacts with the silica and aluminous material to form hydraulic components. Before it is used for mortar it is usually 'slaked' by the addition of water to convert the excess CaO to the hydroxide, $Ca(OH)_2$ in the form of a dry 'hydrate'. All NHLs have the property of setting and hardening under water but atmospheric carbon dioxide contributes to the hardening process in the longer term.

NHLs can only be stored as a dry hydrate as they react chemically with water. The reaction produces calcium silicate and calcium aluminate hydrates which increase both the rate and degree of setting and hardening relative to CL mortars (see under 5.3 Air limes).

Formulated limes

FLs are blends of controlled materials which result in mortars with consistent and appropriate compressive strengths, while retaining some of the properties of lime-based mortars. BS EN 459-1 requires manufacturers of FL products to provide information on their composition and to declare the inclusion of any cement, NHLs or CLs or more than 5 % individual or 10 % total of any other agreed constituents, which can include Portland cement clinker, natural pozzolana, natural calcined pozzolana, limestone, ground granulated blastfurnace slag, calcium sulfate and silica fumes.

The new class of FLs gives manufacturers the opportunity to produce designer products for specific applications. The properties of NHLs depend upon the geology of the stone deposit and conditions under which they are produced, whereas FL products can be individually designed from a wide range of raw materials (chosen from a defined and approved list) to suit the application.

Hydraulic limes

HLs are binders consisting of lime and other materials such as cement, ground granulated blastfurnace slag, fly ash, limestone filler and other suitable materials. There is no requirement in BS EN 459-1 for manufacturers to declare the constituents of HLs.

Hybrid mixes

Publications on lime-based mortars, particularly ones relating to conservation, may contain references to 'hybrid mixes'. These are mortars and renders where the binder is a mixture of CL and HL, selected to provide a particular set of mortar properties[1].

[1] The use of such mixtures was questioned by English Heritage and as a result in 1997 they placed a moratorium on their use in conservation projects (English Heritage, 1997), a moratorium that was found to be unnecessary and that has since been lifted.

5.3 Air limes

Calcium limes

CLs consist mainly of calcium oxide or calcium hydroxide, without the addition of hydraulic or pozzolanic materials. If sufficient water is used in the slaking process, the resulting material is termed 'lime putty' and can be used directly after mixing with sand. If carefully controlled amounts of water are added during manufacture, a dry hydrate powder is produced; depending on the purity of the limestone or chalk source rock and the calcination process used, the resulting CL may be classified in accordance with BS EN 459-1 as CL70, CL80, CL90, depending on the percentage content of calcium oxide.

Pre-mixes of CL, sand and water, are a popular alternative to site-mixed mortars.

CL mortars harden only by carbonation and therefore will not set when submerged in, or saturated with, water.

Dolomitic limes

DLs also consist of calcium oxide and magnesium oxide or calcium hydroxide and magnesium hydroxide without any additions of hydraulic or pozzolanic materials but are produced from calcium magnesium carbonate rocks rather than calcium carbonate rocks. DLs are produced in the UK but there is no record that they are currently being supplied for use in mortar in the UK, although they are used extensively in the USA.

5.4 Mortar mixing practices

With all mortars, the choice of sand used makes a significant difference to the strength, performance and workability of the mortar. With lime-based mortars, a well-graded sharp sand should be used in order to ensure optimum mortar performance.[2]

Care should be taken when mixing mortars on site in order to allow adequate mixing time and to ensure that batch mix ratios are consistent and correct. Since mixing requirements will vary with product and mixer type, contact your supplier, building lime manufacturer or any of the organisations listed later in this document for advice.

Many lime-based mortars can now be supplied to sites in silos. These combine the convenience of bulk deliveries and the rapid supply of mortars to meet site productivity demands with a reduction in the risk of mistakes occurring during site batching and mixing of mortars.

[2] A well-graded Type S sand to BS 1199, 1200 should be appropriate.

6 Specification and the use of lime-based mortars

Studies, and recently completed testing programmes aimed at assessing the performance of NHLs, have now provided design values for the structural performance of lime-based mortar mixes; these values need to be integrated into BS 5628-1 so its design method can be applied equally to cement or lime. The following section uses BS 5628-1 as its starting point and sets out the design values for lime mortar used in masonry designed as set out in BS 5628-1.

There is a good summary of information on the properties and use of lime mortars in BRE Good Building Guide 66 *Building masonry with lime-based bedding mortars* (De Vekey, 2005). A good reference guide for CL is *Lime in building – a practical guide* by Jane Schofield (Schofield, 2005).

The most comprehensive guidance on the specification and use of lime-based mortars can be found in *Hydraulic lime mortar for stone, brick, and block masonry* (Allen et al, 2003). This book is based on a combination of site experience and laboratory testing and provides guidance for specifiers and craftsmen. On the basis of the information in Allen et al, and later research undertaken in a second project by the same team, a 1 : 2 lime : sand mortar made with NHL3.5 HL will be satisfactory in most circumstances in terms of build rate, strength, and durability; it will also be equivalent to a BS 5628-1 designation (iii) mortar in terms of both its compressive strength and durability. A 1 : 3 mix can be considered equivalent to a BS 5628-1 designation (iv) mortar in terms of the compressive strength of the mortar and its durability. Of course the type of binder can affect the strength of the mortar but it is also known that the grading and grain shape of the aggregate can be equally important in determining the properties of the finished product with a well sorted sharp sand likely to produce the best results.

It is difficult to compare the characteristic compressive and flexural strengths of masonry constructed with lime-based mortar and cement-based mortar at present on the basis that the data available for walls constructed with lime-based mortars is limited in terms of the range of brick strengths tested. This limitation is evident when comparing the values contained in Table B and those in Table 2 of BS 5628-1, where, for example, the compressive strength of masonry made with a combination of a 30 N/mm^2 standard format brick and an M2 cementicious mortar is 5.1 N/mm^2 while the compressive strength of masonry made with the same brick and an M2.5 NHL mortar is 5.0 N/mm^2.

TABLE B

Table 2i) from the Draft for Development Standard (Appendix) showing the characteristic compressive strength of masonry (ADDITIONAL CONTENT)

Table 2 — Characteristic compressive strength of masonry, f_k, in N/mm^2 (ADDITIONAL CONTENT)

i) — Constructed with natural hydraulic lime mortar and standard format clay bricks having no more than 25 % of formed voids, or 20 % frogs (ADDITIONAL)

Mortar strength Class/Designation	Compressive strength of unit (N/mm^2)[a]								
	5	10	15	20	30	40	50	75	100
M5	–	–	–	–	6.0	–	–	–	–
M3.5	–	–	–	–	–	–	–	–	–
M2.5	–	–	–	–	5.0	–	–	8.0	–
M1	–	–	–	–	3.5	–	–	–	–

[a] Measured in normal direction of test for units.

NOTE 1 These figures are based on the results of tests carried out on wallettes.

NOTE 2 The strength values contained in this table were determined from tests carried out on wallettes at 91 days; it should be expected that the compressive strength at 28 days would be half these values.

The flexural strengths of lime-based mortars (shown in Table C) are likely to be lower than for cement-based mortars and it is important that this is considered at the design stage in order to provide sufficient resistance to lateral loads. This limitation is evident when comparing the values contained in Table C and those in Table 3 of BS 5628-1, where, for example, the flexural strength parallel to the bedjoints of masonry made with a clay brick having a water absorption of below 7 % and an M2 cementicious mortar is 0.40 N/mm^2, while the flexural strength of masonry made with the same brick and an M2.5 NHL mortar is 0.20 N/mm^2.

TABLE C

Table 3 from the Draft for Development Standard (Appendix) showing characteristic flexural strength of masonry, f_{kx} in N/mm^2 (REPLACEMENT)

Table 3 — Characteristic flexural strength of natural hydraulic lime masonry, f_{kx} N/mm^2 (REPLACEMENT)

	Plane of failure parallel to bed joints			Plane of failure perpendicular to bed joints		
Mortar strength Class/Designation	M5 and M3.5	M2.5	M1	M5 and M3.5	M2.5	M1
Clay bricks having up to 40 % of formed voids and a water absorption						
up to and including 12 %	–	0.20	0.20	–	0.50	0.50
over 12 % (see Note)	–	0.10	0.10	–	0.40	0.40

NOTE Tests to determine the water absorption of clay bricks should be performed in accordance with BS EN 772-7.

Draft for Development Standard

The structural use of unreinforced masonry made with natural hydraulic lime mortars – technical annex for use with BS 5628-1:2005

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Contents

Foreword

This Draft for Development Standard has been prepared with the support of the NHBC Foundation and is intended to be used in conjunction with the following part of BS 5628: – Part 1: *Structural use of unreinforced masonry*.

It has been drafted to provide the technical information needed to allow the design of unreinforced structural masonry made with natural hydraulic lime mortars to follow the design requirements of BS 5628-1.

Currently, this Standard does not cover the use of formulated limes. However, once sufficient data become available, there is no reason why this Standard could not incorporate formulated limes to allow the design of unreinforced structural masonry made with them to follow the design requirements of BS 5628-1.

Introduction

This Draft for Development Standard provides specific technical data and guidance to enable the structural design of unreinforced brick masonry units used in combination with natural hydraulic lime-based mortars – rather than cement-based mortars. It does not cover the use of formulated lime mortars.

The Standard has been drafted to be consistent with the style and format of a British Standard Draft for Development, but it has not been approved by BSI. There are a number of values, particularly in sections 21 and 23 for which there is insufficient data to provide reliable values. Access to additional test data related to these values would be welcomed. It is hoped to submit it to the B525/6 committee once further data has become available.

It is intended to be used in conjunction with BS 5628-1 (dated 8 December 2005; unamended), and has been drafted to be compatible with, and must be read with it. The Draft for Development Standard in this publication contains alternative versions of some clauses and additional clauses to allow it to be used with lime-based mortars.

As a result, the clauses referred to in this Standard are either:

1. Additional to those in BS 5628-1 – either the whole clause is additional in BS 5628-1 or an extra element which has been added to an existing clause in BS 5628-1; or

2. Replacements for those in BS 5628-1 – where the clause numbers remain the same.

Where the clauses in BS 5628-1 do not need to be changed in any way, no reference has been made to them.

To make this Standard as transparent as possible, the following system of clause numbering and description has been adopted:

1. Where a clause, or part of a clause, in this Standard is additional to a clause in BS 5628-1, the number associated with it in this Standard is a continuation of the BS 5628-1 numbering system and the word 'ADDITIONAL' has been appended to it.

Specifically, when the entirety of a clause or sub-clause is an addition to BS 5628-1, the word ADDITIONAL has been appended to the new clause or sub-clause heading; when an extra element has been added to an existing clause or sub-clause in BS 5628-1, the words 'ADDITIONAL CONTENT' have been appended to the existing clause or sub-clause heading;

2. Where a clause in this Standard replaces one in BS 5628-1, then the number associated with it in this Standard is the same as the clause number in BS 5628-1 and the word 'REPLACEMENT' has been appended to it.

Specifically, where an entire clause has been replaced, all the clause and sub-clause headings have the word REPLACEMENT after them; when only a sub-clause has been replaced, only that sub-clause's heading has the word REPLACEMENT appended to it.

For example, clause 13 covers cements. However, as cement is not the binding agent used in natural hydraulic lime mortars, this clause is not needed and a new clause 13, covering natural hydraulic limes, has been drafted. This has been given the following description: "13 Natural hydraulic limes (REPLACEMENT)".

This approach is aimed at ensuring that BS 5628-1 forms the basis of the design methodology; that the minimum number of clauses in BS 5628-1 are affected; and that the appropriate clause to be used in the design is clear.

Section 1. General

1 Scope

This Draft for Development Standard provides the specific technical data and guidance needed to enable the structural design of unreinforced brick masonry units used in combination with natural hydraulic lime-based mortars – rather than cement-based mortars. It does not cover the use of formulated lime mortars.

It has been assumed in the drafting of this Standard that the design of masonry made using it is entrusted to chartered structural or civil engineers or other appropriately qualified persons, for whose guidance it has been prepared, and that the execution of the work is carried out under the direction of appropriately qualified supervisors.

3 Definitions

3.23.8 ***Hydraulic masonry mortar*** (ADDITIONAL CONTENT)

mortar made with natural hydraulic lime in pre-determined proportions, the properties of which are determined by the stated proportion of the constituents.

Section 2. Materials, components and workmanship

9 Rate of laying (REPLACEMENT)

For natural hydraulic lime mortars, the maximum height of wall that should normally be built in a day is 0.5 m. It is however recommended that consideration be given in design to the temporary (construction) loading condition particularly where significant point loads are applied. Where it can be demonstrated that the flexural strength develops at a rate comparable to cement-based mortars then a build rate of up to 1.5 m per day may be achievable.

13 Natural hydraulic limes (REPLACEMENT)

The following natural hydraulic limes are suitable for use in these natural hydraulic lime mortars:

Natural hydraulic lime:

Building limes BS EN 459-1:2001 *Building lime. Definitions, specifications and conformity criteria.*

14 Natural hydraulic lime mortars (REPLACEMENT)

14.1 General (REPLACEMENT)

The use of natural hydraulic lime mortars should be in accordance with the recommendations given in BS 5628-3 where appropriate. However, the different properties of natural hydraulic mortars need to be taken into account.

For site made mortars, the mixing of the mortar should be in accordance with BS 5628-3.

Mortars should be designed or prescribed. For designed mortars, the compressive strength of the mortar provides the control of the hardened mortar quality. When samples are taken from a designed mortar in accordance with BS EN 1015-2, and tested in accordance with BS EN 1015-11, the compressive strength of the mortar should not be less than the declared compressive strength. Table 1 shows the relationship of compressive strength classes to strength.

NOTE 1 The compressive strength at 28 days would be expected to be half of the strength at 91 days.

NOTE 2 As with all mortars, the properties of natural hydraulic lime mortars are dependent on a number of factors including the grading of the sand used in their manufacture and the water content of the mix. Detailed guidance should be sought from the manufacturer.

14.2 Plasticizers (REPLACEMENT)

Plasticizers should not be used with natural hydraulic lime mortars.

Table 1 — Natural hydraulic lime mortars for use with masonry (REPLACEMENT)

	Compressive strength class	Prescribed mortars (proportion of materials by volume) (see note 1)			Compressive strength at 91 days (see note 2) N/mm²	Site tested compressive strength at 91 days (see note 2) N/mm²
		NHL2 natural hydraulic lime : sand	NHL3.5 natural hydraulic lime : sand	NHL5 natural hydraulic lime : sand		
While all natural hydraulic lime mortars will accommodate movement, increasing the mortar designation will decrease the ability to accommodate movement, eg due to settlement, temperature and moisture changes	**HML5**	–	1 : 1	1 : 2	**5.0**	**4.0**
	HML3.5	–	1 : 1½	1 : 2½	**3.5**	**2.5**
	HML2.5	–	1 : 2	1 : 3	**2.5**	**1.5**
	HML1	1 : 2	1 : 3	–	**1.0**	**0.5**

NOTE 1 Proportioning by mass will give more accurate batching than proportioning by volume, provided that the bulk densities of the materials are checked on site.

NOTE 2 The compressive strength at 28 days would be expected to be half these values.

Section 3. Design: objectives and general recommendations

19 Characteristic compressive strength of masonry, f_k

19.1.1 *General* (ADDITIONAL CONTENT)

Table 2i) applies to masonry built with natural hydraulic lime mortars and using standard format bricks of clay, conforming to the requirements of BS EN 771-1 or BS EN 771-2, and having no more than 25 % formed voids (perforations) or 20 % frogs.

It is important to take into account the likely strength of the masonry at both 28 days and 91 days, and it is recommended that consideration be given in design to the temporary (construction) loading condition particularly where significant point loads are applied before the masonry has reached its design strength.

Table 2 — Characteristic compressive strength of masonry, f_k in N/mm^2 (ADDITIONAL CONTENT)

i) — Constructed with natural hydraulic lime mortar and standard format clay bricks having no more than 25 % of formed voids, or 20 % frogs (ADDITIONAL)									
Mortar strength Class/Designation	**Compressive strength of unit (N/mm^2)[a]**								
	5	**10**	**15**	**20**	**30**	**40**	**50**	**75**	**100**
M5	–	–	–	–	6.0	–	–	–	–
M3.5	–	–	–	–	–	–	–	–	–
M2.5	–	–	–	–	5.0	–	–	8.0	–
M1	–	–	–	–	3.5	–	–	–	–

[a] Measured in normal direction of test for units.

NOTE 1 These figures are based on the results of tests carried out on wallettes.

NOTE 2 The strength values contained in this table were determined from tests carried out on wallettes at 91 days; it should be expected that the compressive strength at 28 days would be half these values.

20 Characteristic flexural strength of masonry, f_{kx}

20.2 Flexural strength (REPLACEMENT)

The characteristic flexural strength values for natural hydraulic lime mortars are given in Table 3. These may be used for the categories of brick and mortar shown.

Table 3 — Characteristic flexural strength of natural hydraulic lime masonry, f_{kx} N/mm^2 (REPLACEMENT)

	Plane of failure parallel to bed joints			**Plane of failure perpendicular to bed joints**		
Mortar strength Class/Designation	M5 and M3.5	M2.5	M1	M5 and M3.5	M2.5	M1
Clay bricks having up to 40 % of formed voids and a water absorption						
up to and including 12 %	–	0.20	0.20	–	0.50	0.50
over 12 % (see Note)	–	0.10	0.10	–	0.40	0.40

NOTE Tests to determine the water absorption of clay bricks should be performed in accordance with BS EN 772-7.

21 Characteristic shear strength of masonry made with natural hydraulic lime mortar, f_v (REPLACEMENT)

21.1 General (REPLACEMENT)

21.1.1 *Horizontal direction* (REPLACEMENT)

The characteristic shear strength of masonry in the horizontal direction of the horizontal plane is given by:

$$f_v = f_{vko} + 0.6g_A$$

where

f_v should be taken as not greater than [A] N/mm^2 for masonry built in natural hydraulic lime mortar with strength classes M5 or [B] N/mm^2 for masonry built in mortar strength classes M3.5 to M1.

f_{vko} is the characteristic initial shear strength in N/mm^2; and

g_A is the design vertical load per unit area of wall cross-section due to the vertical loads calculated from the appropriate loading condition specified in Clause 18.

NOTE Currently, no values are available to fill the brackets – and further testing is needed to establish reliable values. Where required the characteristic initial shear strength of horizontal bed joints can be determined in accordance with BS EN 1052-3. However, limited data from testing of NHL3.5 mortars indicates f_{vko} values around 0.20 and coefficients of friction around 0.45–0.55 rather than 0.6 may be appropriate as a first estimate.

21.1.2 *Characteristic initial shear strength of masonry made with natural hydraulic lime mortar,* f_{vko} (REPLACEMENT)

The characteristic initial shear strength of masonry made with natural hydraulic lime mortar, f_{vko}, may be:

a) determined by tests in accordance with BS EN 1052-3;

b) taken as [C] N/mm^2 with clay units having less than 40 % formed voids and concrete units having less than 50 % formed voids for masonry built in mortar strength class M5; or

c) taken as [D] N/mm^2 for masonry built in mortar strength classes M3.5 to M1.

NOTE Currently, no values are available to fill the brackets and so where the characteristic initial shear strength of horizontal bed joints is required it needs to be determined by testing in accordance with BS EN 1052-3.

21.2 Vertical direction (REPLACEMENT)

The characteristic shear strength f_v of bonded brick masonry made with natural hydraulic lime mortar in the vertical direction of the vertical plane may be taken as:

1) [E] N/mm^2 (for mortar strength class M5); and

2) [F] N/mm^2 (for mortar strength classes M3.5 to M1).

NOTE Currently, no values are available to fill the brackets – and further testing is needed to establish reliable values. However, if a first estimate is required, then the value determined for the horizontal bed, f_{vko}, joint may be appropriate.

23 Partial safety factors for material strength, γ_m

23.4 Values of γ_{mv} for shear loads (REPLACEMENT)

The partial safety factor for masonry strength in shear, γ_{mv}, should be taken as 2.5 when mortar not weaker than strength class M1 is used. When considering the probable effects of misuse or accident (Section 5) the value of γ_{mv} may be reduced to 1.25.

Annex A (normative)

Mortar testing of site made mortar (REPLACEMENT)

A.1 Preliminary tests (REPLACEMENT)

At least 15 weeks before construction of the masonry building that will use site made mortar is started, the strength of the mortar designations proposed for use should be determined in the laboratory, with materials from the sources from which the site is to be supplied. Six 160 mm × 40 mm × 40 mm prisms made with mortar of a consistency corresponding to that required on site should be made, cured hydraulically and tested for compression strength, in accordance with the procedures given in BS EN 1015-11.

A.2 Interpretation of test results (REPLACEMENT)

The compressive strength to be expected from the various mortar designations is shown in Table 1. If desired, half of the test specimens may be tested at 28 days. Normally, the results of these tests will give an indication of the strength to be expected at 91 days. For mortars included in Table 1, the strength at 28 days will approximate to half of the strength at 91 days. If the average of these 28-day strengths equals or exceeds half of the appropriate strength given in Table 1, the mortar requirements are likely to be satisfied.

If less, then the designer may choose to await the 91-day strength or have the tests repeated using a more suitable sand. If the 91-day figure fails to achieve the strength given in Table 1, either the tests should be repeated, using a more suitable sand, or the next higher designation of mortar should be used. If the latter procedure is adopted, the strength required of this higher designation should not be that given in Table 1, but should be the strength corresponding to the designation first chosen.

A.3 Site tests (REPLACEMENT)

Six 160 mm × 40 mm × 40 mm prisms should be prepared on site for every 150 m^2 of wall, using any one designation of mortar, or for every storey of the building, whichever is the more frequent. Where possible two sets of six prisms should be prepared – one set from the spot board and a second set after the mortar has been in place for 10 minutes between bricks, in order to establish a “band width” of the strength.

Specimens should be stored and tested in accordance with BS EN 1015-11. Half of the site samples should be tested at 28 days.

The average strength should exceed half of the appropriate 91-day strength given in Table 1.

When the remaining site samples are tested at the age of 91 days, the mortar will be deemed to pass if the average of the values obtained from three prisms or the average of the values obtained from three cubes exceeds the appropriate site values given in Table 1.

Mortar should be sampled in accordance with BS EN 1015-2.

References, further reading and sources of information

References

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BSI

BS EN 459-1:2001. Building lime. Definitions, specifications, and conformity criteria.

BS EN 772-7:1998. Methods of test for masonry units. Determination of water absorption of clay masonry damp proof course units by boiling in water.

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

BS 5628-1:2005. Code of practice for the use of masonry – Structural use of unreinforced masonry.

Cowper AD (1927). Lime and lime mortars. DSIR Special Report No. 9. Reprinted 1998 by Shaftesbury, Donhead Publishing.

De Vekey R (2005). Building masonry with lime-based bedding mortars. BRE Good Building Guide 66. Watford, IHS BRE Press.

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Hammett M (1988). A basic guide to brickwork mortars. Part 1 Materials, mixes and selection. Brick Development Association. Building Technical File No.22. Available to download from www.brick.org.uk.

Lawrence M, Walker P, D'Ayala D (2006). Non-hydraulic lime mortars: the influence of binder and filler type on early strength development. Journal of Architectural Conservation 12 (1): 7–34.

NHBC Foundation (2008). Draft for development. The structural use of unreinforced masonry made with natural hydraulic lime mortars – technical annex for use with BS 5628-1:2005. NF12 (included as an Appendix to this guide).

Schofield J (3rd edition 2005). Lime in building: a practical guide. Black Dog Press, available from Society for the Protection of Ancient Buildings.

Further reading

There are many publications and sources of information, particularly on conservation and restoration, and an increasing number on the use of lime mortars in new build which include useful guidance for a designer or contractor undertaking a project using NHL mortars.

BSI. BS PD 6678:2005. Guide to the specification of masonry mortar.

Hill NR, Holmes S, Mather D (1992). Lime and other alternative cements. London, Intermediate Technology Publications.

Holmes S, Wingate M (2nd edition 2002). Building with lime. A practical introduction. London, Intermediate Technology Publications.

Hydraulic Lime (2007). Best practice guide – hydraulic lime mortars for building and re-pointing. Download from www.naturalhydrauliclime.com/index.php?display=how_to_use_lime&mode=mortar (accessed 4 July 2008).

The Concrete Society (2005). Mortars for masonry – Guidance on specification, types, production and use. Concrete Society Good Concrete Guide 4, Camberley.

Thomas K (1996). Masonry walls – specification and design. Oxford, Butterworth-Heinemann Ltd.

Wingate M (undated). An introduction to building limes. Society for the Protection of Ancient Buildings, Information Sheet No. 9. London, SPAB.

Older publications

The importance of limes and lime mortars in the 19th and early 20th centuries led to the publication of a number of books on the use of lime mortars. Three of these have been reprinted by Donhead Publishing Ltd (www.donhead.com) in recent years and each provides both an insight into the use of lime mortars at a time when they were in common use and also a summary of research and experimentation in the years prior to their original publication:

Cowper AD (1927, reprinted 1998). Lime and lime mortars. DSIR Special Report No. 9.

Pasley CW (1838, reprinted 1997). Observations on limes.

Vicat LJ (1837, reprinted 1997). Mortars and cements.

Sources of information

Building Limes Forum

The Building Limes Forum was founded in 1992 to encourage expertise and understanding in the appropriate use of building limes and education in the standards of production, preparation, application and aftercare. It is a charitable organisation which has about 400 members in the UK and overseas, the majority being actively concerned with the repair of historic buildings or in the use of limes in new build. Its website provides guidance on the benefits of limes for construction and training events related to its use.

Glasite Meeting House, 33 Barony Street, Edinburgh EH3 6NX
Email: admin@buildinglimesforum.org.uk
Web: www.buildinglimesforum.org.uk

Scottish Lime Centre

The Scottish Lime Centre Trust provides specialist advice and training in the use of lime-based materials for the conservation and repair of traditional buildings. It offers a range of training workshops and longer courses for the industry, professionals and homeowners.

Rocks Road, Charlestown, Fife KY11 3EN
Tel: 01383 872 722
Fax: 01383 872 744
Web: www.scotlime.org

British Lime Association

The British Lime Association represents the interests of six member companies responsible for producing more than 95 % of the industrial limes sold in the UK (circa 1.6 million tonnes) for use in a wide variety of applications. One of the Association's key aims is to help broaden the public's knowledge of the benefits of limes and dolomitic limes, as well as representing the interests of the industry in technical, promotional and general matters.

Gillingham House, 38–44 Gillingham Street, London SW1V 1HU
Tel: 0207 963 8000
Fax: 0207 963 8001
Web: www.britishlime.org

Mortar Industry Association

The Mortar Industry Association is the trade body for UK companies supplying all types of mortar products.

Address, phone and fax details as the British Lime Association above.
E-mail: james@qpa.org
Web: www.mortar.org.uk

Society for the Protection of Ancient Buildings (SPAB)

SPAB is involved in all aspects of facilitating the survival of buildings which are old and interesting. The Society produces a series of technical pamphlets, guides and information sheets including 'An introduction to building limes' by Michael Wingate (SPAB Information Sheet No. 9, undated)

37 Spital Square, London E1 6DY
Tel: 0207 377 1644
Fax: 0207 247 5296
Email: info@spab.org.uk
Web: www.spab.org.uk

Heritage organisations

Historic Scotland, English Heritage and the National Trust provide information and guidance on the use of lime mortars, renders and plasters for conservation projects.

English Heritage

Customer Services Department
PO Box 569, Swindon SN2 2YP
Tel: 0870 333 1181
Fax: 01793 414926
Email: customers@english-heritage.org.uk
Web: www.english-heritage.org.uk

Historic Scotland

Longmore House, Salisbury Place, Edinburgh EH9 1SH
Tel: 0131 668 8600
Web: www.historic-scotland.gov.uk

National Trust for England and Wales

PO Box 39, Warrington WA5 7WD
Tel: 0870 458 4000
Fax: 0870 609 0345
Email: enquiries@thenationaltrust.org.uk
Web: www.nationaltrust.org.uk

National Trust for Scotland

Wemyss House, 28 Charlotte Square
Edinburgh EH2 4ET
Tel: 0131 243 9300
Fax: 0131 243 9301
Email: information@nts.org.uk
Web: www.nts.org.uk

NHBC Foundation publications

A guide to modern methods of construction — **NF1**, December 2006

Conserving energy and water, and minimising waste
A review of drivers and impacts on house building — **NF2**, March 2007

Climate change and innovation in house building
Designing out risk — **NF3**, August 2007

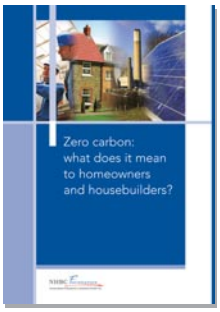
Risks in domestic basement construction — **NF4**, October 2007

Ground source heat pump systems
Benefits, drivers and barriers in residential developments — **NF5**, October 2007

Modern Housing
Households' views of their new homes — **NF6**, November 2007

A review of microgeneration and renewable energy technologies — **NF7**, January 2008

Site waste management Guidance and templates for effective site waste management plans — **NF8**, July 2008



Zero carbon: what does it mean to homeowners and housebuilders?

This report presents the findings of a detailed survey of the views of homeowners and housebuilders on zero carbon homes commissioned by the NHBC Foundation. It reveals current awareness, understanding and attitudes of homeowners towards issues relating to climate change, the Code for Sustainable Homes, airtightness, water conservation and microgeneration.

NF9, April 2008

Learning the lessons from systemic building failures

This review outlines some historic problems with house construction relating to materials, moisture, design and detailing. Using examples to illustrate problems that have arisen with innovative forms of construction, it identifies solutions as well as exploring some of the reasons, to help avoid repeating past mistakes and to ensure that future homes will be robust and long lasting.

NF10, August 2008

NHBC Foundation publications in preparation

- The Merton rule: A review of the practical, environmental and economic effects
- Understanding zero carbon
- Community heating with combined heat and power

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www.nhbcfoundation.org

The use of lime-based mortars in new build

This guide provides a general introduction to using lime-based mortars and is aimed at those who may have little knowledge of this material but who want to apply best practice when used in new build construction projects. It describes a range of mortar types loosely grouped together under the name 'lime mortar' but concentrates on natural hydraulic limes.

A Draft for Development Standard is included at the end of the guide which provides replacement and new clauses for incorporation into BS 5628-1:2005 *Code of practice for the use of masonry – Part 1: Structural use of unreinforced masonry* based on up-to-date information on the properties of lime-based mortars.

NHBC Foundation
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The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the country's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports house builders in developing strong relationships with their customers.

NF12
Published by IHS BRE Press on behalf of the NHBC Foundation
December 2008
ISBN 978-1-84806-066-1