TECHNICAL PAPER 30

HISTORIC LITERATURE REVIEW OF TRADITIONAL LIME MORTARS

HISTORIC ENVIRONMENT SCOTLAND | ÀRAINNEACHD EACHDRAIDHEIL ALBA

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Any enquiries regarding this document should be sent to:

Historic Environment Scotland
Longmore House
Salisbury Place
Edinburgh
EH9 1SH
+44 (0) 131 668 8600
www.historicenvironment.scot

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HISTORIC LITERATURE REVIEW OF TRADITIONAL LIME MORTARS:

EXCERPTS FROM HISTORIC TEXTS 160BC – 1955

NIGEL COPSEY

AUTHOR BIOGRAPHY

NIGEL COPSEY

Starting out as a dry-stone waller in Cornwall, Nigel trained in 1989 as a stonemason and a carver at Weymouth College, working largely thereafter in the conservation industry across the south and south-west of England, and regularly after 1999 in Vermont, USA, as well as in Granada, Andalusia. Nigel was the consultant stonemason for the Irish Hunger Memorial project in Battery Park City, New York, 2001. Since then, Nigel has worked extensively as a consultant and a practitioner in the field of traditional building repair and conservation in North Yorkshire upon a wide range of vernacular and high status buildings; as a building conservation consultant for the Fitzwilliam Estate in Malton, designing, specifying and executing major repair projects to a wide range of historic buildings within the town; as well as researching, designing and specifying a number of building conservation projects on behalf of Natural England, most recently at Scampston Hall. Nigel has contributed to several volumes of the recently published Historic England Practical Building Conservation series. A committed SPAB member, Nigel is also a professionally accredited Conservator-Restorer and determined advocate for the thoroughgoing use of traditional materials in the care and repair of old buildings. In particular, he is a leading advocate for the routine use of hot-mixed lime and traditional earth-lime mortars for most applications. He is working extensively with Historic England and international partners in the delivery of practical training and education in the informed use of traditional quicklime mortars for the repair of historic buildings. A Research Associate of the Department of Archaeology at York University, Nigel regularly delivers hot-mixed earth and lime mortars, and traditional skills training, and leads the Practical Skills module for the MA in Conservation Studies. He is currently writing a book on the historic and practical modern use of hot-mixed lime and earth-lime mortars. Nigel has a BA (Hons) in Political Science from the University of York and a PGDip in Building Conservation from Bournemouth University.

PREFACE BY HISTORIC ENVIRONMENT SCOTLAND

Quicklime based mortars have a long history of use on traditional buildings and structures in Scotland, with visible evidence throughout the country. Since the mid-1990s however, their preparation and use has been largely superseded by dry-bagged Natural Hydraulic Limes (NHLs) that have different properties to their historic predecessors. Growing concern about the compatibility and authenticity of modern lime mortars on traditional masonry structures has encouraged a revival of interest in the use of quicklime-based mortars for repairs.

Hot-mixed mortars are prepared by mixing quicklime with aggregate and water, generating heat and producing a sticky, lime-rich mix. The benefits of hot-mixed mortars and plasters are well-known by practitioners and craftspeople, and have been documented in both, historic and recent texts on traditional buildings and their conservation. They are favoured by many contractors for their workability and early stiffening, allowing efficient building and economy of materials. Despite reservations amongst some specifiers about the predictability and durability of quicklime-based mortars, there is evidence that this method was used almost universally for the preparation of building mortars in the past, and well into the 20th century. This is not the first paper to consider historic sources for information about the preparation of lime mortars, but in general, research has tended to focus on mid- to late 19th century texts, often written with a certain bias toward the appropriateness of its application. In reality, the sources are diverse, span a much broader approach to site practice, and are still available for interpretation. Therefore, this paper seeks to present a wide range of historic texts, allowing the reader to appreciate the full extent of the resource (these are denoted in italics and are often summarised). It will not claim to be exhaustive; it is accepted that accounts of historic working practice will continue to be located and added to the canon.

This Historic Environment Scotland series of Technical Papers aims to assist practitioners in understanding the evidence describing the historic use of quicklime based or ‘hot-mixed’ mortars, and why these materials are still relevant and appropriate in building conservation. It serves as a starting point for discussion on the continued revival of traditional mortars in Scotland and how they fit into the wider range of mortar repairs for traditional buildings. It forms part of a series of papers that examine various technical aspects of hot-mixed lime mortars. They consider the historic evidence for the use of such mortars from written sources; the

micro-structure and performance of historic mortars; the historic evidence still found on buildings in Scotland today; and the specification of hot-mixed mortars for new projects. It is intended that by providing a window into the full extent of the historic written sources, quoting in full where possible, we can better inform conservation work in Scotland and elsewhere. This knowledge is key in preserving the authenticity of the buildings and monuments, maintaining traditional craft practice and delivering technically appropriate interventions.

CONTENTS

1. INTRODUCTION

This Technical Paper is a review of the historic literature relating to lime mortars. It is based on the reading of historic texts that describe the preparation of lime mortars in varying detail. This paper and the others in Historic Environment Scotland (HES)'s series are a result of an identified need to better understand the performance, qualities, materials, preparation techniques, and applications of traditional mortars. It is hoped and intended that these insights will critically engage with and help inform current practice.

Section 2 analyses themes from the historic texts, contextualised by a summary of recent development in craft and site practice. Section 3 comprises the text extracts themselves, arranged chronologically, to which the reader can refer. Many more texts were found than what is included here; these texts were selected for their relevance to Scotland and to represent, as fully as possible, every era in construction from antiquity to the 1950s. Texts were not included nor excluded in order to promote any particular agenda or to support a particular view on the historic preparation of mortars, and in most cases are left to speak for themselves. In some cases, further context is given, and certain texts are interpreted for clarity. Slight editorial license has been used to extract only those sections which are relevant to convey the practices described. Some records are sparse in terms of actual site practice, but are very clear on the materials used and the nature of the labour employed. Readers seeking more detail can refer to the original texts, which are fully referenced and, in most cases, easily accessible online or in archives.

Although primarily concerned with limeworks in Scotland, the nature of the surviving and published material means that much is from elsewhere, and texts from Europe and North America are included to demonstrate the universality of many aspects of craft practice in masonry construction.

This investigation of sources and a proper understanding of common practices has shown that the vast majority of traditional lime mortars were hot-mixed, meaning they were made from quicklime that was generally slaked on site, and were used immediately or very soon after they were mixed. Fat lime (also called non-hydraulic or 'air lime') and hydraulic lime mortars were routinely hot-mixed, a practice which continued with hydraulic limes even after running fat lime to putty became routine.

The ingredients in traditional mortars were quick and efficient to prepare, eminently workable, cheap, accessible and, in most cases, locally available. Importantly, they also offered appropriate durability and performance. An acknowledged slowness of set does not seem to have concerned builders of the past and these mortars achieved the sufficient stiffness quickly enough to be able to perform structurally within the timelines required during normal masonry construction. Their relative softness and pliability accommodated settlement without cracking, and they were vapour and capillary active, readily poulticing moisture and salts. Whenever accelerated set was required, the addition of a variety of readily available pozzolanic materials achieved this without compromising workability or the important properties of a quicklime mortar.

The 20th century, however, saw the industrialized production of pre-slaked and bagged lime binders, particularly of air limes, but also hydraulic limes and cements. Both represented a significant change in site-practice but were quickly embraced by architects and other specifiers who saw themselves as freed from craft practice and reliance upon the skill and expertise (and the associated cost) of brick and stonemasons.

As the risks of using cement-based mortars became apparent, a renewed interest in using lime mortars occurred during the 1980s and 1990s. Since then, there has been a growing acceptance of lime mortars for use in building conservation projects. However, the evidence of the old texts, as well as of more recent material science, is that many of the assumptions of the lime revival were based upon an incomplete or partial analysis of historic practice, and the character and performance of historic mortars. Many of the conventions that are now standard for working with lime mortars were a result of using materials that are essentially modern formulations, and not 'like-for-like' recreations of traditional mortars.

The lime revival was based upon craft practice but referenced an already 'degraded' 20th century practice that differed in crucial ways to the one contemporary with most traditional buildings. Only lime rich 'fat' mortars (traditionally, this included feebly hydraulic limes) offer compatibility with these traditional substrates. This has been demonstrated in the modern day through trial and observational research, such as that by David Wiggins for HES.[1]

[1] David Wiggins, *Technical Paper 27: Hot-Mixed Lime Mortars – Considerations on microstructure and functional performance*, Historic Environment Scotland, 2018.

Selective interpretation of some historic texts has also led to a pervasive assumption that historic mortars were made using lime run to putty, irrespective of their application. The few widely read historic texts (such as Vicat, whose work was republished in English in 1998), confirmed the bias in favour of putty limes, as well as suggesting that moderately or eminently hydraulic limes were historically far more commonly used above ground, than was in fact the case.

This is not to assign blame to conservation professionals; successful work has been achieved with modern limes. Nevertheless, in the author's experience there are contractors and masons working regularly on traditional buildings who have used no form of lime other than NHL in their careers. Climate change has also led to an increased annual rainfall across Scotland, which has created the perception that such wetness prevents the reasonable curing of air lime mortars. While this is often the case, shortcomings in building detailing often mean that the mortar, lime or otherwise, is under increased pressure.

In addition, the building conservation sector continues to overlook the widespread use of earth-lime mortars for masonry construction and interior plastering. These were used in conjunction with eminently breathable air limes for pointing and finish coats until at least the end of the 18th century; texts relating to this area of traditional mortars will be progressed in other work.

The HES sponsored review of recent works with gauged and hot-mixed mortar mixes in Scotland[2] however, shows that a number of masons remain uncomfortable with the specification of straight natural hydraulic lime (NHL) mortars. This paper aims to highlight that modern high-strength and formulated materials have been uncritically embraced in recent years, without an informed understanding of what traditional methods they replace. Therefore, a thorough reassessment of lime mortar practice is due.

The research teams of HES and Historic England continue to commission important research into the character and performance of both hydraulic and hot-mixed air limes. Much remains to be learned and, as the use of quicklime based mortars continues to develop, it will be essential for that knowledge and experience to be widely and openly shared amongst everyone who works in the field of building conservation.

[2] Craig Frew, *Technical Paper 29: Review of Hot-Mixed External Lime Coatings in Scotland 1997-2016*, Historic Environment Scotland, 2018.

2. THE CONSENSUS FROM THE HISTORIC TEXTS

This section provides a contextualized overview of the information in the historic texts. It explores themes in the technical development of lime processing and suggests how these might inform conservation work. The main message is of simplicity in preparation and execution. All the claims in this analysis are derived directly from the historic sources in the next section, and references have been put in the footnotes to help the reader consult the relevant texts.

2.1. Historical developments in the use of building limes

There are few surviving ancient sources on lime, which places a disproportionate emphasis on a handful of authors. Several key and persistent ideas about lime can be traced to just this handful of ancient texts. It is Vitruvius who establishes 3:1 mix ratios and Pliny who says that the best mortar is that matured three months or more (a point commonly misinterpreted and misapplied; he was referring to lime for plastering). During the Renaissance and Enlightenment, Vitruvius in particular, came to be regarded as the authority on classical (and thus neo-classical) construction practice.[3] Ancient sources also advise first on the use of pozzolana and gauging with gypsum.

Although little documentary record from the medieval period survives, particularly in Scotland, visual depictions of medieval building sites across Europe suggest that mortars were mixed on site, immediately adjacent to the works, and used immediately or shortly after mixing. Illustrations show mortar boxes, steam rising from mortar piles, and sometimes mortar being cut from a larger pile of coarse stuff. These depictions of historic activity date from when craft practice was generally not written down, although financial information relating to building projects often was. Examining illustrations from this period could provide valuable insights about site practice, but this is a separate matter for study.

This pattern is confirmed by building accounts, mostly financial, which describe lime burning, slaking and mortar making happening concurrently with the building works. Payments in the Scottish Masters of Works Accounts for ‘lime sieves’ indicate that mortars were being dry-slaked and screened, just as described in Scottish building specifications centuries

[3] Vitruvius’ work, however, survives only in medieval translation, coming down to us second-hand and possibly corrupted.

later.[4] Lime kilns were frequently built on site, as were 'lime houses' for mortar preparation.[5] In England, 13th century records for Corfe Castle show the lime burners arriving on site the week before the masons at the start of the building season.[6] Sand routinely appears in the same account as 'lime from the kiln', and sometimes, as 'earth for mortars'.

In Scotland, the accounts of Masters of Works are a resource, detailing royal construction projects over the course of the 16th and 17th centuries. Though bare expenditure accounts, they lend themselves to interpretation similarly to the medieval English sources. In Scotland, lime is noted as being continually brought to site throughout the year, including during the winter. There are mentions of kilns being built onsite, and references to slaking and working in the lime 'fauld' or slaking pit alongside riddles (sieves).

The 1616 building accounts for the Queen's House, Greenwich, show a similar pattern in England. Payments appear "for slacking, sifting and wetting of lime into mortar". Materials, including lime and sand, arrive regularly on site through the project, and lime is burned throughout the year, including during winter.

The 18th century saw the development of the instructional treatise as a genre. Such texts were widely read and most reference previous works and created a dialogue with them. In Scotland and elsewhere, increasing reverence for classicism, coupled with innovations in engineering and infrastructure, drove builders and innovators to look to antiquity both aesthetically and technologically. The proliferation of ashlar masonry and fine plaster interiors created demand for putty-based lime products, with increasing reliance on gypsum, which accelerated setting. This period also saw ever more ambitious civil engineering works, such as bridges, piers and lighthouses, which sought fast-setting mortars with hydraulic properties suitable for wet environments. Writers, builders, engineers, and architects increasingly admired the demonstrable durability of structures that had survived since antiquity and aimed to replicate and improve on the

[4] 16th-17th centuries - Master of Works Accounts; 1750 - George Semple, Mortar mixing specification; 1776 – Extracts from George Semple's Paper on Hydraulic Lime; 1838 - Specification for making additions, alterations & repairs on Farm Steadings, Ormiston and Peaston, East Lothian.
[5] 1222 - Works at Winchester Castle; 1434-37 - Building Accounts at Tattershall Castle; Salzman LF *Building in England Down to 1540, a Documentary History* (1952), 16th-17th centuries – Master of Works Accounts; 1756-58 – Limeburning and Repairs to the Grounds at Blair Castle, Blair Atholl, Perthshire.
[6] White P. Corfe Castle; Analysis of the Exchequers Accounts of Edward I 1280-94. Unpublished.

qualities of Roman cement. This led to experiments and studies of hydraulicity in mortars, achieved either through additives and pozzolans, or increasingly through nuance in the sourcing and burning of different limes with natural hydraulic properties, which could be further optimised through manipulating the mixing process. The result was a new generation of mortars and cements.

Engineers have exerted a strong influence over the understanding of mortar development. Two individuals in particular, Henry Scott of the Royal Engineers and US Army engineer Quincy Adams Gillmore, sought to rationalise previous thinking and produce 'definitive' accounts during the second half of the 19th century, whilst Searle, Cowper and others did likewise in the earlier 20th century. Although these engineers were enamoured of hydraulic limes, they had much to say about fat limes and aggregates as well. Alongside Smeaton's writings on the Edystone lighthouse (1754), their texts constitute very important contributors to our understanding of lime. Military engineers in France, the USA and the UK led the move towards using hydraulic mortars 'in the air' to produce masonry which could carry the loads of heavy ordnance.[7] Initially, they advocated the use of natural cements; Portland cement only became the norm over natural cement towards the end of the 19th century.[8] US military engineers were the first to begin running fat lime to putty before gauging with natural cement.[9] This practice then extended to Europe using Portland cement. There was more focus in France upon the use of eminently hydraulic limes in this context, though some (such as Treussart) continued to prefer fat limes gauged with pozzolans for water works. Although Vicat wrote extensively and advocated for artificial hydraulic lime (for which he held the patent), it never caught on amongst fellow engineers. Despite the urgings of architects and engineers throughout the 19th century, hydraulic limes were rarely used above ground for domestic or ordinary construction before the tail-end of the century and were displaced by cement-lime mortars.

[7] 1776 – Extracts from George Semple's Paper on Hydraulic Lime; 1791 – Smeaton's Account of the Construction of The Edystone Lighthouse; 1825 – Hassenfratz, *The art of burning limestone*; 1829 – M E Martin*, The Art of The Mason*.
[8] 1859 - Details for the Construction of the Canadian Parliament Buildings in Ottawa; 1861- Construction of Farm Buildings in England; 1890 – A Hammond, *The Rudiments of Practical Bricklaying;* 1899 – George Sutcliffe, Principles and Practice of Modern House Construction; 1901 – William Richards, *Bricklaying and Brickcutting*.
[9] 1842 – George Totten, *Brief Observations of Common Mortars, Hydraulic Mortars and Concretes*; 1845 – W H Wright, Public Works in Boston Harbor

Craftsmen are largely absent as authors, although craft practice is frequently referred to. Smeaton and Higgins were unusual in trusting the wisdom of craft practice, whilst at the same time testing it and sometimes disagreeing with its assumptions. References are frequently derogatory of craftsmen, particularly after 1850. Many insights into craft practice are delivered only in the negative, through pejorative references. Other aspects of craft practice, such as the use of earth-lime mortars across Europe and the Americas before the 19th century, receive little or no mention at all. However, earth building was positively discussed by both Vitruvius and Alberti and by architects during the 19th century, particularly in France, as economical housing for the rural working classes.

The increasing application of science and the development of industrial processes with lime led to a new elitism that pitted intellectual innovators against craftspeople who were perceived as old-fashioned and uncooperative.[10] In the spirit of industrialism, innovation strove for methods that were regularised, pre-prepared and as easily replicable as possible. This led to a de-skilling of the workforce, along with a preference for pre-bagged and pre-slaked limes with uniform, quantifiable properties. Standards in materials evolved to meet this new preference, further distancing the industry from traditional materials and entrenching a perception of their inferiority. The modern heritage sector still tends to operate within this paradigm. The same impulses that discouraged 'messy' (or in other words, 'skilled') techniques like hot-mixing and grouting over the course of the late 19th and 20th centuries, are the same that have made NHLs so popular for conservation projects over the last three decades, despite being essentially a modern material. Negative perceptions of the H&S issues associated with quicklime have also brought perjorative associations.

In the earlier 20th century, the design and nature of regular building mortars was in flux. New 'rules' or conventions of increasing hardness and faster set were being promoted, driven by demand for more quickly built mass housing. Despite the heavy emphasis in written work on cements and hydraulic limes, quicklimes did remain in use even after WWII, especially hydraulic limes (particularly Blue Lias), which were preferred by some over the industrially hydrated versions. High calcium quicklimes remained a common form of lime for the preparation of gauged mixes in the 1950s,[11]

[10] 1914 – Jan Van der Kloes, *A Manual for Masons*; 1915 – Lazell, *Hydrated Lime: History, Manufacture and Uses*

[11] 1950 - Ministry of Works Advisory Leaflet on Limes for Mortar; 1951 - British Standard Code of Practice CP 121.201

though bagged hydrate was by then more typical. As late as 1946, a RIBA Committee was suggesting that hydraulic limes could be usefully deployed for new building works, but that they were variable in quality and lacked a British Standard, indicating that their use was not common. Therefore, the first significant demand for the use of NHLs in the air was created by the conservation industry.

2.2. Techical aspect of historic lime processing

Supply of quicklime

It seems to be commonly asserted that building limes were often of poor quality. This may stem from frequent complaints in London, possibly due to air-slaking during transport, since quicklime had to be imported from Kent or Surrey. To combat this, Smeaton built lime kilns at Plymouth to provide fresh Blue Lias for the Edystone Lighthouse. Generally, however, most areas were served by local kilns from which lime could be carried short distances without detriment. Masons could judge quality on mixing, and if air-slaking resulted in an overly lean mix, more lime could be used to achieve the right 'feel'. In limestone-rich areas, lime kilns were numerous but in sandstone dominant areas, kilns tended to be built at roadsides or along navigable waterways and the limestone carried to them for burning.

Timing of use

Most authors stress that quicklime should be used fresh from the kiln.[12] Independent of air slaking, there is a common notion that it loses quality the longer it is out of the kiln. Once slaked, almost all sources prior to the 19th century concur that building mortars should be made and used immediately or within a few days.[13] The exception is when plastering, where the 'ordinary method' (see below) recommends that hot-mixed coarse stuff be laid down longer to allow late slaking, ensuring a smooth internal finish.[14] It is only toward the close of the 18th century that sources start to state that the older a mortar is, the better it performs.

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[12] 1750 - Batty Langley's Price Book; 1756 – Ware's *Complete Body of Architecture;* 1777 - Marquis de La Faye*, Studies on the preparation of Roman cements*; 1791 – Smeaton's Account of the Construction of The Edystone Lighthouse; 1825 – Hassenfratz, *The art of burning limestone;* 1862 – James Austin's manual on limes and cements.

[13] 1570 – Andreo Palladio, *The Four Books of Architecture;* 1726 – Robert Neve, *The City and Country Purchaser;* 1780 – Bryan Higgins, *Experiments and Observations*; 1799 - William Wilkins, *Specification for repairs at Bayham Abbey, Kent*. Wilkins says no more mortar to be made than can be used on the day – Although Moxon (1703) disagrees, as does Marshall (1796).

[14] 20 BC – Vitruvius, *De Architectura;* 1460 – Alberti, *On the Art of Building in Ten Books;* 1780 – Bryan Higgins, *Experiments and Observations.*

Slaking

The method of slaking materially affects character and performance. Hot-mixed mortar used hot or warm is more porous with the least (initial) compressive and flexural strengths.[15] Mortar mixed to a dry-slake and knocked up when cold is less porous and has the greatest (initial) compressive and flexural strengths. Hot-mixed mortar, used cold, falls somewhere in between. Carbonation rates also vary, but generally the more porous, the faster the carbonation. Of the references gathered, Raucourt (1778) is the first to articulate three received traditional slaking methods, which since have become part of accepted wisdom around lime processing.[16] He calls these 'the three modes', which are the 'ordinary or common', 'immersion' and 'spontaneous', listed below:

'The Ordinary' or 'common' method

The 'ordinary' or 'common' method of mixing was almost universal for fat and hydraulic limes. It combines the processes of slaking and mixing, harnessing the energy of the one to enhance the other. The technique calls for lump lime slaked with just enough, or a slight surplus of water in a ring of sand, banked over to retain heat, mixed as soon as the slake was complete.[17] It was not uncommon to slake the lump separately in a mortar box or pit and then mix immediately after, whilst still hot, but Moxon (1703) thought this produced a weaker mortar. Lime could also be slaked to a dry hydrate (facilitating screening) or to a dough-like paste, mixed immediately, by adding just enough water to affect the slake, either in one helping, or continuously by sprinkling. The resultant lime would be used immediately or soon after. Hydraulic limes took longer to slake and required mixing the sand and pulverised quicklime together before or during slaking. This method presents its own challenges since, when slaking with lump lime in isolation from the aggregate, many pieces will slake late or incompletely. However, adding an excess of water in the midst of the slake will 'chill' the lime, generating a multitude of small lumps impossible to break down.

The Immersion method

Lump lime was dunked under water for several seconds, or until slaking commenced. It was then either tipped out to slake to a dry hydrate and sieved to remove lumps or tipped into barrels and left to cook en masse. It

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[15] Wiggins, *Technical Paper 27,* ibid.
[16] 1778 - Raucourt, *How to Make Good Mortar.*
[17] 1842 – General Treussart, *Hydraulic and Common Mortars and Lime-Burning*; 1864 – Gillmore, *Practical Treatise on Limes;* 1897 –William Millar, *Plastering, Plain and Decorative*; 1909 - Radford's *Cyclopedia of Construction, Carpentry, Building and Architecture.*

could be stored for future use, and usually was reserved for fine stucco or plaster finishes. De la Faye (1777) is unique in recommending it as the preferred method for building mortars. It is probable that lime slaked by immersion was mixed whilst still very hot, which delivers fattier, more workable mortar than when mixed cold. Adding quicklime to an excess of water became the 'normal' method only when the intention was to gauge a mortar with either Portland cement or gypsum.

The 'Spontaneous' or air-slaking method

Lump lime laid out on a platform in an open-sided shed and left to slake slowly by absorbing moisture from the air, which might take up to a year. Although most authors quote this as the third 'traditional mode,' they concur that it is the worst method and rarely employed. Only Smeaton notes it as a common procedure for Blue Lias hydraulic quicklime, and he did not choose it when building Edystone Lighthouse.

Slaking temperature and regulation of water

Two of the three slaking methods described above aim to keep the maximum temperature to around boiling, which was considered important for final performance. Insufficient water leads to higher temperatures and risks 'burning' the lime and then 'chilling' it when more, particularly cold, water is added. This kills the reaction and creates particles that cannot be further broken down. However, the addition of too much water, either through immersion or aspersion, will 'drown' the lime, and prevent it reaching the minimum necessary temperature, leading to a weaker mortar that lacks tenacity. For all traditional methods, a minimum amount of water was added to quicklime, not the other way around, which was routinely counselled against.[18]

2.3. Properties of different lime mortars

Air Limes

Historically, the phrase 'fat lime' referred to both pure and feebly hydraulic lime. These were the norm for 'work in the air' or above ground until the arrival of cement-lime mortars, though frowned upon by some engineers, particularly Vicat and his proponents. In the UK, feebly hydraulic limes were considered 'common limes' (non-hydraulic limes) with slightly enhanced

[18] 1839 - Christopher Davy, The architect, engineer, and operative builder's constructive manual; 1460 – Alberti, *On the Art of Building in Ten Books*; 1842 – George Totten, *Brief Observations of Common Mortars, Hydraulic Mortars and Concretes*; 1859 - Celestino's Construction Manual; 1862 – James Austin's manual on limes and cements; 1871 – Gillmore's Report on Limes; 1901 – William Richards, *Bricklaying and Brickcutting*;

setting power and were generally frowned upon by engineers as little better than pure limes.[19] They expanded similarly and slaked as readily as common fat limes and were preferred for exterior use where available. Masons, bricklayers and plasterers preferred fat limes, whether pure or feebly hydraulic, until at least the earlier 20th century, particularly in rural areas. Lump lime was still commonly used in London after WWII, for example, and well within living memory in Yorkshire.[20]

Water Limes

Hydraulic limes and natural cements were the norm for water or underground works, often colloquially called 'water limes'. The trend towards hard, hydraulic binders in the air began with engineers experimenting with mortars for use under water in the construction of harbours and large infrastructure projects. John Smeaton initiated this approach in the UK, but French, Spanish, American and other British engineers, mainly of military backgrounds, soon started experimenting as well. During the 19th century, these engineers were aided by chemists and architects keen to establish themselves as specifiers of mortars, asserting authority over craftsmen's long-standing preference for lime-rich 'fat' mortars. Although Smeaton and earlier 19th century engineers were content with using fat limes in the air, it became increasingly common for engineers and architects to advocate the use of hydraulic binders for general construction beyond engineering applications, eventually leading to their dismissal of the utility and value of fat limes.

References to craft practice, alongside physical evidence, indicate that the ascendancy of hydraulic binders for general construction in the air did not become the norm until the early 20th century. Furthermore, this was founded much less upon natural hydraulic lime than upon cement-lime mortars. Although natural cements had sometimes been used for repointing and exterior renders since their development in 1796 (the development of Parker's Cement), growing use of moderately hydraulic lime binders in the air across Europe at the end of the 19th century was eventually displaced by cement-lime mortars. These were typically leaner in binder content, 1:2:9 being the standard until recently. Cement-lime mortars offered a regularity that natural hydraulic lime mortars (accounted variable and problematic up until the 1950s mortars) did not.

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[19] 1775 – Smeaton's *Directions for preparing and making mortars*; 1776 – Extracts from George Semple's Paper on Hydraulic Lime; 1791 – Smeaton's Account of the Construction of The Edystone Lighthouse

[20] 1950 - Newbold & Edgar, *Modern Practical Building*

Compatibility

No texts, with the exception of Burnell (1857), make any reference to the principle of compatibility. The engineers' definition of the 'best' mortar was the 'hardest' achievable. It is a common assumption historically, that pointing mortars should be tougher, harder and more weather-resistant than bedding mortars. This is reflected in the use of lime-rich pointing mortars over earth bedding mortars and evolved into a practice wherein lime mortars next became routine for bedding, with the use of feebly hydraulic or natural cement pointing mortars. The change probably occurred once repointing of earlier traditional structures became necessary (e.g. Pasley 1826 and 1838), and continued evolving in the 20th century, with the repointing of lime-built masonry with cement or cement-lime mortars. However, there is evidence that in many parts of Scotland, historic practice showed little difference in composition between core and bedding mortar and the pointing or harling material; there is a suggestion that in some cases this was done at the same time.[21]

Putty lime

Lime run to putty was generally considered to produce a weaker mortar with less bond. [22] Lime was run to putty to facilitate removal of under- or over-burned material and was used for limewashes and interior finishing plasters. It was normally made by adding water to lump lime, diluted after slaking was complete. As a mortar, it was reserved for gauged brickwork and finely jointed ashlar, where strength was of less importance and absence of lumps essential.[23] It was typically mixed with a small volume of water to produce a dough-like putty and used immediately (hot) or soon after slaking (cold). Except for the above applications, when it might be mixed 1:1 with very fine sand, lime putty was not much used as a bulk binder before the 20th century, when in some regions, it became practice to gauge putty lime mortars with either Portland cement or gypsum[24] to enable haste in building.

Maturing of quicklime

References by Vitruvius and Pliny to maturing pits of putty lime for years are frequently quoted, although these sources clearly state that the lime in this case was reserved for plasters and stucco renders, not for mass masonry structures, walls and vaults. Misquotation of this principle

[21] 2019 – Addyman and Meek, *HES Technical Paper 31*
[22] 1777 - Marquis de La Faye, *Studies on the preparation of Roman cements*
[23] 1750 - Batty Langley's Price Book; 1818-23 – Specification for the construction of the Burns Monument, Ayrshire; 1775 – Smeaton's *Directions for preparing and making mortars*
[24] 1845 – W H Wright, Public Works in Boston Harbor

originated in the 18th century and there are strong indications that this countermanded normal craft practice.[25] The authors who quoted these references were Palladian architects who revered classical sources, while simultaneously dismissing craft practice. Even Alberti in 1460 looked back to a notional 'golden age'. He is the only author who specifically says (in a chapter on ornament) that lime putty should be matured for a minimum of three months; in some lime discussions this has become three years. This is the only possible source for the modern proponent for the same.

Hydrated limes

The use of bagged hydrated lime became common for plastering in the earlier 20th century in the UK and US, and although pre-hydrated, it could still be mixed to traditional proportions. During the 20th century, industrially produced hydrated lime was commonly used, both in cement-lime mortars and for plastering. This was run to putty 24 hours before use to fatten.[26]

Limewash

Limewashes were made from quicklime and used immediately, whilst hot, increasing bond and imparting high 'flowability' even whilst thick. Fine sand or chalk were sometimes added, as well as natural oils and tallow for improved water protection.

Grouting

'Hot Lime' grouting is frequently recommended – for brickwork and for stone core-work.[27] A hot grout penetrates deep into the work and then

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[25] 1701 - Contract between the Earl of Strathmore and John Sherres Sklaitor for works at Glamis Castle, Angus; 1703 – Moxon's *Mechanic Exercises*; 1756 – Ware's *Complete Body of Architecture*. Some sources (Moxon, 1703) mention laying down for two or three days, and at Blair Castle (1754) laying it over until next year as 'leftovers' was a matter of convenience. At 1759 Dunkeld (1759) lime for plaster was laid down 'sour up' so that it could be mixed with hair and used 'as soon as possible'. At Brodick Castle (1761) the entire time from quarrying through burning, souring, and building, was 25 days. Plaster at Mount Stuart on Bute was laid aside for 3 weeks (1761). Higgins (1780) slightly disagrees, saying it is common practice to make up more than you can use on the day, and that many builders believe the older a mortar is, the better.

[26] 1912 – Mitchell's *Building Construction*

[27] 1754 – Specification for the construction of the Corn Exchange, Edinburgh; 1776 – Extracts from George Semple's Paper on Hydraulic Lime; 1791 – Smeaton's Account of the Construction of The Edystone Lighthouse; 1799 - William Wilkins, Specification for repairs at Bayham Abbey, Kent; 1818-23 – Specification for the construction of the Burns Monument, Ayrshire; 1826 – Pasley, *Practical Architecture*; 1833 - Loudon's *Encyclopedia*; 1838 - Specification for making additions, alterations & repairs on Farm Steadings, Ormiston and Peaston, East Lothian; 1847 - Returns and Contracts Relative to the New Houses of Parliament, London; 1857 - Dempsey's *Architectural Practice*; Details for the Construction of the Canadian Parliament Buildings in Ottawa (1859)

stiffens through evaporation and completion of the slake. This technique is sometimes called 'implection', and early investigation suggests that masonry was grouted in this fashion, piecemeal as each building lift was constructed.

2.4. Ingredients and additives in mortars

Aggregates

It is often asserted that 'dirty' sands were commonly used in the past; an argument that has sometimes been used to justify using natural hydraulic limes. However, this is probably a misinterpretation of descriptions of earth-lime mortars, combined with confusion over references to road scrapings in mixes.[28] Almost all the old texts state that sands for lime mortars should be clean and washed.[29] Some suggest that road-scrapings give a good aggregate, others, such as Scott (1862) and Pasley (1826), condemn the inattentiveness of many masons to the cleanliness of their sand. Langley (1750) says that 'loamy' and less well-graded sand should be confined to internal use, whilst exterior mortars using the same lime should be made with clean, sharp sand, and that the cleanness and sharpness of the sand was the key to a mortar's durability.

Pozzolans

The addition of certain stone dusts or clays to mortars promotes a strengthening reaction that many authors thought would be most pronounced when the mortars were hot-mixed.[30] Unfortunately there is no written record of this, but it is probable that craftspeople would use pozzolans as required. Langley (1750) is clear that pozzolanic mortars were for use underground or underwater.

Gauging of mortars

Gypsum gauging of fat lime for interior finishing coats and castings has a long history, but gypsum gauging of base and second coats ('coarse stuff' plaster) only arose in the earlier 20th century, in response to time

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[28] 1796 – William Marshall, *Rural Economy of Yorkshire*

[29] 1776 – Extracts from George Semple's Paper on Hydraulic Lime; 1791 – Smeaton's Account of the Construction of The Edystone Lighthouse; 1796 – William Marshall, *Rural Economy of Yorkshire*; 1818-23 – Specification for the construction of the Burns Monument, Ayrshire; 1824 – Specification for reconstruction of damaged Farm Steading, Humbie, East Lothian; 1829 – M E Martin*, The Art of The Mason*; 1834 - Construction of Cottages in Scotland; 1837 - Partington's *Mechanic's Companion*; 1860 - William Copperthwaite's Specification for the extension of an Inn in Yorkshire; 1860 – Daniel Jacques, *Rural Architecture*; 1861 - Ottawa Public Buildings, Specifications and rates

[30] 1771 – Robert Dossie, *Memoirs of Agriculture*

pressures.[31] It was considered pragmatic rather than best practice. Vitruvius unequivocally disapproved of gypsum gauging: "For these (ceiling finishes), gypsum is the last thing one wants to mix in… so that one part will not anticipate the other in drying, but the whole will dry at a uniform rate…" Authors throughout history have understood that only the additive sets quickly, not the main body of the material.[32]

2.5. Mix ratios

Lime to aggregate proportions are expressed below as 'quicklime':'aggregate', except where stated otherwise. The earliest, explicit indications of mix proportions suggest the optimal quicklime:aggregate proportion for fat and feebly hydraulic limes as 1:3 and 1:2 for hydraulic limes (moving towards 1:1 the more hydraulic the lime).[33] The bulk density of the lime is important, although in the past, mortar ingredients were mixed by volume rather than weight. In 1862, Scott, the Royal Engineer, spelt out the importance of paying attention to the variable bulk densities of different limes when mixing by volume. It is probable that most craftsmen would have achieved similar mixes but done so by 'feel'.

The extra setting power of additives such as Portland cement or gypsum allowed the proportions to be adjusted to 1:3, reducing the cost of mortars. Previously, 1:3 quicklime:aggregate (the quicklime roughly doubles in volume upon slaking) had been universally considered the minimum amount of lime and the maximum amount of sand for fat lime mortars, which did not compromise workability and performance.[34] Hydraulic lime mortars, also made on site from quicklime, were rarely mixed leaner than 1:2 (and frequently at 1:1), the slaking expansion of hydraulic quicklime decreasing as silica and alumina content increased. Concretes were the exception to this rule. In the UK, these were mixed hot and typically at 1:7

[31] 1912 – Mitchell's *Building Construction*; 1930s - *Modern Building Practice in 40 Volumes*
[32] 1750 - Batty Langley's Price Book; 1771 – Robert Dossie, *Memoirs of Agriculture*; 1775 – Smeaton's *Directions for preparing and making mortars*; 1780 – Bryan Higgins, *Experiments and Observations*; 1776 – Extracts from George Semple's Paper on Hydraulic Lime; 1791 – Smeaton's Account of the Construction of The Edystone Lighthouse; 1838 – Pasley, *Observations on Limes*; 1952 – Alfred Geeson, *Building Science Materials for Students*; 1930s - *Modern Building Practice in 40 Volumes*
[33] 1703 – Moxon's *Mechanic Exercises*; 1756 – Ware's *Complete Body of Architecture*; 1776 – Extracts from George Semple's Paper on Hydraulic Lime; 1791 – Smeaton's Account of the Construction of The Edystone Lighthouse; 1826 – Pasley, *Practical Architecture*; 1890 – A Hammond, *The Rudiments of Practical Bricklaying*; Salzman *LF Building in England Down to 1540, a Documentary History* (1952);
[34] 1826 – Pasley, *Practical Architecture;* 1845 – W H Wright, Public Works in Boston Harbor; 1856 – Vicat, *Practical and theoretical composition of mortars;* 1864 – Gillmore, *Practical Treatise on Limes.*

or 1:8, with indigenous NHLs significantly less aggressive and much less hard in their set than most modern NHLs, and with a significantly greater free lime content.

Below are some typical mix proportions, based on data gathered from historic texts:

Typical fat lime: pozzolan (true pozzolan, brick dust and other fired clays, forge scales, wood ash): aggregate proportion for water works - 1:1:2. Often 1:3 lime: pozzolan; sometimes 1:1.

Concretes were typically hot-mixed (when lime was the binder) and were surprisingly lean, 1:7 being typical for foundations and water works, 1 being Blue Lias lime or (later) Portland cement. 1:8 or 1:6 OPC:aggregate was still common in 1950, depending on the desired finish.

For cement-lime mortars ratios equalling 1 part slaked lime, or other binder, to 3 parts aggregate only became the norm with the arrival of cement-lime mortars, e.g. 1:3:12; 1:2:9; 1:1:6. This reflects the extra setting power of the cement.

2.6. Mixing methods and site practice

Historically, hydraulic quicklimes were routinely pulverised before slaking to hasten slake. Dossie (1771) and De la Faye (1777) thought it delivered a 'stronger', more tenacious mortar. Pasley in 1826 noted that this method had also become common with fat limes.

Most sources concur that lime mortars, fat and hydraulic, should be well-beaten during and after the making, engaging as much lime as possible, and to break down lime lumps into an effective binder.[35] Once available, mortar mills were usually preferred to hand-mixing.[36] In the author's experience, roller mills continue to produce the best mortar today, though mortar from pan mixers is also very good and hand-mixing should not be ruled out. Recent research indicates that beating increases workability with less water, thus reducing initial shrinkage and also shrinking larger pores to

[35] 1750 - Batty Langley's Price Book; 1799 - William Wilkins, Specification for repairs at Bayham Abbey, Kent.
[36] 1819 – Rees Abraham, *Cyclopedia*; 1839 - Joseph Gwilt, *Rudiments of Architecture*; 1842 – George Totten, *Brief Observations of Common Mortars, Hydraulic Mortars and Concretes*; 1859 - Celestino's Construction Manual; 1862 – Captain Henry Scott, 'Observations on Limes and Cements'

around 1 micron, which increases effective porosity.[37]

A distinct goal of the 18th century engineers and innovators was replicating famously durable Roman concrete. Vitruvius' specification of 1 part *slaked* lime to 3 parts aggregate, which contradicts all later texts and apparent practice, is probably a mistranslation made centuries ago, or refers to the production of fat lime:aggregate:pozzolanic concretes. French, and probably Spanish, concretes ('beton') were made with already slaked lime run to putty, although, as in American military practice in the 19th century, still mixed whilst very hot.[38] Hot-mixing of concretes was the norm in the UK, and Gillmore (USA 1864) describes it as the 'English Method'.

Preparation and Protection

The first mentions of wetting and protection of newly placed mortars (other than covering wall-tops during winter) are in association with the use of hydraulic limes in the air.[39] Similarly, greater emphasis on liberal wetting of building materials and substrates coincides with increased use of hydraulic materials. Pre-wetting was not usually required for hot-mixed fat limes, though it was sometimes recommended.[40] The careful aftercare required for repair works, where the lime layer may not be very thick, is needed much less for newly built walls, as there is a considerable volume of water still within the wall; therefore, it is not mentioned to the same degree.

Tension between craft and specification

Architects were quick to embrace the move away from fat and feebly hydraulic lime mortars, which could be variable and required skill and experience, towards hydraulic lime mortars made with industrially produced and rote-mixable ingredient. They were keen to establish and assert their ascendancy within the construction process. They justified this move by questioning the durability of traditionally used mortars, claiming craftsmen were lazy and lacked integrity, and pretensions to scientific

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[37] Michoinova, D.; Rovnanikova, P. 'High-Calcium Lime Mortar: The Effects of Traditional Preparation and Curing.' *The Journal of Preservation Technology*, 2008, Vol. 39, Iss. 4, 23-29. Also, Wiggins, D., *Technical Paper 27: Hot-Mixed Lime Mortars: Microstructure and functional performance* (Historic Environment Scotland, 2018).
[38] 1829 – M E Martin*, The Art of The Mason*; 1842 – General Treussart, *Hydraulic and Common Mortars and Lime-Burning*; 1854 – Dobson's *Rudiments of the Art of Building*
[39] Kelly T., The New Practical Builder and Workman's Companion (1823); 1890 – A Hammond, *The Rudiments of Practical Bricklaying*; Cassells Building Construction (1906);
[40] Kelly T., The New Practical Builder and Workman's Companion (1823); 1829 – M E Martin*, The Art of The Mason*; 1859 - Construction of the Canadian Parliament Buildings in Ottawa; 1862 – Captain Henry Scott, 'Observations on Limes and Cements'; 1920 – Blake's *Building Repairs*

certainty.[41] Isolated reading of the texts might lead to the conclusion that fat limes were rarely used and that hydraulic limes had become the norm. However, derogatory and pejorative references to craftsmen and 'their ways' tell us a great deal more about actual site practice, than a scientific treatise written to sit on a shelf.

2.7. A note on earth lime mortars

Many of the sources contain implicit or explicit references to earth or earth-lime building or plastering mortars. Cato (160 BC) mentions earth, lime and sand as components of mortar and Vitruvius (20 BC) commends adobe construction with earth mortar between the 'bricks'. Alberti mentions earth building, as well as earthen mortars for stone construction. Marshall notes the prevalence of earth mortars in North Yorkshire, as well as the routine use of road-scrapings in the Cotswolds. Neve details the use of loam for plaster basecoats. In 1726, Bailey and Worlidge proposed building and rendering with earth-lime mortars. In Scotland, there is a growing volume of evidence that masonry buildings with earth mortars are quite common, especially where clay is common. The wealth of material evidence across Western Europe indicates that earth mortars were regular features of craft and vernacular practice, but probably considered unworthy of extensive consideration by experts; a stigma that persists today.

Physical evidence indicates that lime mortars were used as finishes on such constructions, either as pointing over earth-lime bedding mortars or as a finish coat or limewash over earth plasters. This would affect the way lime mortars were slaked and processed, prioritising lump reduction and removal. The few definitive descriptions available of mixing earth-lime mortars stress the importance of mixing as close to the liquid limit as possible, and of the mortar being 'well-tempered' before use. These mortars were soft, very porous and demanded similarly effective porosity of the lime mortars used alongside them. The study of earth lime mortars is relatively new and not the main thrust of this paper, but they deserve mention, as they are an indisputably ubiquitous traditional material.

[41] 1856 – Vicat, *Practical and theoretical composition of mortars*

3. TEXTS FROM ANTIQUITY (References from 160 BC – 500 AD)

Vitruvius's work has exerted perennial influence across many centuries, especially among architects of the Palladian Movement, and including upon the modern 'lime revival', both of which took his detailed proscriptions for the slaking and laying down of lime for plaster finishes and applied them across the board of lime use, whilst not giving sufficient weight to descriptions elsewhere in the text, for general building and for concretes that would seem to indicate 'hot mixing' of lime mortars. Given subsequent historic custom and consensus that mortar proportions were generally related in quicklime:aggregate volumes, the emphasis in Vitruvius upon 'slaked lime' proportion is likely a long-standing mis-translation or mis-interpretation of the original text, adding to the confusions of the 'lime revival'. Beyond this, earth and earth-lime mortars were very commonly used in the Roman period, for both masonry and adobe structures, which latter Vitruvius favourably recommends. An earlier source, Cato the Elder, offers a general specification for normal construction (De Agri Cultura C. 160BC) and includes the necessary ingredients for building mortars: 'stone, lime, sand, water, straw, and earth for making mortar'. That the descriptions of Vitruvius and Pliny for the laying down of slaked lime applied to fine finish coats and lime washes only, and where any unslaked lime inclusions would have hampered the efficiency as well as the quality of the work only was insisted upon by Loriot (1777) and Vicat (1818-1856), French authors who engaged more critically with perceptions of Roman practice than their contemporaries in the UK.

160 BC – Cato, De Agricultura

Reference: Cato the Elder, De Agricultura (Loeb Classical Library, 1934), Chapter 38.

Cato initially discusses the proper construction of kilns, noting that calcining happens from top to bottom. Later in the work, he briefly lists the chief ingredients in mortar-making and notes a roughly 2:1 proportion of lime to sand.

The owner will furnish the timber and necessary material... and deliver it on the ground, and also... stone, lime, sand, water, straw, and earth for making mortar...

The owner... will furnish one modius of lime and two modii of sand for each linear foot...

20 BC – Vitruvius, De Architectura

Reference: Marcus Vitruvius (30-20 BC) *Ten Books on Architecture.* Translated by Rowland I D; eds Rowland I D & Howe T N (1999) Cambridge University Press.

Vitruvius discusses proper mix proportions depending on the aggregate (roughly 3:1) and notes how the intensity of firing combined with pozzolanic additives can enhance or change the properties of a mortar. In discussing plasterwork, he notes that a long-matured putty is required, a method clearly – according to Vitruvius – reserved for finishing and plaster rather than masonry construction. Finally, Vitruvius gives us a recipe for a lime-concrete floor.

From Chapter 5 - Lime for Concrete Masonry.

When it has been slaked, then the materials should be mixed so that if we are using excavated sand, three parts of sand and one of lime should be poured together. If, on the other hand, it is river or sea sand, two parts of sand should be thrown in with one of lime. In this way the rate of mixture will be properly calibrated. Furthermore, if one is using river or sea sand, then potsherds, pounded and sifted, and added to the mixture as a third part, will make the composition of the mortar better to use.[42]

Therefore, whatever the weight of stones when they are cast into the furnace… when they are weighed, although their size remains the same, they will be found to have lost a third part of their weight because of the moisture that has been cooked out of them. And thus, because their pores and spaces lie so wide open, they absorb the mixture of sand into themselves and hold together; as they dry, they join together with the rubble and produce the solidity of the masonry.

Hence, when these three ingredients (lime, rubble and pozzalana), forged in similar fashion by fire's intensity, meet in a single mixture, when this mixture is put into contact with water, the ingredients cling together as one and, stiffened by water, quickly solidify. Neither waves nor the force of water can dissolve them.

[42] There is no mention here of laying down putty to mature. The lime may have been slaked in a ring of sand, or in a mortar box, and mixed with the sand immediately upon slaking, as was very common throughout the remainder of building history and as was illustrated on Trajan's Column.

P38. *[In building with pozzalana underwater] unlike and unequal entities that have been forcibly separated are brought together all at once. Then the moisture-starved heat latent in these types of ingredients, when satiated by water, boils together, and makes them combine.*

From Chapter 2 – Plasterwork

…This will be done properly if clods of first-rate lime are softened long before there is need for them. If a clod is baked lightly in the kiln, then, as it is softened over many days, the remaining liquid, forced to boil away, will bake the clod to an even degree[43]. If it has not been softened all the way through, but is used when only recently fired then, when applied, it will develop blisters, because it has raw grains hidden inside. If these grains are put into the work without having been softened to an even degree, they dissolve and break apart the finish of the plasterwork.

…If the softening has been done reasonably, and the work is to be prepared with care, take an axe[44]), and chop through the softened lime to its core as it lies in the pit, just as if it were wood being chopped. If the axe meets with granules, (P89) then the lime is not yet ready. When the tool comes through dry and pure, it indicates that the lime is weakened and parched. When it is rich and properly softened, then, clinging all around that tool like glue, it shows that it has been tempered in every respect. Then get the machines[45] ready and set the ceilings of the rooms…[46]

P90. *The Greek plaster makers not only create long-lasting work according to these principles, but they also do this: when the mortar trough has been set in place, with the lime and sand poured together into it, they bring in ten-man work gangs who pound the mortar with wooden pestles, and they use it after it has been vigorously worked by these teams.*

From Chapter 2 – Flooring

When the decking is finished in an upper story, it should be strewn with fern, or otherwise with straw, so that the woodwork will be protected from damage by lime.

3. Above this the underlayer is set down of stones no smaller than can fill the hand. Once the underlayers have been installed, if the rubble for the sub-pavement is new, then mix it three to one with lime; if it is re-used, then

[43] The lime is being slaked to a stiff paste.
[44] Otherwise, 'hoe.'
[45] The editors suggest this means scaffolding.
[46] No mention is made of mixing this lime with sand – as it is for the walls.

the mixture should be five to two. Then the sub-pavement is laid in with wooden rods by ten-man work gangs and compacted by steady pounding. By the time the pounding is done, it should be no less than a dodrans (three-quarters of a foot) thick. Above this, a core of crushed terracotta should be installed, mixed three-to-one with lime, and it should be no less than six digits thick. Above the core the pavements should be laid to the square and to the level, whether they are in stone inlay or mosaic…

97 AD – Frontinus, The Aqueducts of Rome

Reference: Sextus Julius Frontinus, *De aquaeductae Urbis Romae,* Bill Thayer, trans.

Frontinus, in discussing repairs to civil engineering infrastructure, notes that April-November is the proper period for carrying out work, with care taken (in a Mediterranean climate) to cease work in the hottest weeks. In the final paragraph, he lays out a brief list of ingredients commonly required in mortar-making.

BOOK II. P119. …*The numerous and extensive works are continually falling into decay, and they must be attended to before they begin to demand extensive repair.*

P121*. As a rule, those parts of the aqueducts which are carried on arches or are placed on side-hills and, of those on arches, the parts that cross rivers suffer most from the effects of age or of violent storms. These, therefore, must be put in order with care and despatch. The underground portions, not being subjected to either heat or frost, are less liable to injury.*

P123. *Repairs that should be executed without cutting off the water consist principally of masonry work*[47] *which should be constructed at the right time, and conscientiously. The suitable time for masonry work is from April 1 to November 1, but with this restriction, that the work would be best interrupted during the hottest part of the summer, because moderate weather is necessary for the masonry properly to absorb the mortar, and to solidify into one compact mass; for excessive heat of the sun is no less destructive than frost to masonry. Nor is greater care required upon any works than upon such as are to withstand the action of water; for this reason, in accordance with principles which all know but few observe, honesty in all details of the work must be insisted upon.*

[47] Rogers' translation says 'concrete work.'

P125. *…It has been resolved that when those canals, conduits, and arches, which Augustus Caesar promised the Senate to repair at his own cost, shall be repaired, the earth, clay, stone, potsherds, sand, wood, etc., which are necessary for the work in hand, shall be granted, removed, taken, and brought from the lands of private parties, their value to be appraised by some honest man, and each of these to be taken from whatever source it may most conveniently and, without injury to them, remain open and their use be permitted, as often as it is necessary for the transportation of all these things for the purposes of repairing these works."*

C. 70 AD – Pliny's Natural History

Reference: Pliny the Elder (23-79 AD) *The Complete Works of Gaius Plinius Secundus,* (Delphi Classics ebook (2015) Hastings).
Reference: H. Rackham trans., Pliny, *Natural History*, Loeb Library (Heineman, London 1938-1962).

Pliny explains the properties of lime that will yield good mortars, and discusses the selection of aggregates, including 'bruised earthenware' to make it 'better.' In discussing plasterwork, he refers to a practice, already ancient by his own time, of requiring lime putty to be laid up for three months prior to using; a practice that has since been frequently misquoted and misapplied to masonry construction. He lists various creative additives that give mortar cementitious qualities and notes the use of gypsum in finishing plasterwork.

BOOK XXXVI. The Natural History of Stones

Chapter 52 – *Cisterns*
Cisterns should be made of five parts of pure, gravelly sand, two of the very strongest quicklime, and fragments of silex not exceeding a pound each in weight; when thus incorporated, the bottom and sides should be well beaten with iron rammers…

Chapter 53 – *Quicklime*
Cato the Censor disapproves of lime prepared from stones of various colours: that made of white stone is the best. Lime prepared from hard stone is the best for building purposes, and that from porous stone for coats of plaster. For both these purposes, lime made from silex is equally rejected.[48] *Stone that has been extracted from quarries furnishes a better lime than that collected from the beds of rivers; but the best of all is the*

[48] Authors note – this could be hydraulic lime

lime that is obtained from the molar-stone, that being of a more unctuous nature than the others. It is something truly marvellous, that quicklime, after the stone has been subjected to fire, should ignite on the application of water!

Chapter 54 – *The Various Kinds of Sand, The Combinations of Sand with Lime*
There are three kinds of sand: fossil sand, to which one-fourth part of lime should be added; river sand; and sea-sand; to both of which last, one third of lime should be added. If, too, one third of the mortar is composed of bruised earthenware, it will be all the better…

Chapter 55 – *Defects in Building- Plaster for Walls*
The great cause of the fall of so many buildings in out City is that through a fraudulent abstraction of the lime, the rough work is laid without anything to hold it together. The older, too, the mortar is, the better it is in quality. In the ancient laws for the regulation of building, no contractor was to use mortar less than three months old; hence it is that no cracks have disfigured the plaster coatings of their walls. These stuccos will never present a sufficiently bright surface, unless there have been three layers of sanded mortar, and two of marbled mortar upon that. In damp localities and places subjected to exhalations from the sea, it is the best plan to substitute ground earthenware mortar for sanded mortar. In Greece, it is the practice, first to pound the lime and sand used for plastering, with wooden pestles in a large trough. The test by which it is known that marbled mortar has been properly blended, is its not adhering to the trowel; whereas, if it is only wanted for white-washing, the lime, after being well-slaked with water, should stick like glue. For this last purpose, however, the lime should only be slaked in lumps.

At Elis, there is a Temple of Minerva, which was pargetted, they say, by Panaenus, the brother of Phidias, with a mortar that was blended with milk and saffron: hence it is, that, even at the present day, when rubbed with spittle on the finger, it yields the smell and flavour of saffron.

Chapter 58 – *Maltha*
Maltha is a cement prepared from fresh lime; lumps of which are quenched in wine, and then pounded with hogs' lard and figs, both of them mollifying substances. It is the most tenacious of all cements and surpasses stone in hardness. Before applying the maltha, the substance upon which it is used must be well rubbed with oil.

Chapter 59 – *Gypsum*
Gypsum has a close affinity with limestone, and there are numerous varieties of it. One kind is prepared from calcined stone, as in Syria… for example… In Syria they select the hardest stones for the purpose, and calcine them with cow-dung, to accelerate the process… Gypsum when moistened must be used immediately, as it hardens with the greatest rapidity… It is very useful for pargetting, and has a pleasing effect when used for ornamental figures and wreaths in buildings…

Chapter 62 – *Terrace-Roof Pavements*
The Greeks have also invented terrace-roof pavements… In making these… the proper plan is to begin with two layers of boards, running different ways, and nailed at the extremities, to prevent them from warping. Upon this planking a rough-work must be laid, one-fourth of which consists of pounded pottery; and upon this, another bed of rough-work, two-fifths composed of lime, a foot in thickness, and well beaten down with the rammer. The nucleus is then laid down, a bed six fingers in depth, and upon that, large square stones, not less than a couple of fingers in thickness, an inclination being carefully observed, of an inch and a half to every ten feet. This done, the surface is well rubbed down with a polishing stone… Wheat-ear tessellated pavements are laid down in a similar manner.

Chapter 63 – *Graecian Pavements*
The ground is well rammed down, and a bed of rough work, or else broken pottery, is then laid upon it. Upon the top of this, a layer of charcoal is placed, well trodden down with a mixture of sand, lime and ashes; care being taken with line and rule to give it a uniform thickness of half a foot.

C. 500 AD – Justinian's Civil Code

Reference: Pomponius, On Sabinus, Book XXXIII.

Pomponius briefly lists the ingredients a mortar suitable for building water channels in the early Byzantine period:

If I have the privilege of conducting water through a channel near your land, the following rights are implied: I can repair the channels; I and my workmen can, for the purpose of repairing the same, approach as near as possible to the place; and I can also require the owner of the land to leave me sufficient space to approach the channel on the right and left banks of the same, and to throw down dirt, loam, stone, sand, and lime.

4. THE MEDIEVAL PERIOD (References from 1220 – 1340)

Few readily accessible texts from the medieval period are obtainable. The records are mainly concerned with the cost and payment side of a construction operation, and they survive in considerable numbers. However, they are not technical descriptions of the works, but inferences may be drawn as to what was used and how much by estimation of volumes of materials, and the nature and timing of the deliveries to site. At a trade level, literacy in medieval construction was low or absent, the oral tradition within the craft guilds being the mechanism of transfer. Images do survive, from illuminated manuscripts, which show the construction process, with varying degrees of naturalism. Those that show mortar mixing, show it to be happening on site, close to the works, and would generally indicate hot mixing for immediate use, though in some cases, a matured coarse stuff or even a lime putty may be being tempered for use on site. Several illustrations clearly show steam rising from the mortar being mixed, whilst others carry the just-mixed mortar to the masons for immediate use. Mixing is often being carried out in a mortar box or trough. It is likely that that a more in-depth study of such illustrations can shed more light on site practice concerning mortars and masonry works from this period.

1220 to 1221 – Works at Dover Castle

Reference: Colvin HM (1971) Building Accounts of King Henry III. London. Oxford University Press.

These building works describe instances of lime slaking immediately following burning, during the summer months.

P31. *On Saturday, that is on the day of the Beheading of St John the Baptist [29 August] a payment was made by the... overseers, To slake 200 loads of lime and quench them... By task the slaking of each hundred costs 32d.*

P47. *For portage of 207 loads of lime from the kiln to the work... For portage of 200 loads of water... For breaking chalk up into small pieces for two kilns made by us below the cliff, that is for 157 loads... For one sieve bought for the works of Dover Castle... For slaking 225 loads of lime, And to two men watching over the aforesaid lime kilns for 3 nights...*

P49. & 51. *On the vigil of St John the Baptist [23 June]... To Richard Portefer for 300 loads of lime... And for portage of 300 loads of lime... And for*

slaking 300 loads of lime, [And for 12 masons for between 3 and 16 days each].

1222 – Works at Winchester Castle

Reference: Colvin HM (1971) Building Accounts of King Henry III. London. Oxford University Press.

This account lists the items 'needed to repair the castle' and acquired immediately prior to the works, notably the construction of the kiln, implying that the lime was to be used very fresh and un-matured. The second paragraph notes additive material – chalk and 'red sand.'

PP137/139. *And paid on Sunday next before the Invention of the Holy Cross [1 May] for things needed to repair the castle obtained during the week immediately preceding... for wood for the kiln... for one bowl and two buckets... for withies [for scaffold hurdles]... for 12 boards to make barrows... for one hare-skin for bellows... for cement... to (a brother) who went to London to the Bishop of Winchester to obtain masons... for one box to measure lime... to Adam the lime-man for making one kiln... to Godfrey of St James, in whose land chalk is dug for the kiln... to Geoffrey Black for 3 sesters of lime...*

The week in the same year (1222) containing the feast of the blessed Mary [8-14 September]. Note concerning the Treasury doorway: *For the wages of a mason repairing a certain doorway in the tower... For the wages of two masons doing the same for the same period... For wages of a labourer to serve the said masons in the castle for the whole week... For three carts to carry water and chalk during the week... For the purchase of 30 sesters of lime... for 40 potts of red sand... for 100 potts of white sand... For two cart-loads of brushwood to found lead for the clamps of the tower... For withies bought for scaffolding.*

1259 – Construction of Westminster Palace

Reference: Colvin HM (1971) Building Accounts of King Henry III. London. Oxford University Press.

The interest of this entry is mainly in the mention of Agnes, a female 'lime burner' of London.

First payment, For Lime and to fell and carry to the water the old oaks in Windsor Forest with which lime will be made for the works... Third payment, Lime. And for 3 hundredweight and a half of lime for the said chimney and

lavatory bought from Agnes the lime-burner of London... Sand. And to Richard the Cellar for 36 cart-loads of sand dug and carried by task... Fourth payment... Lime, Sand. And to Agnes the lime-burner for three hundredweight of lime for the said gutter and cistern... And to Ralph of Bridge for 25 loads of sand... To the same for 75 loads of sand... And for mortar of lime and sand bought of dom. Hugh of St Albans the monk...

1296 – Work on Beaumaris Castle

Reference: Taylor A J (1974); Report by Master James of St George and Walter of Winchester to the Exchequer concerning Beaumaris castle works *The King's Works in Wales 1277-1330*. London. HMSO.

This reference is of interest as it mentions mortar-making during the winter and seems to imply construction as well.

You should know: That we have kept on masons, stonecutters, quarrymen and minor workmen all through the winter, and are employing them, for making mortar and breaking up stone for lime; we have had carts bringing this stone to the site and bringing timber for erecting the buildings in which we are all now living inside the castle; we also have 1,000 carpenters, smiths, plasterers and navvies...

1340 – Works at the Palace of Westminster - Account for a buttress at Westminster Palace extending into the Thames

Reference: TBC Colvins, H. M. Ed. (1971), Building accounts of King Henry III, Oxford University Press.

Where masonry was particularly exposed to the influence of wet, it was a common practice to use, instead of mortar, a cement composed of wax and pitch and resin, applied in a molten condition.

'For 60 lbs of pitch for making cement for the buttress - 3s. For 100 Flemish tiles for making dust for the same cement - 12d. For 3 earthen pans in which to make cement - 6d. For straw bought for the same buttress, to burn upon it and warm it after the Thames floods, because the stone could not otherwise have held the cement - 7d. For an iron for directing and pouring cement between the stones - 4d.'

1419 to 1519 – Works at York Minister

Reference: Browne J (1862) *Fabric Rolls and Documents of York Minster*. York. Surtees Society.

There were limekilns on site. Limestone was brought to site – some of it oolitic limestone; more of it magnesian limestone, which may or may not have been feebly hydraulic. No explicit payments for mortar mixing or lime slaking, except in the final account of 1581, when there is an entry for 'sleckinge, beatinge, and siftinge' of lime, indicating hot mixing/dry slaking. Gypsum was brought from Ripon to be burned on site. It appears generally in association with the laying of tile floors. Translation from the Latin.

1419*. Lime Costs. For 16 loads of limestone, to the vicar of Broghton (Broughton, near Malton). For 6 chaldrons of sea coal, to John Hall 26s. In carrying the same to the cemetery, 3s. For 8 chaldrons of sea coal, paid to the said John 32s. For 1000 faggots to John Bouland for carriage 25s. The expense of each burning (charge) of the kiln 18d. Total 109s 10d.*

1519. *Haulage of lime and gypsum bought. Barnard Pavar for two loads of lime(stone) 3s 4d. And for 3 loads lime(stone) 9s 6d. For 2 loads (quick)lime bought in Tadcaster, 15s 6d. For 4 quarters gypsum bought from Robert Bawmeburgh 8s. For 2 casks of uncalcined gypsum 5s 4d. For one cask 3s. Total 38s 6d.*

1580 – 1581. *The accompte of Stephen Streate, clerk of the workes, prom 1 Jan. 1580 to 1 Jan. 1581. For a dosen and a half of cotrelles to the glasse windowes, 2s. For two longe yron gaddes for stayinge of a pynnacle of the churche, lis.*

For mendinge a pynnacle on the north side the quere, 3s. 4d. To John Gell, tyler, in pavinge the grounde under the table in the quere, 10d. To two labourers helpinge to carie into the wright hous the greate standerdes from the glasse windowes, 4d. For sleckinge, beatinge, and siftinge of lime, 9d.

1426 – Construction Works in Bedale, Yorkshire

Reference: North Yorkshire County Council Record Office, Cront 753 From ZBA/11/8/1/3, Mich 1426-27. Repair of tenements. Bedale.

This entry mentions lime being brought to site concurrently with sand, and at twice the proportion, perhaps implying a lime-rich mix. Futhermore, it makes several mentions of clay for mortar making and for daubing.

8 cart-loads of stone from the Park of Bedale to tenement of John Watson in Ayscogh 4/-... 3 cartloads of wattlyng to same 1/6... Stipends of 2 carpenters carrying stone and clay for the same for 1 day 2/4... 6 cartloads of timber for repair of house of John Clay 2/6... 1 cartload of spars from

Frithbylund to the same... 1 cartload of stone... 600 sclatestane from quarry of Hernby (Hornby, Bedale) to manor of Bedale at 9/- per 1000 6/3... 4 cartloads of lime from Cracall to the Manor 2/8... 2 cartloads of sand for the same 3/-... Stipend of the carter carrying 10 quarters of lime of Burton on Yhore to Bedale 2/6... 2 cartloads of clay for the Lord's house once of John Caterik in Emgate 6d... 3 cartloads of old timber from the tithe grange of Ayscogh to the Manor of Bedale... 2 cartloads of old timber from the tenement of Wm Walker to the Manor... 2 cartloads of spars and watlyng from the Park for the repair of the tenement of Thomas Rudd in Burrell... 2 cartloads of timber for the Manor Gate from the wood... Stipend of John del Cote tiling (tegen) on the Grange, 9 days at 8d... Bread and ale for raising the house of John Watson in Ayscogh... 2 cartloads of clay for daubing (riggat) a grange... 5 cartloads of clay for repairing a wall within a tenement 1/3... Carriage of lime by a hired woman 2d... 4 cartloads of straw brought from the Rectory to the tenement 8d... 2 cartloads of straw to the tenement of John Watson.

1432 – Construction Works at Yatehouse, Bedale, Yorkshire

Reference: North Yorkshire County Council Record Office, ZBA 11/8/1/7 Mich 1432-33 and ZBA 11/8/1/8 Mich 1433-34.

This entry mentions quicklime ('calcet' implying that it has already been burned or calcined) being brought to site, along with earth and clay as key components of masonry construction.

John Pygot for walling le Yatehouse of the Manor 10d... Thomas Harpur hewing and 'stauryng' the same 4/-... 6 cartloads of earth for the same 18d... 1 quarter of lime (calcet) 8/-... 3 cartloads of sand... Schlatstanes bought at Langthorne for roofing the same manor 6/-... Carriage of the same by two mule-drivers 2/2... To Thomas Schlater for roofing 3 roods of a chamber called Dungron and another called Yatehouse 15/-... Same for mending great chamber on east side 4/-... Paid for carriage of baysestanes for the grange in the tenement of John Chalenor 10d... 2 cartloads of wood for the same for wattling and daubing the same 12d.

Carriage of 19 cartloads of stone for the grange of John Hampthwayte 4/9... Carriage of 11 cartloads of earth and clay to the same 2/9.

1434 to 1472 – The Building of Tattershall Castle

Reference: Simpson D. (1960*). Building Accounts of Tattershall Castle*. The Lincoln Record Society.

1434-1435. *Price of 74 cartloads of fuel, felled… in Tateshale chase for burning in 10 limekilns for the said works, to each kiln 7 ½ cartloads…*

1438-1439. *490,700 (bricks) called waltile made by Foys Brekmaker £69 5s 1 ½d… Cash paid to Baldewyn Brekmaker for making 8000 of such bricks… Purchase of such bricks at my Lord's kiln at Boston, with their carriage… Wages of masons called brekmasons… Wages of John Ramsey and his mates called roughbrekmasons… Cost of making quicklime, including purchase of stones and charcoal, with carriage, £42 16s 5d, Wages of labourers… inclusive of board… and for carrying bricks, lime, sand and suchlike from the water into and outside the castle.*

1439-1440. *Purchase and carriage of freestones… Expences on the brick kiln… Carriage of timber, faggots, stone and coal by water… Expences on the lime kiln, with purchase of coal and fuel… Purchase, carriage and mixing of plaster of Paris…*

1435 to 1488 – York Bridgemasters' Accounts

Reference: Stell P M (2003) York Bridgemasters' Accounts. York. York Archaeological Trust.

1435. …*A tiler and his servant on the tenement of Davy Payntour and others… for lime… And for 400 waltyle in the tenement of Roger Joynour for a chimney… And for carriage of sand, lime and plaster… And for one mele and a half of lime… And for 27 bushels and three peckes of plaster for the same chimney…*

1440. *Conyngstrete. …And paid to John Sharow for three and a half bushels… and in firing a kilne of plaster in Castelgate… And paid to William Plumpton for carriage of twenty loads of lime, tiles and sand… And paid to various men for five tuns and a barrel of plaster at various times…*

Castelgate. …William Plumpton for carriage of 25 loads of lime, sand and other things… And Robert Canmsmyth… for le betyng of one kiln of plaster… And for 2000 turf for firing the plaster kiln in the aforesaid messuage… And to a labourer for betyng plaster in the same messuage… And paid to William Walker for dobyng… And paid for earth, litter, dobyng and water… And to William Plumpton for carriage of forty loads of lime, sand and other things… And to William Bouland, limeman, for five mele of lime… And paid to William None for carriage earth and tiles… And to John Brigg for paving in Nessgate… And to William Plumpton for three loads of cobles.

1444. *...And for firewood for burning plaster with carriage of the same... And for pounding of the same... And to Thomas Goodesalve, carrier, for carriage of three tuns of plaster... And to the same Thomas for twenty seams of lime and sand... And to Ralph Somer for two days burning plaster... And for repairing the tubes... For carriage of lime, sand and tiles... And to Richard Porter for carriage of lime... And for ashes of a chimney of John Herte and Joanna Guyl... And for lute and straw with working on the chimney of Elizabeth Bellows...*

1445*. ...Paid for pounding of plaster... And paid for ashes of a chimney... Paid for carriage of three tuns of plaster... And paid... for carriage of 40 seams of sand and tiles... And paid... for carriage of three meles of lime...*

1449. *...To a man pounding plaster for one and a half days... And for 500 tiles... to tiler for 3 days... And his servant same time... And to John West for carriage of lime... And to Robert Hynderwell for carriage of thirty seams of sand... And to Thomas Killom for working on a barn in Holgate Lane for five days (and servant the same)... And to Robert Hynderwell for carriage of twenty two seams of sand and lute... And to John Usburn for doubyng there for ten days...*

1459. *Paid to William Ball for piles... and for seven piles from John Forster... And paid for carriage of the aforesaid timber from the staithe and from a close of the monastery... And paid to Robert Fressell for stone flags bought and placed on the top of the aforesaid piles in the earth... And paid for a cart-load of lute bought for claying of the said piles and for repair of various walls of earth... And for wages of a labourer in claying of the same piles for half a day... And for wages of two carpenters for working and making the said post, somers, bandes and piles, and nailing of the floor of the said tenement there by the space of the foot of a man... And for wages given to John Forster, master carpenter, for his labour, advice and help... And paid for fifty sapplattes and straw bought for mortar...*

1462. *...And for wages for labouring and dobyng within the tenement of John Barneby... and paid for nine seams of lute carried to the same tenement... And paid for four bushels of plaster bought for the repair of a wall in the tenement of William Litwyn... And paid for a burdyn of lime there...*

And for wages for labouring and dobyng within the tenement of John Barneby for three days... and paid for nine seams of lute carried to the same tenement...

Paid to John Spynk for three cart-loads of lime with 4s paid for carriage of the same and 8d for putting in le storehouse 10s 3d. And for five and a half tuns of plaister bought for a price of 2s 9d per tun plus 1d – 15s 6d.

And for wages of Thomas Rymour, tiler, for working and repairing walls of plaster and tiles on the tenements of William Guislay.

(Repairs to the Bull) ...And for lattes bought for the repair of various walls of earth there with 2s 8d paid to Robert Beltoft, labourer, for working and repairing several earth walls... And paid to Robert Cambyssh, paver, for working and paving the pavement in front of the said tenement...

And paid to John Botterell of Buttercrame for six bushels of plaister bought for the tenement of William Marsshall... And paid to John Savage for 800 hertlattes and 700 sapplattes...

Paid for four cart-loads of old timber... and they have paid... for three posts and new spares of timber for the same house... and paid to John Walus for two sele tre and a panpece (ceiling beams and wall-plate). (Payments to carpenters) ...And paid to Thomas Plumpton for leading sabulum (sand) for twenty seams of earth and (daubing)... and paid to a man of Clifton for five cart-loads for daubing of a new house there and paid to John Pereson for daubing and leccyng of the said parclose in the aula there... And paid... for daubing the same new house by agreement made in gross. And paid to the same Thomas for working there three days receiving 4d in the day... And paid to William West for carriage of six loads of lyme for pergettyng of the same house... And paid to Thomas Plumpton for five seams of cobles for the same job (in Gilligate). And for eight seams of wase for the same job there. And paid for dung bought for daubing there...

And paid to John Copper, sledman, for carriage of old timber... And paid for 30 (fagottes) with carriage of the same to the same kylns... And paid to Thomas Rymour, tiler, and his servant for working on the said kylns... And paid for 60 (words missing, probably loads of lime) and carriage of the same... and paid... for pounding of the same (lime, probably lump lime)... And paid to the same Thomas Rymour and his servant for making a plaster kiln (alabaster?)... And paid to James Porter for carriage of 60 loads of lyme...

1464. ...*For seven cartloads of lime bought of John Garnett... for the wages of James Porter for carriage and sledding of the same... For five tuns of plaster bought on le Stathe (of) a stranger at various times... Paid for 3,300*

thaktele… 10s the thousand… And for 200 waltele (at 8d the hundred)… for 600 stanlattes… 1,400 sapplattes… Barn in Holgate. And for the wages of Nicholas Thornthwayte, carpenter, for working in the barn at Holgate… And paid to John Copper for daubing for the walls there, 3d for each cart-load… And for wages of Robert Tynly, labourer, for working and repairing the earth walls there…

Skeldergate. …And for wages of William Tynly, labourer, for… daubing walls around the garden adjacent to the postern of the Friars Minor for ten days… for the wages of John Capper for whitewashing… And paid to John Capper for four cart-loads of daubing earth… And paid for straw and hay for daubing of the walls there bought from various men at various times… And paid in expenses made by Ralph Pullen, his servant James Porter for providing and leading a boat full of sand from the sandbed… namely in bread, beer and meats… And for wages of Ralph Pullen, tiler, and his servant for… tiling the house interior and making a wall called plastering for 18 days…

Bouthombarr. …For the wages of William Barley for working and labouring… in making earthen walls for two days… And for the wages of John Pereson and William Tyndale for… daubing in the tenement of Thomas Fournas for four days.

Fossgate with Fossbrygg. *…For the wages of William Gaille and Andrew Blyth for carrying 326 seams of tiles, sand, lute ('liquid clay or cement used to seal a joint') and wase (bundle of hay or straw)… And to the same… for 45 seams of coble for le paving at various places this year… And for wages of John Plompton for leading sand… And to James Johnson, porter, for 146 pounds of lyme and plaster at various places this year…*

1468. *Paid to John Garnet for a cart-load of lime… and for six modii of plaister bought for repairs of a chimney… and for six bushels of plaister… and for 1000 walltiell… Paid for carriage of seventeen seams of lute for doubyng… including 4d paid for straw bought for mixing with the same… And for wages for working and doubing… And paid to William Gayle for carriage of fifteen seams of sand to various tenements this year…*

1472. *Paid for three cart-loads of earth for repairs of a floor… And paid for two waggons of earth for repair of the daubed walls… And paid for straw for the same job… and paid for 50 lattes for the same job… And paid for two waggons of earth for repairs on the house in the tenure of John Barneby and the house of Michael Bradford… and paid for eighty laths for the same*

job… And paid to the same dawber for doubyng in the same house… And paid to two pavers for paving on Fossebrig… And paid for four carts of earth for the same paving… And paid for cobills for the same job. (To the house of John Taillour and Isabel Santon)… for four bushels of lime… And paid to a tiler there for tiling on a houseof William Colstane… And paid for two seams of sand for the same job. And paid for 200 tiles for the same… And paid for 300 dawbing nailes… And paid for construction of a chimney… and paid for a glass window… And paid for a modius of plaster for repairs of Isabel Santon… And paid to a plasterer plastering there… And paid for making a wall of earth in the house of William Fraunk…

1486. *Stores Bought. And for various payments for two wagonloads of burnt lime… And for 400 hartlaths price 7d per hundred… and for 700 saplaths at 6d per hundred… Nails, namely 1000 le double spikyng; 1000 mydel spikyng; 1000 skotchym; 1000 stanebrod… twenty four loads of lute… twenty loads of sand; 500 tiles for walling and for le rigge tiles. One quarter le playtre; three loads of stones; one pound of solder… For various payments for dibyng for twenty-eight days… on various tenements…*

1488. …*And for purchase of a cart-load of lime bought for the store… And for the purchase of three cart-loads of lute called dobyng earth bought and used… And for the purchase of four quarters of plaister… And paid to James Broun for working and labouring for ten days in le dobyng in various tenements…*

1442 – Construction and Repair Works in Bedale, Yorkshire

Reference: North Yorkshire County Council Record Office, ZBA 11/8/1/10 Mich 1442-43.

The distinction in this reference between lime brought to site and ‘burnt lime’ brought to site, may indicate a preference for buring lime on or near the worksite. It frequently mentions clay as an ingredient in mortar.

To Wm Godale, carpenter. For making anew a small house in the said messuage… To the same for soleing (soland) lez Stothis et postis within the said house… Collecting several stones called baystonis and carrying… Cutting stoups and carriage from the Lord’s wood to said house… Digging and laying in the cart 7 cartloads of clay with carriage from le stonecannse to said messuage… To Robert Morland hired for ‘peyntyng and betyng 7 rood in said capital house… 3 quarters of burnt lime at 16d per quarter… 2 cartloads of sand.

To Cole and Clapham, labourers, hired for mending walls of (John Burrel) in places… Carrying 2 cartloads of clay from le stonecannse to said house… Carrying 5 cartloads of sand… 6 quarters of lime.

John Punderson hired for making anew one wall of a house within the manor called le Carthous… 1 quarter burnt lime for same… 1 cartload of sand.

To John Hamswayt hired to cut and carry from the wood to (Wm Coltonn) house one cartload of 'dowbynstawris'… To Thomas Clapham constructing and daubing the wall of said house… To John Cartere of Harnby for 2600 slatstonis for roofing said house… To Wm Symondeson for 7 quarters of burnt lime for the said walls… To John Hamswey carrying lime from Ffrtheby to said house… To same for digging, laying and carrying 13 cartloads of calay for said house… To same for 3 cartloads of sand.

To John Hamsweyt for cutting and carting 1 cartload of underwood to said grange (of Robert Medilton) for walling the same… To same for digging 3 cartloads of clay for said grange… To Thomas Clapham for mending and daubing walls and for roofing the same… Thatching.

2 cartloads of timber from the Lord's wood for the messuage of Wm Smyth… John Hamsweyt for 4 cartloads of clay for the same

…one sieve for sifting burnt lime…

5. THE RENAISSANCE AND EARLY MODERN (1460 – 1698)

This period saw a renewed interest in what might be termed 'classical antiquity' and a focus on the architecture and aspects of culture from before the fall of Rome. While the focus was mainly on the design and presentation of buildings, there was an acceptance of the technical knowledge of classical societies. However, this was very limited by the texts that were actually available. So, much of this section is about accounts of building mainly concerned with payments and accounts, as with the period before, and not the technical details. Alberti and Palladio are the only authors who go into the detail that this publication has sought, and much of that is from translations of often incomplete accounts of earlier works. Towards the end of the period in the 1680's, we see the spirit of enquiry being born in this area that would become very extensive in the next section.

1460 – Alberti Leon Battista On the Art of Building in Ten Books.

Reference: J, Leach N, Tavernor R (1988) MIT Press Cambridge Massachusetts, trans. by Rykwert.

Alberti seems to refer as much to Vitruvius's description of lime processing for plaster finishes, as to contemporary craft practice, which he mentions only by allusion at the end of the passage. Earth and earth-lime mortars for construction remained the norm for most buildings across Europe at this time, with lime and sand-lime mortars used in conjunction with these as finishes (such as pointing over earth bedding mortars or finish plasters over lime stabilised earth backing coats). Alberti also mentions the use of earth mortars for masonry construction.

Lime is the opposite (to gypsum): it does not need to be crushed, but may be soaked while still in lumps; indeed, it should be allowed to soften in water for a good while before being mixed, especially if intended for plastering, so that any lumps not baked thoroughly enough by the fire will dissolve. If it is used too soon, before it has been properly steeped and softened, it may still contain some small half-roasted stones, which might with time begin to rot, soon developing blisters which disfigure the finish. It should be added here that lime ought not to be soaked by a single dousing, but ought to be dampened gradually with several sprinklings, until it is evenly saturated. It should then be left on its own, mixed with nothing else, in a damp shady place with nothing but a layer of sand to protect it, until the process of time has fermented it into a more fluid paste. It is certain

that this lengthy fermentation greatly improves the lime… Lime prepared in this way requires twice the sand as when mixed freshly slaked.[49]

…It is universally agreed that the addition of one-third measure of crushed tiles will produce a far stronger mortar. Whatever the mix, you must constantly knead it until even the smallest particles are absorbed. And so some will stir and pound the mixture for some time in a mortar trough, in order to mix it thoroughly.

…Lime that has not been properly slaked… is more safely used in the foundation than elsewhere in the wall, and in the infill rather than in the outer skin… There are other kinds of masonry construction – some where mud, not lime, is used in the joints… Walls consisting of 'shell' – as I prefer to call it… should be constructed of seasoned wickerwork and reed matting; this is not a work of any distinction, but was often used by the plebians of ancient Rome. The wickerwork is smeared with a mixture of mud and straw which has been kneaded for three days. It is then dressed… with either lime or gypsum, and finally adorned with pictures or reliefs. If you mix your gypsum two to one with crushed tiles, it will have less to fear from being splashed. If mixed with lime, its strength will be enhanced. In the damp, frost or cold, gypsum will be entirely useless.

Ornament (internal plasterwork):
(For) white plaster, relief work and fresco… lime is prepared like this. It should be soaked in pure water and allowed to macerate for a long time in a covered pool; it should then be chopped with a trowel, like wood. If, during this operation, the trowel meets no solid particle, it shows that the lime is fully macerated. Lime is thought to require three months before it is sufficiently mature. Preferably, it should be thick and extremely glutinous; for if the trowel comes out dry, it shows that the lime is weak and not moist enough. When the sand or some other crushed substance is added, work it over and over again with great vigour; then turn it over once more, until it appears to foam. For the outer coat the ancients used a mortar to pound the lime and temper the mixture, so that it would not stick to the trowel during application.

1529 to 1531 – Works at Holyrood Palace

Reference: Accounts of the Masters of Works, Scotland.

[49] This final statement suggests that the mixing of lime when freshly slaked was common practice at the time, and if matured lime required twice the volume of sand to freshly slaked lime, then the latter will have offered significant economic advantage and reduced costs in the labour of mixing and in transportation.

Masters of Works Accounts have been fully transcribed and are available online at www.archive.org, or at the NRS, NLS and at HES's John Sinclair House library.

The Accounts of the Masters of Works are perhaps the best surviving Scottish resource for building in the Late Medieval and Renaissance periods. They are, however, accounts and nothing more; they are not instructions or specifications. The usefulness of such a resource thus depends upon scrutiny and interpretation of mostly quantitative data. The mentions of 'lyme' in the accounts are so numerous, but so disjoint, that it make little sense to replicate them here in a form amounting to little more than a repetitive list of almost identical entries. In the interests of space, the full citations have been represented by one or two 'typical' examples and supplemented by any that stand out as slightly unusual or particularly interesting. However, detailed bibliographic information has been included for all references found, which the reader is encouraged to follow up at greater length. Several interesting entries that offer more detail have been excerpted below. In general, the accounts are arranged chronologically, usually by location (i.e. the various royal palaces), with entries usually made weekly. These weekly entries are, by and large, substantially identical in almost every respect, varying only in the quantities and costs of items accompted. A typical entry, such as this one from August 1529, thus reads:

Item in lyme... ix dosoun fra Coustoun and Gilmertoune price of ilk dosane vii s... Item sand furnest be the kingis grace awine cartis
(P3, August 1529, Holyrood)

Lime to Edinburgh comes almost exclusively from either Couston or Gilmerton, usually both together. Sand is usually mentioned in the next line, either in an unspecified quanitity when it already belongs to the king (as above), or with a stated quantity and price, if externally purchased. At Falkland, lime is accounted coming from the Lomond Hills and Forthar and for works at Stirling, it is delivered by boat, sometimes from Alloa. Paired references to sand and lime would seem to indicate a relationship from an accounting point of view, as what bookkeeping we do have, is methodically chronological and not haphazard. Often, the entries reference the labour involved in digging and transporting the sand, as in this entry from March 1530:

Item to John Blak in the Lynkis of Leitht castand sand... Item in lyme... fra Coustoun and Gilmertoun vii dosoune vi laid price of ilk dosone viii s.
(P27, March 1530, Holyrood)

The consistency of some names indicates a long-term working relationship with certain labourers and craftsmen. Variations in style of bookkeeping create some difficulty in interpreting the data. For example, the writer of the 1529-32 accounts prefers itemised weekly entries for goods and labour, as described and excerpted above. James Hamilton of Finnart, on the other hand, Master of Works from the 1520s until his execution in 1540, employed a longform, narrative style:

The aucht day of Februar the yeir of God im vc xxxiiii yeris the entres of the carttis to the leding of fre stane to the paliss of Linlithqw and tha continewit to the xvi day of Maii... Item resavit fr john Gryntoun in the Gormyre in Torphiching parrochin fra the first day of Februar the yeir of God im vc and xxxiiii yeris to the xvi day of Januar in the yeir of God im vc and xxxv yeris iiiscore xix chaldir and four bollis of lyme

As evident in Hamilton's receipts, and further indicated by weekly accounts that span the entire year, there is an argument to be made for the year-round processing of lime and construction of stone masonry, although this is never explicity stated. Hamilton describes both, quarrying work and lime, and freestone transport commencing in February for works at Linlithgow. Accounts for work at Holyrood indicate constant building activity – with accompanying weekly deliveries of lime and sand – from October 1531 through spring of the following year. The possibility of seasonal working cannot be eliminated, but such evidence clearly indicates that work could continue through the winter, if necessary.

It requires some lateral thinking to translate the bare facts of the accounts into workable hypotheses or conclusions, particularly in trying to determine how lime was processed and incorporated in mortars. Occasional reference to items such as lime riddles, wheel barrows, mortar tubs and shovels allow us to speculate about their role in the mixing of mortar, but offer little traction for drawing firm conclusions and have not been reproduced here. More intriguing, however, are references to lime mixing and sifting, and working in the 'lime fald' (lime fold), references to which have been included here to enable the reader to draw their conclusions from the source. Looking at the entries *in toto*, it further becomes clear that loads of sand are being delivered in quantities almost exactly twice as those of lime, sometimes slightly over. When we bear in mind that sand will have had uses besides mortar mixing (for example, maintenance of lists, gardens and other recreation areas), and take into account the doubling of volume of slaked quicklime, we can perhaps infer mix ratios of something

approaching 1:1, based on this quantitative data. Earth tended to be sourced on site and may be part of the mortar equation, of course.

1529 to 1532 – Works at Holyrood Palace

Reference: Accounts of the Master of Works Volume 1: 1529-1615, Henry Paton Ed., HMSO 1957.
References to lime (or related) on pages: 3, 5, 7, 13-14, 18, 19-20, 21, 22, 24, 25, 27, 28, 30, 32, 33, 34-35, 36, 37, 39, 40, 41, 42, 43, 44, 47, 48, 49, 50, 52, 53, 54-55, 57, 59, 60, 61, 62, 64, 65, 71, 78, 81, 83, 84, 86, 87, 93, 98, 101

Item xii werkmen this olk with the masounis and in the lyme fald
Item to ane verkman at the sand
Item in lyme... ix dosoun fra Coustoun and Gilmertoune
Item sand furnest be the kingis grace awine cartis
(P3, August 1529, Holyrood)

Item for ane small lyme ryddill
(P5, September 1529, Holyrood)

Item for iii dosoun of clay to the beymfilling ande beting of the... hous
(P7, September 1529, Holyrood)

Item fra Coustone ii dosoune viii ladis of lyme price of the doson
Item sand furnest be our awine cartis
Item John Anderson werkman bringand in the sand fra the cartis to the fald and syftand and myngand the samyn...
(P18, February 1530, Holyrood)

Item to... [3] werkmen servand the masonis and Johne of Cleucht at the luge and siftand and mixtand the lyme and sand in the fald
(P19 & P20, February 1530, Holyrood)

Item to four verkmen... segand the masonis and virkand in the lyme fald...
(P21, February 1530, Holyrood)

Item to vi werkmen... with the layaris at the luggis siftand lyme and sand in the fald segand and berand hewin werk fra the hewaris
(P22, February/March 1530, Holyrood)

Item to the lyme hors of Coustoun and Gilmertoun for the inbringing of deid sand to the laying of the [king's] lystis
(P36, May 1530, Holyrood)

Item to Besse the nutrice duelland within the abbay clois for the furnissing and gaddering of schellis to the aislaris laying the hale somer sessone viz. be the space of six monethis bipast
(P54 & P55, August 1530, Holyrood)

Item to the lyme men of Cousland and Gilmertoun for iiii dosane and vi ladis lyme
Item sand furnist to the forsaid lyme...
(P57, September 1531, Holyrood)

Item for (1,000) sklatis for thekin and pointing forsaid iiii lib. and caryit with the kingis awn cartis togidder with sand for the pointing of the said plais and lyme tane furth of the lyme fauld of the new werk
(P71, November-December 1531, Holyrood)

1531 to 1532 – Works at Stirling Castle

Reference: Accounts of the Master of Works Volume 1: 1529-1615, Henry Paton Ed., HMSO 1957.
References to lime (or related) on pages: 106, 109.

Item for bering of xxi laidis of lyme at sindry tymes per idem tempus fra the stabill under the castell wall to the castell
Item for the carage of xii laidis of lyme fra the said stabill for gergyng and topping of the chymlay heids
Item for tua chalder of sand
Item for the pergenyng of the maister househaldis chalmer
(P109, March 1532, Stirling)

1532 – Works at Falkland Palace

Reference: Accounts of the Master of Works Volume 1: 1529-1615, Henry Paton Ed., HMSO 1957.
References to lime (or related) on pages: 111, 112, 113.

Item... the beting of the new werk and pointing therof togidder with the auld chapel enterit fra Forthir tua chelder of lyme
Item in sand to mixting of the said lyme to Dic Lamb and Thome Mertyne four chelder wynnyng and leding of al costis
...
Item for ane lyme riddill
Item for ane bucket
Item for tua bakkatis for bering of morter
(P111, May-July 1532, Falkland)

Item for tua punsionis the tane for watter bering the uther for keeping of watter for making of morter to the samen
(P112, June-July 1532, Falkland)

Item... for ii chalder of lyme per idem tempus of the hill bevest Faulkland
Item... xlii dosane of sand at sindry tymes led be thaim for mixting therof
(P113, June-July 1532, Falkland)

1534 to 1535 – Works at Linlithgow Palace

Reference: Accounts of the Master of Works Volume 1: 1529-1615, Henry Paton Ed., HMSO 1957.
References to lime (or related) on page: 124.

Item for four ter barrellis to be mortar tubbis
Item for tua scheiffis to riddill sand and lyme
(P124, September 1534, Linlithgow)

1535 to 1536 – Works at Holyrood Palace

Reference: Accounts of the Master of Works Volume 1: 1529-1615, Henry Paton Ed., HMSO 1957.
References to lime (or related) on pages: 133-40, 150, 167-70, 184, 188, 191, 192.

Interpretation of these entries will be aided by some gloss: 'pulder' reads for 'powder' and 'flaikit' can either mean 'flaked' or something closer to 'flecked', 'speckled'; it seems reasonable to suppose that this refers to kibbled or powdered quicklime. An alternative meaning for 'flake' is given as a flat board or platform (the semantic relationship being loosely discernible), which could represent something like a riddle. The DSL entry for 'flake/flaik' cites this 16th century reference from the Edinburgh Burgh Accounts: 'Thre flakes to mak pulder small with.' It seems reasonable to infer that this refers to some form of processed or sieved quicklime and could even be taken as an explicit reference to slaking quicklime, i.e. reducing it to powder.

Item for vi small ryddilis and vi gret ridillis to the faldis
Item for viii gret flaikis for the pulder at sindry tymes
(P150, 1535-36, Holyrood)

Item to xlii barrowmen servand the masonis berand red and flakand [read: bearing, readying, and flaking/slaking] the powder ut supra
(October, 1535, Holyrood)

Item... for ane new lok to the lyme fald dure
(P184, July 1535, Holyrood)

Item to Robert Days pergeonar for pergene... with calk and glew
Item to George Peblis for perginyng harling and beting of the glasin wyndois...
Item to the said Robert for the wyssing of the grete hall with calk and glew
(P191, August 1535, Holyrood)

1537 to 1539 – Works at Falkland Palace

Reference: Accounts of the Master of Works Volume 1: 1529-1615, Henry Paton Ed., HMSO 1957 (December 1537-December 1539).
References to lime (or related) on pages: 201-207, 243-244, 269-270.

The text below shows a process of working at Falkland that involves fresh limestone quarrying and breaking, followed by burning of the 'fresh' limestone, apparently in the hills near the quarry, after which it is carried down within the space of the month to the work area below. Entries essentially identical to the above are recorded monthly for the rest of 1538, showing a consistent work pattern of lime processing throughout the year. The references to 'tua killis' (two kilns) and 'ilk kill' (each kiln) seem to imply that quantities of lime were being measured in kiln-fuls, rather than that the kilns themselves were transported to the worksite from the hills.

Lyme with the furnessing of lyme killis fra the xxi day of December to the xxii day of Februar for ix wolkis
Item enterit fra the Lowmond per iedem tempus xv chalder lyme
Item to James Bisset and Williame Broun for ix wolkis wagis wynnand lyme stanis and brekand the samyn to the furnessing of twa killis
Item to Andro Bell for x dosane ladis colis to tye birnyng of the same
Item to Johne Bate and his marrowis for carriage of the saidis tua killis fra the Lowmond to the werk

Sand enterit to the said werk attour the flaikit pulder fra the xxi day of December to the xxi day of Februar
(P244, December 1539, Falkland)

Attour is an adverb describing pertenance, particularly in the sense of 'over' or 'quantity,' therefore meaning something to the effect of 'the sand entering the said work for/pertaining to/to be put over/matching the flecked/flaked/sieved powder (i.e. quicklime).' Notice, too, the date of December-February.

1558 – Works at Stirling Castle

Reference: Accounts of the Master of Works Volume 1: 1529-1615, Henry Paton Ed., HMSO 1957.
References to lime (or related) on the following pages: 293, 296.

The expenssis of perjonaris
Item to Johne Kelle for harling of the hale chapel within and under the siling…
Item to Callum perjonar for harling of the hale caichpule withot and perjonying the samyn within
Item to the samyn for harling of the est turnpike togydder with the croce hous…
(P293, August 1558, Stirling)

John Grame sclatter for the mendeng thekein and pyntyene (painting) new work and ald work in the Castel of Sterweleng…
…
Item for ane puntion to be penis (paints)
Item for ane bukat to make the morter
Item for ane bukat to the waill
…
Item for thre deson of ladis of sand to the said work
Item for half an chalder of lyme
(P296, March 1558, Stirling)

1570 – Andreo Palladio, The Four Books of Architecture

Reference: Andreo Palladio, *The Four Books of Architeture*, (trans. Ware, 1738, Dover Press).

Palladio repeats Vitruvius, adding detail about the necessary treatment of 'Padua' limestone; clearly a hydraulic lime. Note the incremental addition of water. However, there is confusion; this risks burning the lime, but is said to avoid it. He should rather have said 'to prevent it drowning'. This suggests an unfamiliarity with craft practice.

When calcined, they must be wetted, in order to slack them; observing not to pour on the water all at once, but at several times, to prevent it burning before it be well tempered. Afterwards, it must be laid in a moist shady place, only covering it lightly with sand, taking care not to mix anything with it. When used, the more it is worked up with the sand, the better will be the cement; except that made with scaly stone, like that from Padua,

because that must be used as soon as it is slacked, to prevent its burning and consuming away, otherwise it will be useless.

To make mortar, lime should be mix'd with sand in this proportion: three parts of pit sand to one of lime; and but two of sea or river sand to one of lime.

1570 to 1615 – Works at various Scottish Royal Palaces

Reference: Accounts of the Master of Works Volume 1: 1529-1615, Henry Paton Ed., HMSO 1957.
References to lime (or related) on the following pages: 299, 302, 304, 306-7, 309, 315, 316, 317, 318, 319, 330, 335, 341, 342, 357, 359, 360, 362.

The Masters of Works Accounts describe miscellaneous works at royal palaces, 1570s onward. They contain references to many relevant construction details, but usually lead off with a note about loads of lime and sand, which always seem to arrive in proportion of twice as many loads of sand as of lime.

Item for xxvii laydis of Coustland lyme…
And for xx laydis lyme of the Wasthouses…
Item for viii dossoun sand and and half…
(P299)

Item for twa doussane of Coisland lyme
Item for iiii doussane laidis of sand
(P302)

1 dozen loads lime, 2 dozen sand (304)
8 loads lime, 16 sand (304)
8 loads lime, 16 sand (306-307)
8 loads lime, 28 sand (309)
Last day in August 34 loads lime
Two weeks later 28 loads lime, 120 loads sand (315, Holyrood)
3 loads lime, 6 loads sand 'thairto (316, Holyrood)
16 loads lime, 30 sand 'thereto' (316, Holyrood)
12 loads lime, 22 sand 'thairto' (317, Holyrood).
10 October, 2 loads lime, 4 sand (317)
28th October 4 loads lime, 8 sand (318, Holyrood)
24 August 10 loads lime, 53 sand (319, Holyrood)
2 May, 7 loads lime, 12 sand
3 June, 24 loads lime, 30 sand (330, 1611, Holyrood)

26 June, 8 loads lime, 13 loads sand
29 June 12 loads lime, 20 sand
1 July 8 loads lime, 12 sand
4 July 3 loads lime, 12 sand
6 loads 'dead' sand
20 July 26 loads lime
53 loads sand
29 July 12 loads of lime
24 loads sand
7 August, 12 loads lime
28 loads sand
14 August, 14 loads lime
24 loads sand
28 August, 80 loads lime,
8 loads sand (June-August 1611, Holyrood)

24 loads of lime for Kirkliston Castle, 60 loads sand (341, July 1613)

Thursday 10 loads lime, Friday 9 loads lime, Saturday 37 loads lime (total 46 loads), 100 loads sand (342, Edinburgh/Holyrood, 1613)

Two weeks later, another 72 loads lime, 100 loads sand.
The following July 133 loads lime, followed by 200 loads sand.
Two weeks later 102 loads lime and 200 loads sand.
Later in July 51 loads lime, 100 loads sand.
In August 97 loads lime, 180 loads sand.
Later in August 55 loads lime, 100 loads sand
In November 20 loads lime, 40 loads sand.
In the first week of August (possibly the following year?) 4 loads lime, 10 loads sand.
In February 1615 140 loads lime, 200 loads sand
In March 1615 38 loads lime, 204 loads sand. (357, March 1615, Edinburgh)

In April 1615 40 loads lime, 92 loads sand. (358)
Later in April, 24 loads lime, 68 loads sand (358-59)
Item for 4 score and 17 bollis of lyme stane
Item to the botmen that cariet thame over the water
Item for careing the lyme from Leith to the castell
Item to the careirs to drink
Item to four workmen for loosing the bott with the lyme
Item to tua men that bottit it
Item for xvi bollis of smydie coalles

Item for careing of thame from Leith to the castell
Item for his awin chairgis quhen he went over the watter to by the lyme
Item for tua riddellis to riddill the lyme
(P359, April 1615, Edinburgh)

The above entry lays out a sequence, specifying that it is unburnt limestone brought up from the shore to be burned on site at the castle with the smithy coals mentioned, then riddled. Given the time of year and the active worksite, it seems unlikely that this shipment is destined to be run to putty. Storage for several months would take the working season into the late summer at the earliest, and space would have to be laid aside on site for a limefold for long-term maturing, something that could have easily been done out of the way of the busy construction site-cum-active military fortress.

Item... for mending the tua chimnayis in the smedy with cat[50] *and cley and spairging of thame*
(P360, May 1615, Edinburgh)

Item to the sandmen for leiding of sextene laidis of sey clay[51] *to the abbay*
Item to thame for sand being aucht laid
Item mair for lyme to the owne[52] *in the abbay*
(P362, May 1615, Holyrood)

1567 – De L'Orme, The First Book of Architecture

Reference: De L'Orme P. (1567) Le premier tome de l'architecture (The first book of architecture) Paris. Frederic Morel. trans. Emma Michel 2018.
Philibert de L' Orme (otherwise Delorme) was Royal Architect 1548 - 59 (Henri II) and 1563 – 70 (Charles II & Catherine de Medici).

Lime and stones to make it, some sands and waters to use to make mortars with and the difference and natures of those sands:
We say the best stone to make mortars is the hardest, because it is fattier and more glutinous. Mortars made from marble or stones similar in nature are wonderfully good. So that when used hot, as straight out of the kiln, and mixed with small gravel and sharp river sand which carries other small gravel, [the lime] adheres and thickens (conglutiner = the idea of a liquid becoming viscous) very well with time, such that the whole becomes a rock, a mass of a single piece... You would admit that the best lime is the heaviest and when hit, it sounds like a earth pot well burnt.

[50] 'Building straw.'
[51] Possibly 'sea clay.'
[52] 'Oven.'

We also know [the lime] is of a good quality, if when it is wetted, the vapour and dense 'smoke' rise up immediately and suddenly: better still, if it binds with the larry when mixed (the verb used is 'broyer' = to crush). We have been aware through long-standing hearsay - and I think it is true - that lime from a particular place behaves much better in masonry made with stones from the same place and quarry...

As for the sand, we need good supply, whether to preserve the lime or to mix with it to make a mortar... I would like to advise that sands have different natures, and different qualities: some sands mix better with lime than others. Some are so fat that it needs five parts, even seven, for one part of lime. Some can be mixed with two or three parts and some are so bad that they need as much lime as sand. Some sands are good and adequate for walls above ground, others for underground work; some for plasters, some to make cement or to be used as real cement along with a pozzolan - a black sand used in Rome - which has the nature of a true cement.

Consider Pliny's work about the diversity of earths, the sand of Putzuoli and of several sorts of earths which harden like stone. The best sand in this country (France) and in other places is pit sand... because it is taken from the middle of a field inland, much better than that from rivers, and makes a noise when handled due to sharp grains like little rocks, which is the reason it makes a good mortar.

...Sands have various colours, white, yellow, red and black. You will know their quality when they are wet as they do not soil a sheet as mud does and do not dirty the hands as bad sands do. Have a look at Vitruve's writings on the subject.

As for water, which is the third element in the composition of a mortar... I say sea water is useless to make a mortar because it never dries out and leaves [the mortar] always humid and stops it from binding with the stones. It is the same for marsh and swamp waters... but those from rivers, wells and fountains are really good and clean.

Ways to soak lime, that it may last longer once used and keep a long time and safely, and its use by painters.

In the way that some materials were kept in good supply, not everyone knew how to keep their lime, and when they wanted to use it, it had lost almost all its force, having been badly soaked and prepared in ways other

than it should have been. ...Some are strong; others less so. It comes from the nature of the lime which some soak when it comes out of the kiln with water, but not sand, and make a big mass... However, they are in the danger of burning or drowning it, with too little or too much water, either of which will greatly reduce its strength. Once soaked, they store it in one heap and then, when they need to use to it, they soak it again and mix it again with sand... The other way, as soon as the lime is out of the kiln, is to mix it with a bit of sand and water and make a mass (a coarse stuff) to keep until they want to use it, when they mix in more sand. This method is better than the first one but the one I am going to describe is best, since the lime can keep its strength and fattiness by this method...

The method is this: when you take the lime from the kiln, you will put it in a (pit) with a depth of 2 or 3 feet and of any length and width you would like. You will put a good quantity of pit or river sand of about one or two feet of depth over it...

You will then well water the surface, in such a way that the sand is so wet that the lime beneath cannot fuse, nor burn. If you see cracks in the sand and see vapours emerging, you will close those cracks in order to prevent their escape. With the sand well wetted, all the lump lime will convert into a mass of fat which may be used in 2, 3, 10 years - it will be as a cream cheese and the material will be so fat and sticky that it will be almost impossible to use the larry and will consume great quantities of sand and will be such a good mortar that it will stick to stones as if it was a real and good cement. You will need to ensure when wetting the sand that the lime is fully covered and not be exposed to the air...

[In decoration], the lime soaked thus will not burst the plaster or kill the colours like other mortars do. Sometimes, after soaking the lime, the painter, having produced beautiful work, [discovers] some time afterwards that his colours are fading, or that the lime cracks the plaster and painting, so that some pieces fall or swell like blisters, which is damage and loss for the lord who commissioned the work and a great dishonour to the painter.

1569 – Construction of St Bartholemews Hospital

Reference: Badminton Muniments GBR K1/15, Building account, St Bartholemew's Hospital 1569.

The proportions detailed here would seem to indicate a lime-rich mix. This reference is also of interest as it notes delivery throughout the winter, which probably also implies winter working.

16th Dec: 4 barrels of lyme, 2 loades of sand, 2 loads of stone
28th January: 4 loodes of stone, 3 barrels of lyme, 2 barrowes
3rd February: 2 barrels of lyme… 2 loads of sand
11th February: more barrels of lyme

1616 to 1661 – Works at the Queens House, Greenwich

Reference: Chettle G H (undated) The Queen's House, Greenwich, 14th Monograph of the London Survey Committee. London. The Trustees of the National Maritime Museum, Greenwich. HMSO. From Appendix IV Extracts from the Building Accounts of the Seventeenth Century.

The below would indicate that the lime is being processed at the same time as building proceeds; that it is being dry-slaked and screened before hand-mixing with shovels to a mortar. Most of the masonry work in this account is for brick-laying. Flints appear alongside sand. Pulverised flint may be being added to the mortar for some notional 'pozzolanic' effect, although brick dust would be a more likely addition had this been deemed necessary. The flints may be for the core of footings, therefore.

1616-1618. *Wheelbarrowes, Baskette viz 10 dozen and 6, Shovells 7 dozen, Pails 24, Lime sives viz 6 at 12d the pece and for one more limesive two foote, Caske, viz two barrels… and two hogsheads… to make watertubbes. Samuel Avery, William Browne and others for slacking, sifting and wetting of lyme into morter.*

1661. *Labourers imployed in slacking and sifting of lime… in beating way through a brickwall into ye parke… (and) in digging the foundations for ye bricklayer.*

1639 to 1691 – Building work Cawdor Castle

Reference: *The Book of the Thanes of Cawdor*, The Spalding Club, Aberdeen 1859 held at HES, John Sinclair House, Edinburgh.

This entry shows lime being purpose-burned off site and then carted to the worksite.

P297. Discharge 1639: *"Item, payit out for elding (wood or fuel), and burneing and leiding of chaldris lyme to the house of Calder"*

Here we see masons contracted to burn shell lime, the implication of the final line being that the lime is being burned specifically for the building project.

P283. *Contract betwixt the shireff and the meassones for building the work of Calder, At Calder 15th October 1639: "...And the saidis meassounes bindis theme and ther forsaidis to wine the hail stones, hew the heweine work, and leid th hail stones and watter upone their awne chargis, and to burne the chelis in lyme: with hewine skunchiones to ewerie door and windock as requeris accordinglie pro rato... The said Colein Campbell furnesching to the saidis meassounes peittis and torwis for burneing the lyme...*

P299. Discharge of year 1640: *"Item for schellis to be lyme to the hous of Calder and for carrying of the same fra Ardroseir (Arderseir) to the hous of Calder..."*

"Item given to the meassounes for winning of the stones, hewing thereof and building of the auld hall and kitchen of Calder..."

P334. From a memorandum of instructions written by Sir Hugh at Calder 10th April 1677: *"Item that my uncle James cause burn abundance of lyme and provide all materials timber, sclate, iron and cause win a number of good stones for building of my house at Killorow, and quhen I come ther my self I shall bring meassons with me to build it"*

P391. Copy agreement with masons: *"[T]hey are to cast down the little tower of Calder to the very foundation if need be, and preserve the stones as heal as they can, especially the hewen work... and bring in lyme and clay to build the samen..."*

1671 to 1674 – Works at Stirling Castle

Reference: NAS National Archives of Scotland, E36/34 Works Vouchers.

The final two paragraphs quite clearly delineate that quicklime was being purchased from the kilns to be slaked on site. This perhaps indicates the importance of quicklime or fresh-slaked lime to to the mortar mixing: pre-slaked lime or putty presents a much lower risk in transporting by boat and, assumedly, would have been done, if it were acceptable to the specification.

E36/34 Voucher 15: John Hamilton's debursements from 18 September to 11 December 1671: *'a burn stand, two lime tubs, a bucket: a riddle for lime and sand... girds for lime tubs'* (84).

E36/34 Voucher 41 Account of the debursements at Stirling Castle Palace from 1st December 1671 to last of January 1673:

P6. '*to John Andersone workman… for six bags of lyme at 12s the bag for levelling the bartison of the pallice before the lead was layed on is £3 12s'* (Harrison 92)

P12. Account for sand furnished from 11 Dec 1671 - last Jan 1673 *'Item Fyve hundered & fourtie tuo lead of sand six score to the 100 for mixing of lyme and laying of pavement at 2s the lead…*

E36/34 Voucher 49 John Hamilton's receipt for '13 chalders of full mett Broomhall lime' *carried in John Caddell's ship and delivered 18 Feb 1673.*

1673 June 21st *To John Crawford 'lymeman att Bearhavn' for 15 chalders lime loaded in boats by him to be transported to Stirling Harbour at £5 6s 8d Scots per chalder as the price asnd 2s for other charges.*

1673 July 21st *To Jon Crawford in Bearhavn for the price and other charges of metting, filling and emptying of 18 chalders lime put aboard Jon Caddell's boat.*

1674 June 10th *To Wm Smart for 13 chalders lime from Broomhall limekills at 7 merks each, loaded on John Caddel's boat and transported to the castle for the reparations*

1680 – The Life and Works of Sir Christopher Wren

Reference: New, E H, *The Life and Works of Sir Christopher Wren, from the Parentalia, or Memoirs, by his Son Christopher*, (London: Arnold, 1903).

This description of 'chalk lime' makes it clear that different properties were valued in rendering and plastering, than in mortars. The author notes that the more thoroughly the mortar is beaten, the better it will be.

The next Material is the Lime; Chalk-lime is the constant Practice, which, well mixed with good Sand, is not amiss, though much worse than hard Stone-lime. The vaulting of St. Paul's is a rendering as hard as Stone; it is composed of Cockle-shell-lime well beaten with Sand; the more Labour in the beating, the better and stronger the Mortar.

1684 – An answer to Sir William Petty's query about mortar

Reference: Millar A (1872) The History of the Royal Society of London Vol 4 London, P363.

This source discusses the differences in properties and practicalities of chalk lime versus lump lime. Because lump lime will take up more sand than chalk-lime, the proportions vary accordingly. All is discussed in the context of making coarse stuff for plastering on lath or on-the-hard.

The plaister used by our plaisterers here in Oxford is generally of two sorts, coarse and fine. 1. Coarse mortar is made of lime, sand and hair; the lime used here is of two sorts, viz 1. Chalk-lime, made of chalk-stone, dug at Netlebed etc and burnt; 2ndly, hard stone lime, which is made of hard rag-stone burnt; this last sort of lime is much stronger, and will go two yards square in five farther (for it takes up a far greater quantity of sand and water), than the former, which is the finer of the two, and the more glorious to the eye. One bushel of chalk lime, one bushel of sand, and one peck of hair, mixt altogether, with water, will make coarse mortar; but if you use hard stone lime then one bushel of lime will require a bushel and a half of sand, and a bushel of hair. 2ndly in the making of fine mortar, mix one bushel of chalk-lime with half a peck of hair, or a bushel of hard stone lime with a peck of hair, and as much water as is necessary. Coarse mortar is used next to the lathing, stone, or brick wall; fine mortar is drawn on the other, and makes it white and beautiful.

1695 – Construction of Kilchurn Castle Barracks

Reference: National Archives of Scotland, GD170/705.

The following is an [as yet unpublished] analysis of records of the Breadalbane Estate done in 2017, by Stirlingshire historian John Harrison. It is not a direct quote but is his summary and analysis of what the archival material shows. It gives great insight into the process of working, particularly in its reference to harling occurring in phases concurrently with the building process, rather than as a final act once all is finished.

On 25th Oct 1695, the Earl wrote to Christie about the wages and meal payable to the workmen; only those engaged in burning lime and at the sawmill should be kept on over winter. When Christie finished work (implicitly, for the season) he was to hand the keys of the castle to Barcaldine (GD170/705). On the same day, the Earl wrote testily to Barcaldine that he had agreed with the plasterer to do all the remaining work in the castle at the former price and all materials to be laid in before he began; he expressed concern about the abilities of the lath-makers and wanted a man sent from Rannoch *'to work with them till they learn the trade…'* Christie was to be told of the Earl's annoyance about the way he had built the west gable of the New Work, which was not watertight, in

spite of Breadalbane's positive orders; *he ought to have made that wall five or six feet thick at bottom and have divided it with scarcements of flags on the outside; he ought to have harled every storey as he built it during the drouth of summer. He should put a great cairn of stones before any wall that is built on the west side and, meanwhile, Barcaldine should instruct any mason who was there to rectify the wall which was 'damnified'.*

1698 – Construction of Wardour Castle

Reference: 2667/22/1B/1, Wardour Castle Accounts, Wiltshire Archives.

The building accounts for Wardour Castle make a clear distinction between the lime coming for the masonry construction and the 'slakt lime' required for plastering.

The stone walling 1908.8
The ashler facing 1181-0
For 64 B of lime at 6d for every 30 ft solid 1-12-0
Carriage of 64 load of stone at 10d per load 2-13-4
Carriage of 64 load of sand at 8d 2-2-8
...
For 20.5 tuns of Slatt stone at 10s per tun 10-5-0
Helliers laying and finding for 1541 ft 3-04-4 ¼
For 41 bush of Lime at 6d 1-0-6
...
For carriage of 20 tun of Tyle stone 2-10-0

Lath Plaistering etc 116ft
10 bush Slackt lime at 2d[53]
200 of lath
3 ¼ bush hair at 6d
400 of 3d nayls
750 Tyles 3 ½ gage
nailing and laying a square 0-3-0
6 ¼ bush lime at 4d per
a load of sand
a bundle lath (=100)
5d nails

[53] This would most likely be slaked to a dry hydrate, with water added to make a thick paste (putty) before mixing of the plaster. It will likely be for finish coats – see quicklime deliveries above and below.

6. THE 18TH CENTURY (1701 – 1799)

The 18th century is the start of the extensive written corpus on recommendations as to building design and composition, at a technical level. This increasing desire to write things down and specify might also reflect the decline of the craft guilds and their traditions, and the start of the reduction of influence and control of the practitioners. However, we can be reasonably confident that what is captured in the the texts reflects probably most of what craft practice was doing and might have also captured habits and understanding of the previous generation. The accounts of building works from several large projects are also much more descriptive; it must be acknowledged that they are simply what was located in the search for material within the scope and resources of this project, and that many more are likely to exist.

1701 – Works at Glamis Castle, Angus

Reference: Archive accounts quoted in Slade H G 'Harling and Vernacular or we Are All Gentlemen Now', Vernacular Building, 22 (1998), 32-8, Glamis Castle Archive Box 141 Bundle 11.

This would indicate dry slaking with sandsand slaking and then banking the mortar to sour, before it is knocked up to a mortar for use. This might indicate a hydraulic lime, it might have been to allow for some late slaking, or both. The mortar may be wetter, however, before souring and banking.[54]

…the said John Sherres binds & oblidges him to cast and harle the said noble Earles Castle of Glammis old and new work thereof with lyme… [and] also to point and make water-tight the roof… so soon as lyme, other materials & necessary engines shall be furnished for the work, which he is to perfect and finish betwixt the date hereof (30th March 1701) and the first day of September next to come… as much lyme to be mixed with sand sufficient and sowered as shall cast and harle the said castle and lyme sufficient for pointing etc the roof of the same.

1702 – Repairs at Brodick Castle

Reference: National Register of Archives in Scotland 2177/B2922.

In 1702, a major survey of Brodick Castle was ordered by the Duchess of the 3rd Duke of Hamilton, led by John Hamilton, Balie of Arran and David

[54] Souring is the process of allowing time for late slaking to occur before use. The necessary period of souring might vary with the lime.

Crawford, secretary of the Duchess. Their report found the castle in poor condition and prioritised extensive repairs to ensure its future structural stability. After the repairs were done, it was documented that the whole structure was also to be repointed with "*good sowered lyme and pan cratch"* (referring to the precipitate of lime forming on the sides of slaking and salt pans and traditionally used in harling).

Repairs were carried out over the summer of 1702, with the bailie instructed to burn and prepare six bolls of limestone that had already been shipped to Brodick. This was done in a lime kiln, specially constructed for the task at the '*castell of Aran'*:

"28th day of Maii 1702… the said John Hamilton Baille is instantly to burn the Lyme stone which is already brought to ye castle, and sift and sower the same well and mix the same well with sand, that it may lye some time before it be made use off…"

1703 – Moxon's Mechanic Exercises

Reference: Moxon, J *Mechanic Exercises* (London: Midwinter and Leigh, 1703), online at https://catalog.hathitrust.org/Record/001045922.

Moxon suggests that his work is the first to treat seriously the hand-crafts and intends to disprove the notion that such work is to be despised, and the integrity of its practitioners assumed to be weak. He seeks to assert the 'nobility' of skilled labour. It is a summary of later 17th century craft practice and is the earliest available text to explicitly discuss hot mixing of mortars; especially suggesting that quicklime, which has been slaked in the normal way - with just sufficient water or a little more - but on its own, contributes less strength to the resultant mortar, than when the slaking takes place in intimate association with the sand for the mortar. He asserts the superiority of feebly hydraulic limes (stone limes) for exterior works; chalk limes for interiors. His direct experience is of London practice; elsewhere, lime stabilised earth mortars remained the norm at that time for masonry construction, although lime was more commonly used for brickwork. Moxon favours the laying down of coarse stuff to mature and disapproves its immediate use:

…Vitruvius, his proportion of sand seems too much, although he should mean the lime before it is slacked.

…Here at London, where for the most part our lime is made of chalk we put about 36 bushels of pit sand to 25 bushels of quicklime… And lime mixt with

sand, and made into mortar, if it lie in a heap for two or three years, before tis used, it will be stronger and better, and the reason of so many insufficient buildings, is the using of the mortar as soon as it is made, as Agricola saith.[55]

First, That the mortar be made of well-burnt good lime, and sharp sand and that it have a due proportion of sand, that is to say, if it be very sharp, a load of sand, being about 36 bushels, is sufficient for an hundred of lime, being 25 bushels or a hundred pecks… to wit, to one bushel of quicklime, a bushel and a half of sand[56] *But if the sand be not very sharp, then you may put a greater quantity of sand, for mortar which hath its due proportion of sand is stronger than that which hath less sand in it, altho' some think otherwise.*

Secondly, When you slack the lime, take care to wet it everywhere a little, but do not over-wet it, and cover with sand every laying, or bed of lime, being about a bushel at a time, as you slack it up, that so the steam, or spirit of the lime may be kept in, and not flee away, but mix itself with the sand, which will make the mortar much stronger than if you slack all your lime first and throw on your sand altogether at last, as some use to do.

Thirdly, That you beat all your mortar with a beater three or four times over before you use it, for thereby you break all the knots of lime that go through the sieve and incorporate the sand and lime well together, and the air which the beater forces into the mortar at every stroke conduces very much to the strength thereof…

…If I might advise anyone that is minded to build well, or use strong mortar for repairs, I would have them beat the mortar well, and let it lie 2 or 3 days, and then beat it well again when tis to be used.

Fourthly, If you lay bricks in hot, dry weather, and be it some small piece of work that you would have very strong, dip every brick you lay, all over in a pale of water, which will make the wall much stronger than if the bricks were laid dry… They may [also] throw pales of water on the wall after the bricks are laid…

[55] Georgius Agricola, otherwise Georg Bauer, geologist (1494-1555), not the Roman General….
[56] Giving a mortar 1.25: 1.5 or even 1:1 using hydraulic lime.

Fifthly, Cover all your walls in the summer-time, to keep them from drying too hastily, for the mortar doth not cement so strongly to the bricks when it dries hastily, as when slowly.

Sixthly, Be sure to cover them very well in the winter-time to preserve them from rain, snow and frost, which last is the enemy to all kinds of mortar, especially to that which hath taken wet just before the frost…

1704 – Building wall-heads at Brodick Castle, Isle of Arran

Reference: Douglas-Hamilton family papers, NRAS 332/F1/ Bundle 738: doc ref. 456/17/39.

This account refers to the use of pan-cratch, a lime precipitate which forms on salt pans and could have imparted hydraulic properties.

"*Account dew by Her Grace the Duches of Hamilton to Robert Hunter masson in Aran, 1704… for plastering and lasting of the pavement of the wallhead of the castle with lime and pan cratch, £6…*

1708 – Mortimer, Footings and linings of buildings

Reference: Mortimer, John*, The Whole Art of Husbandry; Or the Way of Improving Land, Book 1.* (London: JH, 1708).

Foundations and footings are essentially water lime applications. Mortimer lists various techniques and ingredients for achieving a mortar which will set masonry below-ground, including terrace (trass), linseed oil, tallow and eggs.

If you design to make your Cisterns under your House, as a Cellar… for culinary Uses, you may lay the Brick or Stone with Terrace[57]*, and it will keep Water very well; or you may make a Cement to join the Bricks or Stones with, with a Composition made of slacked sifted Lime and Linseed Oyl tempered together with Tow or Cotton-wool. Or you may lay a Bed of good Clay, and on that lay your Bricks for the Floor, then raise the Wall round about, leaving a convenient space behind the Wall to ram in Clay, which may be done as fast as you can raise the Wall: so that when it is finish'd, it will be a Cistern of Clay walled within with Bricks, and being in a Cellar, the Bricks will keep the Clay moist (altho' empty of Water) that it will never Crack.*

[57] Trass, volcanic ash from Germany, via Holland.

Or you may make a Cistern or Pool to hold Water by daubing of it with Clay and Mortar, and after draw it over with Mortar; if any cleft happen, stop it with a Cement of clean Hair and Tallow mix'd with unslack'd Lime and Yolks of Eggs well beat, and made into Powder, and mix'd well together.

1716 – Building work at Cawdor Castle

Reference: Papers selected from the Charter Room at Cawdor 1236-1742 published in *The Book of the Thanes of Cawdor*, The Spalding Club, Aberdeen 1859 held at HES, John Sinclair House, Edinburgh.

The distinction in sourcing limes for the construction of Cawdor Castle perhaps indicates that lime from different locations was being sourced according to the appropriateness of its properties to various building applications.

P424. Calder, May 12, 1716: *"Item of lime brought from Darnaway, three kill fulls, Item of lime brought from Connage 25 bolls at 12d per boll, Item of lime brought from Bellnatrait in Ross 20 bolls at 10d per boll*

P426. March 1722: *"For 60 bolls of lime chalk and hair and glue for plaistering the turnpike stair to the wardrop in February and March 1722*

1721 to 1728 – Building at Stanmer Park

Reference: Building Accounts, Stanmer Park, Sussex ACC 6077/22/11.

We see in the Stanmer Park accounts all the items we would expect to in masonry construction, with more detail than usually offered, distinguishing between sea sand and land sand, loam and clay, trass and chalk, showing the sheer variety of materials and mixes that could go into a single building project.

Abstract of all the Workmen's, Artifcer's and tradesmen's bills which were concerned & imployed in the several Buildings & other Works done at Stanmer in Sussex for the use of Henry & Tho: Pelham Esqrs from the year 1721 to 1728 inclusively, shewing the nature, quantity, carriage & value of all the materials used in the said buildings, together with all manner of Workmanship performed by the said Workmen, under the direction of Mr Nicolas Du Bois, surveyor to his Majesty's Buildings

982,950 Bricks – Cost £865-13-9; Carriage £315-19-9 ¼
...
1235 loads of sea sand

339 loads of Land sand
12 loads of Loome £0-6-0 carriage £1-10-0
44 loads of gravel
114 loads of Clay £4-5-0 carriage £28-17-6
110 loads of small chalk
1111 1/8 loads of Lyme £480-4-3 Carriage 29-1-3/4
19 ¼ bushels of Tarriss £3-15-5
1770 bushels of Cow hair £59-0-0 carriage £10-13-0
118 tons by ft cube of Portland stone £234-19-4 ½ carriage £25-11-10 ½
10 loads of sandstone £5-0-0 car £7-0-0
315 loads of old sandstone from limefield £157-10-0 car £283-9-10 ¼
...
34 loads 25 foot of Healing stones from Limefield valued £15-8-2

1726 – Bailey and Worlidge, Dictionary of Husbandry

Reference: Nathan Bailey, John Worlidge (1726) *Dictionarium Rusticum, Urbanicum & Botanicum: Or, A Dictionary of Husbandry, Gardening, Trade, Commerce, and All Sorts of Country-affairs: Volume 1.* Third (revised) Edition.

An interesting and explicit description of the use of clay and earth in mortars and renders, explaining how quickly (or slowly) work must be carried out to achieve the most successful build.

But though burning of Bricks be necessary for building of Houses, &c. yet a Wall or House may be made with un-burned Bricks; for which end, 1. Let your Earth be high and well temper'd, smooth and well moulded, as already hinted, and this done in the hottest Season; then dry'd and turn'd after the manner of Brick-making; only it must be longer exposed to the Sun and Elements, till they become hard and tough, and then use them after this manner: Take Loam or a Brick-earth, and mixing therewith some good Lime, temper them very high till they become tough, smooth and glewy; let the Wall of your House be one Brick or one and an half thick, and your unburnt Bricks being laid in this well-temper'd Mortar, they will cement and become one hard and solid Body, as if the whole were but one entire Brick or Stone:

When you have raised your Wall 4 or 5 Foot high from the Foundation, let it dry 2 or 3 Days before you proceed further; then build thereon 4 or 5 Foot more, making the like Pause as before, and so proceeding till the Wall is finished: Afterwards temper some of the same Earth the Wall was made of, with a little more Lime that was used for the Wall, which you must be sure to temper very well, and with this Mortar plaister all your Wall well on the

other side, which will keep off the Weather; and if you would have it more beautiful, it's only putting more Lime to it and less Loam; and when this is dry, you may colour and paint it, with Red, Blue, or any other colour that you like best.

1726 – Robert Neve, Notes on mortar and plaster

Reference: Neve R, *The City and Country Purchaser*. (David and Charles: Newton Abbott, 1969 Reprint).

Neve was based in Sussex and, in the context of lime and mortars, the most useful aspect of his work is to be derived from his discussions with local craftsmen. Neve, in relating the advice of contemporary craftsmen, is explicit that lime is best used hot and 'quick,' slaking and mixing only as much as can be used immediately.

Mr Worlige says, That if you intend your mortar to be strong, where you cannot have your choice of lime, you may choose your sand and water; for all sand that is dusty, makes the mortar weaker; and the rounder the sand, the stronger the mortar, as is usually observed in water-drift sand; that makes better mortar than sand out of the pit.

Therefore (says he) if you have occasion for extraordinary mortar, wash your sand in a tub, till the water, after much stirring, come off clear, and mix that with new lime, and your mortar will be very strong and durable. And if your water be foul, dirty or muddy, your mortar will be the weaker.

He also tells us, that it is a great error in mason, bricklayers, etc to let the lime slacken and cool before they make up their mortar, and also to let their mortar cool and die before they use it. Therefore (says he) if you expect your work to be well done, and long to continue, work up your lime quick, and but a little at a time, that the mortar may not lie long before it be used.

So that you see, that in this point also, men differ in their sentiments; some affirming it best to use their mortar new, others, after it has lain made for some time.

1746 – The Construction of Inveraray Castle, Argyll

Reference: Argyll Estates Archives, Letters & instructions for building Inveraray Castle for his grace the Duke of Argyll in Argyllshire by R. Morris 1744-47 / NRAS 1209.

Such large quantities of water are being used in mortar making, that Adam advises a system of pipes to be devised to deliver water directly to the lime pits.

William Adam Sept. 29th 1746*: "Water. to be brought in for souring Lime It is thought the water... should be Collected, and brought in the Interim by wooden pipes of 2 In. bore or thereby to the bings of Lime, where the Same is made into Morter for the Service of the building..."*

1749 to 1750 – Repairs to Blair Castle, Perthshire

Reference: Blair Castle & Atholl Estates Archive, Box 40.

Dovetailing with earlier accounts, the accounts from Blair Castle specify that sowered lime is required for harling, though not necessarily for masonry building. They also indicate pan cratch as an additive, imparting hydraulic properties.

Memo taken at Atholl House (Blair Castle) on 22nd May 1749*: "That Mr Walker get half of the first kiln of lime sowered for harling both under of the new house and as soon as it is proper to begin to harl with that lime that he takes two of Adam Brown's masons to work away with him..."*

Memo for John Stevenson dated 29th November 1750: *"...to have the roof of the new house where it joins to the new work secured from the rain getting in either by having a raggle cutt in the wall of the new work in order to fixen lead so as it may overlap the scleates and or in case that cannot be done to have it pointed up with some strong cement such as pan crach or any other thing that will stand the weather."*

1750 – Batty Langley's Price Book

Reference: Langley B (1750) London Prices of Bricklayers' Materials and Works Both of New Buildings and Repairs, Justly Ascertained. London Richard Adams 2nd Edition.

Langley's is an oft-quoted source, detailing the different types, uses, applications of lime (mostly within the context of London), as well as a wealth of gauging materials and additives. It notes that the fatter limes made with loamy aggregate are appropriate for interior masonry work, while sharper, purer sand better withstands the elements. All building applications, by this account, call for 'hot lime' and the proportions are very rich at 2:1 lime to sand. Various additives are mentioned, such as brick dust, trass, coal dust and even horse dung.

The several kinds of Mortar used in Buildings are Eight, viz

1. *Inside and Outside mortar made of Lime and Sand*
2. *Terrace Mortar, made of Lime and Terrace*
3. *Brick-Dust Mortar, made of red Stock Brick dust and Lime*
4. *Bastard Terrace, made of a Smith's Forge Ashes and Lime*
5. *Pargetting Mortar, made of Lime and Horse-dung*
6. *Furnace Mortar, for Furnaces, Ovens, Kilns, etc made of Woolwich Loam or Windsor Loam only*
7. *Plaister Mortar, made of calcined Alabaster*
8. *Fine Mortar, called putty, for rubbed and gaged Works, made of Lime only.*

Inside Mortar
Inside Mortar is used for Vaultings, Foundations, Partition and Party Walls, insides of Fronts, and other Parts, which are hid from the Eye and not exposed to the Weather.

This Kind of Mortar is generally made with Pit-sand which requires more or less lime as it abounds more or less with loamy Particles; and therefore when Pit-sand is of a loamy, fat Nature, to 1 Load, (viz. 24 heaped Bushels) put 1 Hundred of Lime; but when it is a clean sharp Grit as Thames Sand then to 1 Load of Sand put 1 ½ Hundred of Lime, which mix up together as the Lime is slacked in small Quantities. And since that Hundred of unslacked Lime is just 20 heaped Bushels, therefore in the first Case of loamy Sand, the Quantity of Lime is to the Quantity of Sand, as 20 is to 24; that is, in the lead Terms, as 5 is to 6 viz. 5 of Lime, to 6 of Sand.
The Expense, prime cost, of making a hundred of lime into inside mortar with loamy Sand, is as follows, viz 1. Hundred of lime 2. Load of Sand 3. A Labourer ¾ day, to slack, sift, turn up and chafe.

Out-Side Mortar for Fronts, Tiling, &c. exposed to the Weather, should be made with the sharpest Grit-sand that can be had, as being best able to withstand the Insults of Rains, &c. which Loamy Sands cannot so well do — and which therefore should not be used in any Part of a Building, that is exposed to the Weather.

The Proportion that the Lime should have to the Sand, is as 2 is to 1, viz. 2 heaped Bushels of unflacked Lime to 1 ditto of Sand.

Terrace Mortar - As Lime Mortars are made of Lime and Sand, so Terrace Mortars are made of Lime and Terrace. Terrace is a kind of Sand brought from Holland... sold by the Brick and Lime Merchants in London, and

particularly by those on the Fleet-Ditch-side... Terrace Mortar is chiefly used in Walls exposed to Water, as to Rivers, Ponds, Cisterns, Bog-Houses, Cold Baths &c.

The best Terrace Mortar is made with two Bushels, &c. of hot Lime, and one Bushel &c. of Terrace, well incorporated by beating. And which Quantity to beat well, is a good Day's Work for a Labourer.

Bricklayers also sell Terrace dry mixt, with slacked Lime made ready for Beating, which must be done near to the Work where it is used, because of its setting very quickly - which it will always do if it is good and well beaten, and therefore must be instantly used in small Quantities as it is beat.[58]

In the beating of Terrace, great Care should be taken not to over-wet it, but to beat it as stiff as can be and the oftener tis beat, the stronger it is.

Of Brick-dust Mortar - This Kind of Mortar is exceeding good, and in some Cases is better than Terrace Mortar; for unless Terrace Mortar is always wet, 'tis not better than common Mortar made of Lime and Sand.

This Kind of Mortar is thus made, viz. To two heap'd Bushels of hot Lime put one heap'd Bushel of Brick-dust made from red Stock Bricks, which mix, beat, and work up, as before directed for Terrace.

This is an excellent Mortar for to lay Face Tiles or Ten Inch Tile Pavements in on Floors which are naturally wet or damp; and tor Brick Pavement and Tiling, unless for Glazed Tiles and then in the stead of Brick- dust 'tis best to use Sea-Coal Ashes with some unburnt small Sea- Coal Dust mixt in the stead of the Brick-dust.

Of Sea-Coal Mortar, called Bastard Terrace - This is also an exceeding good Mortar for to lay the Coping of Walls in, for to point glazed Pan-tilings, for to lay Slating, Purbeck and Portland Pavement, &c. in and many other Uses, where the Rains are required to be kept out. This Mortar is thus made: To 3 heap'd Pecks of a Smith's Forge Sea- Coal Ashes (which is sold for 4 d. per heaped Bushel) intermix'd with the Iron Flakes put 1 heaped Peck of unburnt Sea-coal Dust and two heaped Bushels of hot flacked Lime which incorporate well by Beating, as before said of Terrace Mortar and use it up as 'tis beat.

[58] i.e., the ingredients dry-slaked together.

Of Pargetting Mortar - This Kind of Mortar is chiefly used for to plaister the Insides of the Funnels of Chimneys and is also very good for to point common Pan-Tiling, &c. and is thus made: To 1 heaped Bushel of fine skreened clear Lime add about a 4th Part of fresh Horse-dung clear from Dirt and Straw; which incorporate with the Lime by well beating it, as is said of Terrace Mortar.

1 Bushel of fine lime, taken out of 2 bushels of unscreened Lime
Horse-Dung and Labour to get it
Labour to slack, sift, turn up and beat

The Mortar in which rubbed and gauged Bricks are set is called Putty, and is thus made: Dissolve in any small Quantity of Water, as two or three Gallons, so much fresh Lime (constantly stirred with a Stick) until the Lime be entirely slacked, and the whole become of the Consistency of Mud; so that when the Stick is taken out of it, it will but just drop; and then being sifted, or run through a Hair Seive, to take out the gross Parts of the Lime, is fit for Use.

Mortar for the Shafts of Chimneys, Parapet Walls, Tops of Garden Walls, Etc should be made with the sharpest and cleanest Sand, (free) from Earth or Loam, that can be got and therefore the drift Sand of Rivers, where it can be had, is the best sort of Sand for these Purposes that can be used. But where Sea- Coal Ashes, clean from Wood Ashes and Dirt, can be had, they are preferable to drift Sand, provided that the Mortar be well beat and used as bastard Terrace. This Mortar is thus made: To 2 heaped Bushels of unslacked Lime, put 1 heaped Bushel of Drift Sand or Sea- Coal Ashes which beat well, and work up hot, as 'tis made ready for Use.

1750 – Construction of St Georges Hospital, Dublin

Reference: Copy of plans and specifications of St. Patrick's Hospital, Dublin by Francis Corbet and George Semple c. 1750 Dublin: National Library of Ireland, Ms. 2758.

Semple's specification is slightly difficult to make out and, by his own account, differs markedly from normal practice. He describes with excellent detail slaking small quantities by hot-mixing with sand, piles of which are allowed to lie covered, until intensely laborious beating and a minimum of water knocks it up for use. The difficulty is in knowing particularly what aspects of this deviate from common practice; distinctions that would have been obvious to a contemporary reader.

It is not intended that the morter, which is to be made use of in this building (St Patrick's Hospital), Should be made in the usual way; particularly for the outside walls. But the principle methods, which I intend to be taken, are Chiefly, To bring the lime in roach from the Kiln to the Work: To Slack but a small quantitie of it at a time, and to cover and mix that with sand directly, ready for the riddle (Whilst the spirit of the lime is hot and quick). But not to be in a hurry to riddle it, But to give it time to cool and infuse its strength among the sand. That the proportion of sand to lime… Be not richer than four of Sand to one of roach lime (That is about 2 to 1 of slack); That after it is riddled and turn'd up, That it be allow'd as much time to soak as conveniently the Work will admit of. That when the Workmen are making use of it that the Labourers shall only cut down a small bed of it at a time. And that Two of them – the one opposite the other – must each Labour each of them small beds, three or four times over with the beaters and then turn it by for the Hodd men etc. And above all, that there be as little Water be made use of in tempering it as possible. But to apply very hard Labour to supply the usual place of water.

1753 to 1754 – Repairs at Blair Castle, Perthshire

Reference: Blair Castle & Atholl Estates Archive, Box 40

In contrast to George Semple's specification above, where lime was mixed with sand in pits in the earth, the Atholl Estates books call for (presumably wooden) troughs for mixing the lime.

"Atholl House (Blair Castle) and at Dunkeld since 1st March 1753:

Making two centres for the masons with 6 lime troughs…

From a list of work done at Atholl House (Blair Castle) from John Stevenson's journal dated 31st December 1754:

"To build a house for holding plaster, hair and lime…

…To making gaberts, 10 lime troughs, 9 ladders, 2 hanging scaffolds for the sclaters…

…To making 4 centres for the new kitchen cutting, making 3 lime troughs for the masons…"

1754 – The Construction of the Corn Exchange, Edinburgh

Reference: Contract of Agreement for Building an Exchange in the City of Edinburgh between the Magistrates and Edinburgh Town Council and the Tradesmen. (Edinburgh: Hamilton, Balfour and Neill, 1754).

The specification for 'lime mixed' is almost certainly a description of mixing quicklime with aggregate (sea sand, in this case), i.e. hot-mixing, followed by grouting. It also describes three coat work to the plaster, describing the different mixes for each coat.

…the whole work in the foundations shall be laid with out and in-band large flat bedded stones packed in a sufficient manner, and with good mortar made of lime mixed, and made up with sea-sand… and as to the other parts of the said rubble-work, the bed of every stone shall be at least two inches broader than it is high… all which shall be sufficiently bedded, grouted and filled up with mortar of lime and sea-sand, and the rubble walls shall be harled as they are carried up…

Vaults… shall be built of good and sufficient flat-bedded stones and mortar as above described…

Roofing slates to be shouldered with plaister lime 'to prevent the wind from shaking them.'

[Paving in Piazza to be laid upon] a bed of till, at least six inches thick, over the whole vaults, composed of clay, lime and smiddy-culm, well and proportionally mixed and ramm'd, and the joints of the pavement, which is to be laid upon this till, to be secured with pan-cratch or terras sufficiently beat and prepared… [paving inside shops and kitchens] bedded in lime to prevent shifting…

And as to the plaistering work… the same shall be execute in the best manner, and with the properest materials and there shall be three coats of plaister done on the ceilings and walls of the rooms in the dwelling houses, Custonhouse and Exchange and all flotted; the stairs, passages, shops and printing houses, shall have 2 coats of good, well-prepared, sanded lime, with handsome, well-proportioned plaister cornishes to the whole rooms… which three coats of hard-finishing thro' the whole building, shall be done in the following manner, viz the first coat with lime, sand and hair, scratched, and thoroughly dried; the second with the same materials and flotted straight; and the third with fine sifted sand, and flotted straight; and plumb and float the whole plaister-work of every kind thro' the whole building.

1755 – Repairs to Blair Castle, Perthshire

Reference: Blair Castle & Atholl Estates Archive, Box 40

A wonderfully explicit reference clearly shows that, while freshly burned lime might be preferable, there was clearly room for 'making do' with leftovers when convenient and economical. It is telling, however, that the older lime described is being used by the plasterer, who might well prefer lime slaked and laid up to mature for as long as possible to ensure complete slaking.

Estate accounts of work done by Thomas Clayton, plasterer:

"15th May 1755 Notes of works... since beginning of April last (1755). List of works done by 4 stucco men and labourers includes:

...Working half kill of lime, 20 stones of plaster hair...

...the kill of lime used by Mr Clayton was burnt last year and there was another shill for masons work burnt last year. One shile burnt this year also for the use of the masons and a shill now burning one half for Mr Clayton and the other half for the masons."

Memo to the Duke of Atholl, August 1755 by Thomas Clayton re Blair Castle: "It will take some more than half a cile of lime to dow the above work but if a whole cill could be had there would be some of it left for next year."

1756 to 1758 – Lime Burning at Blair Castle, Perthshire

Reference: Blair Castle & Atholl Estates Archive, Box 40

These records of kiln firings reveal several interesting insights, among which is clear implication that kilns could be purposely fired in sequence to even out the supply of lime to different needs on the estate. Interestingly, some of this is going to lime for farming, suggesting that the distinction between building lime and agricultural lime was not hard and fast.

Estate memo of *'mason work and other work to be done at Blair and Atholl House' (Blair Castle) January 1756: '...To consider whether paving or gravell... would do best to prevent the splashing of the rain drops... it is said that lime mixed with gravell will make it bind, or burnt clay or even brick dust.'*

Journal compiled at Atholl House (Blair Castle) of firings of the lime kiln(s) at Blair and of the uses to which the lime burned was put. Written 18th October 1756:

"Great part of a kiln here over winter for which is to go to the bridge at the foot of Diana's wilderness…
The first kiln fired 12th May five loads to the land, the rest laid down for the sunk fence Hercules field…
The second fired 19th May one half to go to the stucco men, the rest to finish the sunk fence at Hercules field and to go to the Garden wall…
The third to be fired 3rd June to be laid down to the garden wall…
The fourth kiln to be fired 16th June part to the stretch at Balveny piller and the rest laid down for the Sunk fence at the glebe…
The fifth kiln was fired the 24th June and laid down at the end of the bridge on the 29th where the Clock tower is to be built.

April 1757 at Blair Castle recording work to be carried out:

MacDonald to begin Monday 29th May to build the limekiln, when it is done, the 8 masons to build the papapets… [and] to harl the Clocktower and Summer House. It is thought the old lime do all the above mason work…

Associated memo dated 30th September 1757:

…lime kiln emptied and laid… for building a wall to enclose Toldamph…

Associated memo (undated) titled:
"Work finished at Blair 1758" recording work done as described in the previous memo and the time it took to build:

…Nota Bene All the stone and lime wall seven feet high round Toldamph and Balleran… Was finished in 115 working days of being begun the 26th April and ending the 5th September.

1756 – Ware's Architecture

Reference: Ware I, *A Complete Body of Architecture*. (London: 1756).

Ware refers back to Palladio (whom he translated in 1738), who himself referred back to Alberti and Vitruvius, as well as to his own experience and craft practice. He speaks of laying down lime that needs to be preserved from air slaking, if the lump is not to be immediately used to make a mortar. He criticises the use of too much water by masons in the 'ordinary'

method of slaking, whilst emphasising the utility of matured lime for plastering and interior work.

As the lime is always best when the stone is carried immediately from the rock to the kiln so the mortar is always best when the lime is slaked immediately on its coming out of the kiln.

When lime is to be preserved only a little time after the burning for convenience of any kind, no more is required than to keep it dry, but when it is to be preserved longer, more caution is needful. For this purpose, let a pit be dug in the ground, and over this a vessel set, as for making mortar, with a hole stopped so as it may be opened at pleasure its bottom: let the lime be slaked and worked up in this vessel, and then opening the hole, let it run into the pit. As soon as the pit is filled let it be covered up with a good coat of sand, and thus it will be kept moist and fresh.

Another method is to cover up a quantity of fresh lime with a yard thickness of sand, and then pour on as much water as will slake it, but not reduce it to dust. If the sand crack, and the smoak rises through the openings, close them up, and keep all fast and without vent. The lime will be thus preserved ever so long, and will acquire a new value by the time of its lying. It will be more tough and clammy than any other kind, and less free to shoot out its salts when worked[59]. No lime is so proper as this for inside work, where great nicety is required, and none is so fit for painting upon, because it will not destroy the colours.

The advice of (Palladio) and the practice of our builders, differ greatly with respect to the quantity of sand... He orders three times the quantity of lime is to be pit sand, and twice the quantity of river or sea sand[60] , and the common practice of this time allows less than a third part, more in some places, and in others they are made equal.

To speak from experience and... many trials, it seems that Palladio's proportion of sand is too great, at least for a mortar to be used in our climate, and that what we commonly allow is too little. The medium perhaps will be best, and if any general rule may be laid down, it should perhaps be that two-thirds of lime and one of sand would be the best quantities.[61]

[59] To burst due to late slaking?
[60] 1:3 or 1:2, quicklime to sand.
[61] Viz 2:3.

When the ingredients of mortars are carefully chosen, the limes sound and fresh, the sand clean and sharp, and the water soft and pure, there remains another consideration in which the antients were… careful, and we are… negligent, that is, mixing them well together…

Our people throw in a great deal of water and then a little labour does; the ancients mixed all by little and little, and might be very well said, in the language of the French proverb, to dilute their mortar with the sweat of their brows. They employed a great number of labourers, who constantly worked together upon the the same quantity of mortar, for many days, and it was this which blended every part of it so thoroughly together that when it united it hardened into stone.

1759 – Masonry work at Dunkeld, Perthshire

Reference: Blair Castle & Atholl Estates Archive, Box 40.

As above, we again see Clayton carrying out plasterwork and repairs on the Atholl Estates, for which the lime is laid and 'sowered' ahead of time.

June 1759: *Memorandum of… work to be done at Dunkeld*

-Bricklayerwork… To lay the Barn floor with a mixture of clay, small coal, coal ashes and lime.

-Plaisterers - To write Mr Clayton at Glasgow when the different plaister work is ready for going on that he send two men to execute it.

…to inspect all the rooms already plaistered and repair any cracks in roofs, cornishes and sidewalls…

…for the above purposes 20 bolls of lime to be laid down, one half at the farm house, the other half near to the limehouse, and to have it sowr'd up and mixed with hair as soon as possible

1760 to 1762 – Scamptson Estate, North Yorkshire

Reference: Account for the building of the Bridge within the Park, 1760-1761, extrapolated from Account Book No.3. Agent: Francis Armstrong. Scampston Hall Library.

Work appears to go on through the winters of 1761 and 1762, with autumn deliveries of lime; although we must treat this with caution, as bookkeeping could be out of sync with actual work.

1760
July 19th …for getting up and leading 100 load of Ebberston stone and leading it to Scampston at 2s a load for the stone, 4s a load for leading.
July 24th …for making 126,000 bricks on Scampston Common at 5s per thousand…
August 30th Braithwait for 126,000 bricks made on Scampston Common 24-16-0
October 4th Wilson for mason and brickwork in part 32-0-0
October 10th Pd Rd. Metcalfe and Tho. Carr for getting up 102 loads of Ebberston stone at 2s and 4s per load leading 30-12-0
October 23rd To Geo. Mook for leading lime and brick 3-3-6
December 10th Rd Metcalfe and Company for 61 load of Allerston stone…

1761
January 10th Mr Percival Luccock for lime for the bridge 15-0-0[62]
Geo. Wilson mason and brickwork at the new bridge 49-1-9
April 21st Metcalfe & Carr for Allerston stone for new bridge 11-3-1. Eddon for leading same 11-16-0
May 4th …Geo Wilson for mason work at the new bridge 29-12-6…
October 9th Paid Geo. Wilson for mason work at the new bridge 25-14-0
October 31st Luccock for lime in full 7-2-0

1762
April 16th Paid Geo. Wilson in full for mason and bricklaying work to 29th March 1762 43-9-0.

1761 – Works at Brodick Castle, Arran

Reference: National Register of Archives in Scotland 2177/B5201.

The brevity of the programme from burning the limestone to completion of the work provides strong evidence that the lime must have been applied to the walls immediately, or a matter of days after slaking and mixing. A variety of repairs were carried out between 1761 and 1765, ending with whitening of all the castle walls which were harled with lime in July 1765:

The process of quarrying and souring the lime, and casting the castle took 25 days.

[62] This will be Malton oolite, which makes a fat lime, at most very feebly hydraulic.

1761 – Works at Mount Stuart House, Isle of Bute

Reference: Mount Stuart Archives.

Here, as in Semple's specification above, we have a 'new way' of working, self-consciously out of sync with normal practice of the time. As indicated by above sources, recipes and lime processing for rendering and plastering differed categorically from those for building masonry.

Directions for roughcasting stone walls in the new way: Let the walls be swept clean and watered with a brush so as everey louse partickle may be removed befor the plaister be laid on. Let all the holou parts of the wall be closely and carfuly made up with building lyme and smoke stons in such a manner as the wall may be brought to as near a straight as possible, so as when the plaister is laid on it may be of an equall thickness, and care must be taken that thos holous so made up must be perfitly firm, I mean that the little stons put in with lyme in the hols in the wall... Let a sufficient quantity of lyme of the best kind to be sifted as for plaister to which add a like quantity of the cleanest and best sand free of earth, sifted through the same sieve to which add a small quantity of plaister hair, about 1 ½ stone to each boul of lyme; let all be mixed and soured up with water for about three weeks then beat it all over with a wooden beater. Then begin at the top of the wall and lay on the plaister, still beting it in parcels as it is laid on, beat it on a wooden board or door, lest it take up earth from the ground, lay on the plaister about ¼ inch thick or so, not exceeding 3/5 lest it be too heavy and separate from the wall, and ought to be laid on straight for ornament's sake and while the plaister is wett. Throw it over with pibls afterwards to be described, throwing as many as the plaister will receive and press them a little with the back of a trowel into the plaister but not so much as to sink them entirely. And as a yard or thereby of plaister will be sufficient to be laid on at a time till it be thrown with pibls care must be taken that it be not too dry when thrown... and likewise care must be taken that the plaister thus laid on at separate times be made to joyn closely that ther be no crack at the joynings, which may be prevented by using water.

[pebbles to be whitened with flour of lime before casting]
...whitewashing repeated when needful will defend the worst of walls from the insults of the wether and will last a very long time.

1763 – Repairs to Blair Castle, Perthshire

Reference: Blair Castle & Atholl Estates Archive, Box 40.4.199.

This tiny excerpt from the Atholl Estates records indicates once more, that

lime was being purpose-burned according to the project, and that the riddling and slaking of lime and sand was an integrated process, perhaps occurring simultaneously.

"...7. Burnt first limekiln for masons...

...10. Screened sand and soured lime..."

1771 – Robert Dossie, Preparation of mortars in London

Reference: Dossie R (1771) Memoirs of Agriculture and Other Oeconomical Arts Vol 2.

The 'common method' to which Dossie refers, is the slaking of the quicklime in a ring of sand, with which it will be mixed as soon as slaking is complete, and whilst the lime just slaked remains very hot. He goes on to indicate that the principles of this method should be more generally adopted.

The manner of preparing this mortar is as follows: Take of unslacked lime, and of fine sand, in the proportion of one part of the lime to three parts of the sand, as much as a labourer can well manage at once: and then, adding water gradually, mix the whole well-together by means of a trowel, till it be reduced to the consistence of mortar. Apply it immediately, while it is yet hot, to the purpose, either of mortar, as a cement to brick or stone; or of plaster for the surface of any building.

It will then Ferment for some days, in drier places; and afterwards gradually concrete or set; and become hard. But in a moist place it will continue soft for three weeks or more; though it will, at length, attain a firm consistence, even if water have such access to it so as to keep the surface wet the whole time, After this, it will acquire a stone-like hardness; and resist all moisture.[63]

P23. *Chalk-lime, which is the kind most commonly used in London, is not fit for this purpose, on account of its containing flints; which makes it required to be skreened before it can be tempered with the water and sand. This skreening renders the slacking the lime previously necessary: and the slacking it before it be mixt with the sand prevents its acting on the sand, so as to produce their incorporation; which power it loses, in a great degree, after its combination with the quantity of water that saturates it. Lime made of limestone, shells, or marble, must be therefore had for this purpose: and*

[63] This is very likely a feebly hydraulic lime.

the stronger it is, the better the mortar will be...

The superiority of this to the common mortar is owing to the intimate commixture of the lime with the sand, at the same time it is combined with the water, before its attractive power, be diminished by its combination with water: and this shews the defect in the common method of making mortar: where the lime is slacked before it is (P25) commixed with the sand; and where, in part, old mortar, common earth, or other substances, with which lime has no peculiar specific attraction, are generally added, or used wholly in the place of sand...

When a very great hardness and firmness are required in this mortar, as in several cases where strong cement is wanted for stones; or for projecting parts of buildings, or other purposes; the using of skimmed milk instead of water, either wholly or in part, will produce the desired effect; and render the mortar extremely tenacious and durable.

1775 – John Smeaton's directions for preparing and making mortars

Reference: Directions for preparing, making, and using Pozzelana Mortar, by John Smeaton, Engineer, In *Reports of the late J Smeaton FRS, made on various occasions in the course of his employment as a civil engineer, Vol II*. 2nd Edition, (London: Taylor, 1837).

Smeaton preferred hydraulic lime mortars to be made with dry-slaked lime, by immersion or air-slaking; the latter method, he notes elsewhere, was common in Somerset for the Blue Lias quicklime.

In making mortar of (true pozzolan), it must be mixed with lime in much the same manner and proportion that terras mortar is made: it must be observed that the better and stronger the lime is, the better and stronger the cement will be; but, like terras, it may be used with any lime, and in making comparative trials with terras, the same sort of lime should be used with both.

...[T]he strongest composition I know, is made by an equal quantity of lime, striked measure in the dry powder, after being slaked and sifted, and of pozzelana, ground and prepared as above, and, if put together with as little water as may be, and beaten till it comes to a tough consistence, like paste, it then may be immediately used; but if suffered to set, and it be afterwards beaten up a second time to a considerable degree of toughness as before, using a little moisture, if necessary, it will set harder, but not so quick...
A second kind of mortar is made by using the same proportion of

ingredients as terras mortar, that is, two measures of lime to one of pozzelana beaten up in the same manner, and which, if used with common lime, will fully answer for the faces of walls either stone or brick that are exposed to water, either continually, or subject to be wet and dry…

…I have found that if the mortar last mentioned is beaten up with a quantity of good sharp sand, it nowise impairs its durability, and increases the quantity. The quantity of sand to be added depends upon the quality of the lime, and is thus determined: if to the pozzelana considered as mortar, you add as much real sand as will make out the whole quantity, such as an experienced work man would allow to his lime to make good common mortar, this will shew the quantity to be added, that is, may be originally beaten up together; thus, if the lime is of such quality as to take two measures of sand to one of lime, then one measure of pozzelana and three measures of sand will satisfy two measures of lime.

The compositions above mentioned, are seldom used further than for six inches within the face of the stone, or, at most, for setting the stones and the bricks forming the face of the work, while the backing is wholly done with common mortar, and which, under water, never comes to the hardness and consistence of stone, or forms that bond of union which would arise from a stony hardness ; I have therefore, found it preferable, where pozzelana can be had in plenty, to allow one bushel of pozzelana to eight bushels of the lime composing the mortar for backing. The first composition will assuredly acquire the hardness of stone under water, and in twelve months will be as hard as Portland.

1776 – George Semple on Hydraulic Lime

Reference: The Irish Builder (1875) George Semple on Lime, Mortar and Grout; and original paper: Semple G (1776) *A Treatise on Building in Water in Two Parts. Volume 2* (Dublin. J A Husband).

Works like Smeaton's above and Semple's represent the first instances of the development of the technical treatise as a genre. Semple here is already conscious of a 'historic' or traditional practice that may not be self-evident to his readers and may differ from what he is about to recommend. His descriptions of the 'goal' of lime mortar to re-solidify back into stone, is an early description of what we now call the final stage of the Lime Cycle. His description of hot-lime grouting in effecting this 'return to stone' is especially vivid and illustrates that any masonry work would have involved a number of techniques and mixes, rather than a single one.

"I... have been well acquainted with the nature of lime and sand made in mortar... and tried numerous experiments with them... and learned from old experienced workmen during the course of sixty years, I think I can safely affirm that good mortar made of pure and well-burnt limestone, and properly made up with sharp clean sand, free from any sort of earth, loam, or mud, will within some considerable time actually petrify, and as it were turn to the consistence of stone. I remember I had of my remarks from an old Scotch mason, which I shall give you in his own identical words, that is: "When a hundred years are past and gane, then gude mortar is grown to a stane (stone)."

My father [who was working circa 1675] often told me, and my own repeated observations convince me, that the method masons practised in former times... was to this effect: After they laid the outside courses with large stones laid on the flat in swimming beds of mortar, they hearted their walls with their spawls and smallest stones; and as they laid them in, they poured plenty of boiling grout, or hot lime liquid, among them, so as to incorporate them together as it were with melted lead, whereby the heat of it exhausted the moisture of the outside mortar, and united most firmly both it and the stones, and filled every pore, which (as the masons termed it) set - that is, grew hard immediately... and I affirm, that in many of such old buildings, I have seen the mortar, as it were, run together and harder to break than the stones were...

There are several sorts of limestone, some, indeed, set much sooner and harder under water than others; but any good lime, properly mixed and tempered with sharp, clean sand, will bind and cement as effectually under water as above it... What I mean by good lime is that which is made of clean, close-grained limestone... Chalk will make lime, but it will neither polish nor make good lime for any purpose; therefore, I advise you to choose the closest grained, the hardest and consequently the heaviest limestone for any work, but particularly for water works...

It is better to put too much sand in your mortar than too little. I know workmen choose to have their mortar rich, because it works the pleasanter, but rich mortar will not stand the weather so well, nor grow so hard as poor mortar will do; if it was all lime it would have no more strength, in comparison, than clay...

Our limestone will make exceedingly good Tarrass for water works, for which you are to prepare it thus: Get your Roach-lime brought to you hot from the kiln, and immediately pound or rather grind it with a wooden maul,

on a smooth large stone, on a dry boarded floor, till you make it as fine as flour, then without loss of time, sift it through a coarse hair or wire sieve, and to the quantity of a hod of your setting mortar… put in two or three shovels-full of this fine flour of the Roach-lime, and let two men… beat them together with such beaters as the plasterers make use of, and then use it immediately.[64] *…For cisterns… build all your outside and inside courses with wet bricks, and with Tarrass mortar made as above directed; observing that your mortar is to be a little too soft for work, and then the heat of the lime-flour will bring it to a proper consistence immediately; but never throw water upon it when you are beating it, for that will chill and slack your lime-flour… but make the men temper it with the utmost expedition, and what you want in water to make it fit for your work, give it elbow-grease; and this rule ought to be observed in making all sorts of mortar.*

The grout which you lay your middle row with, must be thus made (in a tub or bucket) pour your water on the roach-lime, which must be pure and well-burned, very leisurely; and when it is boiling, you may strain it… so as it may be tolerably free from stones, and then let it be used directly and be sure your sand is sharp and clean, and when you are using it, do not take the thin that is uppermost, but stir it up and take plenty of sand with it; but in Mason's work, when the outside and insdie courses of cut stone are set, pour in this boiling hot Grout, and instantly lay down your middle course of wet bricks between them… and that will press and squeeze the grout into all the inside pores that are next to it, and so they will all unite, and by the heat of the grout and dryness of the bricks, they will all set together immediately, and become staunch and solid; but if you were making your cistern of rough stone, mix one-fourth of the powder of tiles, or well-burned bricks with your mortar.

Take ten pounds of limestone, fresh quarried, pound it into very fine powder, and take the like quantity of sharp, clean, and fine sand; get thoroughly burnt roach lime hot from the kiln, the like quantity, put it into a vessel, and pour water upon it leisurely, and stir it gently till you find it is all dissolved, and as it were melted into a hot liquid; rub and thoroughly mix the flour of limestone with the sand, and without letting the lime liquid have time either to cool or evaporate, stir in and most effectually mix and work them all together very stiff, and beat them thoroughly on a clean boarded floor…

Irish Builder Editorial comment: *Mortar [today] is commonly prepared by*

[64] This is identical with Loriot's prescription for making 'Roman' mortars.

mixing one part of freshly slaked lime, and two or three parts of sand with sufficient water to form them into a paste. These quantities—if the lime be good and the sand sharp and clear—would make mortar of a good quality, but in the speculative buildings of the present day, and even in others where there exists no necessity for "scamping," the sand that is used is little better than loam or "riddlings," and the lime is poor and deficient in quantity.

1777 – La Fayes' notes on Roman mortar and techniques

Reference: Marquis de la Faye. Recherches sur la préparation que les Romains donnaient à la chaux dont ils se servaient pour la construction et sur la composition et l'emploi de leurs mortiers. 1777. Royal Printers, Paris. trans. Michel 2016.

This text is a review of techniques garnered from antique sources referenced above, notably Vitruvius. In his second chapter, Vitruvius does not indicate any mixing of sand or marble dust with this particular lime (slaked and laid down) and says that it has to be matured. He adds that the polish of the plasters is destroyed only when the lime is freshly 'fused' and that the grains did not have time to dissolve until later. Thus, this lime from Pliny and Vitruvius, was reputedly used after 3 years, but in reality, this was closer to 3 months (see modern Pliny translation above). As clearly labour intensive, this was not for the composition of building mortars, but for uses in which ill-mixed grains would have caused problems (e.g. plastering and fine work) and was reserved for whitewashing the walls and to give the perfect finish to the plasters; in other words, for light works that the authors call 'albaria opera'.

...If we soak limestone after it has been burnt in a kiln, it will warm up and its pores will open, facilitating its mixture with the sand and give some solidity... If we mix two parts of sand freshly extracted from the river with one part of powdered quicklime, it will create a very fatty and adherent mortar.

Fused lime:
We crush quicklime in a tub by submerging it in water until it has no longer any heat and it is completely soaked. This material turns into a paste after 24 hours, then we add sand without any real proportions and we will add again some water. This drowned lime produces a mortar that dries up slowly and will never reach a good consistency, because this drenched lime has lost its aptitude to stick to other materials.

Method to prepare mortar for construction: You will have to obtain lime from hard stones freshly cooked; you will cover it until you reach the site to avoid humidity and rain mixing with it. You will put this lime on a dry, covered, swept floor.

In that same place, you will have dry barrels, and a big tub three quarters full of river water or a water which is neither flood- nor mineral water. You will only need two workers for this operation. One will break the limestone with a hatchet until the lumps are the size of an egg. The other will take a shovel and fill a flat basket. He will put the basket in the water until the surface starts to boil, then removing the basket, leaving it for a few moments and then pouring this soaked lime into the barrel. He will do this same operation until all of the lime is in the barrel. This lime will heat up considerably and will give off steam, opens its pores and falls into powder and finally loses its heat. This is the state of the lime that Vitruvius calls calx extinâla.[65]

As soon as the lime stops steaming, the barrels will be covered with a thick cloth or a mat…

1778 – Antoine Raucourt – How to make good mortar

Reference: Raucourt, Antoine. (1778) Traité sur l'art de faire de bons mortiers et d'en bien diriger l'emploi. Paris. Malher

First method: ordinary slaking
We throw an adequate amount of water on the quicklime as soon as it is out of the kiln. It splits, blisters and melts until it becomes a thick mash that we call 'melted lime' or 'flowed lime' = coulée.

Second method: slaking by immersion
The limestone is immersed in water and removed before the beginning of its fusion, then it whistles, bursts with noise and falls into powder, radiating scorching vapors. When it is soaked, the heat is quite lowered. The lime gives in volume one and a half slaked lime for one quicklime, measured in powder. The hydraulic lime, that divides well, gives in the same circumstances, two for one.[66]

Third method: spontaneous slaking
By letting the quicklime slake in a slow and continuous action of the atmosphere, it reduces into powder with no great heat. With this natural

[65] 'Extinguished lime.'
[66] Feebly hydraulic lime.

slaking, the lime increases two fifths of its weight, five to six times less than with the ordinary method of slaking. The lime and the mortars give in volume from one and two thirds, to two and a half for one and, when reduced into a paste, only 2/3 of its weight.

The first method is the one usually used, the second was employed for diverse works, the third has always been avoided and the lime from that method was considered wasted.

Fourth method: complex slaking
After the slaking with either the second or third method, we can turn the powdered lime into a paste, whereupon it produces another expansion.

Footnote - if we throw water into a powdered lime slaked by the second or third method, the volume of the powder diminishes but the particles of which it is made increase in volume long after the making.

1780 – Bryan Higgins, Notes on making plaster and mortars

Reference: Higgins B (1780) *Experiments and Observations made with the view of improving the art of composing and applying Calcareous Cements and of Preparing Quicklime*. (London: Cadell).

Higgins, an Irishman resident in London, was a chemist. In common with others at this time, Higgins sought to 'invent' and then patent a new mortar. His key addition was bone ash. Although it was tried here and there by London architects, it did not become established. Higgins goes on to recommend slaking with previously prepared lime water, to give a tougher mortar.

The workmen usually slake the lime mixed with the sand or gravel in great heaps, and do not screen it until the most useful part is debased by that which slakes after five or six hours or more, and which is little better than so much powder of chalk. But if they would screen the lime in about half an hour after the water is thrown on it, the mortar would be much better, although the quantity of lime in it should be much less; for I observed in all the foregoing specimens, that those which contained the smallest quantity of lime were the best; and this quantity is much smaller than is usually employed in making mortar.

...builders slake a great quantity of lime at once, more than they can use for some days, and that all those whom I conversed with esteemed mortar to be the better for being long made before it is used; and that plasterers

particularly follow this opinion in making their finer mortar or stucco for plaistering within-doors, I was desirous to discover the grounds of these measures…

I found… mortar which had been used quite fresh, to be harder and to resist fracture and the separation of it from the bricks in a much greater degree than any other specimen… I concluded that mortar grows worse every hour that it is kept before it is used in building, and that we may reckon as another cause of the badness of common mortar, that the workmen make too much at once, and falsely imagine that it is not the worse, but better for being kept some time…

The plaisterers, who use a finer kind of mortar made of sand and lime, observe that their plaster or stucco blisters, when it contains small bits of unslaked lime; and as their purpose is to work their stucco to a smooth surface, and to secure it from cracking, or any such roughness… and as the hardness of the stucco is not their chief object, they very properly keep their mortar a considerable time before they use it, to the end that the bits of imperfect lime, which passed through the screen, may have time to slake thoroughly.[67]

A mortar made of terras powder and lime was used in water fences by the Romans, and it has been generally employed in such structures ever since… It is preferred before any other, for this use, because it sets quickly, and then is impenetrable to water: whence some people hastily conclude that it is the best kind of mortar for any purpose. But by experience I know that mortar made of lime and terras powder, whether coarse or fine, will not grow so hard as mortar made with lime and sand, nor endure the weather so well; but… is apt to crack and perish quickly in the open air. The efficacy of it in water fences is experienced only where it is kept always wet.

There are three methods [of slaking] in use.

The 1st and most usual is by pouring or throwing the necessary quantity of water over the lime after it is spread out into a shallow heap, surrounded by the whole or a portion of the sand with which it is to be incorporated. The 2ndly by immersion, or plunging the lime when deposited in a basket or other suitable receptacle for a few moments into water until the surface

[67] Higgins is describing hot-mixing to a dry-slake, then made to a coarse stuff to be laid down.

lime begins to effervesce or boil and then turned out into heaps to afford time and opportunity for the slaking to be completed.[68]

3dly, by mere exposure to the atmosphere, the lumps of lime having been previously broken up to about the size of a pigeon's egg, or somewhat smaller, so as to secure a more speedy and effectual calcination of the whole, but this operation must not be performed in wet weather, nor in too damp an atmosphere; it must be carefully watched, and so soon as the slaking is complete, the quicklime must be immediately used or deposited in close casks till required. This method is seldom adopted except for plasterers, who consider lime made in this way preferable for their work, as it is said to make the lime stronger. This mode suits fat limes (such as slake freely) better than poor limes. Lime slaked by the second process will keep well for months in a dry, sheltered spot.

But in every case where water is employed for slaking lime or mixing the mortar subsequently, care must be taken not to 'drown' the lime… and also not to go to the opposite extreme, but to put the quantum suff. at once, which is usually computed at about one and a quarter of the weight of the lime… for if the water be applied tardily or sparingly, the lime will be benumbed, or imperfectly calcined, and gritty.

The ashes of wood and sea coal are frequently mixed with water, or used in the place of sand, in laying tiled floors and even in external incrustations.

Some workmen say they are used in the former case to save sand; others that they serve to resist moisture… and that they hasten the drying and induration and prevent the cracking of mortar which is laid very thick in order to fill the depressions of walls which are to be stucco'd and that they are used in finer incrustations with the sole view of preventing cracks.

After a great number of experiments… with the elixated ashes, I found that they rendered the mortar spongey, disposed it to dry and harden quickly, and prevented it from cracking, more effectively than the like additional quantity of sand would do it.

1791 – Smeaton: The Construction of The Edystone Lighthouse

Reference: John Smeaton (1791) – a narrative of the building and a description of the construction of the Edystone Lighthouse with stone; to

[68] This is not lime putty as we know it and is used very soon after slaking, perhaps whilst still hot.

which is subjoined an appendix, giving some account of the lighthouse on the Spurn Point, built upon a sand. Nicol London

This text, although written near the end of the 18th century, describes works and experiments carried out from 1756 onwards.

P102. *Book III Chapter IV Containing experiments to ascertain a compleat composition of water cements; with their results.*

On this subject, I was already apprized that two measures of quenched or slaked lime, in the dry powder,[69] mixed with one measure of Dutch Tarras, and both well beat together to the consistence of a paste, using as little water as possible, was the common composition, generally used in the construction of the best water works both in stone and brick, and which, after being once set[70] would afterwards become hard, without ever being completely dry, nay, that it would in time grow hard, even under water. This therefore seemed to be the kind of cement adapted to our use…

P169. *The first object of enquiry… whether good or bad burning affected the quality, or the quantity of the lime produced from a given quantity of stone, or both…*

I therefore tried a quantity of powder-lime that had fallen from a stone imperfectly burnt, and an equal quantity of lime from one that was thoroughly burnt, and having in other respects treated them in the same manner, both with sea water and fresh, I found the former to work somewhat more harsh, but that ultimately there was no material difference in the quality of the mortar, and from hence I (concluded)… that the complaints of workmen on this head were rather founded upon the great waste and small produce from imperfectly burnt lime, than from a real difference in the quality of what is produced.

P104. *(Method in these tests:) I took as much of the ingredients as would ultimately form a ball of about two inches diameter – this ball, lying upon a plate till it was set and would not yield to the pressure of the fingers, was then put into a flat pot filled with water, so as to be covered by the water, and what happened to the ball in this state was the criterion by which I judged of the validity of the composition for our purposes.*

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[69] Either air-slaked or slaked by immersion, therefore.
[70] 'Once set:' This is the term used in the application of calcareous mortar, which denotes a first step, or degree of hardening, but in this state, though it has lost its ductility, is a very friable substance.

[Further testing showed that similar balls of just lime and sand would dissolve under water. Some 2:1 lime: tarras also failed under water. Only 1:1 was entirely reliable in its hardening.]

Question 1st. What difference in the effect results from lime burnt from stones of different qualities, in point of hardness?

P105. *Chalk lime is generally considered by workmen as the weakest of all, and it is accounted for in general, by its being burnt from one of the softest of all limestones. The marble rocks near Plymouth are of so hard a nature, [and] from observations of the buildings about Plymouth that had been constructed with this lime, at different periods of time, it appeared to me to be very nearly of the same nature with chalk lime, not only being of the brightest white, but of the same weak, crumbly nature. I therefore made a couple of balls of tarras mortar of each sort of lime in the above stated proportions of two to one, and also equal parts, and the result of several trials… was that there was no apparent difference in the strength thereof for the purpose of water building (footnote – confirming Higgins' 1780 conclusions). Hence it appeared, as the effect of the two limes was the same, that the strength of the lime must depend upon some other quality than the hardness of the stone.*

Question 2nd. What difference results in the strength of the mortar when made up with fresh or with Sea Water, the compositions being immersed in the same water?

(Balls as before, immersed in fresh water)… the result was that… there was no apparent difference, but of the balls which remained entire, when kept under water for two or three months, those made up with sea water appeared, if there was any difference to have the preference. Hence I concluded, there was no need to burden ourselves with carrying out fresh water to the Edystone… [and] all future trials, except as otherwise mentioned, were carried out with salt water.

Question 3rd. What difference results from different Qualities of Limestone, so far as I could procure the specimens?

Having heard of a lime produced from a stone found at Aberthaw… that had the same qualities of setting in water as Terras… (acquired some and burnt it into lime)… Having made up a couple of balls according to each of the former proportions, and also a couple of balls with common lime (Plymouth lime), the difference of hardness after 24 hours was very remarkable, the

composition of two measures of Aberthaw to one of Tarras, considerably exceeded in hardness that of common lime and Tarras, in equal parts; the composition of Aberthaw and Tarras in equal parts was still considerably harder, and this difference was more apparent, the longer the compositions were kept.

(because re-tempering would be desirable out on the rock… and because) of a notion entertained by workmen, respecting Tarras mortar, that the longer it was kept and the oftener it was beaten over, the stronger it would set…

Question 4th. Whether Tarras mortar, after having been once well beaten, becomes better by being repeatedly beaten over again?

P106. *…I made up a couple of balls of Abethaw lime (in same proportions as above)… and laid them in a damp place upon a water soaken brick, sprinkled them with water, and covered them up with a wet cloth, so that they might be as slow as possible in setting. These I broke down and beat over again, every morning and night for three days and then prepared a couple of balls of the same materials afresh, and beat them very well. These balls were, when set, put altogether in salt water. Between these, where the composition was equal parts, there was no discernable difference, but of those in which the lime predominated, the preference seemed due to such as had had the repeated beatings, though the difference was not very remarkable. The same experiments being tried with common lime the preference was evidently more in favour of repeated beatings in that composition in which the lime predominated than that of equal quantities.*

Hence, though the practice of workmen is very right, where common lime and the smaller quantity of tarras… are used, yet where the tarras is not spared, and the lime is of superior quality, the repetition of beatings appears not to be material.

Ultimately for the Edystone Lighthouse Smeaton chose to go with 1:1 Aberthaw and Tarras to save labour and time in re-tempering. It should be noted that Smeaton is in pursuit of maximum hardness.

P173*. I had heard that Shell Lime… set very hard and made an excellent mortar for under-drawing and inside work. It is mentioned in Wren's Parantalia as having been made use of in St Paul's Cathedral for this purpose, and found excellent. On trying some of the mortar I found it to set hard, and readily, without any admixture of sand, tarras or other matter. In*

short, for water work tarras scarcely appeared to improve its natural quality. On being put into water, after it was set, it did not dissolve, but did not acquire an additional hardness, on the contrary, by degrees it macerated and dissolved, not internally, but gradually from the surface inwards, and hence I concluded it totally unfit for our use. I was afterwards informed, that a part of Ramsgate Pier had been done with this kind of lime, but was afterwards obliged to be taken up…

P174*. Having observed how speedily Plaster of Paris, from a semi-fluid state would set into a hard substance, I conceived it might probably be of some use in our work. On making up a ball as I did with the mortars, but without beating, it readily set, and did not dissolve on putting it into water, but I soon found that, whilst in a moist state, it had little firmness, and did not acquire any additional hardness underwater and by continuance it became less firm… (and) re-disolved, either throughout its substance or by maceration of its surface, like the shell lime (footnote: I am lately told that Plaster of Paris is liable to be perfectly dissolved in a large quantity of water, if suffered to remain in it for a length of time, and especially if the water is frequently changed or much agitated)… However, the great readiness wherewith I observed plaster to set to a moderate degree of firmness, suggested to me this thought… that when there was not time for our cement to set before it was subjected to the violence of the sea, if it was coated over with plaster, it might thereby be defended till it had time to set, and then, if the plaster should be washed off, it would be of no consequence…*

Smeaton asks, if the hardness of the limestone not the cause of harder limes able to set under water, then what was the reason? He then took advice on analysing stones and tried burning out lime with aqua fortis.

…if from the solution little or no sediment drops, it may be accounted a pure limestone… as containing no uncalcareous matter, but if from the solution a quantity of matter is deposited in the form of mud, this indicates a quantity of uncalcareous matter in its composition. (Both Chalk and Plymouth limestone left no residue)… On trying Aberthaw lime in this way, it was dissolved in the aqua forte but the solution appeared very dark and muddy and… I found a small quantity of undissolved sandy particles at the bottom, some of them transparent like crystals, but mostly very minute, and of a dirty appearance… (weighing) nearly one-eighth part of the original mass (12.5%).

P179. ...*I was convinced that the most pure a limestone was not the best for making mortar, especially for building in water, and this brought to my mind a maxim I had heard from workmen, that the best lime for the Land was seldom the best for Building purposes, of which the reason now appeared, which was, that the most pure lime afforded the greatest quantity of Lime Salts, or impregnation, would best answer the purposes of Agriculture, whereas, for some reason or other, when a limestone is intimately mixed with a proportion of Clay, which by burning is converted into Brick, it is made to act more strongly as a cement. (footnote: It is not to be wondered at, that workmen generally prefer the more pure limes for building in the Air, because being unmixed with an uncalcareous matter, they fall into the finest powder, and make the finest paste, which will, of course, receive the greatest quantity of sand (generally the cheapest material) into its composition, without losing its toughness beyond a certain degree, and requires the least labour to bring it to the desired consistence, hence mortar made of such lime, is the least expensive, and in dry work the difference of hardness, compared with others, is less apparent).*

This suggested to me... that an admixture of Clay in the composition of limestone... might be the most certain index of the validity of a limestone for Aquatic Buildings, nor has any experience since contradicted it, as all the limestones in repute for waterworks, that I have met with, have afforded this mark, even the Dorking lime much esteemed for these uses in London, and in the country round about, is plainly nothing but a species of chalk, impregnated with clay, of which it makes one full seventeenth (5.8%) part of its original weight.

P180. *Having thus satisfied myself in repsect to limestone, that, if I had not arrived at the best in the world, I had found one competently good... for the Edystone Lighthouse, I considered that though Tarras was really endowed with those qualities which had justly obtained it a reputation for water building, yet it was generally admitted to have some properties, that for our use were not quite so eligible – in the first place, though it will cause most kinds of lime to set and become hard under water... yet if the Cement grows dry by a gradual exposure to air, it never sets into a substance so hard as if the same lime had been mixed with good clean common sand, but is very friable and crumbly and if, after it has acquired a considerable degree of hardness by immersion in water, it is then exposed to the air, it loses a considerable part of its firmness, and also becomes crumbly... [I]n our case, those parts... liable to be wet only in storms, and hard gales of wind... being wet and dry by intervals, tarras is known not to answer well...*

the mortar is the most liable to fail, and to be affected by the frosts, whatever its composition may be, has put artificers upon trying other mixtures, one of the principal of which was communicated to me by Lord Macclesfield:

Letter in footnote from Lord Macclesfield*: …the lime generally made use of in our neighbourhood is made from chalk… The manner of making (ash) mortar is as follows: Take of lime that is very fresh two bushels and take wood ashes three bushels. Lay the ashes in a round trench, and the lime in the middle of the trench, then slake the lime and mix it well with the ashes. Let it lie until it is cold, and then beat it well together and so beat it for three or four times before it is used… Mortar thus made is reckoned, by our bricklayers, to be much more strong than that prepared with Tarras in places that are at sometimes wet and at others dry, though they acknowledge that the terras mortar is better in work that is constantly under water… said to be useful in making calcareous mortar to set in water… Terra Puzzolana… found in Italy.*

P182. *On trial of this I found it to be in every respect equal to terras, as far as concerned hardening of water mortar, if not preferable to it… I perceived it in every state of it (wet, moist or perfectly dry), if made into a mortar with Aberthaw lime, it exceeded in hardness any of the compositions commonly used in dry work, and in wet or dry, or wholly wet, was far superior than any I had ever seen or experienced… I did not doubt but to make a cement that would equal the best mechantable Portland Stone in solidity and durability.*

Smeaton then turns his thoughts to grout, to fill perpends in the stones of the lighthouse.

P110. *…to consolidate the upright joints by pouring in liquid mortar, commonly called Grout in so fluid a state, as to run into every cavity and crevice. The common way then in use of doing this was, by putting as much slaked lime into water, as when stirred would be sufficiently fluid to answer the end, which is called puttying. And the best practice was to put the ingredients together according to the due proportion to make the species of mortar intended, and with as much water as would render them fluid, and after stirring them well together to pour the mixture into the joints.*

P184. Smeaton is concerned that this allowed no beating of the mortar - shown to make mortars stronger - so he designed an experiment entailing the making of mortar balls, allowing them to set, and then beating them

again with an excess of water. This apparently set hard, setting slower than 'undissolved' liquid mortar allowed to dry and then dissolved, but it became ultimately harder.

P187. *Seeing that both Tarras and puzzolans agreed in two of their obvious properties – porosity and resistance to the actions of aqua forte, as well as the hardening of calcareous mortar under water, and also as volcanic substances, as having passed the fire, I was induced to try experiments on several porous substances, that appeared to have some similarities to them, such as Pumice stone, Coal Cinders, Brick and Tile Dust, and such like. I found them all possessed of an absorbent property, which caused the mortar made with them to set somewhat more quickly, than when made up with sand alone, so that where hardness is expected from drying, and time is wanted to produce the effect fully, they may be useful (P112) to this end, as procuring it to be done more speedily. But being, when set, immersed in water, they did not appear to possess any powers of resistance to their dissolution, more than the same lime would do with common sand, if, by a little more time, the composition was become equally set.*

P188. *Having made up my mind that the proper composition for our mortar was lime of blue Lyas and Puzzulano, in equal quantities…*[71]

P114. *…I wished to examine all those limes which discovered any degree of fitness for Water Building, and more especially, if possible, to find out a substitute for Tarras and Puzzulano in this kingdom, that we might be in possession of all the best materials for water building within ourselves…*

P201. *The experience of ages has shewn that a considerable quantity of sand and other matter may be introduced with advantage in the making of mortar, but the proportion has never been agreed in, yet from common experience it appears that there is scarcely any lime, but what, if well burnt, well beaten, a load, or measure of lime, will take two loads, or measures, of sand, that is, the quantity of sand that can be introduced into its composition may be equal to the lime in powder (and one trass to two also best), to make the composition acquire the proposed degree of hardness under water.*

[71] Lias lime from Watchet, but length of journey made it prudent to import the limestone and to burn it at Mill Bay, Plymouth.

...I found that (lime) with good beating, would take in for every two measures of slaked lime, one measure of trass, and three of clean sand (2:1:3)...

Water Lime with Puzzolana	*Lime Powder*	*Puzzolana*	*Common Sand*
1. Edystone mortar	*2*	*2*	*-*
2. Stone mortar	*2*	*1*	*1*
3. ditto, 2nd sort	*2*	*1*	*2*
4. Face mortar	*2*	*1*	*3*
5. ditto, 2nd sort	*2*	*½*	*3*
6. Backing mortar	*2*	*¼*	*3*
Water Lime with Minion		*Minion*	
7. Face mortar	*2*	*2*	*1*
8. ditto, Calder composition	*2*	*1*	*3*
9. Backing mortar	*2*	*½*	*3*
10. ditto, 2nd sort	*2*	*3/4*	*3*
Common Lime with Tarras		*Tarras*	
11. Tarras mortar	*2*	*1*	*-*
12. ditto, increased	*2*	*1*	*2*
13. ditto, increased further	*2*	*1*	*3*
14. ditto, increased still further	*2*	*1*	*3*
15. Tarras backing mortar	*2*	*¾*	*3*
16. 2nd sort	*2*	*1/2*	*3*
Common Lime with Minion		*Minion*	
17. Ordinary face mortar	*2*	*2*	*2*
18. 2nd shot	*2*	*1*	*3*
19. Ordinary backing mortar	*2*	*½*	*3*
20. 2nd sort	*2*	*¼ or ¾*	*3*

P122. [A table of mortars, most of which Smeaton has used in different situations and for different circumstances. It should be recalled that Smeaton is using quicklime already slaked to a powder, either by air or by immersion.]

Observations on the preceding table

1st…the materials are all supposed to be in a dry state when measured

2nd That the lime is supposed to be thrown into the measure with a shovel, with some degree of force, for to put it in as light as possible[72]*… and the same may be said of the puzzolana, the tars and the minion.*

P123. *3rd Respecting sand, it is particularly to be noted that if in a moist state, the real quantity is considerably less under the same measure, than if dry… and as moist sand is most frequently brought for use, it is advisable that the operator should take a means of finding the difference of proportion and allowing accordingly in measure.*

4th …If the sand is not naturally a composition of fine and coarse, it should be rendered so by an admixture of different sorts…

5th The due beating of the mortar is, however, of great consequence… a degree of beating sufficient to give it all possible consistence and toughness before it is used, is in reality indispensible and the method I have found to answer the end in the most satisfactory way is, to mix the due proportion of lime and the puzzolana, the tarras or the minion, together in the dry powder… put as much water to the lime as that with a shovel or beater you can bring it to a paste of moderate consistence, but rather more wet than to be properly used as a mortar in that state, then by degrees, beat in the moist sand and afterwards the dry, bringing it to a consistence by beating after every addition. The dry sand is intended to take up the superfluous moisture, so as to render the mortar immediately fit for use, and if this has not brought it to a sufficient stiffness, you may let it lie till it inclines to set, and then beat it up to the due consistence, or, if immediately wanted, you may beat in a little dry lime powder to drink up superfluous moisture (but not to neglect the beating)…

[72] i.e., uncompacted, as this will better reflect purchasing conditions.

6th The customary allowance for tarras mortar beating, first and last, is a day's work of a man for every bushel of tarras, that is, for two bushels of lime powder with one bushel of tarras…

Book IV Chap 1. (Account of the construction process)

P221. The mortar, which was compounded as shown (above)… was prepared for use by being beat in a very strong wooden bucket made for the purpose, each mortar-beater had his own bucket, which he placed upon any level part of the work, and with a kind of rammer or wooden pestle, first beat the lime alone, about a quarter of a peck at a time, to which, when formed into a compleat, but rather thin paste with sea-water, he then gradually added the other ingredient, keeping it constantly in a degree of toughness by continuance of beating. When a stone had been fitted and ready for setting, he whose mortar had been longest in beating came first, and the rest in order; the mason took the mortar out of the bucket, and if any was spared, he still kept on beating; if the whole was exhausted, he began upon a fresh batch…

1792 – Construction of Kennet House, Clackmannanshire

Reference: Contract between Alexander Bruce esq of Kennet and Messrs Adam & Thomas Russell, Architects for building of a new mansion house to a plan by Thomas Harrison, Architect of Lancaster, May 1792. Brucefield Archives.

This brief excerpt from a construction contract in Scotland calls for lime to be freshly slaked for a hydraulic application.

"…The drain to be arched of an oval form for conveying the water from the house to the gollet of good ruble set in mortar made with sharp sand and new slaiked lime…"

1794 – General View of the Agriculture of the Central Highlands of Scotland

Reference: Marshall, William. General View of the Agriculture of the Central Highlands of Scotland: With Observations on the Means of Their Improvement (1794).

In burning lime, in the Highlands, the chief fuel in use is peat; a weak ineffectual firing. It is usual to slake the lime as it is drawn out of the kiln, shake it in a sieve, and return the numerous unreduced cores, to pass through the fire a second time. (This practice, when the lime is intended for

the use of building, appears to be very wrong; especially when it is suffered to lie in that powdered state several months before it be used).

Blocks of wood, and especially the large roots of trees, are frequently thrown in with the peats, to strengthen the fire, placing the fuel and the stones layer over layer, as in the use of coals; making the strata of fuel thick, proportionably to its strength. The Highland kiln, too, tends to the inefficacy of the fuel: it is too shallow and spreads too wide at the top; suffering the fire to escape before it has fulfilled its intention. It is sometimes built of sods, set upon the surface of the ground from whence, perhaps, the sods were taken, and. this perhaps the best soiled part of the farm: having, however, performed their office as walls of the kiln, they are themselves carried to the field as manure. From these temporary sod kilns, perhaps, were copied the shallowness and width of the present stone kilns of the district.

1796 – William Marshall, Notes on mortar making in Yorkshire

Reference: Marshall W. (1796) The Rural Economy of Yorkshire Vol 1. London. G Nicol. Elibron Classics Reprint 2006.

Marshall seems to contradict other writers in claiming that older, laid-up mortar sets more effectively than a fresh-made one. He also notes the slaking of lime to a powder or hydrate as a 'new idea' and advises using damp aggregate to affect the slake without producing a paste and incorporating the binder within the mix.

...in practice, it is observed, that fresh-made mortar does not set so well, does not cohere into a stone like substance so readily, as that which has been prepared some time before it is used...

It is common, in practice, when mortar is not used presently after making, to cover it up closely from the outward air. ...[I]f mortar be buried within the surface of the ground, it may be kept twelve months in perfection.

...[A] new idea relative to the slaking of lime for mortar: Lime, whether it be intended for cement or for manure, ought to be reduced entirely to a dry powder. And, for cement, it ought to be mixed, in this state, evenly and intimately with the sand.
It is difficult, if not utterly impossible, to reduce lime entirely to powder, with water alone; some part of it will always be supersaturated, and thereby be reduced to a paste; while the outsides... will (unless the stone be extremely fine) fall into granules, not into powder... But if, instead of water,

wet sand be used in slaking the lime; (piling it with the lime in knobs, layer for layer, and covering up the heap with it;) those evils are avoided: no part is supersaturated, nor are any granules formed by the action of the outward air.

Besides, another great advantage is obtained by slaking the lime, in this manner, with the sand with which it is intended to be incorporated. The two ingredients, by being repeatedly turned over, and by passing through the sieve together, necessarily become intimately blended; more intimately, perhaps, than they could be mixed by any other process, equally simple.

If the sand be washed (and all sand mixed with lime for cement ought to be washed) the labour of preparation is, by this method of slaking the lime, considerably lessened.

...Mortar floors. A new species of cottage flooring has lately been thought of, and is now pretty commonly formed, in this neighborhood. The materials are lime and sand; mixed in nearly the same proportion, and prepared in the same manner, as the common mortar of bricklayers; except, that for forming floors with is generally made stronger, and is always made up softer, than it is usually done for laying bricks in.

The method. The bed being prepared, the materials are carried on, in pails, in a state between paste and batter; laying them on four or five inches thick, and about one inch higher than the intended height of the floor, to allow for the settling, in drying. The whole being well worked over with a spade, the surface is smoothed with a trowel; and as it dries, is beaten, repeatedly, with a flat beater, to prevent cracking; the workman, in this operation, standing on planks.

A fortnight or three weeks dry weather will render it stiff enough to walk upon...

1796 – William Marshall's Notes on cement made from road scrapings

Reference: Marshall W (1796) The Rural Economy of Gloucestershire; Including Its Dairy: Together with the Dairy Management of North Wiltshire; and the Management of Orchards and Fruit Liquor, in Herefordshire, Vol II Cotswold Hills. Gloucester. Raikes.

Marshall notes that, where lime is expensive, the precipitate lime in roads corrupted with unnameable additives, makes an effective mortar for rough work.

P16. III. FARM BUILDINGS.

CEMENT. Lime is excessively dear; and sand not to be had, I believe, at any price; nevertheless, an excellent mortar is here prepared, at a moderate expense. Invention is seldom more successful, than when necessity prompts it.

The scrapings of the public roads; namely, levitated lime stone, impregnated more or less with the dung and urine of the animals travelling upon them, are found to be an excellent basis for cement. For ordinary walls, the scrapings alone are frequently used. And, from what I can learn, the proportion, for the best building, is not more than one part lime to three of scrapings. Nevertheless, I found mortar, which had not lain in the walls more than ten years, of a stone-like tenacity: much firmer than the ordinary stone of this country... Similar scrapings might be collected, in any district where limestone is used as a material of roads.

The method of PREPARING this CEMENT is, simply, that of collecting the road-scrapings, slaking the lime, mixing them intimately together, and, as the mass is worked over, carefully picking out the stones or other foulness, which may have been collected. This, for stonework, is found sufficient: for brickwork, however, it might be necessary, that the materials should pass through a skreen or sieve; previously to their being made up... The kilns small, with funnel tops; to carry off the smoke, and, by breaking off the wind, to give a more regular draught. Smeaton J (1791) a Narrative of the building and a description of the construction of the Edystone Lighthouse with stone; to which is subjoined an appendix, giving some account of the lighthouse on the Spurn Point, built upon a sand. London. Nicol London.

1799 – Repairs at Bayham Abbey, Kent

Reference: William Wilkins, Architect, Specification for Repairs at Bayham Abbey, Kent Pratt Manuscripts, Kent Archives U840.

Wilkins' detailed and interesting specification for the consolidation of a ruin makes it clear that he considers lime, which is not freshly burnt and slaked, to be unacceptable for the purpose. He recommends the same for grouting and, interestingly, he specifies additives to control the colour of the mortar to harmonise with the older masonry.

"*Although it is desirable the ruins be preserved from further injury, yet, they should not wear the appearance of being recently repaired...*

“In preserving the Ruins of Bayham Abbey the following Mortar Cement is recommended.

Stone lime – well burnt and new from the Kiln every two or three days – The lime to be slaked with but little water and no more mortar to be made up than can be used in the Day. To half a Bushel of slaked lime mix a Bushel of clean sharp road or wash(ed) sand which will be quantity sufficient for a Days use, this must be beaten in small quantities by two Labourers for three hours at Least & they must keep on beating it – in the same way that Tarriss (trass) is prepared for water; a small quantity of smiths ashes should likewise be added to give it the color of the old mortar – and if any remains to be used when the Days work is nearly over, some of the larger stones may be laid with it when a greater quantity of cement may be used in a short time, because I consider the mortar as of no use the day after it is made – The grout which is designed for pouring into the loose walls should also be prepared in the same manner – that is: the same proportions of lime, sand & smiths ashes to be made of, consistence thin enough for running into & filling up the Interstices – the work as I have before observed should be previously pointed to prevent the Grout from running through & Smearing the face of the walls.”

7. THE 19TH CENTURY (1805 – 1899)

The continued progression of the designer in construction, be they the Engineer or Architect, saw further development of written specifications and instructions. The fast pace of development caused by the Industrial Revolution, and the extensive civils that go with such work also saw extensive construction activity in the non-domestic area, ports, harbours, railway infrastructure and sewerage. In these areas the use of hydraulic lime increased significantly but references to hydraulic limes being used below ground, and quicklime-based mortars elsewhere do occour. The period also saw works on natural cements, and the development of Ordinary Portland Cement (OPC).

1805 – General observation of making lime mortar in Orkney

Reference: History of the Orkney Islands by Rev. Dr. George Barry 1st edition 1805 p. Longman et al. (Also 2011 British Library reprint in Historical Print Editions series).

Water sufficient to slake the free lime only will be added in this scenario, otherwise the hydraulic set would proceed. This would be to allow time for late-slaking to occur.

"The inhabitants (of Orkney) mix this sand with lime brought from the Firth of Forth (Charlestown Limeworks). They then make a heap of it until the next year after which time they plaster the outside of their houses with it, thus preserving much and long from the injuries of rain".

1805 – John Malcolm, A compendium of Modern Husbandry

Reference: Malcolm J (1805). A Compendium of Modern Husbandry, Principally Written During a Survey of Surrey Made at the desire of the Board of Agriculture; Illustrative also of the best practices in the neighboring Counties, Kent, Sussex, etc. London

Malcolm articulates the chemical process of calcination and notes the ways that road scrapings, which incorporate pozzolanic material like flint, make the hardest mortars, even more so than clean, sharp sand. He cautions against winter working, because of the risk of frost.

The best lime is that which is most quickly divided by immersion in water, and affords the greatest quantity of heat in this process, which causes it to fall into the finest powder. Good lime should likewise dissolve in the acetous acid, without effervescence, and leave the least possible quantity

of residue. Lime continually endeavours to resume the acid and the water of which the stone was deprived by calcination: consequently when it is left exposed to the air, it cracks, becomes heated, falls into powder with an increase of bulk, and resumes the property of effervescing. It is therefore of importance to use lime that is newly made, if the mason or builder is desirous of possessing its whole force…

Mortar is made simply by working sand or other bodies insoluble in water, together with slaked lime, and is used for the purpose of joining bricks or stone together. The sorts of sand generally used are pit sand, river sand, and road sand. The former is almost always altered by admixtures of vegetables and calcareous earth, which weaken its efficacy; the second is purer and better suited for the purpose; and the last being generally the fragments of pulverized flints, or the gravel of flints, is by much the best. The angles which these fragments present, and the roughness of their surface, contribute to give a consistence to the mortar…

It does not obtain the greatest degree of hardness of which it is susceptible, until it has resumed all the carbonic acid of which the stone was deprived; and this operation is very slow, unless the combustion be facilitated by well known methods, which consist in mixing with the mortar substances which contain either the carbonic acid, or a principle analogous to it, such as vinegar…

Loriot, in the treatise which he has written upon the subject, has attributed the superiority of the mortars of the antients to the means which they used to dry them speedily; and in consequence of these principles, he mixes powdered bricks with flints, works the whole together with slaked lime, and dries the mass with one fourth part of quick lime. Care must be taken to use only lime which is finely pulverized and sifted; for otherwise, the mortar would crack, and be very imperfect.

Before the mortar is thoroughly dry, we often see how easily it is injured by frost, and thereby we are made sensible of the impropriety of doing such work as requires mortar at the latter end of the season, but especially in the winter…

The burning of lime in the large way depends on the disengagement of the carbonic acid by heat; and, as lime is infusible in our furnaces, there would be no danger from too violent a heat, if the native carbonate of lime were perfectly pure; but as this is seldom the case, an extreme degree of heat produces a commencement of vitrification in the mixt stone, and enables it

to preserve its solidity, and it no longer retains the qualities of lime, for it is covered with a sort of crust which prevents the absorption of the water when it is attempted to be slaked. This is called also over-burnt lime. It is therefore principally by attending to the disengaging the carbonic acid by a regular and uniform heat from the native carbonate of lime that we can produce lime in any tolerable state of purity…

Water cement, or mortar, which has the property of hardening under water, may be prepared, according to Guyton, by mixing together four parts of blue clay, six of black acid of manganese, and nine of carbonate of lime; this mixture is to he heated to a white heat, in order to decompose the carbonate of lime. It is then mixed with 60 parts of sand, and formed into mortar with a sufficient quantity of water.

1810 – John Cleland, The Building of Glasgow Prison

Reference: Cleland J (1810) Specification of the Manner of Building and Finishing a Set of Public Offices and a Prison, with Court-Yards etc for the City of Glasgow. Glasgow Hedderwick & Co.

Interestingly, Cleland calls for two-coat plaster, but with a third on-the-hard layer, insulating the lath from the masonry. As expected, he calls for the plastering lime to be 'well soured.'

Mason and bricklayer: The mortar to be used in these buildings, is to be made of lime from Netherwood, Campsie, or Kilbride quarries, mixed in the proportion of twelve bolls of shells to forty five cubic feet of sharp river-sand.

Plasterer: … [T]he face of the walls… are to have one coat of plaster put on them before they are lined or lathed, so as to prevent the cold air or the smoke from coming through the walls.

The walls and ceilings of every apartment in these buildings… are to be covered with two coats of plaster, well straighted and smoothed; the lime for which may be taken from any of the quarries quoted in the Mason's Specification, and is to be mixed with a due proportion of clean river sand, and long fresh hair; it is then to be beat and well soured, so as to prevent blisters.

The walls of all the apartments in the public offices, justiciary-hall, turnkey's lodge, jailor's house, and chapel, are to have a third coat of plaster, made of Irish lime, and properly mixed with fine riddlings from the shivers of white

stones. Three Coats of Plaster on Ceilings. The ceilings of all those last mentioned apartments, are to be gauged with stucco of the first quality.

1818 – Louis Vicat, Research on the ways of slaking lime

Reference: L. J. Vicat (1818) Recherches Experimentales sur Les Chaux de Construction, les Betons et les Mortiers Ordinaires. Paris. Goujon. trans. Michel E. 2016.

Vicat's experiments became definitive in establishing the three 'traditional' slaking methods. An engineer, he made his fortune in pioneering and producing cement, and his works were foundational in construction (at least, academically – how they were applied in practice is less certain) throughout the western world in the 19th century. As he was in the business of manufacturing hydraulic lime, he had a bias against other types.

Three ways to slake lime and resulted phenomena

First method: lime out of the kiln is thrown in a suitable amount of water, cracks with noise, swells, produces a great amount of scorched vapour, is slightly caustic and melts into a thick gruel. In this state, we call it chaux fondue (melted lime) or chaux coulée (flowed lime, idea of liquid). This method is widely used, but the stonemasons abuse it, they drown the lime in great amount of water until the lime is reduced to a milky consistency and then pour it into permeable pits where it dries up and loses its qualities.

Common, very fatty limes, slaked into a thick gruel, give in volume up to 3 and one tenth for one; there are hydraulic limes that can only give one and one fifth.

...M. Sage says if we throw water a second time right after the lime has reacted to the first amount of water with noise, it will create a noise similar to a hot iron soaked in water. This fact is true, but this alchimist doesn't seem to have noticed the consequences that are important and known to the masons. The hot bits, non-fused and touched by the water will divide badly and the gruel will have grains. The cooler the water is, the more sensitive it is on lime, especially the fat limes. When we want to obtain a perfectly melted lime, we have to throw the water in one go, or add some more when the lime has cooled down.

Second method: Quicklime immersed in water for a few seconds and then removed before the beginning of the fusion, bursts with noise, diffuses scorched vapours and becomes powder. We call it, lime slaked by immersion.

It can be kept a long time if protected from humidity. This lime does not get warm again when it is wetted... Common fat limes are reduced with difficulty into fine powder with Lafaye's method (1777 – recommending this method for slaking lime for construction mortars) if we only break the limestones in the size of an egg before immersion as some authors state and let them fuse. More than half fall into peas size fragments, and these fragments once cooled down, can retain water for a long time without turning into a paste (mortars made this way always seems badly crushed and are subjected to cracking). But we resolve this problem in breaking the limetone into nut size before the immersion and putting them right after into boxes, the heat is then trapped, a great amount of evaporated water goes then back to the lime which can then dissolve better.

(Footnote: It is a mistake to think that Lafaye's method is inconvenient and difficult to achieve... On the work on the bridge de Souillac, we only needed 168 days to slake by immersion 128m^3 of quicklime...)

Third method: Quicklime submitted to the action of the atmosphere falls into a very fine powder, with a slight emanation of heat but without any visible vapour.

These are the three methods, the first one is widely used, the second was only tried as an experiment on diverse works and the third was banned due to the loss of energy when mixed.

1818-23 – The building of the Burns Monument, Ayrshire

Reference: Ref. from Burns Monument Trust archives, NTS.

Several copies of the specification exist (some undated); one dated July 1818. These were written by Thomas Hamilton Junior, Architect. It describes the grouting of the masonry and the bedding of the slabs using additives, such as lead and oil, and specifically calls for lime to be incorporated with the sand while hot. This is in contrast to the mortar for plaster, which should be cooled and well-matured.

Mason (referring to general walling & hearting):

The whole to be laid on their natural and flat beds in properly prepared Mortar and at the top of every face course to be grouted with thin well made grout Mortar and finished off quite flush with the upper bed before another course is begun, the rubble of every fifth course to consist of large stones breaking bond..."

Mason (referring to laying setting of floor slabs & steps):

"…The pavement of the interior to be at least 3 Inches thick cleanly polished, and laid upon a layer of dry stone shivers with a proper bedding of lime and sand, the joints to be close and well squared the whole thickness, and laid with white lead and oil.

The Steps of Stair leading to platform to be polished the side walls of Staircase to be droved, and the whole finished in a workmanlike Manner.

The platforms to be laid with droved Arbroath pavement (or any other of good quality and equally impervious to wet) not less than 3 ½ thick, bedded on Mortar with a close joint, well squared and laid with a cement composed of white lead and oil mixed with river sand, clean washed and burnt…"

Mason (again a reference to the general masonry work at the end of the section):

"The whole of the Masonry to be biuts/buits and run with lime Mortar composed of such lime as shall be approved of and sharp pit or river sand in proper proportions, the lime to be kept in the state of shells covered up with sand and slacked only at such lengths of time before using as shall from the nature of the lime be directed by the inspectors and must be mixed up with the sand whilst hot - all the joints of the Ashlar to be sett at least 3 inches in breadth with fine putty or cement"

Plaisterer

"The walls and ceiling of interior of Basement to be plaistered with three coat plaister done in the very best manner with slacked lime mixed with clean sharp sand well beat and cooled before laying on, and to be entirely free from rents, blisters and blemishes of every description… The ceiling of the Superstructure to be formed with Roman Cement of the best quality, divided into compartments and recessed as shewn by the drawings, the whole to be finished in the most accurate and approved method and tinted in Imitation of Stone".

1818 – Farmhouse Construction, East Lothian

Reference: Specification for Farmhouse at Muirston, East Lothian; Hopetoun Estate Archive NRAS 888/ 2707

Consistently with the above sources, this specification calls for clean, sharp sand for a rubble masonry build.

Specification for Masonry work: *"...the whole of the walls to be built of the best rubble work and well prepared mortar composed of good lime and clean sharp sand well mixed".*

1819 – Abraham Rees' Universal Dictionary

Reference: Rees Abraham (1819) The Cyclopedia or Universal Dictionary of Arts, Sciences and Literature Vol 28 & 29. London Longman, Hurst, Rees, Orme & Brown.

This is one of very few texts of this period to seemingly advocate the laying down of slaked lime for mortars, albeit primarily for plastering, and albeit not for long. If so, this is lime slaked to dough-like material, not modern putty.

Souring as described was setting aside slaked lime mixed or unmixed with sand to allow time for late-slaking to occur. A slight excess of water would have been added to produce a mix dry enough to allow screening but not so dry as to prevent slaking of then unslaked lime, being later knocked up with more water to form a workable mortar. Alternatively, a wetter hot mixed sand and lime mortar might be set aside and knocked up prior to use with a minimal addition of water. However, there is ample evidence in both old texts and material science to indicate that it was common for plaster to be applied after only a short souring, and often whilst still hot. The debate about how soon to use mortar or how long to lay it down before use goes on throughout history. Prompt use seems to have been the most common response by craftsmen on site.

Souring lime for mortar and Plaster, in rural economy, the practice of macerating and rendering it proper for these uses. It has been stated by the writer of an Essay on Quicklime as a Cement, that when lime is to be employed for making plaster, it is of great importance that every particle of the limestone be slaked before it is worked up; for, as the smoothness of the surface is the circumstance most wished for in plaster, if any particles of lime should be beaten up in it, and employed in work before they have had sufficient time to fall... will then expand themselves in a forcible manner, and

be productive of... blisters.

Consequently, if it be intended to have a perfect kind of plaster, which is capable of remaining smooth on the surface and free from blisters, there is an absolute necessity for allowing the lime of which it is composed, to lie for a considerable length of time in maceration with water, before it is wrought up into plaster, which is a process or operation that is here termed souring.

Where the limestone is of a pure quality, and has been very perfectly calcined or burnt, there will seldom be any danger of the whole of the lime falling at first; but where it has been less perfectly burnt, there will be many particles, which will require to lie a long time before they will be completely reduced into powder. This macerating process or operation is consequently more necessary with impure than pure lime; but still it ought on no occasion to be omitted or neglected, as there is not the smallest probability, but that some blisters would appear on the surface of plasters made with even the purest lime, when worked up and applied immediately after being slaked, without undergoing this souring process in some degree. The practice is also common of souring the lime when it is intended for being used in mortar; but although it is not so indispensably necessary in this case, as in that where it is designed for plaster, yet, when properly performed, it is evident, it is said, that it must even in this instance too be of utility; as any dry knots of lime that may fall after the mortar is used, must have a tendency to disunite the parts of it, which have already been united, and to render the mortar or cement much less perfect than if the whole had been properly mixed up with the materials and allowed to sour before using. More circumspection is, however, requisite, it is said, in souring lime for mortar than for plaster; for, as it is not necessary that plaster should be endowed with a stony degree of hardness, there is no loss sustained by allowing a great proportion of the lime which is designed for that purpose to absorb its air before it be used; for a very small quantity of caustic or quicklime will be sufficient to unite the whole into one slightly coherent mass. Consequently, the only circumstance which is necessary to be attended to in souring lime for plaster is, that it be allowed to macerate long enough, as there is no danger of ever erring on the opposite extreme. It is indeed necessary, it is said, on some occasions, it should lie a very long time, before any certainty can be had, that all the particles are thoroughly slaked, as pieces of lime-shells have been known to lie upwards of six months exposed to all the changes of the winter weather, and fall after that period. ...Such slightly burnt stones are indeed, it is said, usually separated in sifting the lime for plaster; but as some small chips may escape, it is always the safest way to allow lime to lie in the sour a very considerable length of

time. Another advantage of some consequence likewise, it is said, attends this practice; as, if by such means a large proportion of the lime be allowed to absorb its air, and become in the mild or effete state, when it is wrought or beaten up for use, the water... will only separate the particles of the caustic lime more perfectly from each other, so as to permit it to dry without cracks of any kind, and render the surface of the plaster a great deal more smooth and entire, than could have been the case, if the whole had been made use of while in the perfectly caustic state... On all which accounts, the practice of suffering lime, which is designed for plaster, to macerate or sour a long time with water, should never, it is said, except in cases of necessity, be neglected or overlooked.

However, as lime, from the moment of its being fully slaked, begins to absorb air, and continues to take up more and more every minute from that time until it becomes perfectly mild or effete, so as to be rendered gradually less and less proper for forming mortar of any kind, it necessarily follows, that where lime designed for this purpose is permitted to lie long in the sour, a great part of it will be converted into chalky matter, or uncrystallized mild or effete lime, in which state it will be (in)capable of having so much sand added to it, or of forming so good a mortar as would have been the case, if a larger proportion of the sandy material had been made use of in the first place, and been wrought up as speedily as possible, without so much souring, into mortar, and immediately made use of. The evil will also be increased where the lime has been but slightly burnt, consequently the best burned lime should always be preferred for this use, which, when carefully sifted after slaking, will soon fall sufficiently for this purpose; as the main point here is to have the mortar firm and binding; and the falling or bursting of very small unslaked particles of lime in the mortar afterwards, will not be productive of such evident inconvenience as is the case in the making and using of plaster.

In the making of good mortar, it will consequently be necessary to get the best burnt lime, and to only suffer it to macerate or sour with water a very short time before it is wrought and applied. The best burnt lime, however, mostly requires some days to macerate and sour with water, before the whole becomes fully slaked and fallen for this use.

[Vitruvius] it is said, expressly recommends that the lime should be macerated or soured in water, for exactly the same reasons... that the plaster can be prevented from blistering...

[Pliny] points out, it is said, in a still more clear manner, the difference

between the quality of the lime, which is necessary for making mortar and plaster… [Pliny] strongly contrasts, it is said, mortar (cementa) with plaster (intrita). The first, he contends, by implication, ought always to be composed of lime… which still retains its gluten, cementing or adhering principle; lime that still keeps or possesses that quality, by which it is enabled to unite detached matters into a solid body, and glue them, as it were, together. In other places of the same work, the author, it is said, describes it as… 'lime in its most acrid state;' that is, perfectly caustic lime. And this quality he plainly hints, it gradually loses by time, so as to come at length to be sine ferrumine suo: in which state, as it is impossible to become a good firm mortar or cement for building with, those who make use of it as such are severely reprehended. But although the practice of using old and inert lime for mortar is condemned, it is immediately added, as has been seen above, that for plaster it is better than new, because it is not so subject to crack in the work. Thus it would seem, that the importance of the souring operation or process, for these different purposes, was well known at an early period…

Monsieur Loriot… imagined that he had made a perfect discovery of the way in which the ancients employed their quick-lime… to obtain such an extraordinary firm cement… [T]he ancient cement consisted of lime and sand nearly in the same proportions as are commonly employed for that purpose at present. But instead of making it of slaked lime entirely, as is done now [which is to say, just-slaked, as in the 'ordinary' method], he contends that they employed a certain proportion of their lime unslaked, which they mixed with their mortar immediately before it was used….

That such effects… will invariably be produced, merely by adding a certain proportion of unslaked lime in powder to mortar, or even by making the mortar entirely with powdered quick-lime, I may without hesitation venture to deny… from actual experiment… corroborated by the experience of Mr. Dossie….

Mortar Mill… A pit is dug in the ground, which is bricked at the bottom and sides, into which the operator puts the lime. He has the command of a small stream of water, which is conveyed at pleasure into the pit, and in a few days the lime is sufficiently slaked; he then puts the lime and sand, or gravel, into the mill, which not only mixes both together, but incorporates them in a very effectual manner; and, as the lime is sufficiently moist when taken out of the pit, no more water is required for the mortar.

Besides the common mortar used in laying of stone, bricks, &c. there are several other kinds: as, Monran, used in plastering the walls and ceilings; made of ox or cow's hair mixed with lime and water, without any sand. The common method of making this mortar is one bushel of hair to six bushels of lime.

1823 – Construction of The Edinburgh Academy

Reference: Specifications recorded in the Academy Director's Minute Book. From "The Clachan and the Slate: the story of the Edinburgh Academy" M. Magnusson, Collins 1974.

This Scottish specification again calls for clean, sharp sand and notes that the lime for plastering should be matured before use.

"The whole stone of whatever description used in the building must be laid upon their natural beds, and lime will be mixed up with clean sharp pit sand and pure fresh water. The whole walls and ceilings in the building will be finished with three coat plaster... The plaster lime must all be mixed with hair of the best quality, and prepared at least six weeks before it is laid on the walls...

1823 – Kelly's New Practical Builder and Workman's Companion

Reference: Kelly T., The New Practical Builder and Workman's Companion, London, Paternoster Row 1823.

Many interesting points come from this excerpt. Kelly describes the techniques and benefits of true hot-mixing and mentions that it should be carried out in small batches, but he seems to prefer it to be laid up to mature before use, rather than be used fresh. Plaster, on the other hand, is to be slaked to semi-liquidity. Rather than categorically warning against winter working, he indicates that different consistencies work better in different weather.

Walls... are formed of very small pieces, that they may have a sufficient quantity of, or be saturated with, mortar, which adds greatly to their solidity. To saturate, or fill up, a wall with mortar, is a practice which ought to be had recourse to in every case, where small stones, or bricks, admit of it. It consists in mixing fresh lime with water, and pouring it, while hot, among the masonry in the body of the wall...

In slaking lime, use as much water only as will reduce it to a powder, and only about a bushel of lime at a time, covering it over with sand, in order to

prevent the gas, or virtue of the lime, from escaping. This is a better mod than slaking the whole at one time, there being less surface exposed to the air. Before the mortar is used, it should be beaten three or four times over, so as to incorporate the lime and sand, and to reduce all knobs or knots of lime that may have passed the seive. This very much improves the smoothness of the lime, and, by driving air into its pores, will make the mortar stronger: as little water is to be used in this process as possible. Whenever mortar is suffered to stand any time before used, it should be beaten again, so as to give it tenacity, and prevent labour to the bricklayer. In dry hot summer-weather use your mortar soft; in winter, rather stiff...

Fine Stuff, is pure lime, slaked with a small portion of water, and afterwards well saturated, and put into tubs in a semi-fluid state, where it is allowed to settle, and the water to evaporate. A small proportion of hair is sometimes added to the fine-stuff. Stucco, for inside walls, called trowelled or bastard stucco, is composed of the fine-stuff above described, and very fine washed sand, in the proportion of one of the latter to three of the former. All walls, intended to be painted, are finished with this stucco.

Another method of making this composition is, to make a mixture of the dry materials; i.e. of the sand, brick-dust, and powdered quick-lime, in the prescribed proportion, which mixture may be put in sacks, each containing a quantity sufficient for one or two troughs of mortar. The above mentioned old slaked-lime and water being prepared apart, the mixture is to be made in the manner of plaster, at the instant when it is wanted, and is to be well chafed with the trowel...

In order to the greatest induration of mortar... it must be suffered to dry gently and set; the exsiccation must be effected by a temperate air, and not accelerated by the heat of the sun or fire; it must not be wetted soon after it sets; and afterwards it ought to be protected from wet as much as possible, until the mortar is finally placed and quiescent; and then it must be as freely exposed to the open air as the work will admit, in order to supply acidulous gas, and enable it sooner to sustain the trials to which mortar is exposed in cementing buildings, and other incrustations.

Fresh made mortar, if kept from the air under ground in considerable masses, may be preserved a great length of time without injury, and the older it is before it is used, the better, the builder taking the precaution to beat it up afresh previous to using it, for it not only sets sooner, but acquires a greater degree of hardness, and is less apt to crack.

Plasterers, who use a finer kind of mortar, made of sand and lime, observe that their stucco blisters, if it contain small bits of unslaked lime, and as smoothness of surface is with them of more consequence than excessive hardness, they take care to secure the perfect slaking of their lime by allowing sufficient time for the imperfect parts to be penetrated by the moisture. The bricklayers, trusting, perhaps, more to the judgment of the plasterers, in this respect, than to their own, and considering it very convenient to slake a large quantity of lime at once, follow the same practice, without caring for or apprehending the real fact, that mortar, when exposed to the air, is worse for every hour it is kept, and that they are taking such measures as will prevent it from ever acquiring that degree of hardness in which its perfection consists.

1824 – Repairs to a Steading, East Lothian

Reference: Specification for reconstruction of fire damaged Farm Steading, Humbie, East Lothian; Hopetoun Estate Archive NRAS 888/ HHP 900.

This specification for shell lime calls for a 3:1 mix, using clean, sharp sand.

"... the lime mortar shall be composed of one parts of the best quality lime shells from an approved kiln to three parts sand well mixed with pure water and thoroughly wrought... The sand to be all of fire sharp pit or river sand, free from all impurities and washed perfectly clean..."

1824 – Construction of the Byers Hill Monument, East Lothian

Reference: Specification for erection of Monument on summit of Byers Hill, East Lothian; Hopetoun Estate Archive NRAS 888/ 2707

This specification describes grouting every 4-5 feet and using clean sand mixed directly with the lime.

"...There will be no packing with small stone shivers in the heart of the wall unless in levelling the beds or filling up the rough joints and at the height of every four or 5 feet, the whole surface of wall will be run over with thin lime..."

Mortar: "The lime is to be uniformly mixed with clean washen water sand and afterwards to be completely wrought together with water into mortar."

1825 – Hassenfratz's Theories on Burning and Mortar Making

Reference: Hassenfratz, M., Traité théorique et pratique de l'art de calciner la pierre calcaire et de fabriquer toutes sortes de mortiers. trans. Michel E. 2016

Hassenfratz advocates fresh lime, slaked to a hydrate, and then mixed with water and aggregate, used immediately. He is explicit on the use of fat lime for ordinary construction and 'beton' or hydraulic mortars for wet applications.

In this country (he probably means region, not country), as well as in the vicinity of Metz, where the lime has similar properties [hydraulic], we are accustomed to employ fresh lime just made and to slake it by aspersion or instantaneous imbibition. It falls into dust and we make a mortar by adding water to the powdered slaked lime to reduce it to a paste. When slaked by immersion and maceration, the lime should be used in the following eight days of its slaking otherwise it hardens and loses its property to bond, gather, attach and adhere stones together…

In the slaking by immersion, fusion and maceration, two successive operations must be distinguished. The first how lime reacts to water and by the action of the mass, forces the water to solidify with lime. The second, the action of water on the lime hydrate, increased by the water mass, transforms the hydrate into a liquid. In the first case, we have a dry hydrate lime and in the second water lime or a dissolution, a mix in a pasty state, of lime hydrate in water.

…A few builders add water incrementally to maintain the lime in a liquid paste. Several advise to be careful in adding too little or too much water. They say that too much water drowns the lime and that too little burns it, dissolves its particles and reduces it to ashes…

We think fresh made lime… used straight out of the kiln… should produce a good mortar and this, because this… undergoes fewer alterations and contains less carbonic acid…

Some [builders] shape a basin with sand or cement with which the mortar will be made. They place the quantity of lime needed and slake it by adding all the necessary water. When slaked, they mix in the sand or cement and prepare the mortar to be used immediately. Others place the lime in a small sandy basin, shape a heap and cover it with sand, then slake it by aspersion under the sand, as the same method of the Ancients… When the lime has slaked, they mix it with the sand and prepare their mortar by adding the necessary amount of water…

In… ordinary constructions, we prefer to employ fat limes and sand to gather stones and to build walls because this mortar is abundant and

cheaper. In humid places, in particular underwater, wherever we wish to stop the action and infiltration of water we use a mortar that hardens underwater or... 'béton'.

1826 – Charles Pasley, Practical Architecture

Reference: 1826 - Pasley C. W. Practical Architecture. Reprinted 1862 by Royal Engineer Establishment, Chatham. Reprinted Shaftesbury. Donhead Publishing 2001).

Pasley cautions agains mortars that are either too fat (preferred by masons for their workability) or too short (preferred for being more economical) and recommends a 1:2 mix for poor quality lime, 1:3 mix for better quality lime. He contradicts much of the earlier sources in condemning the practice of lime-rich mixes, and in using lime run to putty as soon as possible.

[I]t is known that when the lime is in excess the mortar may be plastic and convenient to use, but that it never hardens properly. If... the sand be in excess, the mortar becomes too short, as the workmen style it – that is to say, not sufficiently plastic at first, and may eventually crumble to pieces. It is agreed, however, that all the particles of sand should be just separated, and... cemented together, by the smallest quantity of lime capable of effecting this object...

When lime is of inferior quality, or there are not the means for mixing the mortar well, it is considered that one part of unslaked lime to two parts of sand is the proportion necessary for obtaining a compound of proper tenacity.

If the lime be of good quality, and dependence can be placed upon the diligence of the persons employed making the mortar, one part of unslaked lime to three of sand, has been held as a better proportion than the above, and has very often been used in Government works.

It appears to me that, for common mortar [which is to say, fat or feebly hydraulic lime mortar] for the walls of buildings, the former [1:2, quicklime:sand] may be considered the maximum, the latter [1:3, quicklime:sand] the minimum, proportion of lime that ought to be used...

Recently, a custom has been introduced of grinding, or pounding, the lime about to be made into mortar or grout, previously to slaking it... chiefly advantageous when the water limes are used, which do not slake so quickly as common lime...

I ascribe the comparative inferiority of the older mortar, in this case, to a practice which seems to have prevailed in London in the last century, of building with mortar composed of about equal parts of lime and sand for inside work, but of no less than two parts of lime to one of sand for outside work (references Batty Langley book from 1750).

In the new docks in Her Majesty's yards at Sheerness and Chatham, grout was... composed of Dorking lime ground in the mortar mill, but not slaked, and of the proportion used for the lower part of the foundation...one part of lime to four parts of sand. These ingredients, mixed together dry, were wheeled to the walls, and made into grout... and pouring it instantly into all the vertical joints of each course of the brickwork. (Later inspection during an alteration showed a... very intimate cohesion of the parts...).

Hot lime grout has also frequently been used in rough work. This is made by stirring up slaked lime in water, without any other ingredient, and pouring it into the joints of each successive course...

The term putty... is nearly the same as hot lime grout, it is made by dissolving in a small quantity of water, as much hot lime as, when slaked, and continually stirred up with a stick, will assume the consistency of mud... It is then sifted, in order to remove the unburnt parts of the lime, and should be used without delay. It is only proper for gauged brickwork, or for the ornamental outside work of brick walls...

1827 – New Farm Buildings at Humbie Farm, East Lothian

Reference: Specification for new Farm Buildings at Humbie Farm, East Lothian; Hopetoun Estate Archive NRAS 888/ 3533

This specification again calls for clean, sharp sand, and notes the use of lime for packing and pointing.

Specification for a court of offices on the farm of Humbie by Hugh Russell, April 1827: "... Walls... well packed with lime and the whole of the walls to be best rubble work... well packed and neatly pointed with properly prepared lime mortar, the sand sharp and water pure."

1828 – Biston's Practical and Theoretical Manual on Lime-burning

Reference: Biston V (1828) Manuel Théorique et Pratique du Chaufournier. Paris, Roret. trans. Michel E 2017.

Biston expands upon Vicat's 'three methods' and in this excerpt, we see

the beginning of a sensibility that workmen's knowledge is inferior and must be corrected against.

Section I: the slaking of lime

Lime is slaked by three methods 1 by fusion with the water, 2 by immersion, 3 spontaneously from the the action of the atmosphere.

P 196 Art. I Slaking by fusion. Slaking by fusion, also called ordinary slaking, has to be done in impermeable basins with only the necessary quantity of water to reduce the lime to a thick mush. We will be careful to give all the water it needs in the first instance, only coming back to it at the moment of the effervescence (to add more) or else, wait for it to cool and then add some more water. We will forbid in all cases, the method followed by some masons of drowning the lime in a large quantity of water, reducing it to a milky consistency before pouring it into permeable pits where it dries out and loses its qualities. When we need to keep the lime after it has been run, we will cover it with earth or sand...

Art. IV Slaking in general. Every experiment shows that the method of slaking has a great influence on the quality of the mortar, although less on the ordinary mortar than on the hydraulic one...

Ordinary slaking does not present any difficulty, it is essential only to give the strictly necessary amount of water.

With care, we will need to put the quicklime into a basin, to put a quantity such as will not spill out during slaking. We will then throw the water on the lime, wait a bit and when the bubbling begins to decrease, we will stir the gruel in such way as to be sure that all parts of the limes are dissolved. When the gruel is homogenous, it will be run through a grid opening into an earth pit to conserve the lime until it is used. It is essential to throw into the basin all the water necessary for the slake. It there is not enough, we will have to wait until the gruel has coolled down before adding any more water, otherwise, the lime will become lazy, will remain grainy and resistant to mixing...

We should particularly distrust, in the choice of slaking methods, the ignorance and the routine of the masons, who often reject the best method of slaking only because it produces less expansion than the other.

1829 – Martin's Art of The Mason

Reference: Martin M E (1829) The Art of the Mason L'encyclopédie populaire ou les sciences, les arts et les métiers, Paris, Audot éditeur.

Martin distinguishes between hydraulic and non-hydraulic applications and gives fat limes their place, while recommending pozzolanic additions to mortar for underwater work. He recommends mixes of varying lime-richness and describes that they are first run to putty and then incorporated laboriously with the sand.

Study of Materials – P38 Quality and of use of plaster (plâtre).

We mentioned the plaster stone (alabaster) used sometimes as rubble, or ashlar in constructions but this habit is not widespread and is always in poor taste. The main characteristic of this stone is to acquire, from a slight slaking, the property of becoming a paste with water and to quickly solidify a large volume of liquid.

They are several grades of plâtre: The finer one, remarkable for its finesse, its gloss and its creamy texture, is reserved for sculptural ornament. The one less soft and less white is used for inside plaster, and the rougher one is used for partitions and walls…In the same kiln, we can obtain, if desired, different qualities of plaster. In all cases, we reduce it to powder before using it and the more delicate the work, the finer the powder should be.

…Plaster should be stored away from moisture and from contact with the air… Otherwise, it will become air slaked… This material offers great disadvantages when used for wall constructions. It falls apart rather quickly with the humidity it absorbs – indeed, we should never use it in humid areas. Moreover, the property the plaster has to expand and bulge when it is still fresh, requires caution in the working method. The best plaster for construction is that which contains some lime…

(Fat) limes mixed with common sand make mortars that dissolve underwater and are unsuitable for works in humid places. If we want to make mortars capable of hardening underwater, the sand would need to be replaced by clay, sandstones, pulverised and burnt slates or by fragments of tiles and pottery and ashes of earth coal. These substances, associated with a certain quantity of common sand, form with fat lime, cements of good quality, perfectly resistant to humid and underwater locations.

…We choose sand with rough and angular grains, as it binds better with the

lime and we sieve it when it contains larger gravel. Sand of this type is excellent for most constructions. However, when the limes are very fat, we prefer a sand containing clay.

Ordinary Mortars. We make this mortar by mixing 3, 4 or 5 parts of sand to 1 part of quicklime. The lime has to be of good quality and not be air slaked. After being slaked in water and turned to a buttery paste, we mix it with the sand.

The sand... should be cleaned of loamy/silty parts. We have to incorporate it into the lime by long and continuous work...

When we mix powdered quicklime and sand in the proportions of one part of lime to 2 of sand and we moderately wet the mix while kneading it, we obtain a mortar which sets quicker than the first one and hardens better. But we should avoid letting it dry too quickly.

Equal parts of fine sand and sharp sand, a sixth part of quicklime and 1/12th of burnt bones, make a good quality mortar, which hardens quickly when mixed right before using it, another quantity of powdered quicklime. The use of quicklime, advised for the first time by M. Loriot, gives to the mortar the property of setting up immediately, like (gypsum) plaster...

Mortars, Cements, Concrete of Different Composition
Ordinary mortar is of better quality when we replace one part of the sand with fragments of tile or powdered pottery. This is only if it is a fat lime; if it was hydraulic lime, any such addition would seem pointless.

In Africa, we sometimes use a cement made of one part of sand, 2 parts of ashes and 3 parts of quicklime, sieved together, mixed and kneaded with water 3 consecutive times and wetted alternatively with linseed oil and water. This cement acquires a particular hardness.

...We prepare a cheap cement mortar by kneading 2 parts of lime, 1 part of coal (houille), well sieved and half a part of clay. This mortar is damped slowly and well stirred. Then it is left in a heap for several days after which it is beaten and stretched; it is then left to rest once more until it is flexible and pliable. This mortar can be used to create floors in attics...

In Italy, we make surfaces in the ancient way which is worth knowing: We lay a first coat of cement made of 3 parts of tiles and 1 of lime. We spread

the cement well, we let it rest for a day or two depending on the season.

After that, we beat it with force with an angled-iron-bar and we repeat this operation each day until the bar does not produce any impression on the layer. On this layer, we then spread another thinner one in which the lime is in equal proportion to the tiles and we sprinkle on this, still fresh coat, small pieces of marble by pressing them with a cylinder. When done, we beat the layer again and when it is perfectly resistant and dried, we polish the surface with sandstones and water. We work it after that with pumice. The last task is to give two layers of hot linseed oil and rub it to a polish.

Coatings/Plasters of Common Mortar or Crépis. Mortar coatings are usually called crépi (plaster, render) when it is made of only one coat and the method is slightly rough. In all cases, the first coat should contain more lime than the ordinary mortar and should be made preferably from old slaked lime. It needs to be well beaten and softened. And if it is made from recently slaked lime, it should be left in a heap for a long time and then moistened and beaten once more. To the first coat, once well dried, we add a thinner coat made with finer sand and in more quantity, applied with not only a trowel, but also a small wooden ruler with a handle that we run along the wall by damping it. Once this work done, we limewash the wall with a lime milk. If we would have wanted a better looking plaster, the lime would have been very fine, slaked for a long time and conserved in sand - grind it with chalk and then apply a layer upon the second coat with the trowel and the ruler as we just mentioned. This third coat would be capable of taking a polish. When the 'crépi' has to be applied on a smooth surface such as wood, it is good to nail laths and hatch the timbers.

In regions where we lack (gypsum) plaster (I assume it's gypsum plaster) and where lime is abundant, we can compose a mortar to replace the gypsum plaster in the construction of cornices and other ornaments, by adding 3 parts of quicklime in powder to a liquid mortar made of 2 parts of fine sand and one part of pulverised tiles slurried into clear gruel with a sufficient quantity of old slaked lime to bind everything together. The addition of the powdered quicklime is done in the trough where the mortar has been previously poured and we briskly mix the ingredients together to use it right away.

(Gypsum) Plaster. (Gypsum) plasters are almost always used in the regions where the substance is not too expensive. We start by wetting the wall well, then we throw with a broom, some very clear plaster and then we cover this layer

which is full of asperities with another coat applied with the trowel which we do not try to smooth over. We then add a third coat of fine plaster with the trowel and we smooth it as much as possible. When it is done, we scratch the protruding bits with a sort of toothed copper drag on one side and smooth on the other

Batifodage. We often substitute for the plaster, for economy, or for obtaining a lighter and warmer plaster (enduit), heavy soil, kneaded with care, mixed with a certain quantity of hair (bourre) and if we want, a fifth of old slaked lime. P104 This mix we call batifodage can be used as a plaster for walls and ceilings, we give a white colour with white of Spain (fine crushed chalk) wetted with strong size. (eau de colle forte).

Stuccoes. We give the name of stuccoes to the plasters capable of being polished. The best ones are made from well selected lime, slaked with care, well beaten and then conserved for several months in the sand. To make the stucco, we mix with this lime, an equal quantity of white marble or any types of heavy stone or even chalk. We crush it in such way to form a pliable paste. We apply it on a moist, slightly rough surface in layer of about two lines (millimetres?). When it is dry, we polish it with a moist cloth and with pumice. We continue to rub it with the palm of a hand and we finish by polishing it with a very small quantity of linseed oil... When the stucco has to be applied to interior surfaces, protected from the weather, we can apply a (common) mortar plaster (un enduit de mortier) made of lime and sand with gypsum. But when it is meant for exterior surfaces, we should give it a better resistance and thus put it only on a good cement, made from lime, pulverised tiles or pozzolan, and scoria...

1830 – Construction of the Burns Monument, Alloway

Reference: Specification for the Burns Monument Garden Boundary Wall, Alloway, from Burns Monument Trust archives, NTS.

It is not signed, however is thought to be by Thomas Hamilton Jnr., Architect. This wall was built largely as specified and still exists today as the boundary wall to the Burns Monument Gardens.

"*Each rood of building to have at least fifteen bolls of lime. Standard measures. Properly mixed with sharp pit or sea sand. The coping on top of the wall to be all clean droved stone, from Lady Kirk quarry [some 10 miles North nr. Monkton, Prestwick]. & none of these cope to be less than four feet long & eight inches thick, properly finished with oil puttie.*"

1830 – Manuel Del Rio - Spain

Reference: Del Rio (1830) Memoria sobre los conocimientos actuals de las materias propias para la formación de los morteros y argamasas calcáreas que se emplean en la construcción de las obras civiles e hidráulicas. Madrid. Real Academia de San Fernando. trans. NC 2016.

Del Rio references a number of engineers and their writings on lime mortars – Vitruvius, Berthier, Bruyere, Caudemberg, Raucourt, Petot and De La Faye. The text makes clear that he was heavily influenced by Vicat – with whole passages from Vicat delivered almost verbatim. He shares similar prejudice against pure limes and is in general pursuit of the hardest possible mortar, favouring the use of hydraulic limes in the air, as well as underwater and underground.

Quicklime is slaked by three different methods or procedures: 1, by aspersion - which is the ordinary method, 2 by immersion, 3 spontaneously.

One takes the quicklime as it leaves the kiln and one throws upon it a convenient quantity of water... The lime sinks and opens after a time with noise, and entirely cracks, gives off steam and becomes very hot and slightly caustic, and in very little time it is reduced to molecules so fine they form an impalpable powder; as well as producing great heat. Lime slaked in this manner is called, variously molten lime; precipitated lime and most commonly slaked (switched off; extinguished) lime or dead lime.

This procedure is the most commonly followed, moreover, they abuse it extraordinarily, reducing it to the consistency of grout in a tank (or pit) from where they pass it to someone else with which to make the mortars, resulting in a white paste which, although very fine and sticky up to a point, nevertheless, it has not the same kind of ductility (workability) as the clays.

During slaking with a surplus of water, fat lime sometimes melts to dryness in parts of the tank or pit, where the water has not run or has not been sufficient; if one throws more water too quickly upon these parts, it hisses like the quenching of a hot iron, indicating the burning [others would say 'chilling'] the lime, and they tell us, that this lime will then divide very poorly and remain permanently grainy. The colder is the water when you throw it, the more pronounced will the effect, particularly the fattier limes; when you want to obtain a very fine lime in paste to lime wash walls, it is essential to throw enough water at the beginning to effect the slake without the need to add more water during slaking...

Very fat limes only will break coarsely before immersion, and if they are left will divide on the ground but with difficulty to a fine powder: more than half remains in small fragments the size of a chickpea, and these fragments, once chilled, will remain for a long time without dissolving. To overcome this difficulty first reduce the lump lime to the size of an egg and, above all, collect it immediately after the immersion in large pipes, barrels or troughs, as a result of which the heat will be concentrated and a large part of the water evaporates at the start and cannot escape but is absorbed by the same lime, and hereby it is divided (reduced) in a satisfactory manner…

Ordinary slaking is the one of the three that most divides the fat limes and the hydraulic limes of all kinds, due to its bringing the fusion to its highest degree; in second place and under the same conditions, spontaneous slaking is better for fat limes than for hydraulic and eminently hydraulic limes, and conversely in slaking by immersion.

Artificial Pozzolans
Under this heading we understand clays, sands, the sammites and wastes conveniently calcined: iron scales, peat and coal ash and lastly the waste from potteries and brickworks.

This is the summary of the substances which concur (agree) with lime in the formation of calcareous mortars; moreover, these substances are generally composed of silice and alumina, but don't all behave in the same way: some unite well with fat limes, others with moderately or eminently hydraulic limes, and between these two 'alloys' some offer good resistance in the air, outdoors as well as to the action of water; some will at last lose all adhesion when submerged in water.

Among the rocks or earths essentially composed of silica and alumina, those are chosen which most easily transform: 1. clays; 2. brown or yellow schist sammites, which will form a clayey paste with water; 3. sands rich in clay; 4. various types of waste.

Fire is the agency employed and the conditions of transformation are: 1. that the material acquires enough cohesion without forming a paste with water; 2. that has the minimum specific gravity and the maximum porosity; 3. that which is most accesible to chemical agents, such as weak acids…

Choosing The Method of Slaking.
The nature of the lime and the ingredients employed determines the choice of slaking procedure. The facts lead us to these general observations:

That for all fat lime plasters, the order of preference of the three procedures is i) spontaneous slaking; ii) slaking by immersion; iii) ordinary extinction.

1832 – Shaw, A Theoretical and Practical Treatise of Building

Reference: Shaw E (1832) Operative Masonry; or, A theoretical and practical treatise of building; containing a scientific account of stones, clays, bricks, mortars, cements, New York & Boston; Marsh, Capen & Lyon.

Shaw is very particular about the type of sand used – sharp, clean, and fresh-water, and recommends a mix as lean as possible, ranging from 2:1 to 4:1, incorporated through thorough beating. For hydraulic applications he recommends 2 parts hydrated lime, 1 part trass, and 3 parts sand. He also describes hot-lime grouting.

In order that the mortar should be of a good quality, great care and skill are requisite... The lime should be well burnt, and free from fixed air and carbonic acid. Hence, lime that has become effete from exposure to the atmosphere, is impaired in its quality. The sand most proper for mortar is that which is wholly siliceous, and which is sharp, that is, not having its particles rounded by attrition. Fresh sand is to be preferred to that taken from the vicinity of the sea-shore, the salt of which is liable to deliquesce and weaken the strength of the mortar: it should be clean, rather coarse, and free from dirt and all perishable ingredients (P54). The water should be pure, fresh, and, if possible, free from fixed air. The proportions of lime and sand to each other, are varied in different places; the amount of sand, however, always exceeds that of lime. The more sand that can be incorporated with the lime, the better, provided the necessary degree of plasticity is preserved; for the mortar becomes stronger, and it also sets, or consolidates more quickly, when the lime and water are less in quantity and more subdivided. From two to four parts of sand are commonly used to one of lime, according to the quality of the lime, and the labor bestowed upon it. The more pure the lime is, and the more thoroughly it is beaten, or worked over, the more sand it will take up, and the more firm and durable does it become...

The materials of terras mortar, generally used in the construction of the best water work, are one measure of quick-lime, or two measures of slaked lime, in the dry powder, mixed with one measure of terras, well beaten together to the consistency of paste, using as little water as possible. Another kind, almost equally good, and considerably cheaper, is made of two measures of slaked lime, one of terras, and three of coarse sand; it

requires to be beaten longer than the foregoing and produces three measures and a half of excellent mortar…

To saturate, or fill up a wall with mortar, is a practice which ought to be had recourse to in every case, where small stones, or bricks, admit of it. It consists in mixing fresh lime with water, and pouring it, while hot, among the masonry in the body of the wall.

1833 – Loudon's Encyclopedia

Reference: Loudon J. C. (1833 and 1846) edited by Loudon J. W., An Encyclopedia of Cottage, Farm and Villa Architecture and Furniture London Longman, Brown, Green and Longmans.

Loudon describes the construction and role of lime in various traditional building types of what he supposes to be the 'English manner.' Like many other authors, he spends much more space detailing the different types and provenances of aggregates, and devotes comparatively little time to the sourcing of lime, its properties, or its slaking and mixing methods.

Design XXXII. — A Cottage Dwelling with Two Sitting Rooms, in the Old English manner, where Timber, Brick, and Slate are the materials used for the Walls and Roof.

P111. The mortar to be composed of the best well burnt grey lime (grey lime-stone, not chalk lime-stone), and clean, sharp, pit, or river sand, well tempered together; and to be sifted through a screen, whose wires shall be at equal distances, and not less than thirty in every foot in breadth. — The walls of the foundations and cellars, up to the level of the platform, to be worked in brickwork, and grouted with hot lime and sand; the rest of the walls above ground to be of brick-work, and the external face to be worked with a neat flat ruled joint.

P331. Flint Walls… Build up the flints in frames, and pour cement into the interstices; the foundation should be on brick arches; and the cement employed may be composed of thoroughly burnt chalk, slacked with water, to reduce it to the finest dry powder; and then sifted, and added to two parts of rough sharp sand, with small sharp gravel stones. The whole should be mixed together dry, and then a sufficient quantity of water should be poured upon it to make it into a liquid paste, which should be used immediately. The slacking of the lime, the mixture, and the application to the walling, should follow one another without delay. A quantity of the sand and powdered lime ought to be at hand to throw into the moulds, in case

the mortar should appear too thin…

P504. Construction of the Dwellings. The walls and partitions of the whole of the private dwellings may be of earth, plastered over internally and lined, and coloured in imitation of stone externally. For this purpose the outside and party walls are shown eighteen inches in thickness, and the partition walls a foot. As no chimneys are required, and no second story, nothing can be more simple and economical than the construction of these walls. The floor may be formed of loose stones, gravel, or whatever material of the kind may be most conveniently had; and its upper surface may either be paved, or covered with a mixture of lime and gravel, mixed while the lime is yet hot, and spread out over the rough materials, and immediately beaten perfectly smooth. This mixture is called by London builders concrete, and, when covered with a thin coating of cement, forms an excellent flooring for either bed-rooms or sitting-rooms…

…Common plaster, on brick or stone walls, ought not to be whitewashed or coloured in less than a year; or, if on lath and plaster, six spring or summer months. Where oil colours are used, the stuccoed plaster requires, in ordinary cases, to dry for one or two years…

Cements for Stuccoing are chiefly the Roman cement, of which there are two kinds common in Britain, Parker's and Mulgrave's; the Puzzolano; the tarras; the gypsum; the mastic; Frost's cement ; the metallic cement; and Bailey's composition… Puzzolano earth, tarras, and Frost's cement are better calculated than the Roman cements to indurate with lime; because they do not set so quickly…

A very hard and durable cement may be formed of stone lime recently burned, and, immediately after being slacked, mixed with clean, sharp sand. This about London is called Bailey's composition, and is packed dry in casks, and sent to any distance. The usual proportions are, three of sand to one of lime… In England, the scrapings of the public roads, where limestone or sandstone is the material employed, are found to serve as a substitute for sharp sand, provided care be taken to wash from them their finer earthy particles… The object of covering the outside of the walls of cottages with cement is generally to imitate stone…

P529. Roughcasting, or Harling as it is called in Scotland, is a mode of outside finishing well calculated to protect walls from the weather. It is not capable of such a high degree of beauty as a covering of cement…
The following is the process : — Plaster the wall over with lime and hair-

mortar; when this is dry, add another coat of the same material, laid on as smoothly and evenly as possible. As fast as this coat is finished, a second workman follows the other, with a pail of roughcast, which he throws on the new plastering. The materials for roughcasting are composed of fine gravel, reduced to a uniform size by sifting or screening, and with the earth washed cleanly out of it; this gravel is then mixed with pure newly slacked lime and water, till the whole is of the consistence of a semi-fluid: it is then forcibly thrown, or rather splashed, upon the wall with a large trowel, which the plasterer holds in his right hand, while in his left he has a common whitewash brush. With the former he dashes on the roughcast, and with the latter, (P262) which he dips into the roughcast, he brushes and colours the mortar and roughcast that he has laid on, so as to make them, when finished and dry, appear of the same colour throughout...

P536. A whitewash which will adhere to woodwork, and preserve it from the weather, is thus composed : — To three parts of unslacked lime add two of wood ashes, and one of fine sand, or of coal ashes sifted through a fine sieve. Let these be mixed with as much linseed oil as will bring the mixture to a consistence for working with a painter's brush. If the mixture be ground together, it will be an improvement. Two coats will be required; the first thin, and the second thick. The hardness of this wash increases over time. (Smith's Art of House- Painting, P36)...

P538. Water colours for outside walls are generally formed on a basis of quicklime, Roman cement, tarras, or Puzzolano. With one or other of these the colours are mixed as wanted, and are immediately laid on with a whitewashing brush...

P539. Glutinous colours for outside walls also take for their basis quicklime or some cement; and the glutinous matter is either blood, kept stirring till cold, to prevent it from becoming clotted, stale milk, or vegetable oils. Size and paste are sometimes used as glutinous media; and, in such cases, alum is mixed with them, to prevent them from fermenting, and becoming mouldy on the walls; but they are not durable, and, if exposed to driving rains, soon wash off. The desired colours are added to the glutinous matter, which is laid on of such a consistence as to part easily from a common whitewasher's brush.

The Floors of Cottages of the common kind...
A very good composition for laying under such (paved) floors is made of one part of quicklime, two of sharp sand, and as much oil of any kind as will bring the other ingredients to the consistence of mortar. A sound, warm,

and durable floor is formed in the following manner: the ground being well drained, and covered to the depth of a foot with loose stones, lay on these a stratum of a mixture of gravel and newly slacked lime, to the depth of six inches; let this be well beaten, and brought to a perfect level, and after it has dried a week or a fortnight, according to the weather, cover it, to the depth of two inches, with a composition of equal parts of quick lime and powdered smithy ashes, brought to the consistency of mortar by the addition of bullock's blood, stale milk, oil, or any other description of greasy matter. As soon as this is laid on, it must be well beaten with the back of a spade, or rolled with a cast-iron roller...

Particulars of the several Works to be done in building a Bailiff's Cottage at Bury Hill, near Dorking, Surrey, for Charles Barclay, Esq.

...The mortar to be composed of the best well-burned grey lime, and clean sharp sand, well tempered together. The footings and foundations to be built of sandstone, and below the ground line to be grouted with hot lime and sand... the flues to be properly gathered and pargeted (this operation is usually performed with loam and cow-dung; but quicklime and pounded brick are found far better, and are now generally used by the best London builders)...

Design I. — A Parochial School, in two Stories, for 400 Children, with a House for the Master and Mistress.

...good, sound, hard, well burnt, stock bricks and mortar, composed of well burnt fresh Dorking lime, and sharp dry seasoned road grit under ground, and with Thames sand to the parts above ground, mixed in the proportion of at least one part of lime to two parts of sand... rub and set in putty all the gauged arches to the doors and windows with the best picked marl bricks.

1834 – Construction of Cottages in Scotland

Reference: Smith G (1834) Essay on the Construction of Cottages suited for the Dwellings of the Labouring Classes for which the Premium was voted by the Highland Society of Scotland. Glasgow

Smith, too, is very particular about the effects of the aggregate and other additives (coal ash, hair) on the efficacy of the lime, but offers little advice on other details.

Whatever roofing is adopted, whether slate or tile, it is of the utmost consequence that the lime used for pointing should be properly prepared.

The slater's lime ought to be mixed up with pure sea or river sand, all the clay or earthy particles completely washed out; the coarser the sand, the more durable will the lime be; care should be taken not to mix up too much hair with it, as it soon rots, and makes the lime porous, and prevents it from taking a fine surface. All lime composition for outside work, ought to be so pre pared as to take on a fine close surface, and to be impervious to water, and able to resist the winter's frost.

Design 1: The roof to be formed of dram battens covered with... sarking, and slated the same as the others. The walls to be plastered inside with one good coat of lime.

The floors... to be formed of a composition of lime, earth, and engine ashes, mixed up in equal proportions; this to be laid over to the thickness of 3 inches above a level stratum of dry stone shivers well beat down...

Plaster Work. All the walls, ceilings, and partitions, to be finished with two coats of good plaster lime, hard finished.

1836 – Construction of Cottages on the Isle of Arran

Reference: Specification for cottages to be built at Lamlash, Isle of Arran Douglas-Hamilton family NRAS 2177/ Bundle 2919.

Details, such as specifying the amount of lime to last per length of building work, are a vernacular substitute for a formal mix ratio and much profit could be gained in examining specifications to draw conclusions about what proportion of lime this might imply.

"Specification for cottages to be built on the shores of the Island of Arran, Lamlash 17th February 1836: Mason Work... the outside walls to be two feet in thickness, the stones to be laid on their natural beds and to be good rubble building, sufficiently built, with sixteen bolls lime (4 bushells to the boll) to each rood of building (NB: walls to be raised not less than seven feet above the level of the sole). The lime to be properly prepared with good sharp sand..."

Plaster work: "The low parlour to have three coats plaster, and ceiling lathed. The other apartments to have two coats plaster, all well prepared with a composition of good lime and hair and good sharp sand..."

1837 – Partington's Mechanics Companion

Reference: Partington C F (1837) Mechanics Companion, or, the Elements and Practice of Carpentry, Masonry, Painting, Joinery, Slating, Smithing & Bricklaying, Plastering, Turning etc. London.

Partington draws a distinction between unfired clay, as an impurity, and fired clay dust, as a pozzolan. He again calls for clean sand and cites Smeaton as advocating essentially a 1:1 mix (that is, of slaked quicklime). His recommended method for hydraulic applications is the liberal addition of pozzolans.

For making mortar, the lime should be immediately used from the kiln, and in slacking it, no more water should be allowed than what is just sufficient: and for this purpose.

…The sand made use of, should be perfectly clean; if there is any mixture of clay or mud, it should be divested, of either or both, by washing it in running water. Mr. Smeaton has fully shown by experiment, that mortar, though of the best quality, when mixed with a small proportion of unburnt clay, never acquires that hardness, which without this addition, it speedily would have attained… the sharper and coarser the sand is, the stronger is the mortar, also a less proportion of lime is necessary.

Mr. Smeaton observes, that there is scarcely any mortar, that if the lime be well burnt, and the composition well beat in the making, but what will require two measures of sand, to one of unslacked lime; and it is singular, that the more the mortar is wrought or beat, a greater proportion of sand may be admitted…

…The mortar should be made under ground, then covered up and kept there for a considerable length of time, the longer the better [Higgins, Treussart and others asserted the opposite]; and when it is used, it should be beat up afresh. This makes it set sooner, renders it less liable to crack, and more hard when dry…

Nothing more is wanting, than that the chalk, lime-stone, or marble, be well burnt and thoroughly slacked immediately, and to mix it up with a certain proportion of clean, large-grained, sharp sand, and as small a quantity of water as will be sufficient for working it; to keep it a considerable time from the external air, and to beat it over again before it is used: the cement thus made will be sufficiently hard…

Water cements are those which are impervious to water, generally made of common mortar, or of pure lime and water, with the addition of some other ingredient which gives it the property of hardening under Water... for (most) aquatic works, as locks, basins, canals, &c. a composition made of lime, pozzolana, sand, and water, in the following proportion: viz. two bushels of slacked aberthaw lime, one bushel of pozzolana, and three of clean sand, has been found very effectual.

M. Loriot's mortar, the making of which was announced by order of His Majesty at Paris in 1774, is made in the following manner: take one part of brick-dust finely sifted, two parts of fine river-sand skreened, and as much old slaked lime as may be sufficient to form mortar with water in the usual method, but so wet as to serve for the slaking of as much powdered quick-lime, as amounts to one-fourth of the whole quantity of brick-dust and sand. When the materials are well mixed, employ the composition quickly, as the least delay may render the application of it imperfect or impossible.

1837 – Louis Vicat's Treatise on Mortars and Cements

Reference: Vicat L. J. (1837) Practical and Scientific Treatise on Calcareous Mortars and Cements, Artificial and Natural. trans. by Capt JT Smith, Madras Engineers. London. John Weale. Donhead Reprint 1997.

For ordinary building applications, Vicat describes the ideal amount of water to give the best slake and the proper storage method for mortar made up in advance. Water lime applications, however, he notes as being categorically different and recommends hydraulic limes, in contrast to rich limes.

Rich lime, at the moment of being quenched with much water, sometimes... being numbed by this sudden aspersion, afterwards falls to powder very imperfectly, and continues gritty. The colder the water thrown upon it, the more marked is the effect, more especially with the rich limes. When we wish to procure a slaked lime of great fineness (for whitewashing walls eg) we should have a sufficient quantity of water at first, to avoid the necessity of replenishing it at the moment of effervescence...

In the work-yards, rich limes slaked by the ordinary process, are preserved by placing them in trenches nearly impermeable, and covering them over with 30 or 40 cm of sand or fresh earth. When slaked by immersion, or spontaneously, they may be kept without change for a tolerably long time, either in casks or under sheds, in large bins covered with cloths, or with straw.

P77. The hydraulic limes harden in a short time in a trench: they cannot be kept long, nor especially be much carried about... unless they be slaked by immersion, and then secured in that state in casks, or sacks of cloth...

We may... bring lime which has been slaked by immersion or spontaneously, to the condition of a stiff paste or pulp, when we take it in the pulverulent state; but this is no longer possible when we have to deal with lime slaked by the ordinary process, if it has been drowned at first in too much water. To avoid (this)... we ought to employ, at the moment of slaking by that process, no more than the water rigorously required... to cause the lime to pass from the (lump)... to that of a stiff paste...

We have already said in Chapter IX, that the only mortars capable of standing the vicissitudes of the atmosphere, and of acquiring at the same time great hardness, were those composed exclusively of the pure quartzose, granitic, or calcareous sands, and of the hydraulic, or powerfully hydraulic limes. If then, in what follows, we treat of the ordinary mortars, or the mixtures of sand and rich limes, it is because we are compelled to do so to complete the history of the phenomena which we have to describe. For it is our most decided opinion, that their use ought forever to be prohibited, at least in works of any importance.

(Discussing Rome) ...in general... all the lumps of lime... are sometimes so multiplied, that it is impossible to attribute them to defective manipulation. The extinction by immersion, as applied to a very rich lime, can alone account for it. [or hot-mixing by the ordinary - or sand-lime combined - method].

1838 – Charles Pasley, Observations on Limes and other mortars

Reference: Pasley (1838) Observations on Limes, Calcareous Cements, Mortars, Stuccos and Concrete, and on Puzzolanas, Natural and Artificial. Cambridge University Press.

Pasley continues to flog the horse about masons' ways of working and what he considers proper ways of working. He warns against economy making mortars too short and is very rigid in recommending a 3:1 mix. He describes a recipe for concrete, made by grinding quicklime to powder prior to slaking.

A smaller proportion of sand such as 2 parts to 1 of lime is however often used, which the workmen generally prefer, although it does not by any means make such good mortar, because it requires less time and labour in

mixing, which saves trouble to the labourers, and it also suits the convenience of the masons and bricklayers better, being what is termed tougher, that is more easily worked. If on the other hand, the sand be increased to more than the above proportion of 3 1/2, it renders the mortar too short... and causes it also to be too friable, for excess of sand prevents mortar from setting into a compact adhesive mass. In short, there is a a certain just proportion between these two ingredients, which produces the best mortar, which I should say ought not to be less than 3 nor more than 3 1/2 parts of sand to 1 of lime, that is when common chalk lime or other pure limes are used, for different limes require different proportions.

When the proportion of sand to lime is stated in the above manner, which is done by Architects as part of their specification or general directions for the execution of a building, it is always understood, when nothing is expressed to the contrary, that the parts stated are by fair level measure for the lime, and by stricken measure for the sand, and that the lime is to be measured in lumps, in the same state in which it comes from the kiln, without slaking or even breaking into smaller pieces... the expert labourer employed in this operation, on receiving general directions to use as much sand as possible without making the mortar too short, will from habit serve out the proper proportions of lime and sand with all necessary accuracy, without measuring them...

The pure carbonates of lime form a good mortar for all dry situations, and for inside work, but not for building in damp or wet situations, in which they never set, as the process of induration is technically termed by workmen, but always remain in a soft pulpy state...

Concrete is formed by mixing lime, coarse gravel and sand together, with a moderate quantity of water, which is usually done on a large square board, having a margin raised a little above it on three sides only. The lime used for this purpose has usually been reduced to fine powder by pounding or grinding it, whilst fresh from the kiln; and it is generally considered of so much importance not to slake it until ready for use, that it has been customary to mix it with the gravel and sand in a dry state for a little while, before the water was added; after which the whole of these ingredients have been intimately mixed, with as much expedition as possible, by employing two labourers to work together at each of the mixing boards, which being always placed as near to the spot previously prepared for the foundation as possible, the concrete is either thrown down at once or wheeled a little way and dropped down from a temporary scaffold with moveable planks... into the excavation, where it is spread and leveled, and

trodden down or sometimes rammed by other labourers below… Concrete made in this manner, according to the system first introduced by Sir Robert Smirke, throws out a moderate heat on the slaking of the lime, and soon begins to set, forming in time a kind of artificial rock…

1838 – Alteration and Additions on Farm Steadings, East Lothian

Reference: Specification for making additions, alterations & repairs on Farm Steadings, Ormiston and Peaston, East Lothian Hopetoun Estate Archive NRAS 888/ 2706 and 2707.

The specifications, like others, calls for sharp, clean sand, and also describes riddling lime and sand together, implying a hot-mix.

Specification by Thomas Brown, Architect, Uphall May 1838:
"Foundations: The foundations to be laid with large flat stones well dressed, close laid and grouted with lime…
Rubble: …stone laid on natural and broadest beds and all well packed and pointed with properly prepared lime mortar, sand sharp and both sand and lime well riddled…"

Specification by Thomas Brown, Architect, Uphall 21st July 1838:
"Foundations: The walls to be founded with large flat stones well dressed, close laid and all grouted with thin lime and packed with stone chips…

Rubble: …both sides of wall carried up at the same time and all well packed and pointed with properly prepared lime mortar, sand sharp and both sand and lime well riddled…

Composition floors: The part of the straw barn floor not specified to be paved shall be laid with a composition of lime and engine ashes and all well riddled, worked, laid 3" thick."

1839 – Christopher Davy's Constructive manual

Reference: Christopher Davy (1839) The architect, engineer, and operative builder's constructive manual; or, A practical and scientific treatise on the construction of artificial foundations for buildings, railways, &c: with a comparative view of the application of piling and concreting to such purpose …2nd Edition London John Williams.

Davy describes two similar slaking and mixing methods, one which produces a transportable dry powder, the other which makes a mortar ready within a few hours.

...Bath brown lime... when prepared for cementing, or in combination with the patent metallic cement, is what is locally termed "wind slacked-" namely — after having been burned, it is placed in covered sheds, but open at the sides, the atmosphere being allowed to operate upon it; should the slacking proceed too slowly, a small quantity of water may be sprinkled upon it to stimulate the process... it is therefore much, better (if possible) to allow the atmosphere to act for this purpose. The lime, when thus slacked, is converted into fine granulated particles, and is among workmen said to be "alive," as it will run from an iron shovel similar to quicksilver. The colour of the lias, previous to burning, is blue; when it has passed the kiln, it is brown.

The greater number of specifications prepared by surveyors for the erection of buildings, direct that the mortar shall be composed of stone-lime and sharp river-sand, to be mixed in the proportions of one part of lime to three parts of sand. These proportions will make excellent mortar if properly compounded; but, as the quality of the lime varies considerably, so will it take more or less sand.

Builders employ two methods of compounding their mortar: — First, when it is required to convey it in a dry state to the work, it is done by forming a bed of lime, surrounding it with sand, and then throwing on the lime a sufficient quantity of water to slack it, and covering it up immediately with sand; after it has remained some time in this state, it is turned over, and, if necessary, screened. The mixture is now in the state of a dry powder, and can be carted to the work, where more water is added and it is chafed up for use.

The other method is employed when there is convenience for making it up at the work. In this case it is what is termed "larryed." Thus: — the lime is put into the middle of a bed of sand, and a large quantity of water thrown on, and with lime-hoes mixed up immediately until completely incorporated. It is then allowed to remain for a few hours, when it becomes set, and of proper consistency for use. The lime when turned up in this way will admit of a larger quantity of sand, as all the particles of lime are dissolved, whereas by the first method there are always small particles of the lime which cannot be properly mixed, however much it may be chafed up.

Chalk-lime mortar requires two parts of lime to three of sand, and is now chiefly used for plasterers' work.

1839 – Joseph Gwilt, Rudiments of architecture

Reference: Joseph Gwilt (1839) Rudiments of architecture, practical and theoretical. London, Priestley and Weale.

Gwilt describes a strange method of screening lime vertically, but in other respects, dovetails his advice with previous writers in recommending thorough mixing to incorporate a mixture of lime and sand. He is among the first to advocate the use of a pug-mill for this purpose.

In the metropolis, there is now no excuse for the use of chalk-lime, except for the commonest purposes. It is received from Kent and Essex, and often lies at the different wharfs under open sheds long enough to lose every good property it originally possessed: whereas the stone-lime may be had at a short distance from the metropolis, not only in abundance, but of the best quality.

The lime, when slaked, must be passed through a sieve so as to leave only a fine powder; this is usually performed by means of a screen made of wire, set at an inclination to the horizon, against which the lumps of slaked lime are thrown. That which ought passes through it, the remainder or core falls on the side of the screen against which the lime is thrown. For mortar the core must be entirely rejected; it is, nevertheless, excellent as dry rubbish for filling in the sides of foundations, under wood floors, where they would otherwise lie next the earth, and the like.

The sifted or screened lime is now added to the sand, whose proportion to the lime must vary as the strength of the latter. It is however most important that the lime and sand be well tempered and beat together after the water is added to them, and the better this is effected the smaller will be the necessary consumption of lime. For this purpose, what is called a, pug-mill, is the best calculated, being of the same nature as the clay-mill used for making bricks. When, however, this is not at hand, it should be well tempered with wooden beaters, and turned over repeatedly, so as to be thoroughly well mixed.

…The screened lime and sand are shovelled and mixed together, then the water is added, the less in quantity the better; afterwards it is tempered by beating and chafing or by passing through a pug-mill, as above mentioned. When mortar is made, it should be used immediately, that is, supposing the lime to have been well burned…

In respect of that used by plasterers, who employ an inferior lime, it is the practise to make a large quantity of mortar at a time, and either bury or cover the fresh lime with a yard or so in thickness of sand, and then pour on as much water as will slake it, but not reduce it to dust. If the sand open, and the smoke rise through the openings, these should be closed up…

Cement. So far with respect to common mortar: but in works under water it is necessary to use a cement that will harden quickly in those situations, which common mortar will not do, though it may stand the water well enough when entirely dry, and set… Pozzolana and Dutch Tarras are now little used in this country, Parker's cement having superseded them.

1840 – Alexander Smeaton, The Builder's Pocket Manual

Reference: Smeaton A C (1840) The Builder's Pocket Manual Containing the Elements of Building, Surveying & Architecture.

Smeaton, for the first time, gives us an explicit articulation that mortar-making methods have changed enough to resemble closely the making of plaster, which only a few decades before, were two distinct processes.

There are two kinds of cement used in building: that in which lime forms a prominent combination with water. and this is called a water cement; and that which combines with carbonic acid, which is called a mortar…

Mortar is made of lime and sand, thoroughly mixed together, and brought into the consistency of a paste, by the addition of water. Different proportions of these substances are used by builders; and this must necessarily be the case, for a larger or smaller quantity of sand must be added in proportion to the quality of the lime. A good lime will take more sand than a bad one, and the value of the cement may, in a great measure, be judged of by the quantity of sand it contains. Builders are accustomed, for instance, to use more sand with stone-lime than with chalk-lime; not that there is in general much difference between the two, when first burnt, but because the quality of the chalk-lime is speedily injured by a very rapid absorption of carbonic acid…

Coarse Stuff (for plasters) Coarse stuff; or lime and hair, as it is sometimes called, is prepared in the same way as common mortar, with the addition of hair procured from the tanner, which must be well mixed with the mortar by means of a three-pronged rake, until the hair is equally distributed throughout the composition. The mortar should be first formed, and when the lime and sand has been thoroughly mixed, the hair should be added by

degrees, and the whole so thoroughly united that the hair shall appear to be equally distributed throughout.

1840 – New Farm Buildings at Gateside, Fife

Reference: Specification for construction of new Farm Buildings at Gateside, Fife; Hopetoun Estate Archive NRAS 888/ 3533.

Again, we see references to grouting and to clean, sharp sand riddled together with quicklime.

Specification for erecting new barn, straw barn, engineer & boiler house, chimney stalk at the farm steading of Gateside, the property of the Earl of Hopetoun by Thomas Brown, Architect, Edinburgh 1840:

"Foundations: …walls …well packed and grouted with lime and the interstices filled in with small stone chips…

Rubble work: …walls …well packed and pointed with properly prepared lime mortar, the lime to be from silver mine, the sand clean and sharp and both to be well riddled…"

1840 – Bartholomew's Specifications for Practical Architecture

Reference: Bartholomew A (1840) Specifications for Practical Architecture. London. John Williams

Specifications for an Artificial Foundation of concrete work. Bartholomew, like Pasley, calls for grinding quicklime to powder, before mixing into concrete.

…The concrete-work is to be formed in the proportion of six parts by admeasurement of clean Thames stone ballast, unscreened, and with rough and fine intermixed, and one part by admeasurement of the very best fresh burnt Dorking stone-lime (or other stone-lime as the case may be) beaten to fine powder on the premises without being slaked.

The ballast and lime are to be thoroughly mixed with each other in small quantities at a time, the lime being slaked with a small quantity of water at the moment of admixture; sufficient scaffolding is to be provided and erected by the contractor, and all the materials of the concrete-work are to be from thence thrown down a depth of not less than 10 ft. into the bed of the work, so as to be the better consolidated in the intended layer of the foundation.

1841 – Hitchcock, Geology of Massachusetts.

Reference: Hitchcock E (1841) Final Report on the Geology of Massachusetts by Massachsetts Geological Survey.

Hitchcock agrees with European writers that the 'best' limes are those which admit the most sand, making them economical and workable.

Fat Lime. This being derived from an almost pure carbonate of lime, slacks with great energy and the evolution of heat; forms a fine paste with water; admits the addition of a great deal of sand; is more easily laid on by the mason; and therefore, is the most economical for common purposes. On all these accounts it is regarded as the best kind of lime; and sought after the most.

1841 – Nicholson's Practical Masonry, Bricklaying and Plastering

Reference: Nicholson P (1841) Practical Masonry, Bricklaying and Plastering 'Practical Builder and Mathematician'.

Nicholson relates Dr Bryan Higgins' methodology for slaking lime with lime water and for employing bone ashes in the mortars. By common consent, this method was rarely, if ever, used in practice. Nicholson himself says that this method should be used 'only when a very superior kind is wanted' and that it is not the procedure in common use. Most of what Nicholson says is taken from earlier works, usually without reference.

Let the sand be sifted in streaming clear water, through a sieve which shall give passage to all such grains as do not exceed one-sixteenth of an inch in diameter... [but also save the fine sand that did not wash away]. Let stone-lime be chosen, which heats the most in slaking, and slakes the quickest when duly watered; that which is the freshest made and closest kept; that which... leaves in the residue the smallest quantity of clay, gypsum, or martial matter...

[L]et the lime be slaked, by plunging it into a butt filled with soft-water, and raising it out quickly, and suffering it to heat and fume...

Let fifty-six pounds of the aforesaid chosen lime be slaked, by gradually sprinkling the lime-water on it, and especially on the unslaked pieces, in a close clean place. Let the slaked part be immediately sifted through the last mentioned fine brass-wired sieve: let the lime which passes be used instantly, or kept in air-tight vessels; and let the part of the lime which does

not pass through the sieve be rejected. This finer and richer part of the lime, which passes through the sieve, may be called purified lime.

To the wetted sand [56 lbs of coarse sand; 42lbs of fine] add fourteen pounds of the purified lime, in several successive portions: mixing- and beating them up together, in the mean time... then add 14 pounds of bone-ash. [1 lime to 8 aggregate by weight].

...[T]he preceding method of making mortar differs, in many particulars, from the common process...

When the sand contains much clay, the workmen find that the best mortar they can make must contain about one-half lime; and hence they lay it down as certain, that the best mortar is made by the composition of half sand and half lime...

(For plastering) The safest mode of preparing lime and hair, when the stone is of a strong nature: ...A large tub must... be procured into which the lime, after having been well slacked must be put and mixed with a proper proportion of water, and run through a sieve with apertures not exceeding a quarter of an inch, until the pan is filled, when the hair and sand must be added, the whole being well incorporated with a drag or three-pronged rake. There must then be a small hole made at a suitable height in the side of the pan, to allow the water to escape. After thus remaining until it be sufficiently set, it may be taken out of the pan and made fit for use by the labourers.

This composition is used for the first or pricking-up coat, and for the floating of ceilings and walls. It is also used for mouldings and cornices which require much stuff, in which case it is mixed with plaster of Paris...

The plaster (of Paris) commonly used in the metropolis is prepared from a sulphate of lime, produced in Derbyshire, and called alabaster. It is brought to London in a crude state, calcined, and afterwards ground in a mill, when it is ready for use, being usually sold in brown paper bags, each containing about half a peck...

Roman Cement, which is by plasterers, for the sake of brevity, called Compo... was originally known as Parker's Patent Cement... but there is now a much superior article prepared from a stone discovered... on the estate of the Earl of Mulgrave... near Whitby... which is now universally known by the appellation of Atkinson's Cement. The latter... will bear a great deal more

sand than the former; is of a more delicate stone colour, and for situations constantly exposed to the action of water, not to be surpassed by any cement now in existence...

When the work is all finished in the stuccoing... drawn and jointed to imitate well-bonded masonry, it may be coloured with washes composed of five ounces of copperas to every gallon of water, mixed with a sufficient quantity of fresh lime and cement, adding the colours necessary to produce an exact imitation of any particular stone which may be required. When this mode of colouring is executed with judgment, and finished with taste, so as to produce a picturesque effect, by touching the divisions with rich tints of ochre, umber, &c., it is with difficulty distinguished from real stone.

1842 – General Treussart on Hydraulic and Common Mortars

Reference: Treussart, C (1842) Essays on Hydraulic and Common Mortars and on Lime-Burning. trans. from the French by M Petot and M Coutois, with Brief Observations of Common Mortars, Hydraulic Mortars and Concretes.

Treussart refers to Vicat and repeats the 'three traditional methods' model. He describes a way devised of streamlining hot-mixing, by building special on-site premises and careful batching, which seems to be an interesting application of industrial principles (efficiency, replicability, automation) to a traditional craft (hot-mixing mortar).

(Vicat) did not content himself with experiments on a small scale: a manufactory was established near Paris by his means, where artificial hydraulic lime is made in large quantities; he moreover exerted himself to extend the use of hydraulic mortar every where, and he succeeded.

There are three modes of slaking lime. The first consists in throwing on the lime, as it comes from the kiln, enough water to reduce it to thin paste. This process is the one generally employed with fat lime. Too much water is added, almost always - that is to say, as much as is required to make it a thin cream.

The second method of slaking consists in plunging quick-lime into water for a few seconds. It is withdrawn before the commencement of ebullition; slakes with the water it has absorbed, and falls to powder. It is preserved in a dry place. The operation is performed with baskets into which the lime, broken to the size of an egg, is put. Mr. de Lafaye, in 1777, proposed this

mode of slaking lime, as a secret recovered from the Romans… but experience has not realized the great results anticipated.

The third process consists in leaving the quick-lime exposed to the air… Lime, thus exposed, slakes slowly without giving out much heat, and falls at last to powder. This mode of slaking is called air-slaking, or spontaneous slaking. It is employed, more or less, in several countries. It is spoken of in several works on constructions, and is generally condemned.

Since 1817, this process [aspersion] has been employed at Strasburg, where considerable masses of lime were operated on. A small building was erected near the works, into which the hydraulic lime, not allowed to arrive too fast from the kiln, was put, to be protected from the weather… There was a measure, without a bottom, which contained about 10 cubic feet, each dimension of the box being about 2.20 feet, this was placed on the floor and filled with lime… [T]he same… was used for the sand, which was placed around the lime, without covering it: with large tin watering pots of known capacity, water, equal in bulk to about one-quarter the bulk of the lime, was thrown on… a given number of times… As soon as the slaking became energetic, the lime was left to itself until the vapours had ceased; it was then turned a little with a shovel, or a rod was thrust in, and if any lumps were found still entire, either for the want of water, or because they were too much burned, a little water was poured on… [T]he surface being slightly pressed with the back of the shovel, the lime was covered with the sand that had been placed around it. This process was completed towards evening — as many heaps being prepared as it was presumed would be required during the whole of the ensuing day. By thus leaving the lime, over night, in heaps, the slaking is complete… and the water becomes thus uniformly diffused through the heap.

In the morning the sand and lime of each heap were mixed together, and passed twice under the rab (rabot) before adding any water: in this way, if there were any… pieces… imperfectly slaked, they were easily found and rejected. Water was then added in sufficient quantity to bring the whole to the state of very soft paste; because in this dilute state the mortar is, with less labour, mixed more perfectly…

…[T]he precaution was always taken of making up only one or two heaps of mortar at a time; so that it should not… dry before being used, and that the masons might find it in the state of paste, in the heaps in which it was deposited after being well worked…

There are two modes of obtaining hydraulic mortar; the first consists in mixing natural, or artificial, hydraulic lime with sand; the second consists in mixing ordinary fat lime with certain substances such as puzzalona, trass, certain coal-ashes, and brick dust, or tile dust…

[After many experiments, concludes]… [W]e are much more certain to obtain uniform results with hydraulic mortars, composed of fat lime, sand and factitious trass [brick or tile dust; certain ashes], than with those that can be made of artificial, or natural hydraulic lime, and sand only…

…[G]ood hydraulic mortar is always obtained by mixing fat lime, in equal parts, with sand and natural or artificial puzzolana. By air slaking the result is the least good.

The best mode of slaking hydraulic lime is to sprinkle it, as it comes from the kiln, with about one fourth of its bulk of water… Before sprinkling the lime, it is to be surrounded with the mortars [he must mean sand/aggregate] that are to be mixed with it, and when it is slaked and gives out no more vapours, it is to be covered with these mortars. The lime is left in this state for twelve hours at least, and for eight or ten days at most. The quantity of water necessary to bring the mortar to the ordinary consistence is afterward added.

…It is the opinion of a great many constructors that when… fat lime is to be used, it is necessary… to lie… in pits for a long time: it is asserted, that the older it is the better it is… we cannot but think that slaking fat lime into vats and letting it lie there… is a mistaken practice… [better, he concludes, to mix them fresh from the kiln and to use them immediately].

We are in the habit of composing our mortars of fat lime and sand that in the air, as well as in water, better mortars are generally obtained with fat lime, sand, and substances analogous to puzzolana, than with hydraulic lime and sand…

If, in general, no better results are obtained with fat lime than those obtained by me, the practice of making mortars of fat lime and sand only should be abandoned. A small quantity of hydraulic cement, or of some substance of similar nature, should always be mixed in the mortar; that is to say, all air-mortars should be hydraulic mortars. The expense will be a little greater it is true, but there will be full compensation in the duration of the masonry.

1842 – George Totten on Mortars and Concretes

Reference: Totten J G (1842) Brief Observations of Common Mortars, Hydraulic Mortars and Concretes and An Account of Some Experiments made Therewith at Fort Adams, Newport Harbor, R I, from 1825 to 1838 by J G Totten, Lt Col of Engineers, United States Army.

Totten repeats the 'three modes' and describes an effective model for a mill that will both grind, slake and mix mortars to a better standard than hand-mixing.

Three modes of slaking the lime were tried in these experiments, namely:

1st. Slaking by Sprinkling - In this mode, water, in quantity sufficient to slake the lime to dry powder, but not enough to afford moist powder, was sprinkled upon the lime. The lime was not made into mortar until it had become cold.

2nd. Slaking by Drowning - In this mode, water enough was given... to reduce the lime to a cream of such consistency as to afford mortar of proper "temper" for common use without any further addition of water, provided the mortar was made up immediately. If the making the mortar was delayed, a further supply of water became necessary.

3d. Air-slaking - In this mode, lime, reduced to pieces about the size of a walnut, was left in the air to slake spontaneously.

...[A] mortar mill was constructed at the commencement of the works at Fort Adams in 1825... The mill consists of a very heavy wheel about eight feet in diameter... moving in a circular trough... The lime is slaked under the wheel, and ground until, with suitable additions of water, it has become a homogeneous paste sufficiently dilute to make mortar of the ordinary consistency. The requisite quantity of sand is then gradually sprinkled in, as the wheel is in motion... It was found convenient to use three barrels of lime to each batch of mortar... Mortar made in the mortar-mill was superior to mortar made by being mixed, in the common mode, with the hoe...

Slaking by drowning, or using a large quantity of water in the process of slaking, affords weaker mortar than slaking by sprinkling...

...in mixtures of lime and sand in various proportions, the mortar was generally stronger as the lime was slaked with less water...

That mortars of lime and sand are materially improved by the addition of calcined clay, but not so much as by the addition of cement…

Of lime kept for three months after being slaked, before being made into mortar - the lime slaked into powder by sprinkling one-third of its bulk of water, gave the strongest mortar - represented by 250 lbs.; the lime slaked into cream gave the next strongest mortar - represented by 210 lbs., and the lime slaked spontaneously during three months, the weakest mortar, represented by 202 lbs.

1844 – Webster's Encyclopedia of Domestic Economy

Reference: Webster T (1844) An Encyclopedia of Domestic Economy. London. Longman, Brown, Green and Longmans.

Webster defines a process of producing hydrated lime and also distinguishes between limes that are non-hydraulic in their natural qualities (pure limes), and those whose impurities make them hydraulic.

The newly-burnt caustic lime is next to be slaked by pouring water upon it; the lumps immediately crack, fall to pieces, and soon become a fine white powder, at the same time giving out much heat, which occasions abundance of steam. But the greater part of the water is absorbed, enters into combination with the quicklime, and passes into a solid state; for instead of a moist paste being the result, as might be expected, the lime remains quite dry in the state of white powder. The union of the water with the lime forms a hydrate of lime, and is termed by builders slaked lime. Limestones… may be divided into two kinds, as far as relates to their affording lime for mortar. Those which consist of pure, or very nearly pure, carbonate of lime; and those which, besides lime and carbonic acid, contain likewise a portion of clay, iron, magnesia, and sometimes a minute quantity of other matters. The lime procured from the first is capable of making a mortar that dries hard in the air, and which, when well made and become thoroughly hard, will not afterwards soften in water; but if water he kept in contact with it before it has dried, it will never set or become hard: hence it is totally unfit for hydraulic purposes, or building under water. On the contrary, all those limestones that contain a considerable proportion of clay, and particularly if that be ferruginous, afford, when burned, what is called hydraulic or water lime, because, when made into mortar by the addition of sand and water, such mortar sets hard even under water; on which account it is extremely valuable for building piers, docks, and similar works… Our common mortar is composed of lime made into a paste with

water and sand, which, when completely dried, becomes of a stony hardness…

The lime used for common mortar in and about London is made from white chalk, often imperfectly burned; but a superior kind is procured from employing the grey chalk of Dorking, which contains some clay, yet not enough to form the best hydraulic lime…

To form mortar, fresh slaked lime is mixed up with a sufficient quantity of proper sand, water enough being added to make it into a tough paste. In mixing the lime and sand together, considerable labour should be used; as it is found that the beating the mortar well, so as to incorporate the materials thoroughly, is essential to make it of good quality, and fit for the mason or bricklayer.

1844 – Works to Brodick Castle, Isle of Arran

Reference: Papers relating to the affairs of Thomas Brownlee, Builder in Glasgow… (TD-949 /2 bill) stored at the Mitchell Library, Glasgow.

This brief entry indicates a trough used both for mixing and storing lime mortar, as described by authors above.

"The Most Noble the Marquis of Douglas and Clydesdale to Thomas Brownlie, Brodick Castle. Dog Kennel from 2nd May to 2nd June 1844.

- *4 carts lime shell & sand @ 20/-*
- *1 large trough, working & laying lime @ £1/10/-…"*

1845 – Masonry Collapse at Brodick Castle

Reference: Thomas Hamiltons Report on a Masonry Collapse at Brodick Castle; National Register of Archives in Scotland 2177/ B6164.

The next reference relates to the expansion of the castle in 1844, designed by James Gillespie Graham for 10th Duke of Hamilton. During the construction project, in March 1845, the new SW tower collapsed while under construction and the Corrie (Arran) lime was thought to be at the root of the cause. Thomas Hamilton Jnr. Architect was employed to provide an independent expert opinion. He reported as follows:

"…I would suggest however… in order to admit of greater expedition in its reconstruction, you might get different Lime to that of Arran, which is I understand unusually long in setting; this peculiarity of the lime, coupled with the rapidity with which the work was executed, must have been the

great Cause of the Accident. I am informed that the Tower in question is founded on a Rock, and the Circumstance of having fallen to within a few feet of the ground, renders it impossible to come to any other Conclusion than above stated…"

Corrie limestone can contain around 98% Calcium Carbonate and is known to have produced non-hydraulic to feebly hydraulic lime. Further investigation into the primary sources, including Gillespie Graham's specification & correspondence surrounding the incident, might uncover interesting information related to the mixing and use of mortar in this case, and perhaps some very relevant insight into mortar practices and building conventions of the time.

1845 – W H Wright, Public Works in Boston Harbor

Reference: Wright, W H (1845) A Brief Practical Treatise; Mortars: An Account of the Processes Employed at the Public Works in Boston Harbor Ticknor & Company.

Wright repeats the 'three modes' and points out that hydraulic mortars, because of their fast chemical set, should not be prepared more than a few days in advance of using. He describes the efficacy of pozzolans but gives proper place to traditional mortars, outside of underwater applications.

There are three modes of slaking. The first consists in throwing upon it sufficient water to reduce it to a thick pulp. This is the ordinary method, but it is generally abused by pouring so much water upon the lime as to drown it, or in other words to form a thin cream, and thus impair its binding qualities…

P34. There is one precaution to be observed in employing the method of slaking, above described. Sufficient water to produce the desired result should be used at first; or at all events, any additional quantity that may be requisite, should be supplied very gradually. If any portion of lime is permitted to slake to dryness, and water is afterwards thrown suddenly upon it, it appears to become benumbed, and falls to powder very imperfectly.

P35. The second method of slaking lime consists of plunging it into water, and then with drawing it after a few seconds, before the commencement of ebullition. The lime hisses, bursts with noise, and falls into fine powder, evolving hot vapor at the same time. It is then said to be slaked by immersion. The powder thus obtained, does not again become heated upon

being made into paste with water, and may be preserved for a long time, if care be taken to protect it from the atmosphere.

In order to ensure the best result in slaking by immersion, the fragments of quick lime served, should be reduced in the first place to the size of a walnut, and heaped together, immediately after they are withdrawn from the water, in casks or large bins. The heat is thus concentrated, and a large amount of vapor, which would otherwise escape, is absorbed by the lime, which is brought in consequence to a more thorough state of division.

(Spontaneous) extinction was formerly proscribed, and the powder resulting from it regarded as worthless…

Hydraulic limestone is calcined with difficulty to the proper degree, and when not sufficiently burned, the resulting lime slakes badly. The mortar, made with it in such a state, is less tenacious, and is moreover apt to swell after being used, to the great injury of the masonry. To ensure thorough slaking, it should generally be allowed, after extinction, to remain twelve hours or more before it is employed, but it is best in every case to ascertain approximately the time required for this purpose, by experimenting in a small way. Hydraulic lime becomes hard, however, in a short time after being converted into paste, and should never be slaked in greater quantity than will suffice for two days' consumption at most…

(Pozzolans and fired clays) offer very important advantages in the improvement of mortars, and deserve particular attention, because hydraulic cement is not always to be had, and hydraulic limes often give mediocre results, unless they are mingled with a certain proportion of pouzzolana; and the latter has, moreover, this advantage over the hydraulic limes - its qualities are scarcely at all impaired by exposure to the air and moisture…

Four modes of measuring lime have been employed. The most ordinary mode is to measure it in lumps, as it comes from the kiln; a second method is to measure it in slaked lime powder; a third, in quick lime powder; and a fourth, in slaked lime putty or paste.

The first method is usually employed by builders, when their works are not on a large scale, and is always supposed to be adopted, if nothing be said to the contrary…

In ordinary practice, the cohesion of the mortar is greatly impaired by too large a proportion of sand, which should not in general exceed two volumes, for every volume of lime paste.

In preparing ordinary mortars, it will be convenient to place the unslaked lime upon a plank floor, under shelter from the sun and rain, and then (without covering) to surround it with the proper quantity of sand. The water, requisite to produce a thick paste, previously ascertained by experiment, should be poured on the lime with the aid of watering pots of known capacity. The lime must then be well stirred, so as to expose every part of it to the action of the water, and afterwards left to itself, until the vapors have ceased entirely. The ingredients may now be thoroughly incorporated by means of the hoe and shovel. If the mixture is made with difficulty, a little water may be added, but only enough to produce a homogeneous mass…

(Mortars at Fort Warren mixed by mortar mill and lime slaked by being thrown into a surplus of water…)

The lime, thus deluged with water, loses probably some portion of its binding qualities, but the mortar at Fort Warren almost always contains hydraulic cement; and as this substance sets rapidly, it is highly essential that the lime should be thoroughly slaked before the admixture of the ingredients. With the view, therefore, of ensuring this, as well as from regard to convenience and economy, the lime is reduced to the milky consistence before-mentioned, and allowed to remain in the vat as long as possible. It should be remembered, that the above method applies only when cement is added to the lime. When no cement is used, the lime must be slaked in the ordinary way, as the drenching of the lime would greatly impair its binding properties…

1846 – Masonry coatings at Brodie Castle

Reference: letter from James Wylson concerning repairs to the exterior of the same.

Wylson was an architect who was brought in to complete major works, begun in 1824 under architect William Burn. He recommends against historic roughcasting as ineffectual, unless done from scratch, and interestingly specifies a cementitious pointing mortar to achieve the same weatherproof effect; it is of note that there is a desire to leave the stone exposed, by the use of pointing.

…I am doing everything in a plain, substantial manner, leaving the ancient character in view and doing no more than what seems necessary.

I have been thinking a good deal about the Rough-casting, and have come to the conclusion that it ought not to be repeated. [W]hen… repaired, the rain gets between the coats and flakes it off, especially in case of frost… In the present case, if it is adopted, it must be done from the very root, and five distinct operations are necessary, namely:

Scraping it all off and raking out the joints; Washing to remove dust and ensure adhesion; Pointing the beds and joints; Coating; Dashing – with colouring.

…As something ought to be done, I have to propose a mode of treatment which I think would be better in point of durability – and antiquity, and which would also harmonise better with the newer buildings… after scraping, raking out and washing, to point the joints and cracks out solid and flush with the following composition: 2 parts lime, 1 part sand, and 2 parts scoria from a blast furnace, or the forge scales and filings from a smithy, or a combination of these; the foundry and smithy waste to be pounded and sifted, the sand also sifted; the lime used hot from the kiln, and the mixture made as the lime is slacked, the joint to be struck with the trowel as in ordinary rubblework. (This would be very hard and not especially breathable). The great property of induration which is possessed by a mixture such as this, and which it derives chiefly from the presence of iron, is well known, and its dark colour, as it approaches the tone of the old masonry, is in its favour rather than otherwise. This method I consider would be in itself superior to the rough-casting; and if you thought proper then to coat the whole of the old building with boiled linseed oil, it would be an excellent protective for the stone, entering as it would, into the surface and there hardening and rendering it impervious to water. (Such treatment and such misconception was not at all uncommon in the past and was certainly applied to York Minster during the 19C). It ought to be done in the dry season, if hot, perhaps the better, but more expensive.

1847 – Works at the New Houses of Parliament, London

Reference: Accounts and Papers, Post Office; Public Works and Buildings; Shipping Vol 22. 1847-1848. London. House of Commons.

Except for the use of feebly hydraulic lime, explicitly distinguished from ‘chalk lime’, at least, this list shows that the palette of mortars and binders has changed little since Batty Langley’s summary in 1750.

That they the said Henry Lee and John Lee (builders) shall and will forthwith proceed to do, perform and execute all the excavators', pile-drivers', builders', bricklayers', masons', smiths', carpenters', and all other work requisite and necessary to be done and performed in and about the forming, erecting and completing the Cofferdam, River Wall and other Works forming part of the foundations of the intended New Houses of Parliament... and also, that they the said Henry Lee and John Lee, their executors and administrators, shall and will, at their own proper costs and charges, find, furnish and provide all the stone, iron, timber, bricks, pozzolano, lime, gravel, sand, clay and all other materials of every kind and description whatsoever requisite or necessary for the doing and performing the said Works... and that the same stone, iron, timber, bricks, pozzolano, lime, gravel, sand, clay and other materials shall be the best of their respective sorts and qualities...

Schedule of works for Cofferdam, River Wall and other Works forming Part of the Foundation of the proposed new Houses of Parliament.

...The concrete of the foundations of all the walls is to consist of 6 measures of gravel and sand to 1 of ground lime, mixed dry, and then well worked together with water, and in this state teemed and thrown into the work from a height of at least 10 feet, and is to be brought to a level surface at the proper depth to receive the first footing-course, which is to bed solid upon it...

The stonework is to be laid out on a thin bed of mortar prepared as hereafter directed, the front joints being pointed with cement and then grouted full, and all the stones are to be worked on the ground and set with lewises and proper tackling...

The space between the river wall and the front wall of the building is to be brought up to the level of the top of the walls with concrete composed of 10 measures of gravel and sand to 1 of unslacked lime washed in with water, and levelled in regular and thin courses as the work proceeds.

Mortar and concrete: The mortar throughout is to be composed of 1 measure of the best fresh-burned Merstham, Dorking or other equal and approved lime, 1 measure of finely-ground genuine Italian pozzuolana, and 2 measures of sharp above-bridge river sand, all clean and free from rubbish, dirt and other impurities; the proportions are to be correctly ascertained, after which the lime (which is to be brought from the kiln in small quantities, as required, and kept dry under cover) is to be slacked and

mixed with the pozzuolana and sand; they are then to be passed together in the dry state through screen, the water added, the mortar well tempered and worked to a tough and proper consistency in horse or pug mills for the work generally, but for the stonework, ground with edge stones worked either by horses or by means of gear attached to the steam-engine for pumping the water out of the dam. Fresh-burned lime of the above description, and clean coarse river gravel, having mixed with it a proper quantity of sharp sand, are also to be used in proportions stated in making the concrete that has been specified for the foundation of the walls and the backing.

(Further foundation works)

Bricklayer: The bricks to be sound, hard, well burned square stocks, equal to a sample to be approved by the Architect and deposited with the Clerk of the Works; the whole of the brickwork to be laid English bond, and no four courses to exceed 11 ½ inches, and every course flushed up solid in mortar. The mortar to be composed of stone lime and sharp river sand, in the proportion of three measures of sand to one of lime, the whole well mixed in a pug-mill. The lime to be kept in an inclosed shed, and no more mixed at one time than is sufficient for the day's consumption. Signed Charles Barry (Architect), Henry and John Lee 08.11.1837.

For completing Carcase of the River Front, and the North and South Flanks of the Building. Thomas Grissell and Samuel Morton Peto, both of Lambeth, in the county of Surrey, Builders and Co-partners (submitted lowest tender and were accepted)... Charles Barry.

Bricklayer: The backing up of the stone facing of the external walls and the whole of the inner walls of the building, shown by a tint of red, are to be of brickwork, and built of the several heights and thicknesses as shown on the accompanying drawings, of the best hard, well-burnt, sound stock bricks, laid in mortar composed of the best Dorking or Merstham or other equal and approved stone lime, and clean sharp river sand, free from all filth and impurities, well mixed together in the proportion of two equal measures of sand to one equal measure of lime, ground and tempered in a pug or horse-mill until it becomes of an equal and proper consistency. The lime is to be thoroughly and freshly burnt, and must be kept in an enclosed shed; and no more mortar is to be made at one time than is sufficient for each day's consumption...

The backs of the stone parapets to be rendered with Keen's Patent Cement, properly jointed with the flashings. All the Roman Cement to be composed of one measure of the best fresh-ground Roman Cement that can be procured, mixed with one equal measure of clean sharp sand, to be well chafed up for use in small quantities and used immediately.

Mason: The plinth of the external walls… is to be of the best granite from the Fogging Tor Quarries, Devonshire, from Penryn, or from the Island of Guernsey, of a fine grain, similar to that of the best Aberdeen, or from Aberdeen, and of an even colour throughout, being entirely free from large crystals of quartz or felspar, as well as from redness or stains…

The granite work throughout is to be laid on a thin bed of mortar prepared as hereafter described, the face of the joints being pointed with cement, and the rest grouted full with mortar…

The mortar for the granite work is to be composed of one measure of fine ground genuine Italian pozzolana, two equal measures of clear river sand, and one equal measure of good fresh burnt Dorking lime mixed with water and well worked to a proper consistency, and in that state ground with edge stones…

(Cramps to be grouted in with Roman Cement; window stones etc to be bedded in the same) Signed 26.09.1839.

Specification of Works to be performed and Materials used in forming the Foundations of a Portion of the South Flank of the Building, the Royal Staircase and adjoining Rooms, the House of Lords and its Appuitenances, the Public Corridors and Central Hall, and the House of Commons and its Appurtenances.

The mortar is to consist of the best fresh burnt Merstham or Dorking lime, and clean sharp river sand, in the proportion of three measures of sand to one equal measure of lime, well compounded together in a proper pug-mill. The lime is to be kept in an inclosed shed, and the supply to be duly regulated by the quantity of work in hand, so that the same may be used in a fresh state; and no more mortar is to be made up than is required for the day's consumption…

Contract No.7, For the internal Finishings of the Building generally.

Bricklayer: Brickwork, including Scaffolding — the Bricks to be all bedded, drawn up and flushed with Mortar.

Reduced brickwork done with hard well-burned sound grey stocks, chalk lime and river sand... Rubbed and gauged arches, straight on the plan, either circular or camber soffites, with red stocks or malms set in putty with 4-inch soffites... Flat joint pointing with coal ash mortar, including raking, dubbing and scaffolding ---------- Ditto, ditto in cement --------- Tuck pointing with a neat joint to new work, including scaffolding - Tuck pointing to old work, including scaffolding, raking out the joints, cleaning down and staining the brickwork...

Tiling: Pantiling, laid dry, including hips and ridges, laid in mortar, heading and filletting... Pantiling, bedded and pointed inside with lime and hair... Pantiling, bedded and pointed outside with lime hair... -Pantiling, bedded and pointed inside and outside with lime and hair... Pantiling, laid dry, including hips and ridges laid in mortar, all but tiles... Pantiling, bedded and pointed inside with lime and hair...

Lime, Mortar, Sand, &c. Delivered at the Works.

Dorking or Mertsham lime, Chalk lime, Lime and hair, Pargetting, Fine stuff, Blue pointing mortar, darkened or coloured pointing mortar, Stopping mortar for tuck pointing, White mortar for ditto, Cement, Windsor loam, Stourbridge ground clay, Clean river sand, Plaster.

1847 – Alterations to a House at Society, Mid-Lothian

Reference: Specification for additions and alterations to House at Society, Mid-Lothian Hopetoun Estate Archive NRAS 888/ H047.

Here we see reference to lime from shell, three-coat work for the internal plaster, as well as a call for clean, sharp sand, riddled together with quicklime.

Specification for making additions and alterations on Mr Scott's house at Society by Thomas Brown, Architect, Edinburgh 9th June 1847: "... no stone to be made more than 9" high on the face and all well packed and pointed with properly prepared lime mortar, composed of slaked lime shells with fresh water and pit sand and both well riddled..."

"...the new apartments walls and partitions to be plastered with the best three coat plaster, the two first coats composed of riddled lime, sharp sand,

freshwater and hair, the last coat of putty lime and washed sea sand and all well straightened, floated, trowelled and made free of cracks and blisters."

1852 – Simon Brees, Dictionary of construction terms

Reference: Brees S C (1852) The Illustrated Glossary of Practical Architecture and Civil Engineering. London Savill and Edwards.

Brees, in addition to identifying the common hydraulic limestones, interestingly adds that lime can be given hydraulic properties by mixing pozzolans prior to the burning, rather than later as part of the mortar mix.

Concrete: an artificial cement composed of lime and gravel, or sand, and in high repute at the present time for the foundations of structures. It was first used in the year 1815, by Mr. Ralph Walker, C.E., at the West India Docks, and subsequently at the Custom House of London, after piles had failed.

Concrete is prepared in various proportions; about one-seventh or one-eighth of ground lime is the most general, but it depends entirely on circumstances. Two-thirds of the ballast should consist of small stones, with none larger than a hen's egg, and one-third of sand. This, in fact, constitutes Thames ballast, which makes excellent concrete when combined with Dorking lime. It should be mixed together, and slaked like mortar, and always used hot, and thrown from barrows wheeled along planks from a height of 10 or 12 feet to the site of the intended foundation.

Hydraulic, or water lime: a lime which possesses the property of hardening when used in water operations. A small mixture of ground burnt clay, smiths' forge scales, or calcined basalt (pozzolano), added to the lime at the time of burning, will give it this quality; or brick and tile dust; but natural pozzolano, or Dutch terras, form the best substances, and are very valuable in hydraulic works. Blue lias lime is an excellent water lime. It appears that even common chalk lime may acquire a setting property like the former description, by being long exposed to a certain degree of heat.

Mortar: a cement used for building purposes, composed of lime, sharp coarse sand, and the hair of cattle, which should be thoroughly mixed together in a pug mill, or well-tempered with wooden beaters, with a small portion of water, in the proportion of 1 of lime to 2 of sand, well chafed. The lime should be used as fresh and stiff as possible, and it ought to be kept under an enclosed shed.

No more than about a bushel of lime should be slacked at one time, and no more water should be employed than is required to reduce it to powder, when it ought to be immediately covered with sand to prevent the gas escaping, which constitutes its indurating quality. The mortar should be beaten three or four times over, so as to incorporate the lime and sand together, and to break any pieces of lime that may have passed through the sieve, the operation being performed with scarcely any water. This improves the strength of the mortar considerably. If the mortar is laid by for any time, it ought to be beaten up again before being used, to save the time of the bricklayer, and it should be used soft in summer, and rather stiff in wintry weather.

...It is the practice of plasterers to mix a large quantity of plaster at once, by either burying or covering the fresh lime with a great thickness of sand, say a substance of two, three, or more feet, and then pouring on sufficient water to slake it, and wherever the sand opens and allows the heat and smoke to escape it is carefully closed; this method has the effect of thoroughly slaking the lime, which is a great object, since the blisters so often observed on the face of plastering are caused from bits of unslaked lime cracking and bursting out.

1852 – Samuel Sloan, Architecture Manual (Philadelphia)

Reference: Sloan S (1852) The Model Architect Volume 1.

With little complimentary to say about traditional mortar mixers, Sloan advocates mixing aggregate with lime run to putty and, with the irony of current hindsight, recommends the hardest mortars possible, as the surest way to preserve a building the longest.

The Mortar. It will doubtless be a matter of surprise to some that this subject should receive an extended notice... Unfortunately, however, it is one of the points in which little or no care is exercised, and the master mason usually builds with mortar prepared either by a careless apprentice or an ignorant laborer. He never thinks of the permanence of his work, unless it be surrounded by extraordinary destructive agents, but if the finished structure stands, he and his employer are satisfied.

Experience has shown that the best plan in preparing mortar is first to bring the lime to the consistence of a smooth and uniform paste before adding the components. The sand must be gradually intermixed and the whole thoroughly worked together. This is a point usually but little attended to...

The name hydraulic is given them because of their property of setting under water, and heretofore they have been used almost exclusively for marine and other hydraulic works. It is highly important, however, that we should possess and put into practice the means of giving greater durability and security to our ordinary buildings, and there is no reason why the hydraulic mortars should not be used to this end. They act equally well, if not better, in air, and with skill can doubtless be made so economically that the difference in expense is no ground of preference for ordinary mortars. It is only necessary that the experiment be made a few times. Success is certain, and will be the greatest, the most valuable advance in modern construction.

1853 – Mortar in Trinity, Edinburgh

Reference: Broomhall Archives – Charlestown Limeworks letterbooks: Book of the Year 1863: Letter to Samuel Freeman Esq., Contractors Office, Trinity, Edinburgh, 27th October 1853.

"The lime shells fall from being slaked and with sharp sand – two parts sand and one of lime. When the sand is not so sharp, two and a half of sand may be used. We can grind the shells for you if you choose."

1854 – Dobson's Building Manual

Reference: Dobson E (1854) Rudiments of the Art of Building. London. John Weale. Pages 143 to 147.

Dobson categorises the hydraulicity of the common London building limes and describes lime slaked to a hydrate, as the most common form for mixing mortar.

In making mortar the following processes are gone through. 1st. The limestone is calcined by exposure to strong heat in a kiln, which drives off the carbonic acid gas contained in it, and reduces it to the state of quick-lime. 2nd. The quick-lime is slaked by pouring water upon it, when it swells, more or less, with considerable heat, and falls into a fine powder, forming a hydrate of lime. 3rd. The hydrate thus formed is mixed up into a stiffish paste, with the addition of more water, and a proper proportion of sand, and is then ready for use.

Pure Limes. Chalk is a pure carbonate of lime, consisting of about 5 parts of lime combined with 4 of carbonic acid gas. It expands greatly in slaking, and will bear from 3 to 3 ½ parts of sand to one of lime, when made up into mortar. Chalk lime mortar is, however, of little value, as it sets or hardens

very slowly, and in moist situations never sets at all, but remains in a pulpy state, which renders it quite unfit for any work subjected to the action of water, or even for the external walls of a building…

Water limes have obtained their name from the property they possess in a greater or less degree of setting under water. They are composed of carbonate of lime, mixed with silica, alumina, oxide of iron, and sometimes other substances.

Dorking lime, obtained from the beds of the lower chalk, at Dorking, in Surrey; and Halling lime, from a similar situation near Rochester, in Kent, are the principal limes used in London for making mortar, and are slightly hydraulic; they expand considerably in slaking, but not so much as the pure limes, and will make excellent mortar when mixed with 3 parts of sand to 1 of lime. Mortar made with these limes sets hard and moderately quick, and when set, may be exposed to considerable moisture without injury; but they will not set under water, and are therefore unfit for hydraulic works, unless combined with some other substance, as puzzolana, to give them water-setting properties.

The blue lias limes are the strongest water limes in this country. They slake very slowly, swelling but little in the process, and set very rapidly even under water; a few days only sufficing to make the mortar extremely hard. The lias limes will take a much smaller proportion of sand than the pure limes, the reason of which will be understood when it is remembered that they contain a considerable proportion of silica and alumina, combined with the lime in their natural state, and consequently the proportion of sand which makes good mortar with chalk lime, would ruin mortar made with Aberthaw, Watchet, Barrow, and other lias limes. In the Vale of Belvoir, where the lias lime is extensively used, the common practice is to use equal parts of lime and sand for inside, and half sand to one of lime for face work…

Before that time [1796 and the invention of Parker's natural cement], hydraulic mortar, for dock walls, harbour work, &c, was usually made, by mixing common lime with trass, from Andernach in Germany, or with puzzolana from Italy…

Concrete and beton: P154. This mode of forming foundations, in situations where solid masonry would be inapplicable, has been revived in modem times; in England under the name of concrete, and on the Continent under the name of beton. Although very similar in their nature and use, there are

yet great differences between beton and concrete, which depend on the nature of the lime used, concrete being made with the weak water limes which will not set under water, whilst beton is invariably made with water-setting limes, or with limes rendered hydraulic by the addition of puzzolana. Describing the two by their differences, it may be observed that concrete is made with unslaked lime, and immediately thrown into the foundation pit; beton is allowed to stand before use, until the lime is thoroughly slaked: concrete is thrown into its place and rammed to consolidate it; beton is gently lowered and not afterwards disturbed : concrete must be thrown into a dry place, and not exposed to the action of water until thoroughly set; beton, on the con trary, is made use of principally under water, to save the trouble and expense of laying dry the bottom.

1856 – Vicat's Paper on the composition of mortars

Reference: L J Vicat (1856) Traité pratique et théorique de la composition des mortiers, ciments, et gangues à pouzzolane. Translated by Emma Michel 2016.

Vicat suggests that best practice in mortar consistency is directly opposite the contemporary normal practice by masons. He cites 1820 as the year from which chemistry and scientific knowledge advanced building and saved it from the errors of traditional practice; another reference to hydraulic limes and cements being superior to older works.

In some areas, we gradually form the lime as a heap while spraying it, we then cover it with fresh sand in which the lime crumbles to powder and can be conserved and used for a few days.

Making and employment of fat lime mortars. These mortars are made, as is commonly known, of sand and lime in paste mixed with water and generally in average proportions of two measures of sand for one measure of [slaked] lime. Sharp sand is better for this mortar than fine sand...

Fat lime mortars are better when mixed several times, which justifies the 'Lyonnaise' method, in which they make a big heap in advance and take only the amount needed for the day, softened by the addition of water... To conclude, fat lime mortars, without their insoluble crust covered on their surfaces with carbonic acid and without their superficial resistance to the rain would be a worse choice than a good 'pisé' = rammed earth (construction). However, as it is those mortars we use generally in buildings of low importance, and that rubble is sufficient for the core, it is possible to obtain the least worst possible mortar by doing the opposite of what masons do.

Instead of drowning the lime to slake it and to waste the mortar with a very soft, almost fluid consistency, lime should be employed in a firm state and to add water only if the sand is too dry and if it absolutely needs it in order to obtain a mortar of good consistency. With all these precautions, we will never achieve a mortar in practice in which its final cohesion is more than 3kg per centimetre square (0.294 Mpa – highly improbable, lest it be a particularly sandy earth mortar).

…The Roman mortars are usually all similar to each other; we can recognise them thanks to the presence of sand mixed with gravel, the lime lumps are sometimes so numerous that it is impossible to think it is a defect of grinding. The incomplete slaking of fat lime by spraying or immersion is the only way (to explain it)…

Our great superiority since 1820, in this part on the art of building, is from now on unquestionable. Chemistry has taught us by which routes, the elements contributing to the solidification of calcareous parts form an intimate link in chemical combinations. We can determine, with the proportions, the reasoned choice and the preparation of materials, how to satisfy all requirements in building. Such is the current progress in this report, that after a few months with our eminently hydraulic mortars and after a few days with some cements, our masonries can equal in solidity the best ancient masonry.

1857 – George Burnell, notes on Mortars

Reference: Burnell G R. Rudimentary Treatise on Limes, Cements, Mortars, Concretes, Mastics, Plastering, etc. first edition 1857. London.

Burnell, among a discussion of concretes or betons, describes mixing mortar from a dry hydrate that has been mixed into paste. Most interesting though, is his final sentence as quoted here, an unequivocal distillation, 150 years ago, of the principle of compatibility: '*To use a hard, quick-setting material upon a yielding base, is a degree of ignorance totally unaccountable on the part of any professional man of average discernment.*' - which is in nice contrast to the Vicat extract in the section above.

On The Making of Mortar. The making of mortar comprehends the slacking of the lime and the mixture of the ingredients worked up with it. As we have already seen, both the former process and the nature of the latter differ, according to the lime to be dealt with. It is, however, a universal rule, in contradiction to the slovenly practice of London builders, that all limes,

of what nature soever, should be reduced to a paste before being mixed with the other ingredients.

The degree of consistence of this paste should vary with the nature of the extraneous materials. It should be stiff whenever it is intended to form a gauge for substances whose particles are hard and palpable, and which are capable of preserving sensible distances from one another. It should be more liquid when the substances to be mixed with it are pulverulent, of impalpable and fine grains, presenting an homogeneous appearance, and in which it is impossible to distinguish the separate elements, such as the puzzolanos etc. To secure a proper state of hydrate, it is of great importance, however, not to use too much water in slacking the lime. So much should be used, and only so much, as is necessary to cause the quicklime to fall to powder [so - dry slake and immediately mix to a paste and then mix with sand?]. It is also equally important not to mix up into the state of paste more lime than is immediately required to be used. In France, where great care is required in the fabrication of mortars, the lime is worked up into a paste in a mill, consisting of two vertical stones working in a trough. The lime, after going through this operation, is then mingled with the sand in a pug-mill, or by hand, upon a floor.

...It is better to wet the materials to be used and to employ a stiff mortar, than to follow the course usually adopted by masons and bricklayers of using very soft fluid mortar...

The term 'concrete' is usually applied to a species of rough masonry of small materials, consisting of gravel or broken stone mixed with a lime, either previously worked into a mortar or not, as the nature of the lime may require. It is principally used for the purpose of distributing the weight of a large heavy construction over the greatest surface possible; or for the backing of coursed masonry, in cases where walls are required of great thickness. Properly speaking, it would be better to apply the word 'concrete' to this sort of masonry, when executed in the manner usually adopted in our country, by slacking the lime upon and in immediate contact with the gravel. When the lime has been previously worked into a paste, the French word 'beton' might be applied, for the sake of distinguishing the two processes.

...A very excellent concrete for either sea or river works is made by a mixture of a mortar made of three parts of fine sand to one of hydraulic lime unslaked, with equal quantities of gravel or broken stone...

Broken limestone appears to add very much to the qualities of concretes, betons and mortars. Very probably this may be attributed to the affinity between the molecules of the already formed carbonate of lime, and that which is in the process of formation; the new crystals may group themselves more easily about bodies whose form is similar to the one they are themselves to assume. Or possibly there may be a tendency in the chemical elements to arrive at a state of equilibrium; and the carbonate of lime may, therefore, be supposed to part with a certain portion of its carbonic acid gas.

…To use a hard, quick-setting material upon a yielding base, is a degree of ignorance totally unaccountable on the part of any professional man of average discernment.

1857 – Dempsey's Architects Manual

Reference: Dempsey (1857) Architectural Practice, Containing Detailed Working Drawings, Specifications, Bills of Quantities, Estimates, Tenders, etc etc. London: Archly and Co.

An endorsement and brief description of hot-lime grouting.

In thick walls the use of grout is the best safeguard against the too frequent carelessness of workmen. This composition should not be merely the mortar thinned with water, but should be mixed separately in large tubs, in the same proportions as mortar; and should be used moderately hot, so that it may not impoverish the mortar with which it comes in contact, and that it may set more quickly.

1858 – Walsh's Manual of Domestic Economy

Reference: Walsh J H (1858) A Manual of Domestic Economy; Suited to Families Spending from £100 to £1000 a Year. London. G Routledge and Co.

MORTAR is made of varying proportions of lime and sand, depending greatly upon the species of lime used. The average proportion is as 1 of (quick)lime to 3 of sand, but with many kinds 1 to 4 is a still better and stronger proportion. Sometimes cinders are added to increase the hardness or give colour, both of which purposes they effect. Common mortar is made as follows: A bed of sand is first made by heaping it up around the space which is to be occupied by the mortar. In this area the quicklime is then heaped, and water thrown over it sufficient to slack it; after this, enough sand to cover all up is thrown over the surface, and the whole is left till the

next day, during which time the lime becomes thoroughly slacked. The next operation consists in mixing in more sand and water, which is done by labourer, usually with his shovel, beating it over again and again, until the whole is thoroughly incorporated. It is now fit for use, and should never be laid on more than a day or two old, if it is desired to set strong, and to adhere firmly to the bricks. The contray opinion is very commonly held, but it is merely an excuse for laziness, and to avoid the waste which occurs when mortar long mixed is rejected. I am quite satisfied that the strength of brick walls mainly depends upon attention to this point. Sometimes a mortar pug mill is used when large works are in hand... (but for smaller works)... it mixes too large a quantity at once.

CONCRETE consists of lime and gravel, mixed as fast as it is used, and poured into the trenches cut for the foundations from a height of six or eight feet, using a stage for this purpose...

PLASTER for the walls requires all the lime to be slacked in a large iron furnace or wooden tub, where it is mixed with water till it assumes the consistence of cream. It is then strained off into a large area, bordered by sand to a height of about eight inches, where it is left for ten days or a fortnight, and is then mixed with sand in the proportion of three, four or six parts of sand to one of lime. Sometimes Bristol lime is used, in which case no sand is mixed with it, and the mortar is as white as snow, and it is called 'putty'. Hair is sprinkled over the lime before the sand is added, and worked thoroughly in with a rake. Plaster mixed largely with sand, and hair addeded to it, is called 'coarse stuff' and is used for the first rough coat. Lime mixed with water, and left to get thick, with or without the addition of hair, is denominated 'fine stuff'...

ROUGH CAST AND STUCCO are forms of mortar used for external work, the former being mortar mixed with fine gravel, while the latter is composed of sand and lime, mixed when dry carefully together, and then tempered with water, and used as rapidly as possible.

PUGGING is rough plaster mixed with chopped hay, spread over rough boards fixed between the floor and the ceiling, to break the sound between the several floors.

1859 – Celestino's Construction Manual, Spain

Reference: Espinosa Pedro Celestino (1859) Manual de Construcciones de Albañilería. Ingeniero Jefe de primera clase de Caminos. Canales y Puertos. Madrid. Severiano Bas. Translated NC 2016.

Celestino slightly inverts the order in which the 'three modes' are normally presented, citing both sand-ring hot mixing and slaking to a cold putty, as comparably 'ordinary' methods, suggesting they are equally common and accepted. He recommends a method of laying up mortar to mature and knocking back up for use, but he describes this pejoratively, as only for poor quality or impermanent works.

There are various methods of slaking lime, which are the following:

First method: called ordinary aspersion or the ordinary method. It consists in throwing water onto lump lime, by sprinkling or other means. It is necessary that the quantity of water that is added is not excessive, lest the lime should be drowned. This method is that which achieves the largest part of the extinction of common and hydraulic limes, especially when the latter will air slake soon after burning. Lime is considered to have been well-slaked when it is left with a dough-like consistency, when the whole mass is cold and contains no lumps or unslaked particles. To test if all the above has been met, one randomly pokes it with a stick and examines the lime that has stuck to it.

To slake lime by the ordinary method, put it upon a dry horizontal surface, and form a ring (enclosure) around it, with the intention of afterwards mixing with it the materials which will constitute the mortar. These 'basins' are commonly made with the same sand with which it will be mixed. It is better to form a shallow pit with sides of stonework, when the works will be of long duration, the same is also more convenient when slaking hydraulic limes.

Lay out the lime in layers of between 20 and 25 centimetres at the most, and throw on the water in a way that it will reach all of the hollows; one must be careful not to disturb the layer until all has slaked… (be careful with hydraulic limes not to give them too much water, unless they are to be used immediately, because they will set. Have two tanks - one to slake, another to mix to mortar); it can take up to 12 hours for (hydraulic quicklime) to slake. In order to obtain slaked lime or mortars of the consistency wanted (for different purposes), one should have various tanks, staggered when the ground has the necessary gradient. These are connected by pipes…with the objective that the cleanest grouts (of lime) will flow to the lowest tank. They are beginning to use these in England, where it is becoming widespread to use an apparatus (mill) not only to slake the lime but also to mix the lime with the sand and make the mortars.

Second Method. Immersion consists in placing the lime in a sack or basket and submerging it in water for some seconds; sometimes for some minutes, depending upon the class of lime. It is removed from the water when it stops absorbing it, which can be known by the ceasing of the slight noise produced by the absorption; but this should be verified before beginning the slaking to doughy consistency. One should immediately heap the lime to concentrate the heat and facilitate the slake. …When the lumps of lime are large, they slake with difficulty by this method. If one has left the lime exposed to the weather before slaking, many small lumps will be left after slaking by immersion; to avoid this one should reduce the lump you are going to slake by this method roughly to the size of walnuts; placing it in barrels on removal from the water can concentrate the heat which would otherwise dissipate in evaporation and makes the work easier for being better slaked… It takes approximately one man day to break, immerse and slake three cubic metres of quicklime…

Third method or spontaneous extinction - consists in spreading the calcined stone on the floor, forming a layer of some 20 to 50 centimeters deep, exposed to the atmosphere, in (an open-sided) shed to prevent it being rained upon…

In works of little duration or importance, one makes the mix (la mezcla - vernacular for mortar), by taking the lime as quickly as possible after it has slaked and heaping it with sand in the adopted proportion; sprinkling the surface of the heap - this forms a crust that preserves the interior. From here, one takes what is necessary, beating the mortar with water in a ring ('enclosure') which one forms out of sand. It is easier and more convenient to beat the mortar in pans or (shallow) tanks, like those in which lime is slaked.

1859 – Construction of the Canadian Parliament, Ottawa

Reference: Fuller T & Jones C Architects (1859) Contract and Specifications for the Parliament Buildings Ottawa (Toronto Public Library).

The lime used was from Hull, Ottawa; a lime that when tested by Royal Engineers, building St Lawrence Canal, would not set under water. It was, therefore, a fat or feebly hydraulic lime. In addition to many interesting facets, the specification calls for hot-lime grouting, as well as a lime-rich hot-mix, mechanically ground, for the rubble work.

Foundation: Large, well-bedded and well-bonded stones laid in mortar and properly grouted with hot liquid mortar… The outside face of the walls to batter…

Flying Buttresses of Library: …joints most carefully wrought… to have slate dowels and be set in mortar formed with the best hydraulic lime or the best Portland cement.

Pinnacles (to have similarly tight joints) and be set in cement.

Floors: 9" thick concrete with 1 ½" of Portland cement laid by plasterer. Concrete to be formed of the best well-burnt hydraulic lime to 7 measures of gravel, sand and broken stones. The lime is to be ground and kept dry under cover in bags until used.

Masonry: All the mortar for rubble masonry to be composed of 2 measures of fresh, well-burnt lime to 5 measures of sand. All the mortar used in the brickwork to be of the best fresh burnt brown lime, 1 part lime and 3 of clean, sharp pit sand.

The whole to be properly mixed together dry and a sufficient quantity of water added, the whole to be ground under edge runners or in pug mills.

The mortar to be used as hot as possible and no more mortar to be mixed in one day than can be used on the same.

The pointing mortar – 1 part best brown lime, 1 part sharp forge ashes, 1 part iron scales. [this would have been immediately incompatible and extremely hard with minimal free lime left]. *Mixed and ground under the edge runner to a fine paste as required for immediate use.*

Interior joints – fine mortar made with lime and sand formed of the stone or marble used.

External brickwork – tuck-pointed with dark mortar. When any is being done in dry weather, the joints are all to be first well-wetted.

Plasterer: Best fresh-burnt Ottawa lime or other approved, the best clean pit sand and best long hair… the lime is to be run some considerable time before being used (from hydrate?). Setting coat of lime and marble dust.

Lime whiten 3 times, all walls.

Floors finished with 1 ½" Portland cement – the cement to be mixed with an equal quantity of clean, washed sharp river sand… finished all in one coat… the whole of the cement used to be best Portland from Messrs White & Co, Millbank, London, England.

Skirtings also of cement.

1860 – Extension of an Inn in Yorkshire

Reference: William Copperthwaite's Specification for the extension of an Inn in Yorkshire; North Riding Archives… NYCCRO ZPB(M) PP7-71.

The 1 part lime called for in this 3:1 mix will be quicklime, which will double in volume upon slaking. Again, we see a call for clean, sharp sand.

Bricklayer: The whole of the walls to be built with good hard well burnt bricks laid in good mortar composed of North Grimston Lime Co lime and clean sand in the proportion of 3 of sand to 1 of lime. […To carry up all Chimney flues and properly plaster the same…]

Plasterers Work: The whole of the work to be plastered with good hair mortar composed of clean sand and Grimston Lime Co lime. All the laths to be good Baltic red fir laths. All the wall and stoothings to be finished 3 coats trowelled smooth for colour or paper. All the ceilings to be finished 3 coats with fine lime putty, the sitting room adjoining Newbiggin to have a neat plaster moulding 16" girth.

1860 – Daniel Jacques, Limewash mixtures

Reference: Jacques D H (1860) Rural Architecture: Or, How to Build Country Houses and Out-Buildings etc New York.

Jacques recommends three different slaking and mixing methods for three different, often considered related, lime applications.

The following cheap and excellent paint for cottages is recommended by Downing. It forms a hard surface, and is far more durable than common paint. It will be found preferable to common paint for picturesque country houses of all kinds. Take freshly-burned unslaked lime and reduce it to powder. To one peck or one bushel of this add the same quantity of fine white sand or fine coal ashes, and twice as much fresh wood ashes, all these being sifted through a fine sieve. They should then be thoroughly mixed together while dry. Afterward mix them with as much common linseed oil as will make the whole thin enough to work freely with a painter's brush.

For the outside of wooden cottages, barns, out-buildings, fences, etc., where economy must be consulted, the following wash is recommended: Take a clean barrel that will hold water. Put into it half a bushel of quick lime, and slake it by pouring over it boiling water sufficient to cover it four or five inches deep, and stirring it until slaked. When quite slaked dissolve it in water, and add two pounds of sulphate of zinc and one of common salt, which may be had at any of the druggists, and which in a few days will cause the whitewash to harden on the woodwork. Add sufficient water to bring it to the consistency of thick whitewash…

Stucco and Stuccoing. Take stone lime fresh from the kiln and of the best quality, such as is known to make a strong and durable mortar (like the Thomaston lime) [a high calcium lime from Maine]. Slake it by sprinkling or pouring over it just water enough to leave it when slaked in the condition of a fine dry powder, and not a paste. Set up a quarter-inch wire screen at an inclined plane, and throw this powder against it. What passes through is fit for use. That which remains behind contains the core which would spoil the stucco, and must be rejected. Having obtained the sharpest sand to be had, and having washed it, so that not a particle of the mud and dirt (which destroy the tenacity of most stuccoes) remains, and screened it to give some uniformity to the size, mix it with the lime in powder, in the proportion of two parts sand to one part lime. This is the best proportion for lime stucco… On the tempering of the mortar greatly depends its tenacity.

1860 – Robert Scott-Burn, Construction Manual for work abroad

Reference: Scott Burn R (1860) Handbook of the Mechanical Arts, concerned in the construction and arrangement of dwelling houses and other buildings (1860) Edinburgh & London William Blackwood and Sons. Originally prepared for the exclusive use of colonists and emigrants.

Although at first an unassuming work with little to say about the mixing of mortars, Scott-Burn's manual for construction was originally prepared to inform Scottish emigrants in the skills and materials of carrying on their construction traditions abroad.

The brickwork to commence on the concrete, the first course being laid and bedded in mortar… The mortar to be composed of one-third well-burnt Dorking, or other approved stone-lime, and two-thirds of sharp, clean, river or other approved sand or road grit, free from salt, the whole to be well laboured. No four course of the work to rise more than ¾ inch beyond the collected height of the bricks; every course to be filled in and fully flushed

up with mortar; and grouted with liquid mortar of hot lime and sand every second course below level of ground floor, and every fourth course above.

Plasterer. Externally. Compo the whole of the external walls, and run the whole of the cornices, strings, mouldings, and dressings generally, with Greaves blue lias lime, mixed with clean sharp river-sand, in the proportion of two parts sand and one part lime…

Internally. The lime to be used for internal work (P48) to be the most approved chalk lime—to be run through a fine sieve, mixed with clean sharp grit sand and strong cow-hair, well mixed and tempered together, prepared a proper time before using, and every precaution to be taken to prevent blistering…

The following is Mr Roberts' plan of forming hard, cheap, and durable floors: "A foundation or substratum should be prepared about 6 inches thick, with coarse gravel, or brick bats and lime-core, well beaten to a level surface. In damp situations, tar may be added to the concrete on which the ash-floor is to be laid, thus prepared: Take good washed sand, free from all earth and stones, together with the ashes of lime fresh from the kiln, in the proportion of two-thirds of sand and one-third of lime-ashes (where obtainable, the sub stratum of the third portion of smiths' ashes, or pounded coke for one-half of the sand, increases the durability and hardness of the floor); mix the sand and lime-ashes well together, and let them remain in a body for a fortnight, in order that the lime may be thoroughly slaked; then temper the mortar, and form the floor with it 3 inches thick, well floated, and so worked that it be not trodden till it has lain for three days, or according to the dampness of the weather, when it should be well rammed for several successive days, until it becomes hard—taking care to keep the surface level; then use a little water, and smooth it with a trowel; after this keep the floor free of dirt, and when perfectly dry it may be rubbed over twice with linseed oil, which gives the appearance of stone instead of sand. Where joists are used, a durable and cheap floor may be made as follows: Reeds are laid across the joists, or, if these cannot be obtained, laths may be used; these are laid close to one another, perhaps two or three deep; across these long laths are nailed to the joists, to keep the laths in their places. The plaster-of-Paris is then mixed and laid over these, spread with a large scraper, and levelled with a mason's level, till of a uniform thickness…

A solid and lasting floor, that will be impervious to wet and impenetrable to rats, is made of mortar in the following way: Break a quantity of stones, so

as to pass through a ring 2 inches diameter; lay these in an even layer on the floor to a depth of 5 or 6 inches; make a gravel-and-mortar concrete, with small gravel and newly slaked lime; pour this in a thin state equally over the stones to a depth of 2 or 2 ½ inches. When this layer has set, spread over it another layer about 1 ½ inches thick, composed of one part lime to two parts sand; just before this is dry, go over the smooth surface with a whitewash brush; this outer finish will last nearly as long as the floor itself. Where hydraulic cement can be obtained, it makes a first-rate floor.

1861 – Hitchcock, et al. The Geology of Vermont

Reference: Hitchcock E, et al. (1861) Report on the Geology of Vermont, Descriptive, Theoretical, Economical and Scenographical.

"To obtain lime for water cement, the impure limestone should be broken into small pieces and subjected to a heat sufficient to expel the carbonic acid... care must be taken that the heat is not too intense, for if it is, the rock will become partially fused, and a glassy substance will result from the alkaline and silicious constituents of the rock. After calcination, the rock should be thoroughly pulverized and mixed with sharp sand, after which water may be applied until the mass assumes the consistency of common mortar, when it should be used immediately, especially if it possesses the setting property of some cements. The proportion of sand to be used with the cement, varies with the composition of the lime."

Meagre Lime. Although this kind of lime often slacks slowly and less perfectly than fat lime, and when water is added, forms a less perfect paste, and therefore, does not work so well with the trowel; and as it takes up less water and bears less sand, is therefore more expensive, yet after all, it hardens with greater certainty, and to a greater degree, and forms a more enduring and stronger cement. It is especially valuable for the property which much of it possesses, of hardening in damp as well as in dry places; and where mortar is exposed to the weather, it is by far the best. Nevertheless many of the circumstances mentioned above, produce a prejudice against this sort of lime, especially among bricklayers...

Having occasion to plaster a building upon the outside it seemed to me that this lime would be well adapted for the purpose. I tried it by mixing one part of unslaked lime with one part of sifted ashes, and one part of sand, and found it to produce a cement that spread well and became very hard.

1861 – Ottawa Public Buildings - Specifications and rates

Reference: Contract, Specifications and Schedules of Prices of Departmental Buildings, Ottawa City 1861, Augustin Cote, Quebec.

Stonemason: Pointing to be with an indented joint in blue mortar, prepared with smith's blowings and other materials as will be directed. ¼" thickness. Mortar for rubble work: 1/3 best hard burnt lime from the Gloucester quarries and 2/3 clean sharp gravel or coarse sand. And grouted with lime and sand in a liquid state every foot in height. The mortar to be mixed, ground in a pug-mill and used fresh from day to day. All the cut stone dressings to be laid in putty.

Bricklayer: ...Mortar – 1/3 best burnt lime and 2/3 sharp sand also mixed in a pug mill and used fresh from day to day, every course to be fully flushed up with mortar and every 4th course carefully grouted with hot grout as before described.

Plasterer: The mortar of the first and second coats to be compounded of the best hard burnt lime, of the district, and clean sharp gravel or coarse river sand, mixed in the proportion of 3 parts of sand and 2 of lime and a sufficient quantity of long cow hair. The lime to be all run through a screen and mixed at least 3 months before it is required to be used. White finish – the lime used for the finishing coat of plastering is to be brought from Guelph, mixed with fine sharp clean sand. (Guelph was a source of dolomitised limestone).

1861 – Construction of Farm Buildings in England

Reference: Stephens H and Scott Burn R (1861) The Book of Farm Buildings, their arrangement and construction. Edinburgh and London. Blackwell.

Portland Cement. — The most important of the artificial hydraulic cements is that known as Portland. It is "made from carbonate of lime mixed in definite proportions with the argillaceous deposit of some rivers, running over clay and chalk." The whole are pounded together and afterwards dried and burnt. It is called Portland cement from its colour, resembling that of the well-known Portland stone. It is a cement possessed of extraordinary strength, being four times nearly as great as that of any of the natural hydraulic cements. It forms, when mixed with small or even with broken bricks, a concrete of great strength: the proportion of cement required being so small as a tenth or even a twelfth part...

Exterior Finishings, Rough-Casting, Stuccoing. — We purpose giving a few hints on the finishing of external walls, as rough-casting, stuccoing, &c. The outside walls of prairie houses are finished in two ways — these are, rough-cast and stucco.

Rough cast consists of a small quantity of mortar diluted with water in a tub; to this a trowelful of pure lime is added, so as to make the whole of the thickness of cream. To finish the walls with greater expedition, the joist-holes may be left not filled up; into these, joists may be inserted, on which to place scaffolding to bear the operatives. The walls are prepared for plastering by indenting them all over from top to bottom with numerous hammer or pick marks: the closer these are to each other the better. The rough-cast is laid on as follows: The indentations in the wall being first carefully swept, the wall being sprinkled with water, the workman takes his brush filled with rough-cast mortar and dashes it against the wall. The indentations in the wall give the appearance of the ordinary rough-cast with pebbles in it. The scaffolding being placed at the top of the wall, he lowers his scaffold, takes out the joists, fills up the holes with bricks, mortar, &c, and, fastening his scaffold lower down, proceeds as before.

Stucco for outside work is made with one bushel of unslaked lime to six bushels of clean sharp sand. Stucco-finishing is laid on as follows: The walls being previously indented, swept, and sprinkled with water, the workman places some mortar on a flat piece of board 12 inches square, provided with a handle, and with a plastering-trowel lays this on the wall, pressing it closely between the indentations, and working the surface, finally, fair and level, it being sprinkled at the same time by means of a brush with some of the thin mortar, — the poorer the mortar the better the stucco. Lime-wash is used as a final covering to the stuccoed wall. This is made by dissolving some unslaked lime in clear water, and sprinkling it on the wall before the stucco is dry. When applied in this manner the stucco sets very hard, and the white colour of the wash is so incorporated with it that it will never wash off, although no size or oil is used — indeed, the using of these renders the white dead and less brilliant; whereas, if the lime-wash is alone used, the colour will remain naturally as long white as the plaster lasts. All the plastering should be done at one time: new plastering never sets well with old. It is absolutely essential that the walls shall be thoroughly dry before the plaster is laid on. If this is not attended to, the plaster will inevitably scale and blister off, leaving unseemly spots.

The method of Rough-Casting Rubble Stone or Brick Walls is as follows: First wash the earth from the gravel or coarse sand, and bring it to a

uniform size by sifting it, or passing it through a screen; mix the gravel with newly- slaked lime and water, to the consistence of thick cream. Having cleaned the part of the wall to be operated on with a rough brush, a coat of lime and hair is laid on smooth, and, as fast as some two or three square yards are finished, the rough-cast is thrown upon it. Some recommend the first coat of lime and hair to be allowed to dry, and a second coat put on, upon which the rough-cast is finally thrown. Instead of throwing the rough-cast on, small pebbles may be stuck in the mortar while yet in a soft state. This, however, is a tedious process.

Whitewash for External Walls. — A cheap wash for the outside of wood cottages, outbuildings, &c, is made by slaking fresh quicklime with boiling water, and adding some sulphate of zinc — sufficient water being put in to bring the whole to the consistence of cream. The addition of the sulphate of zinc tends to harden the wash, and make it more durable. The addition of a little sulphate of iron will give the wash a warm tint, which will be much more agreeable to the eye than the pure white resulting from the above.

1861 – Specifications for Departmental Buildings, Ottawa

Reference: Stent and Laver Architects (1861) Contract, Specifications and Schedule of Prices of Departmental Buildings. Ottawa City, CW. Quebec Augustin Cote.

East and West Blocks, Parliament Hill (formerly Barrack Hill), Ottawa

Mason. ...All these several walls are to be constructed... with good, flat, even bedded stones laid in mortar, compounded of one-third best hard burnt lime from the Gloucester quarries, and two-thirds clean sharp gravel or coarse sand, the interstices, of the stone work to be filled with stone chips or spauls, and grouted with lime and sand in a liquid state every foot in height ; the mortar to be mixed, ground in a pug mill, and used fresh from day to day. Thorough bond-stones to be laid throughout all the walls, at Bond - intervals not exceeding 6 feet in length and 2 feet in height having a bed of not less than 3 superficial feet, and a mini mum thickness of 8 inches. All the cut stone dressings are to be set in putty, the external pointing to correspond with the specimen referred to.

Bricklayer. ...The bricks to be set in mortar, so that no four courses of brick are to rise more than one inch above the actual thickness of the bricks themselves. All the brickwork to be built in Flemish bond for 13 inch, and in English bond for 9 inch walls, and the mortar to be composed of one-third best burnt lime and two- thirds sharp sand, also mixed in a pug mill, and

used fresh from day to day, every course to be fully flushed up with mortar, and every fourth course carefully grouted with hot grout as before described.

Cut Stone Mason. ...All copings on parapets and other portions where the upper surface of the stone is exposed to the weather, are to be both set and joggled in hydraulic cement... Each of the Entrance Hall floors, terminating at the inner doors, is to be formed of a bed of concrete, 9 inches in thickness, and upon that a layer of finer concrete 1 ½ inch thick, formed of gravel about the size of a pea, and clean sharp sand and hydraulic lime, and on this a layer of Portland cement 1 ½ inch thick, mixed with a proper proportion of fine sand, this finishing coat to be laid by the Plasterer. The cement is to be laid in the best and most workmanlike manner and as will hereafter be directed, and so floated that no joint or unevenness may be seen after completion. The concrete to be formed of the best well burnt hydraulic lime (fresh burnt) mixed in the proportion of one part of lime to seven parts of gravel, sand and broken stones. The lime is to be ground under the edge runners, and left dry under cover in bags till required for use. The paving of the basement rooms and passages to be formed with the same material...

Plasterer. The mortar for plastering of the first and second coats, to be compounded of the best hard burnt lime, of the district, and clean sharp gravel or coarse river sand, mixed in the proportion of 3 parts of sand and 2 parts of lime, and a sufficient quantity of long cow hair.

The lime to be all run through a screen, and mixed at least 3 months before it is required to be used. The lime used for the finishing coat of plastering, is to be brought from Guelph, mixed with fine sharp clean sand. ...All the floors mentioned in cut stone Masons Specification are to be of Portland cement, done as there directed. The cement to be the best Portland cement manufactured by Messrs. B. White & Co. Milbank, London, England, and the Contractor will be required to produce and deliver to the Architects a written guarantee from the manufacturers that their best cement has been supplied. The cement is to be mixed with an equal quantity of clean sharp washed river sand, laid to the proper thickness, and finished all in one coat... All external angles of chimney breasts, or otherwise, to be worked in Keenes' or Martin's cement, made perfectly straight and plumb...

All the rooms on the basements, which are not plastered, together with the water closets and offices, are to have two coats of white lime wash, the brick or stone work being first neatly pointed with mortar.

1862 – Captain Henry Scott, Limes and Cements in Military applications

Reference: Scott H (1862) Observations on Limes and Cements; their properties and employment. Papers on Subjects Connected with the Duties of the Corps of Royal Engineers Vol. XI. Woolwich. Jackson.

Scott makes a strong case for the use of hydraulic limes in the air and summarises the growing conviction among military engineers – from Vicat onwards – that fat limes should not be used, whilst acknowledging very clearly that masons preferred them and that craft practice was the biggest obstacle to the embrace of hydraulic limes for building in the air, as well as in water. Unlike Vicat and others, Scott endeavours to make the case with reasoned argument, rather than just by assertion. He also offers a concise literature review of other engineers' – particularly French engineers' - work on limes, aggregates and pozzolans. The primary context, however, is the provision of military defences, not domestic architecture. Many of his observations on fat and feebly hydraulic limes – slowness of set, in particular, are valid. They are not, however, especially relevant in the context of like-for-like repair and compatibility. Scott did not consider this, as did no historic writers on lime. He offers examples of lime mortars that have never set at depth, but also remarks that many of these are in buildings many hundreds of years old, but he does not then go on to wonder if the slowness of set matters structurally. Excerpts here will be limited, but Scott's treatise is one well worth seeking out.

It is frequently supposed that, except in wet or damp situations, pure (or "fat") lime mortars attain great strength, and that there is no advantage in employing hydraulic limes excepting where the presence of wet or moisture renders a water setting material necessary. It is still more frequently, indeed generally, believed that though the limes do not set at first as rapidly as the cements, yet, that ultimately, they attain an equal or greater degree of hardness, and that the cements offer so much uncertainty in their use, as to make it advisable to use them as little as possible. A consideration of the causes which influence the setting of mortars will show that these ideas are probably erroneous…

When exposed to the air… (fat limes) will gradually harden from the surface inwards, but always at a slower and slower rate, until, after the lapse of some years, no further perceptible progress is made…

Sir Charles Pasley's testimony is characteristic, and the more valuable because he once held a different opinion — "I had ascertained," he writes, "more than 12 years ago, that the pure limes, such as chalk lime, Carrara

marble, &c., were utterly unfit for the purposes of hydraulic architecture, as they dissolved away on the outside, and never set at all in the inside of walls exposed to the action of water. But I was of opinion at that time that the mortar of these limes was good for dry situations and for inside work, provided that the external joints were protected against the effects of beating rains, by pointing them either with cement or some superior sort of lime... Having, however, acquired much more experience, partly from experiments, and partly in consequence of continual observations of new buildings in progress, or of old buildings being pulled down, since the first sheets of this work were sent to press, I am compelled to retract the above opinion in favour of chalk limes, which I now consider bad under all circumstances, even in the driest situations, as it never attains any great degree of adhesiveness, even when only exposed to the atmosphere, and its resistance is so insignificant, that it rather dries than sets in air. All that can be said in favour of chalk lime mortar is, that it is better than none; and that walls built with it will not fall to pieces in process of time, as General Treussart asserted, without external violence" (Pasley on Cements Appendix CX).

"We are in the habit of composing our mortars," says Treussart, "of fat lime and sand, our mortars consequently have little durability. We shall not obtain durable masonry in the air until we can make use therein of hydraulic mortars" (Memoir sur les mortiers, section 2 Chapt 14).

It might have been supposed that testimony so strong and unanimous, and from such reliable authorities, would have quite settled the question as to the unfitness of pure limes for fortification works at least, but so firmly rooted in the minds of our engineers was the old notion that good mortar could be made from pure lime (a notion by no means confined to Military Engineers) that we have, notwithstanding, used the fattest of limes for all the masonry at Gibraltar not exposed to the action of the waters of the bay, and within the last few years the pure Plymouth lime has been used for works at Devonport.

[On the best lime:sand proportions]
...Enough has now been brought forward to show how unsatisfactory and contradictory are the statements made and the rules followed, by the theorizers on the effect of sand on mortars used in brick and stone masonry, and it is hoped a consideration of all the evidence will lead to the conviction that this is not a question to leave to be resolved by the convenience of the workman and the interests of the builder. Exception is taken, not so much to the proportion of sand specified for works, (for this is

generally moderate, and would cheapen the mortar without materially detracting from the resistance of the masonry) as to the practice which permits a departure from the specification, and any quantity to be introduced that does not render the mortar "short," on the supposition that the plasticity which best satisfies the skilful workman is the surest criterion by which to judge of the proportion of sand and lime to secure the greatest resistance...

The Slaking of Lime.
The next point to be considered is the mode in which the lime should be slaked. Many opinions have been expressed on this subject also, but fortunately, the most generally approved is also one of the simplest of execution.

The methods employed have been generally divided into three — ordinary extinction, immersion, and spontaneous or air slaking. The first, which is most commonly used on the continent and often in this country, consists in throwing on the lime, as it comes from the kiln, enough water to reduce it to a thin paste. Too much water is in this method generally added in order to facilitate the mixture with the sand. The lime is, as it is termed, drowned, and the slaking is checked.

The second method of French writers consists in plunging quick lime into water for a few seconds, and then throwing it into a heap and allowing it to fall to a powder. The operation is performed in baskets, the lime being broken to the size of an egg before immersion. M. de Lafaye proposed this method towards the end of the last century as a secret recovered from the Romans. There are various difficulties in this mode of slaking lime, the chief being that the workman cannot be made to hold the lime in the water the requisite time.

A modification of this process is much used in this country. Enough water is thrown on the lime to slake it to a powder, and then sand is heaped over it to cover it all up and retain the warmth and moisture. The quantity of water necessary to bring the ingredients to a paste is added subsequently.

Writers are not at all agreed as to the best method of effecting the operation of slaking, or on the absolute resistances obtainable according as the one or the other method is employed...

General Pasley says... [that] "for both in cement and in lime I have found by experiment, that what M. Vicat aptly terms drowning is prejudical to them."

In this last opinion all writers are in accord, and since the first method is allowed to lead to this abuse, and it does not secure the perfect slaking of over burned particles of hydraulic lime, it should be proscribed for making mortar for heavy masonry [in favour of dry-slaking)...

On Mixing the Ingredients of Mortars.
...Colonel Raucourt de Charleville has given a good reason for grinding or pounding being beneficial with hydraulic limes, and especially with puzzuolanas and other earths of a like kind. The remarks made above on the wretched mixing of the mortar used at Eastbourne, where particles of lime larger than peas, and in great abundance, escaped slaking before the mortar was introduced into the work, or the inspection of any hand made mortar, after setting, will show how little the sweat of the labourer has done towards moistening it, and how important it is not to trust to his care and diligence, or even to his powers of making a good mixture, whatever his will.

Davy indeed prefers the ordinary or larrying method of making mortar, because the mixture of lime and sand can thereby be made more perfectly, whereas by the method of sprinkling, recommended in this paper, there are, he states, always small particles of the lime that cannot be properly mixed, however much it may be chafed up.

...We may then assume that wherever the work is of sufficient extent to justify the first outlay on machinery, hand made mortar should not be allowed. The cheapest good method of mixing is probably that, now commonly adopted on large works, of grinding the ingredients together under an edge stone. This is recommended, not with the view of reducing the sand to a powder, but of breaking down all unslaked particles, and of perfectly incorporating and condensing the ingredients. If the edge stone system is too expensive to adopt, a pug mill forms the best substitute for it. The safest plan with strong hydraulic limes is undoubtedly to grind the lime to a fine powder before mixing it with the sand.

Puzzuolana, and other like substances, absolutely require to be ground very fine as well as to be intimately mixed with the lime in order to develop their properties...

When the lime is first ground to a powder, and is then partly mixed with the sand before any water is added, as is done with cements, it is probable that much better hand mixtures could be made, but there is danger in permitting lime to be ground before it is brought on to the ground... and it

is essential that it should be finely ground, for the over-burned particles which generally escape grinding are precisely those which most require it.

On Estimating The Ingredients of Mortar.
[Scott stresses the need to confirm the relative bulk densities of different quicklimes and forms of lime – lump or powder, etc. – to inform the appropriate gauging with sand by volume, adjusting the volume of lime accordingly.]

…There is an immense difference in the absolute quantity of lime in the same bulk of different sorts of lime. A bushel of grey chalk lime weighs only 50 lbs.; a bushel of Plymouth pure lime about 70 lbs.; and a bushel of Keynsham lias lime, 80lbs. It manifestly, therefore, would be an inaccurate mode of proceeding to estimate the quicklime by volume alone, without reference to weight. If the lime is delivered ground, the time which may have elapsed since the lime left the kiln, the degree of exposure to which it has been subjected, the degree of compression given to it, and the season of the year, will greatly affect the amount of lime in a given volume.

The best method would appear to be to determine the weight of a given volume, and then, with reference to this weight, to calculate the requisite volume in lump to supply the required actual or absolute amount of lime for a certain bulk of sand. The proportions for the two in volume being thus determined on, measures of wood may be made to allow of the two ingredients being added in the requisite quantities without the necessity of fractional estimations…

The workman compounds his mortar pretty much as he chooses, or as his own immediate employer may direct, if by so doing he does not increase his own labour; and as Sir Charles Pasley states, "Actual measurement is not employed at all, the proportions of the ingredients being left to the tact or sagacity of the labourers who make the mortar, or if measure be used the rudest sort only is employed, that is, shovelsful or barrowsful."

On Proportioning The Ingredients of Mortar.
…we may conclude, that with hydraulic limes such as the Lias (weighing 50lbs. the cubic foot), 2 cubic feet of sand may be added to 1 cubic foot of lime; that with feebly hydraulic limes, such as the Dorking and Halling grey chalk limes, 2 ½ cubic feet of sand may be added to every 50lbs. of lime; and in the case of pure limes, if we are compelled to use such miserable stuff, we shall not be losing much in resistance if we increase to 3 cubic feet of sand for every 50 lbs. of the lime…

On The Proper Employment of Mortars.
We must now proceed to the consideration of the manner in which mortar should be employed. The first point, to which attention must be directed in its use, is the necessity of thoroughly wetting the materials it is intended to bind, particularly if they are of a dry absorbent character. The second point, that the mortar shall be as stiff as it can be used without inconvenience, and without danger of the joints remaining unfilled when the bricks and stones are forced home. The third, to prevent rapid desiccation which, with hydraulic limes, produces very injurious results. It is sometimes thought that the precaution of wetting bricks is unnecessary with lime mortars, and excepting in very hot weather, when the bricklayer finds their warmth and dryness inconvenient, it is rarely done. Cements, on the other hand, are supposed to suffer in their adhesion if the bricks are not wetted, and consequently it is usual to specify that they shall be so treated... if the hydraulic lime mortars require to be kept moist to secure their induration, as all writers assert, it is nearly if not quite as necessary to make the proviso, that the bricks shall be wetted when used with lime mortars, as when used with cement...

Mr. Burnell, in the preface to his work on Limes and Cements, says, "That which is to be desired above all things is to rouse the professions of engineers and architects from the apathy with which they treat such subjects as the one before us — the very alpha and omega of their business." His representations, however, have been as ineffectual as those of the distinguished men whom he follows. Smeaton long since explained, "It is not to be wondered at that workmen generally prefer the more pure limes for building in the air, because being unmixed with any uncalcareous matter, they fall into the finest powder, and make the finest paste, which will of course receive the greatest quantity of sand (generally the cheaper material) into its composition, without losing its toughness beyond a certain degree, and requires the least labour to bring it to the desired consistence; hence mortar made of such lime is the least expensive; and in dry work the difference of hardness, compared with others, is less apparent." ...the workman, however, preserves his empire...

It is a difficult matter to alter the practice of those who have grown grey in exalting "practical experience," and in the comfortable persuasion that the bricklayer knows best how to make good mortar, and can be trusted to make it...

I look confidently forward to the day in which we shall feel quite independent, as respects mortar making, of the workman's traditions.

1862 – James Austin's Manual on Limes and Cements

Reference: Austin J G 1862. A Practical Treatise on the Preparation, Combination and Application of Calcareous and Hydraulic Limes and Cements. New York.

On the preparation of common mortar. The lime when properly prepared or burnt in the kiln should be speedily withdrawn, and packed for transportation to its intended destination, in sound casks or air-tight vessels well closed down, and should be kept entirely free from all moisture; and when received by the builder should be deposited until required for use (which should be as early as possible) in a shed or other dry building, or if left out of doors should be closely covered down with a tarpaulin, or boards, and each cask should be unheaded and opened only as required. three (slaking) methods in use:

The 1st and most usual is by pouring or throwing the necessary quantity of water over the lime after it is spread out into a shallow heap, surrounded by the whole or a portion of the sand with which it is to be incorporated.

The 2nd: By immersion, or plunging the lime when deposited in a basket or other suitable receptacle for a few moments into water until the surface lime begins to effervesce or boil and then turned out into heaps to afford time and opportunity for the slaking to be completed.

3rd, by mere exposure to the atmosphere, the lumps of lime having been previously broken up to about the size of a pigeon's egg, or somewhat smaller, so as to secure a more speedy and effectual calcination of the whole, but this operation must not be performed in wet weather, nor in too damp an atmosphere; it must be carefully watched, and so soon as the slaking is complete, the quicklime must be immediately used or deposited in close casks till required. This method is seldom adopted except for plasterers, who consider lime made in this way preferable for their work, as it is said to make the lime stronger. This mode suits fat limes (such as slake freely) better than poor limes. Lime slaked by the second process will keep well for months in a dry, sheltered spot.

But in every case where water is employed for slaking lime or mixing the mortar subsequently, care must be taken not to 'drown' the lime… and also not to go to the opposite extreme, but to put the quantum suff. at once, which is usually computed at about one and a quarter of the weight of the lime… for if the water be applied tardily or sparingly, the lime will be benumbed, or imperfectly calcined, and gritty…

The purest limes require the largest proportion of sand, and require the most water in slaking, and harden in less time than the common limes…

Various Recipies
Beavans mortar, or building cement is composed of marble, flint, chalk, lime and water, and when dry, is capable of a high polish. Its proportions are equal parts of marble, flint and chalk; pulverized, mixed together and passed through a very fine sieve; add to this one part of lime which has been slaked three months, and sufficient water to make the whole into a thin paste; and in this state to be applied over a coarse ground (or previous coat), as thin as possible, and rendered smooth on the surface; and when dry may be polished by Venetian talc. If buildings are to be covered with it, a preparatory rough ground should be attached, formed of river sand and lime…

Dutch trass, terras or tarras (is) abundantly used in the construction of mounds, weirs and other aquatic works. The celebrated mortar is made by covering a previously prepared mass of quicklime of about a foot in thickness (and sprinkled with water), with an equal quantity of powdered terras, and then left for two or three days, after which the quantity required for immediate use is… beaten up to a proper consistency.

One measure of quicklime, and two of slaked lime, in powder, and one of terras, well mixed and beaten together to the consistence of a paste, with as little water as possible, forms the terras mortar in general use; and a cheaper kind is made by mixing two parts of slaked lime, one of terras and three of coarse sand together. These cements indurate very quickly under water and remain very firm…

Meager or poor limestones are best suited for hydraulic mortar, such as contain from 8 to 25 per cent of foreign matter, such as slica, alumina, magnesia etc; these, though calcined, do not slake when wetted, but when pulverized, will absorb water without heat or swelling and form a paste which will harden under water in a few days, but will never become greatly indurated by simple exposure to the air.

All sorts of lime can be made hydraulic by mixing slaked lime with solutions of common alum, or sulphate of potash to mix with the lime or lime and clay.

…Beton, used for constructing marine works, consists of 12 parts of puzzolana or Dutch trass, 6 parts of sand, 9 parts of unslaked lime, 13 parts

of stone fragments, about the size of an egg, 3 parts of tile dust, cinders or scales from a forge; the whole well worked and beaten together.

From experiments, Colonel Totten deduces the following general results:

1st That mortar of hydraulic cement and sand is the stronger and harder as the quantity of sand is less.

2nd That common mortar is the stronger and harder as the quantity of sand is less.

3rd That any addition of common lime to a mortar of hydraulic cement and sand weakens the mortar, but that a little lime may be added without any considerable diminution of the strength of the mortar, and with a saving of expense.

4th The strength of common mortars is considerably improved by the addition of an artificial puzzolana, but the more so by the addition of a hydraulic cement.

5th Fine sand generally gives a stronger mortar than coarse sand [this contradicts the observations of others].

6th Lime slaked by sprinkling gave better results than lime slaked by drowning. A few experiments made on air-slaked lime were unfavourable to that mode of slaking.

7th Both hydraulic and common mortar yielded better results when made with a small quantity of water than when made thin.

8th mortar made in the mortar mill was found to be superior to that mixed in the usual way with a hoe.

9th Fresh water gave better results than salt water.

1864 – Gillmore's Manual on Mortars

Reference: Gillmore Q A (1864 & 1886) Practical Treatise on Limes, Hydraulic Cements and Mortars.

Gillmore is the most articulate and considered of all the historic writers upon the subject, with the possible exception of Henry Scott (see below). He had a strong grasp of the practical, as well as enormous intellectual

capacity. Few of his words are wasted. For this reason, his work is quoted extensively below (written in 1861 but published later).

Calcareous mortar, being composed of one or more of the varieties of lime or cement, natural or artificial, mixed with sand, will vary in its proportions with the quality of the lime or cement used, the nature and quantity of sand, and the method of manipulation. No fixed rules for its preparation, that shall be equally well adapted to all the varying circumstances of locality, temperature, and the seasons, can be prescribed.

In practice... mortars are weakened by the addition of sand (or other aggregates, including brick). These... have the important effect, however, of preventing or diminishing shrinkage, of hastening the induration of rich limes, and of rendering all kinds of mortars less liable to crack in drying, which is often of very great advantage. They are, moreover, by far the least costly ingredient of mortar, and a due regard for economy compels their use in the largest possible proportions.

(However, whilst)... it might be inferred that the minimum amount of the cementing material that can be used in any case is exactly equal to the volume of the voids in the sand, when the latter is well compacted [typically 1:3]. This theory supposes that there is no shrinkage in the matrix while hardening, and that the manipulation [slaking] is complete. But as these conditions can never be fully attained in practice, it is unsafe to descend to this inferior limit. Moreover, mortars composed on this principle would be deficient in both adhesive and cohesive power, from the fact that the particles of sand would present a large area, practically void of matrix, to the surfaces of the solid materials that are to be bound together, and would, for the same reason, be in more or less intimate contact with each other throughout the mass. In order to avoid these defects, it is customary to determine the amount of cementing matter to be used in any particular case, by adding 45 to 50 per cent to the volume of void space in the sand.

Three methods of slaking lime are usually described in works on mortars; on the continent of Europe, the third method, and in the United States, the second and third are seldom resorted to in practice.

The first or ordinary method termed drowning from the excessive quantity of water sometimes injudiciously employed, consists of pouring upon the lumps of lime, collected together in a layer of uniform depth not exceeding six to eight inches, either in a water-tight wooden box or a basin formed of the sand to be subsequently added in making mortar, and coated over on

the inside with lime paste, to render it impervious to water, a sufficient measure of fresh water – previously ascertained approximately by trial – to reduce the whole to the consistency of thick pulp. It is important that all the water required for this purpose... should be added at the outset, or, at least, before the temperature becomes sensibly elevated. In this condition the lime will remain entirely submerged, and comparatively quiescent, until after an interval of five to ten minutes, the water becomes gradually heated to the boiling point, when a sudden evolution of vapour, a rapid increase in volume, and a reduction of the lime to pulp, ensues.

This process is liable to great abuse at the hands of workmen, who are apt to use either too much water, thus conferring upon the slaked lime a condition of semi-fluidity, and thereby injuring its binding properties; or, not having used enough in the first instance, they seek to remedy the error by adding more after the extinction has well progressed, and a portion of the lime is already reduced to powder, thus suddenly depressing the temperature [?] and chilling the lime, which renders its granular and lumpy.

As soon as all the water required has been poured upon the lime, it is recommended to cover up the vessel containing it with canvas or boards, in order to concentrate the heat and the escaping vapour, and direct their action upon the uppermost portions deprived of immediate contact with the water, by the swelling of the portions at the bottom. When it is not practicable to apply this covering, a tolerable substitute is found in the sand to be subsequently added to the mortar. This can be spread over the lime in a layer of uniform thickness, after the slaking has well progressed.

Another precaution of equal, and perhaps greater importance is not to stir the lime whilst slaking; but to allow it gradually to absorb the water by capillary attraction and its natural avidity for it, taking care that all portions are supplied with it to that degree requisite to produce a paste of the slaked lime, and not a powder. When the lime is to be used for whitewashing or grouting, the water should be added at the outset in larger quantities than specified above, and the whole mass should be run off while hot into tight casks, and covered up to prevent the escape of water.

Slaking by Immersion. The second method of slaking (by immersion) consists in suspending the quicklime, previously broken into pieces of about the size of a walnut, and placed in a basket or other suitable contrivance, in water, for one or two minutes, taking care to withdraw it before the reduction commences. The lime should then be quickly heaped together, or emptied into casks or bins, and covered up, in order to concentrate the

heat and prevent the escape of vapour. In this condition it soon begins to swell and crack, and finally becomes reduced to a fine powder, which may be preserved several months without serious deterioration, if packed in casks, and kept from direct contact with the atmosphere. The expense which would ordinarily attend the practical application of this process, and the difficulty, and even impossibility of securing with certainty, at the hands of workmen, the period of immersion, have led to a modification of it, which consists in sprinkling the broken fragments formed into heaps of a suitable size, with one-fourth to one-third of their volumes of water. This should be applied from the rose of a finely gauged watering-pot, after which the lime should be immediately covered with the sand to be used in the mortar. In this condition it should not be disturbed for at least a day or two, and the opinion prevails in the southern portions of Europe that the quality of the lime is improved by allowing the heaps to remain several months, without any other protection from the inclemency of the weather than an ordinary shed, open on the sides. In the vicinity of Lyons this custom very generally obtains, the autumn being usually selected for slaking all the lime required for the following season's operation. In Europe this method of slaking is applied to the fat and slightly hydraulic limes only, and not to those that are eminently hydraulic, upon which it seems to act disadvantageously, by depriving them, in a measure, of their hydraulic energy…

General Treussart entertained the opinion that they should be made into mortar and used soon after their extinction. This idea finds few advocates at the present day, although the practice in this country conforms to it with singular unanimity… When mortar is to be made in quantities sufficiently large to warrant the expense, a mortar mill of some approved pattern should be provided, for incorporating the ingredients, as the mortar thus obtained is invariably superior to that produced by the use of the hoe and shovel only…

When ordinary lime mortars are… made by hand, it is customary and convenient to slake the lime by the first method described, and in no greater quantity than may be required for immediate use. The operation should be conducted under a shed. The measure of sand required for the 'batch' is first placed upon the floor, and formed into a basin for the reception of the unslaked lime. After this, the latter is put in, and the larger lumps broken up with a mallet or hammer; the quantity of water necessary to form a stiff paste is let on, from the nozzle of a hose, or with watering pots, or even ordinary buckets. The lime is then stirred with a hoe, as long as there is any evolution of vapour, after which the ingredients are well mixed together with the shovel and hoe, a little water being added

occasionally if the mass be too stiff. At this stage of the operation, it is customary to heap the mortar compactly together, and allow it to remain until required for use. When circumstances admit, it should not be disturbed for several days, and during the period of its consumption should be broken down and 'tempered' in no larger quantities than may be required for use from day to day…

Coarse stuff [for plastering] is nothing more than common lime mortar, suitable for brick masonry, to which has been added a quantity of well-switched bullock's hair, to act as a kind of bond. The following proportion is a good one: 1 cask lime – 8 cubic feet of paste, Sand – 16 to 18 cubic feet, hair – 1 ½ cubic feet. When ample time for hardening cannot conveniently be allowed, it will be advantageous to replace 12 to 15 per cent of the lime paste in the coarse stuff, by an equal volume of hydraulic cement or plaster of Paris.

In England, some years ago, when concrete first came into extensive application, common or feebly hydraulic lime, such as the Blue Lias limestone yields, was generally used for the cementing substance. The quicklime, having been first reduced to a powder by mechanical means, was incorporated with the sand and coarse materials in the dry state. Water, in sufficient quantity to slake the lime, being then added, the concrete was rapidly mixed up with a pug-mill or with shovels, conveyed away in barrels or carts, and used while hot. It was employed extensively for foundations, or as a sub-stratum in light and yielding soils. In order to secure the requisite degree of compression and density, it was customary to throw it into its position from a height, and sometimes to ram it afterwards… Of late years, the practice of laying fat lime concrete hot has grown into disrepute among English architects and engineers. They now prefer that the lime should be thoroughly slaked, reduced to a pulp, and made into a mortar with the sand before the coarse materials are added. This process is always followed in making beton. The advantages of it are, immunity from the danger of partial slaking before use, superior homogeneity in the mass, and economy in the amount of lime required.

1870 – Lyman & Croffut's Manual for farm and estate works

Reference: Lyman C R; Croffut WA (1870) A Helping Hand for Town and Country: An American Homebook of Practical and Scientific Information Concerning House and Lawn; Garden and Orchard; Field, Barn and Stable: Apiary and Fish Pond; Workshop and Dairy…New York. Moore, Wilstach & Moore.

How to set Posts Firmly. — Take equal quantities of water lime and quicklime, and mix with sand as usual; put two or three inches of mortar and coarse gravel in the bottom of the hole, so that the end of the post will not come to the ground; then set the post in, top-end down; fill in several inches of coarse gravel; pound it down; then mortar and more gravel, and so on until the cement is raised above the ground several inches around the post. Slant it away from the post in every direction, so as to turn off the water; then take coal tar and a brush, paint around the bottom of the post, and fill the interstices between the post and the cement with coal tar. Only mix enough mortar for one hole at a time. The post will be as solid as if set in stone; it don't heave out with the frosts and sag around and pull the boards off, as the water and air can not get to it.

1871 – Gillmore's Report on Limes

Gillmore Q A (1871) Report on Beton aggloroate, or coignet-beton and the materials of which it is made (1871). Professional papers, Corps of Engineers, US Army, Government Printing Office, Washington.

Common or fat lime. — The lime should be air-slaked, or, better still, it may be slaked by aspersion with the minimum quantity of water that will reduce it to an impalpable powder. It should be passed through a fine wire screen to exclude all lumps, and used within a day or two after slaking, or else kept in boxes or barrels protected from the atmosphere.

In ordinary practice, when sand and hydraulic lime only are employed, it will be found to answer very well to mix the two together dry, with shovels, and then spread them out on the floor and sprinkle them with the requisite minimum amount of water. The dampened mixture is then shovelled into the mill and triturated, as already described. When a portion of Portland cement is used, it may also be incorporated with the other ingredients before the water is added, or introduced into the mixture in the mill, as may be preferred.

1875 – Precautions in Building, and poor-quality mortars

Reference: From an article entitled "Precautions in Building" in The Australian Town and Country Journal, 4 December 1875.

...How is it that mortar is often such perishable stuff, that new buildings often require pointing after a few years? Almost invariably the reason is, that loam is used in order to economise the lime, whereas good mortar consists essentially of lime and siliceous sand alone, the lime in the state of hydrate.

The lime should be fresh, the sand a sharp grit and quite clean, and the water pure and free from salt. The sand is made into the form of a basin, into which the lime is thrown in a quick state; water is then thrown upon it to slake it, and it is immediately covered up with sand; after remaining in this state until the whole of the lime is reduced to powder, it is worked up with the sand, and then passed through a wire screen, which separates the core. More water is then added, and it is well worked up or larryed for use.

1886 – Allen Bruce, Cottage Building

Reference: Bruce Allen C (1886) Cottage Building, or Hints for Improving the Dwellings of Working Men and Labourers. London Crosby, Lockwood and Co.

Lime-ash floors are formed in several ways, according to the locality. One of the most approved methods is the following: the sand to be used, after being well washed and freed from earth, is mixed with lime ashes, in the proportion of two- thirds sand to one-third lime ashes, both thoroughly mixed together. It is then, after being suffered to remain for two or three days, tempered with water, and laid on the ground, or other surface to be covered, to the depth of about 3 inches. In two or three days it becomes sufficiently hard to bear treading on, and is then beaten all over with a wooden mallet, till it becomes perfectly hard, using at the same time a trowel and a little water to render the surface as smooth as possible...

1888 – The Dereham Times 'Good News for some Workers'

Reference: Archive Newspaper cutting.

Hitherto British bricklayers have been on the verge of poverty all through that part of the winter when frosts have been keen. They supposed that whoever else worked, they needs must be idle. Now, however, we learn on the authority of our Consul General in Norway that this all comes of our workers being too conservative in following the methods which satisfied their fathers and forefathers. Norwegian bricklayers rather prefer winter work, because the walls built then dry quicker and better. The advantage is simply the result of using, on dry bricks, unslaked lime as mortar, and preparing the mortar in small quantities immediately before it is used. The remedy for idleness is so plain and simple that it ought to commend itself both to British masters and men.

1889 – George Powell, Foundations and Foundation Walls

Reference: Powell George T (1889) Foundations and Foundation Walls New York City Building Laws, 1871.

Mortar, of what materials, and how used. The mortar used in the construction, alteration, or repair of any building shall be composed of lime (quicklime) or cement, mixed with sand, in the proportion of three of sand to one of lime, and two of sand to one of cement, and no lime and sand mortar shall be used within twenty-four hours after being mixed…

Sand. And all sand shall be clean, sharp grit, free from loam; and all joints and all walls shall be well filled with mortar.

Inside plastering… The proportion for the scratch coat is as follows: one part quicklime, four parts sand and one quarter to one third measure of cattle or goat's hair. It is usually put on from three-eighths to one half inch in thickness.

…Some of the mason builders in New York and vicinity who are large contractors, make building mortar for brick walls of the following proportions: one barrel of lime; six barrels of sand - sharp bank sand, which is calculated to lay 1000 bricks… The proportion of one measure of quick-lime, either in lumps or ground (when lumps exceed three inches each way they require to be broken), and five measures of sand is about the average used for common mortar by many masons. However, architects generally specify one part of lime to three of sand…

Where there is heavy working strain brought on piers, or parts of walls, it would be best to use some proportion of cement as the tenacity or cohesion of some mortars is not to be relied upon until four to six months after being used. This is only important where structures are heavily loaded or of considerable height…

Common mortar of ashes is prepared by mixing two parts of fresh slacked lime with three parts of wood ashes and when cold to be well beaten, in which state it is usually kept for some time… by some it is considered equal to some of the water cements.

1890 – A Hammond, The Rudiments of Practical Bricklaying

Reference: Hammond A (1890) The Rudiments of Practical Bricklaying (7th Edition). London. Crosby Lockwood and Son.

This is an excellent text in its explanation of many aspects of bricklaying craft practice. In its discussion of mortars, their preparation and uses, it well-illustrates the state of flux, as well as the uses of traditional and then-modern materials, such as Portland cement, without much critical thinking. The typical characteristics of Portland cement are seen as a benefit, not a hazard for the buildings they are used upon, though the materials it is displacing, both natural cement and feebly hydraulic limes, were more benign. There is no consideration of cement-lime mortars here. Concretes and most ordinary mortars are being hot-mixed, including pointing and putty mortars for gauged brickwork. The author recommends the use of 'superior' blue lias lime, whilst acknowledging the rarity of its use in London (and perhaps other metropolitan centres) at that time, where feebly hydraulic grey chalk/stone limes remain the norm, even for concrete. As the more hydraulic limes came to be used, in keeping with the author's recommendations, sand-slaking and banking (with the lime allowed to cool before mixing with the sand laid around and over it) became more common (see Frost, The Modern Bricklayer, 1925, as well as the British Standard 1951), to allow for both slow initial slaking and late slaking of the more hydraulic limes. Lime for plaster mortars is being slaked on site with a minimum of water, diluted after slaking to form a thin paste before being sieved and mixed, probably whilst still warm or even hot. Lime for use on its own as a putty is being slaked and diluted after slaking, but then laid down for a period to stiffen before use. The author advocates such laying down for the lime also for coarse stuff, acknowledging that this was not much done at this time.

Concrete. The 'limes' generally used for concreting in this country are obtained from Dorking in Surrey and Rochester in Kent, besides other places where the grey limestone is to be obtained.

This lime is ground and mixed with ballast while in a powdered state; it is then wetted and turned over twice, to mix them well together; this is then wheeled in barrows to an elevated position and thrown into the trenches, and afterwards levelled to receive the brickwork. This kind of concrete is mixed in the proportions of one part of lime (quicklime) to six or seven parts of gravel. Although this kind of concrete is very much used in and about London, it is considered a very imperfect method, although economical as regards the labour: it proves most expensive in the material, for if the work was properly executed it would not require nearly so much of the latter (?).

The method of concreting which is thought by most engineers to be the best is to reduce the lime to the state of a thick paste, and then it is made into a soft mortar by mixing about an equal quantity of sand with it before it is mixed with the gravel; and instead of shooting it down from a height and leaving it to settle by itself, it ought to be wheeled in upon a level and beaten with a rammer; for it is thought by being thrown from a height the materials separate, and by so doing some parts get more lime than they ought to have, while others get but very little.

Limes & Cements. Of limes, blue lias is reckoned the best in this country, because it is equally adapted for work below water-level or for moist situations as for dry ones. But it is not generally used for ordinary building purposes, principally on account of its taking but a very small proportion of sand before its setting properties are weakened; so it is thought best only to use little more sand than lime in the mixing.

This lime must not be made into mortar a long time before it is required as other limes often are, or else it will get so hard that it will be of very little use for the purpose of laying bricks.

This lime will take less water than the other limes usually do; and it ought to be slacked several hours before it is made into mortar, as some parts will take much longer than others. The principal supplies of the lias limestone are obtained from Aberthaw, near Cardiff; Barrow, near Mount Sorrel, in Leicestershire; and Watchet.

Dorking and Halling Limes. These may be considered the principal limes used in and about London for making mortar, owing to their taking a greater quantity of sand than any other before their setting properties are weakened, the usual proportions being three or four parts of sand to one of lime. But it must be remembered that very often it is not the quantity but the quality of sand that destroys the lime; for the cleaner and sharper the sand, the better the mortar will be.

These limes are obtained from Dorking in Surrey; and between Rochester and Maidstone in Kent.

Chalk Lime is seldom used in London for outside work, because it sets so slowly, and in damp places never sets at all. But it is used to a great extent for plastering the inside of houses, where there is no dampness; and although it is not used in London for outside work, it is very much used in

many parts of the country, where it is very cheap, and better limes are not so easily obtained.

Cements
The cements used by the builder are of various kinds, such as Portland and Roman for external, and Keen's and Martin's for internal decorations. Portland Cement is considered the best for general use, owing to its fine setting properties and its cheapness; for it takes a greater quantity of sand than any other before it is much weakened... and will take two or three parts of sand to one of cement for ordinary purposes... Roman cement, although possessing many good qualities, is greatly inferior to Portland, and therefore is but little used by the builder...

Frost
If the brickwork is carried on in frosty weather, all walls must be carefully covered up with weatherboards, straw, or something that will protect them; if not, the frost will penetrate into the work, and greatly destroy the strength of all that which is damp...

Plastering
All internal plastering, as a rule, is done with chalk lime, hair, plaster of Paris, and Keen's and Martin's cements. The following are the different methods of mixing them.

Lime and Hair, or Coarse Stuff
For this purpose the sand should be clean, sharp and screened. Then form a pan to receive the lime. This is slacked in a tub, and sufficient water is afterwards added to bring it to the consistence of cream, and is then run through a fine sieve into the pan formed with the sand (this will still be warm to hot). After a sufficient quantity is run out to carry the sand, the hair is thrown into the lime and thoroughly raked about with a two-pronged rake, so as to part the hair and mix it well with the mortar; but it would be better to run the lime into putty, as for fine stuff, and when cold, mix the hair with it; this will not be so apt to rot the hair, and so add to the stability of the work.

For this purpose bullocks' hair is generally used, and this should be well beaten with small laths, or else laid in water a day or two before it is mixed with the lime. The whole is then mixed and allowed to stand for a short time.

Fine Stuff or Putty, is made of pure lime, and is mixed in the same way as lime used for coarse stuff; but instead of running it into a pan of sand, this is run into a 'putty bin' built with bricks according to the size required, and allowed to remain there until the evaporation of water has brought it to a proper thickness for use; if the water rise to the top, it can be drawn off if required, and the putty will get dry the sooner.

For lime stucco the sand is mixed with the putty according to the quantity required. This stucco, when left for painting, is left smooth from the trowel... Portland, Roman and lias cements are those generally in use for all external plastering; and as regards quality and cheapness, Portland is decidedly the best.

1893 – Heaths Manual on Lime and Cement

Reference: Heath AH (1893) Lime and Cement, a Manual on Their Treatment and Use in Construction. London & New York. Spon.

This text expresses the increasing trend away from hot mixing, as well as from the use of fat limes for other than interior works, with feebly hydraulic chalk limes and more energetically (if variably) hydraulic blue lias limes being much more used for general building purposes; the feebly hydraulic limes being preferred for above ground works, and the lias lime for wetter places and for concretes. The text offers a chemical analysis of the more hydraulic limes, demonstrating their high free lime contents, discusses and analyses common pozzolans, and uniquely defines the size grading and ranges of 'coarse' and 'fine' sharp sand, indicating that these were generally finer than many modern 'sharp' sands used with lime. He also identifies key - and sometimes obscure - weights and measures.

In the London district chalk lime is sold by weight and by measure. About 2 cubic yards of ordinary chalk lime in lump make a ton weight; and 16 heaped bushels in the lump make a cubic yard, and 14 heaped bushels of ground lime powder... A measure of lump lime, a London yard, or load, of lump lime is 27 cubic feet and contains a very little more than 21 striked bushels. A cubic foot is about 0.78 of a striked imperial bushel, and this bushel is 1.283 cubic feet. A hundred of lime is 100 pecks, or 25 bushels... The London yard of lump lime is from 21 to 22 striked bushels and makes 18 striked bushels of ground lime (nine 2-bushel bags)...

The property of hydraulicity may be conferred on pure limes by the admixture of substances containing soluble silicates. A volcanic ash, called pozzolana (consisting of... of silicic acid... alumina... oxide of iron... lime,

and... other substances) added to pure lime, confers hydraulicity, and the resultant mortar may be used in engineering construction. Smeaton used Aberthaw... infra-lias lime, and pozzolana shipped from Civita Vecchia, in the construction of the Eddystone lighthouse in 1756-9...

[True] Pozzolana... is a volcanic ash. It is partly powder, partly coarse grained, or like pumice stone scoriae or tufa stone, and the colour ranges from white, whitish gray, blackish gray, brown to vilet red. The best is said to be the white to blackish-gray. It is largely used in the district, and in Rome; sometimes it is mixed with a pure lime only, sometimes the fine powder is mixed with 70 parts (by volume) of pozzolana, consisting of both powder and small stones, which serve instead of sand; the mortar is used for brickwork. The mixture of equal bulk of sand and pozzolana powder can be used for hydraulic work. Pozzolana differs much in quality, analyses give the following range of composition:

Silica from 44-56%, Alumina 10-15%, Sesquioxide of iron 7 to 29%, Lime 1 to 10%, Alkalies 5 to 15%, Sand 0 to 5%, Water 0 to 9%

A similar volcanic ash is found... on the west bank of the Rhine, and is called 'trass'; and another volcanic ash used in the Mediterranean is known as Santorin earth (from Santorini)... Trass is largely used in Holland in fresh-water and marine submerged engineering work; and Santorin earth has a great reputation for conferring hydraulicity on rich limes. Analysis of trass from Andernach...

Silica 46-57%, Alumina 14 to 20%, Magnesia 1 to 7%, Iron oxide 5%, Lime 2 to 11%, Potash & soda 8 to 15%

...It is stated that... on the east coast of Sicily... there are beds of clay which have been covered by deep streams of molten lava, with the result that the clay has been burnt and converted into a small red gravel, or powder. This material, mixed with a little quicklime and water, furnishes a mortar which has been used for centuries with excellent results. The buildings of Catania are stated to be constructed of stones of lava cemented together with this mortar, which is also used as an external, and internal, plaster... so excellent is the mortar that house walls are built four and six stories high of this (small and irregular) material, which is, in fact, a lava rubble concrete. It has also been used in athe construction of a harbour breakwater... the small lava rubble being moulded into large blocks liberally cemented together with this mortar...

…Finely powdered burnt brick, provided that soluble silica be present (that is, the bricks have been made of a plastic greasy clay and not of a snady clay), will also confer this property of hydraulicity on pure limes. The… brick, or… clay, must be thoroughly burned… to the point of incipient vitrifaction; and the crushing must be carried out to the finest possible state of division; the finer the particles, the more effective is the result of the admixture. The caustic lime must also be reduced by crushing, or by thorough slaking, to a similar degree of fineness.

The upper, or white chalk is found plentifully… in a belt or tract of country running from Dorsetshire to Cambridgeshire and Norfolk, thence to the north of Lincolnshire and into Yorkshire as far north as Flamborough Head… It is a carbonate of lime, containing from 1 to 6% of silicates and other bodies…

When calcined, it loses nearly half its weight and becomes a caustic lime, fit for use, when mixed with water to a paste, in plastering thin coats on rough surfaces protected from the weather. It is called rich or fat lime…

The gray chalk of the lower chalk division is also carbonate of lime, containing a little alumina (from 5 to 15% of silica, iron oxide and alumina); when the silicate of alumina is above 8%, the lime is good for cementing purposes. It is found in the same localities as, and beneath, the white chalk and it is known in the London district and the southern counties as 'Gray stone Medway', 'Halling' (Rochester), 'Wouldham', 'Burham' (Kent); 'Mertsham', 'Dorking' or 'Guildford' lime. Sometimes it is specified simply as 'stone' lime; the term probably arises from from a fallacy of Marcus Vitruvius, that the harder the stone, the stronger the cement made from the calcined stone. …Gray chalk limes in slaking do not greatly increase in bulk, and only a moderate heat is generated; the time of slaking is longer, and the chemical action is less intense than with white chalk limes.

The lumps of calcined lime are heaped up in a hollow formed in sand, the heap is wetted, and is then covered with dry sand, and sometimes also with sacks, to keep in the heat and assist the slaking. This is a good cementing material for ordinary constructive purposes above ground…

In the Lias series are thin beds of limestone separated by seams of clay. These… contain silicate of alumina in the proportion of from 10 to 30%, with carbonate of lime, and small proportions of other ingredients.

Analyses give as an average…: Carbonate of lime 68-80%, Silica 20 to 10%

Magnesia about 1 ½%, Alumina about 3 to 4%.

It must always be borne in mind that… not only do the different seams of stone vary widely in the character of their composition, but also there is no certainty of permanent composition in any seam.

The quicklime produced by calcination of selected lias limestone is eminently hydraulic, its faculty of hardening when submerged in water grows with the increase in the proportion of silica. It gives good results as a cement for all ordinary work, either above ground or beneath in damp situations, or even in still water…

The stone is calcined in open topped cup-shaped kilns, the fuel is interstratified with the limestone, about 6 to 7 tons of coal are burnt to produce 25 tons of lime.

The calcined stone must be thoroughly ground to a fine powder, then spread in a layer of about 12 inches thick on the floor of a dry, weather-proof shed and exposed to the air for two or three weeks before it us used in building. A good plan is to fit up the aeration shed with shelves, or trays, on which the lime can be placed.

Lias lime can be slaked in the ordinary manner, but ample time must be given – not less than three days, and the slaked lime must be sifted through a fine-meshed sieve, to reject all coarse, imperfectly slaked particles…

An analysis of Aberthaw limestone gives: Calcium Carbonate about 86%, Magnesium carbonate abt 2%, Silica abt 8%, Alumina abt 1%, Iron Oxide abt 2%, Water abt 1%.

…Ordinary pure or chalk lime in calcined lumps can be slaked, that is reduced to hydrate of lime in the form of a dry powder, by sprinkling the lumps of quicklime with water… Pure lime is often slaked by total immersion in water for some days. Grey-chalk lime is slaked by throwing water over the quicklime lumps, and covering them with sand to retain heat.

Blue lias and other limes possessing a high degree of hydraulicity do not slake readily. Some hydraulic limes will slake if, after being wetted, the heap of watered lime is covered with sand and with sacks etc to retain heat in the mass. Slaked blue lias lime should always be sifted before use, so that all the imperfectly slaked pieces may be separated and again treated…

Sand should be in all cases clean, free from clayey matter or vegetable earth; when rubbed between the hands should not soil them, and when dropped into water should not cause muddiness; should consist of sharp angular siliceous fragments not less than 1/24 inch in diameter, and not exceeding 1/8 inch; and should have a rough texture of surface. Calcareous or argillaceous sands are unsuitable, as the former will dissolve, and the latter partly dissolve in acids.

Fine sand may be defined as composed of fragments whose diameters range between 1/24 and 1/16 inch, coarse sand between 1/16 and 1/8 inch...

Coarseness of texture is... of greater importance than size of grains, and... Sands that are much water-worn... are not so suitable for making either mortar or concrete; they are, however, often used in default of a better material...

Loamy and clayey sands are injurious in cement mortar, and to a less degree in lime mortar...

(Questions virtue and effectiveness of grouting dry laid hearting material)... a better method is to fill the shallow basin enclosed by the facework with comparatively stiff mortar, softened if need be with a little water, and remixed with a long-toothed rake called a 'larry'. The bricks or stones are then well bedded by hand in the pool of mortar paste. This process is called 'larrying'.

MORTAR MIXING BY HAND.
For small quantities of mortar, the mixing is usually carried on by hand labour, spades or shovels and rakes with long prongs being used. The sand and slaked lime should be well mixed in the dry state, being turned over with spadework three or four times... Then water is sprinkled on while the mixing continues, until the whole is a soft, plastic uniform paste. About 6 or 8 turnings over are the minimum required. Ground blue lias lime is sometimes mixed with sand and water without previous slaking, then left for 6 or 8 hours, or longer, and then remixed, to ensure the complete slaking and wetting of all particles of lime.

MORTAR MIXING BY MACHINE.
The process of mixing in the edge runner mortar mills is to place the slaked lime in the pan and grind it under the runners for at least three minutes in a dry state, then water is added gradually, through a rose jet or a finely

perforated tube, and finally the sand is put into the pan (takes about 30 minutes).

(sand added last to reduce crushing, but) ...if pozzolana, semi-vitrified brick, or similar burnt clay or forge ashes be added to the mortar, it should be ground for as long a time as the lime, that is, put in the mill pan at the same time as the lime...

A method said to be adopted at Christiania (Norway) for building during severe frost, down to 14 degrees F, consists in the use of unslaked lime. The mortar is made in small quantities only, from unslaked lime, and used at once, and the greater the cold, the larger the proportion of lime in the mortar. The bricks used must be dry, and the mortar is probably used in a very moist condition, and in thin joints. The new work is always protected as soon as built, especially against rain, snow and cold winds...

CEMENT AND LIME MIXED MORTAR.
In building massive works it is sometimes desirable to use a strong and quick-setting mortar for the facework only. Such mortar can be made by adding Portland cement to the lime in general use. In one case, one measure by bulk of Portland cement was added to one of Burham gray chalk lime, and five to six measures of good sand. The cement should be well mixed with the lime in dry powder. Another instance gives 1 cement to 3 sand and ½ of a good slaked lime... gives a good dense mortar for foundation and above-ground work.

1897 – Richardson on Lime, Hydraulic Cement etc.

Reference: Richardson, C. Lime, Hydraulic Cement, Mortar and Concrete. The Brickbuilder Journal Vol 6, parts I - IV. Boston 1897.

The slaking of lime. Caustic lime combines with water with the evolution of heat to form calcium hydrate. Every 100 parts of caustic lime require 32 parts of water for its conversion into hydrate. If one third of its weight of water is sprinkled on quicklime it becomes very much heated, cracks open, if of the massive variety, swells up and falls to powder.

The heat developed is sufficient, at times, to ignite wood. The quicklime becomes slaked lime. This consists of 75.7 per cent, of calcium oxide and 24 3 per cent of water. It has a specific gravity, when pure, of 2.07. The increase of volume in the process of slaking is due to the formation of steam, which tears the particles of lime apart and expands the mass. If a

current of dry steam is passed over heated caustic lime confined in a tube it becomes slaked without any increase of volume.

The smaller the amount of impurities the more energetic is the act of slaking and the greater the increase of volume. In rich and pure limes the increase of volume under ordinary conditions will be over twice that of the unslaked material, including the voids, while with very poor limes it may be much less. The statement frequently made that lime increases three volumes in slaking (Vicat, amongst others) is based upon the increase in volume due to the excess of water often used in slaking. In this case it may be as great as 3.4. The amount of increase of volume for the same lime may be very variable, depending on the conditions under which it is slaked. We have seen that it is a reaction between water and caustic lime where much heat is generated, and that to the steam evolved is largely due the expansion of the lime. It is evident, therefore, that the provisions for augmenting and retaining this heat are of importance. If water is added slowly but comparatively little heat is developed, while slaking in an open space will not give as much as when it occurs in a closed box. Cold water also will not accelerate the action as well as warm. The amount of water used has a marked effect on the volume of slaked lime produced. With an equal volume of water the increase for a good, rich lime is from 2 to 2.4. An increase or reduction in the amount of water or in the volume weight of the lime may increase or diminish this. The following experiment shows the effect of different amounts of water on an ordinary lime

Volume of water	*Increase in volume*
½	*1.6*
1	*2.0*
2.5	*2.5*

With poor dolomitic lime the volume increase was only 2 to 1.7.

It appears, therefore, that the increase of volume to be expected of any lime is dependent on conditions which may be very variable. For example, a peck of lump lime with 44 per cent, of voids between the lumps gave, on slaking with its own volume of water, 2 pecks of fine powder of slaked lime, which is a fair increase in volume for lump lime. From I peck of closely packed lime, however, 2.5 volumes of slaked lime were obtained. The difference in volume is of course due to the difference in weight of the lime as packed in the two ways.

The proper comparison, therefore, is one of volume from weight 10 lbs. of

caustic lime, for instance, should give 6.8 bushels of slaked lime, an increase of volume of 2.25. Gilmore found in some of his experiments increases as great as 2.46, 2.83, 3.21, 2.40, and 2.14, but the weight of lime in his unit volumes was much greater than occurs in practice, and large amounts of water were used in slaking so that he was dealing with paste instead of dry slaked lime... General Totten found in experiments on slaking limes no increase in volume greater than 2.27 when no more than an equal volume of water was used. The increase of volume is commonly used as a test of the quality of lime.

Air Slaking. Slaked lime is also produced by exposure of caustic lime to the air, from which it absorbs sufficient water to become hydrated, as well as some carbonic acid. This is known as air-slaked lime. It is of little value for mortar making, because there has not been enough heat produced in its formation to tear apart and expand the particles which will alone enable it to form a rich paste. The larger particles have also to a certain extent become hardened on their surfaces by a kind of setting, and by the absorption of carbonic acid from the air.

Practice in Lime Slaking. In practice, the slaking of lime for mortar is conducted in several ways. Either sufficient water is sprinkled over the lime to combine with it and resolve it to a powder, providing also an excess for that lost in the form of steam, or an excess is added at once, sufficient to make the finished mortar.

The first method is in some ways the best, because a finer, looser powder is produced, in the manner already described, and because the poorer limes are much more easily and thoroughly slaked in this way with the aid of the greater heat evolved. When too large an amount of water is used the development of heat is prevented, and the operation is much less complete. The particles of lime which are left unslaked go into the mortar in that condition and, being subsequently slowly hydrated by the moisture of the air, expand with injurious effect after it has been used. The popping of mortar, frequently noticed in the walls and ceilings of dwellings, is due to this cause. For the same reason, given above, all the water which is to be used should be added at once or nearly so. If it is added in small portions the effect is to cool down the whole mass and prevent thorough slaking.

We have seen that a third of its weight of water is theoretically necessary for slaking lime. In practice, however, to allow for vaporization as steam, and for the slight excess necessary to bring all the particles in contact with moisture, this amount must be increased to at least an equal weight. It is

difficult to say what volume of water should be used, as this depends on the volume weight of the lime, which is variable. It is ordinarily about that of the lime itself plus its voids. Practically it is convenient with fat lime to use two and a half volumes of water, which will suffice for slaking and for the production of a paste. Poor magnesium limes require less.

As heat assists in the expansion of the lime, the operation is best carried on in a covered box. One half of the water is added at first, and as soon as the lime begins to fall to pieces the rest is poured in and thoroughly mixed with the slaking material. The entire mass will thus be raised to a high temperature. The operation thus carried on takes place rapidly, but it can hardly be considered completed until the mass has become cool, or until even after a longer time. In cold weather it is advantageous to use warm water, especially with poor limes.

Water for Slaking and Mixing
Water used for slaking lime and making mortar should be pure. When it contains salts, such as chlorides and sulphates, the mortar effloresces and gives rise to stains. For this reason sea water is unsuitable, although it has been used successfully with hydraulic cement.

Lime Paste or Cream
The lime paste made in the manner previously described may be too stiff for mortar if a very rich lime has been used, or if a very large volume of sand is to be employed in making the mortar. There is no difficulty in thinning it, however, to the proper consistency, depending on the character of the mortar to be made. If, however, more than two and a half volumes of water are added to the lime at first the resulting paste will have a tendency to be granular and to contain lumps which, in the thin cream, it is impossible to break up. In careless practice as much as three or four volumes of water are sometimes used in slaking lime, when it is intended to make a mortar with a large volume of sand. Stretching the cream in this manner to make a small amount of lime fill a large volume of sand voids makes the resulting mortar very porous when dry. Good paste of lime should not contain at the extreme more than three volumes of water as compared to the measured volume of the quicklime. As there are generally some hard and unslaked particles even in the best limes, the cream should be run through a sieve if possible, after standing over night, before mixing it with the sand. It should be remembered that the longer the paste stands before use the smoother it becomes. As will be seen later, this improvement goes on after the mortar has been mixed.

Proportion of Sand to Lime
A mortar made of lime paste should, theoretically, contain so much sand that the cream of lime will more than fill the voids, that is to say, the volume of the mortar should be greater than that of the sand. In fact it is necessary that it should considerably more than fill them in order to thoroughly coat each particle and provide for shrinkage. If too much sand is present there is not sufficient cementing material to make a firm bond, while on the other hand, if there is too little the mortar will tend to shrink and crack on drying. If too little lime is used the deficiency must be made up with water, that is to say, the paste is made very thin.

In ordinary sands the voids are from 30 to 40 per cent, of the volume of the sand. With sand, having 40 per cent, such as that which is used for the best lime mortar, 1 volume of paste would fill the voids in 2.5 volumes of sand with no excess. As a matter of fact, practice leads to the addition of only from 1.25 to 2 volumes of sand to 1 of paste which, when the caustic lime yields 2.5 volumes of paste, means 3 to 5 volumes of sand to 1 measured volume of caustic (quick) lime. In this way a plastic mortar and one that will not crack in drying is made. With fat lime and sharp sand 3 volumes of sand to 1 of lime forms a rich mortar and these proportions are often required in the best specifications. The greater part of the mortar used in ordinary brickwork is, however, made with 5 volumes of sand, or more, and is probably satisfactory...

Volume of Sand for Mortar
If but twice the volume of the lime is added to the paste in the form of sand, the resulting mortar is too rich. It contracts and cracks on drying. Three volumes of sand make a very rich and satisfactory mortar such as should be used for laying up fronts and pointing.

Five volumes form a mortar good enough for ordinary brick masonry where not exposed to moisture, while greater amounts of sand furnish mortars which are very porous, but serve for cheap work in absolutely dry situations...

Amendments to lime mortar. Lime mortar, made of ordinary rich lime, is not suited for masonry where it is exposed to water, dampness, or to the absorption of water by capillarity from the soil. The hardest lime mortar will absorb 15 to 21 percent of its volume of water. If hydraulic cement cannot be substituted for it, on the score of economy, a certain degree of improvement may be made in the mortar by mixing it with finely ground brick-dust or burnt clay, which yield the necessary silica to make it

somewhat hydraulic and less porous; or a certain portion of the lime, one third, for instance, may be replaced by hydraulic cement...

Setting of Lime Mortar
The setting of lime mortar is the result of three distinct processes which, however, may all go on more or less simultaneously. First, it dries out and becomes firm. Second, during this operation, the calcic hydrate, which is in solution in the water of which the mortar is made, crystallizes and binds the mass together. Hydrate of lime is soluble in 831 parts of water at 78 degs. F; in 759 parts at 32 degs., and in 1136 parts at 140 degs. Third, as the per cent, of water in the mortar is reduced and reaches 5 per cent, carbonic acid begins to be absorbed from the atmosphere. If the mortar contains more than 5 per cent, this absorption does not go on. While the mortar contains as much as 0.7 per cent, the absorption continues. The resulting carbonate probably unites with the hydrate of lime to form a sub-carbonate, which causes the mortar to attain a harder set, and this may finally be converted to carbonate. The mere drying out of mortar, our tests have shown, is sufficient to enable it to resist the pressure of masonry, while the further setting furnishes the necessary bond.

1897 – William Millar's plain and decorative plastering

Reference: Millar (1897) - Plastering, Plain and Decorative. Reprint, Shaftesbury. Donhead.

There are three methods of slaking 'lump-lime' - the first by immersion; the second by sprinkling with water; and the third by allowing the lime to slake by absorbing the moisture of the atmosphere. Rich limes are capable of being slaked by immersion and kept in a plastic state. They gain in strength by being kept under cover or water. All rich limes may be slaked by mixing with a sufficient quantity of water, so as to reduce the whole to a thick paste. Lump lime should be first broken into small pieces, placed in layers of about 6 inches thick and uniformly sprinkled with water through a pipe, having a rose at one end... and covered quickly with sand. It should be left in this state for at least 24 hours before being turned over and passed through a riddle. The layer of sand retains the heat developed and enables the process of slaking to be carried out slowly through the mass... the quantity of water should be properly regulated, as if over-watered a useless paste is formed. If a sufficient quantity is not supplied, a dangerous powdering lime is produced. Slaking by sprinkling and covering the lime lumps is frequently done in a very imperfect and partial manner, and portions of the lime continue to slake long after the mortar has been used.

Special care must be exercised, and sufficient time allowed for the lime to slake when this method is employed...

In most parts of England the lime for making coarse stuff [for plastering] is generally slaked by immersion, and is run into a pit, the sides of which are usually made up with boards, brickwork, or sand, the lime being put into a large tub containing water. When the lime is slaked, it is lifted out with a pail, and poured through a coarse sieve. It is sometimes made in a large oblong box, having a moveable or sliding grating at one end to allow the lime to run out, and also to prevent the sediment from passing through.

In preparing lime [mortar - for Millar lime and mortar are interchangeable] for plasterwork, the general practice in the north of England is to slake it for three weeks before using... Now, while all this precaution is taken in regard to plastering, in making mortar for building, the lime is slaked and made up at once, and it is frequently used within a day or two. But this is not all. Limes which are unsuitable for plasterwork, known as hot limes, and which, when plasterers are obliged to use, must be slaked for a period of - not three weeks, but more - nearly three months before using, and are then not quite safe from blistering, are the limes mostly used for building purposes.

Mortar... for plasterwork it is usually composed of slaked lime, mixed with sand and hair and is termed 'coarse stuff'... In Scotland the coarse stuff is generally obtained by slaking the lump lime... with a combination of water sprinkling and absorption. The lime is placed in a ring of sand, and in the proportion of one of lime to three of sand, and water is then thrown on in sufficient quantities to slake the greater portion. The whole is then covered up with the sand, and allowed to stand for a day; then turned over, and allowed to stand for another day; afterwards it is put through a riddle to free it from lumps, and allowed to stand for six weeks to further slake by absorption. It is next 'soured' - that is, mixed with hair ready for use. Sometimes when soured, it is made up in a large heap, and worked up again as required for use. This method makes a sound, reliable mortar. In some parts lime slaked as above is mixed up with an equal part of run lime. This latter method makes the coarse stuff 'fatter' and works freer...

Grinding is another process for making mortar or 'lime', and if made with any kind of limestone is beneficial. It thoroughly mixes the material, increases the adhesion, adds to the density, and prevents blistering. When there is a mortar mill, either ground or lump lime can be used, and the coarse stuff may be made in the proportion of 1 part lime and 3 parts sand... The process should not be continued more than thirty minutes. Both

material and strength is economised if lump lime is slaked before being put [immediately?] into the mill... It should be borne in mind that a complete incorporation of the ingredients is essential in the slaking and mixing for coarse stuff, whether done by hand or machine.

...Smeaton found that well-beaten mortar set sooner and became harder than mortar made in the usual way...

...Lias lime should be mixed dry with sand, and damped down for seven or ten days to ensure slacking. It should not be used fresh for floating or rendering.

...Mortar made from Hydraulic Limes should be mixed as rapidly as is compatible with the thorough incorporation of the materials, and used as soon as practicable after mixing, because if put aside for any length of time [or knocked up later] its setting properties will deteriorate.

...many of our limes are comparatively poor in carbonate, and associated with silica, alumina, magnesia, and oxide of iron, which may either be partially combined in the natural state, or enter into combination with the lime during the process of calcination, and these limes might be termed slightly hydraulic.

1899 – Sutcliffe's Principles of Modern House Construction

Reference: Sutcliffe G L (ed) (1899) The Principles and Practice of Modern House Construction Vol 1. London, Glasgow & Dublin. Blackie.

Mortar ought to serve at least three purposes: it ought to form a soft but gradually hardening bed to receive the various building-materials, so that these shall obtain an uniform bearing notwithstanding the irregularity of their surfaces; in the second place, it ought to prevent the passage of wind and rain through the joint of the walling; and, lastly, it ought to have adhesive and cohesive strength enough to bind the component parts of the wall into one solid mass.

The by-laws of the London County Council relating to mortar: All brick and stone work shall be put together with good mortar of good cement. The mortar to be used must be composed of freshly-burned lime and clean sharp sand or grit, without earthy matter, in the proportions of one of lime to three of sand or grit. The cement to be used must be Portland cement, or other cement of equal quality, to be approved by the District Surveyor, mixed with clean sharp sand or grit, in the proportion of one of cement to

four of sand or grit. Burnt ballast or broken brick may be substituted for sand or grit, provided such material be properly mixed with lime in a mortar mill…

Excellent mortar can be made from hydraulic lime, such as the well-known Lias limes, mixed with sand in the proportion of 1 to 2. The lump or shell lime may be used, but the ground lime is much to be preferred, especially where a mortar-mill is not available. The ground lime can be distinguished from Portland cement by its yellow colour… When a mortar-mill is not used, all grit and lumps should be carefully screened from the sand and lime before these are mixed, as they would tend to crack the bricks and stones if used in the mortar…

Mortar made from cement or hydraulic lime must be mixed in small quantities and used fresh. Mortar which has once 'set' to any appreciable extent cannot be remixed without loss in ultimate strength…

As water is absolutely essential not only for the initiation but also for the continuation and completion of the chemical processes involved in the setting and hardening of hydraulic limes and cements, it is imperative that the moisture should not be abstracted from the mortar too soon. Hence the necessity of protecting stucco from brilliant sunshine, or of repeatedly spraying it with water; hence also the necessity of dipping bricks in water immediately before using them, and of sprinkling a dry course of bricks with water before the bed of mortar is spread above it to receive the next course. With lime mortar, a moderate use of water in the same way is advantageous, although the lack of it has not so marked an effect as with cement and hydraulic lime.

Rough cast is a covering now seldom used for buildings as a whole, except in the case of cottages and farm buildings, but it is still occasionally adopted for the gables and some other portions of the upper parts of country houses and cottages. It is executed by throwing a very thin paste of hot lime, coarse sand, and grit or fine gravel, upon a wet plastered surface. The whole requires an annual coat of limewash, which may be tinted with ochre or other colouring matter.

8. THE 20TH CENTURY (1901 – 1952)

The 20th Century saw the continued development in the use of harder mortars, both in civil engineering applications and in commercial and domestic construction. Major conflicts played their part in accelerating technical developments in construction and the continued reduction in the use of the mason or trades in the specification of the mortar. By the mid 20th century, it could be said that traditional mortars existed at a fragile end of the construction spectrum, with even repair and conservation work often using modern mortars. Such traditional knowledge as recorded in the references is often opaque and survived mainly in the plastering trades. More recently, a developing appreciation of the benefits of traditional mortars has resulted in a reasonable regeneration of capacity, although within the conservation sector the nature of the different types of lime used is still a live debate. Written specifications and the desire in construction to push responsibility of the mortar further away from site to the product manufacturer, has resulted in a reluctance to adopt vernacular or traditional mixtures and a preference to premixed products of various types.

1901 – William Richards, Bricklaying and Brickcutting

Reference: Richards H W (1901) - Bricklaying and Brickcutting, London, New York, Bombay. Longmans, Green and Co.

Both Richards and Sutcliffe are writing in the brief moment when hydraulic limes were more routinely being used in the air in the UK (although very likely mainly in metropolitan centres, along with increasing use of strong Portland cement mortars). Indeed, one might say that blue lias and other modestly hydraulic limes were being used in situations, where previously feebly hydraulic or fat lime mortars had been the norm; and Portland cement mortars, where previously these hydraulic lime mortars would have been deployed. The demand for 'hardness' had gone up a notch, as well as - or because of - the demand for speed of construction. All 20th century texts illustrate a period of significant flux, when previous norms were being challenged and generally overthrown, in favour of significantly harder mortars, usually industrially produced, reliable and much more 'foolproof', specified with confidence by architects and others. Most authors accept the case for this and believe the use of air lime and feebly hydraulic to be mistaken. However, throughout the period of the following texts, fat limes continued to be slaked, either run to putty or hot mixed. In both cases, the resulting coarse stuff would be gauged with Portland Cement or gypsum. Within the living memory of numerous old craftsmen, working in the 1950s,

mortars continued to arrive on site ‘steaming hot’ (In Redcar, Cleveland, eg). Immediately after WWII in London, with cement and sand in short supply, London County Council housing was built using quick lime, which would arrive on site as lump, ‘still hot from the kiln’ and was hot-mixed with brick aggregate to form lime concrete floors, and for coarse stuff. Plasterers would slake their quicklime to putty and press this through a sieve before mixing it with sand, until in the 1960s ‘lime putty began to arrive on site in blue Tilcon bags’. Cement-lime mortars (typically 1:2:9) were being made using local quicklime (Pickering, North Yorkshire), which would have been more expensive as bagged hydrate. Hydraulic limes were being slaked on site long after fat limes were being routinely run to putty, pre-hydrated NHL being mistrusted by many builders. Ministry of Works Advisory Leaflet No.6, Lime Mortars, published in 1950, shows clearly that, still at this time, the variety of limes and lime mortars available, as well as their appropriate deployment, was very well understood and broadcast only 25 years before the onset of the ‘lime revival’. Similar understanding and nuance is being displayed in texts written for construction apprentices and professionals training in the 1950s. Portland Cement displaces Blue Lias hydraulic lime as the principle binder for concretes, but at similarly lean proportion and having had significantly lesser compressive strength than currently.

Concrete.
…the matrix should consist of either Portland Cement or Blue Lias lime and sand. The proportions for the concrete must depend upon the situation in which it is to be used; but for ordinary purposes the following may be accepted: 5 parts clean broken stone, brick etc: 2 parts sand: 1 Portland cement or Blue Lias lime. Or 7 parts Thames ballast (already containing sand): one part Portland cement, or Blue Lias lime [note the equivalence of Portland cement or lias lime. Compare this to a modern 1:3 or 1:2 ½ NHL 5: sand lime concrete].

…Building mortar may again be divided into two classes: cement mortar and lime mortar… The decision as to the quality of the mortar will depend upon where it is to be used. Thus, for work underwater, footings, piers receiving heavy weights etc Portland cement or Blue Lias would be used; for ordinary purposes, fairly [feebly] hydraulic, such as grey stone lime. Fat or poor limes should never be used for building brickwork.

(Recommended proportions :)
Above ground: fairly hydraulic lime, one part to three sand [unslaked lime]; eminently hydraulic lime: 1 part to 2 sand [little or no expansion upon

slaking]; Portland cement: 1 part to 5 sand. For footings: eminently hydraulic lime, 1 part to 1 sand; Portland cement: 1 part to 2 sand. For work washed by water, such as river walls, etc: Portland cement and sand in equal proportions.

Mode of Mixin: A clean site or platform having been chosen, the lime and sand should be measured out in a yard measure. In the case of fairly hydraulic lime which is supplied in lump, the screened sand is formed into a ring, the lime shot into the middle, and sprinkled with just sufficient water to slake it. Some of the sand is then turned over the lime, and it is left in this state till the lime has become thoroughly slaked. Water is then added, the remaining sand gradually pulled in, and the whole mass carefully incorporated with a larry and shovel.

For hydraulic limes and cements, which are supplied in a powdered state the lime and sand are again measured and shot upon a platform, the sand first and the lime on top of it. These are mixed together, first in a dry state, and then with just sufficient water to form a fairly stiff paste... with the latter mortar small quantities only should be mixed at a time...

Mortar for Pointing.
...Putty for pointing is made of silver sand and stone lime [feebly hydraulic grey chalk lime], 2:1.

The lime, being dry-slaked, is mixed with the sand, passed through a very fine sieve, mixed with sufficient water to form a very hard paste, oil sometimes being added to make it work better, and then well-beaten with a club hammer or other heavy instrument. For black putty, vegetable black is added to the above.

1903 – Alterations to a Farmhouse, East Lothian

Reference: Specification for building additions to Farmhouse at Peaston Bank, East LothianHopetoun Estate Archive NRAS 888/ 328.

Specification by A Dickson, Clerk of Works 1903: *"Rubble work: ...all stones laid on their natural and broadest beds, free of pinnings, all well packed with common lime and pointed outside with Arden lime... common lime from Cousland, sand to be sharp & clean of fresh water deposit."*

1905 – Construction of Isleburgh House, Lerwick

Reference: Specification of Isleburgh House, Lerwick Shetland Museum & Archives D1.619/1/1.

Mortar for rubble work: "Sand to be clean selected pit sand free from saline or earthy matter, if any beach sand same to be laid up and weathered and fresh water washed before use. Lime to be well burnt Scotch or Girlsta, free from impurities.

Mortar to be composed of well burnt lime mixed with prepared sand in proportion of one of lime by two of sand by measure well mixed, soured and matured, beat and heaped for fourteen days before use, rebeat and prepared for use in walling."

Plasterwork: "Plaster to be composed of best quality fresh burnt Scotch or Girlsta lime, well and timeously slaked, mixed with long fresh hair in proportion of 1lb of hair to 2 cubic ft mortar and clean fresh water, sand in due proportion soured up, matured, mixed, beat up and heaped for 21 days before use. Fine stuff matured and run into pit for finishing and settled one month before use."

1906 – Cassell's Building Construction

Reference: Adams, H, Cassells Building Construction, Cassell & Co London, 1906.

Bricklaying in Frosty Weather. There is no recognised time or period of the year in which bricklaying should be suspended on account of frost; this is a matter that is determined by the weather and by local custom. Generally speaking, in England work continues throughout the winter, the only protection being a scaffold board, laid on the top course; but sometimes sacking is laid over the upper courses when the work is left for the night. If a hard frost sets in, the work may be suspended until the frost breaks; but in Sweden and Norway building operations are not so readily interrupted, as sugar is added to the mortar in order to lessen the liability to freezing. In the United States and Canada brickwork in cement mortar is continued in frosty weather by using hot water for mixing the mortar…

Lime mortar in London is usually composed of 1 part of best grey stone lime (Merstham, Halling, or Dorking), and two parts of clean sharp sand. Blue lias lime is a hydraulic lime having the power to set under water, and may therefore be used in wet ground; those named above being suitable only for dry situations. Chalk lime is unsuitable for use in brickwork owing to its solubility and want of setting power.

…The common proportion for London mixture is 3 to 1, instead of 2:1 as given above, but most architects specify the 2 to 1 proportion.

1909 – Radford's Cyclopedia

Reference: Radford, H. Cyclopedia of Construction, Carpentry, Building and Architecture 1909 Chicago.

Common Lime Mortar. The first step in the preparation of common lime mortar is the slaking of the lime. This should be done by putting the lime into a water-tight box, or at least on a platform which is substantially water-tight and on which a sort of pond is formed by a ring of sand. The amount of water to be used should be from 2 1/2 to 3 times the volume of the unslaked lime...

Although close accuracy is not necessary, the lime paste will be injured if the amount of water is too much or too little. In short, the amount of water should be as close as possible that which is chemically required to hydrate the lime, so that on the one hand it shall be completely hydrated, and on the other hand it shall not be drowned in an excess of water which will injure its action in ultimate hardening...

Lime mortar [for plastering] need be left standing only long enough for all its particles to be thoroughly slaked, and, if properly mixed and wet down in the first case, a great deal of time need not be required to effect that result. This once secured, the quicker the mortar is mixed and put upon the building, the better and stronger will be the plastering that is obtained...

...Once certain that the lime is slaked, it would appear better that not more than a week should elapse before the use of this mortar; and a less time than that is, under many circumstances, undoubtedly desirable. It is evident that no more lime and sand mortar should be mixed at one time than can be used within a few days at the most. The length of time that mortar should be allowed to stand is determined more or less by the dryness or moisture of the atmosphere.

1910 – Rene Champly, New Practical Encyclopedia

Reference: Champly, René (1910-1914) Nouvelle encyclopédie pratique du bâtiment et de l'habitation. Volume 2, avec le concours d'architectes et d'ingénieurs spécialistes. Paris. H. Desforges.

Lime slaking - fat lime is placed in a basin formed of planks, masonry or even a simple hole dug in clay soil. We water the lime with a spray, the burnt stones crack, expand and melt into a beautiful white, cohesive and creamy paste ready to make a mortar.

This slaked lime can be conserved from one year to the next by covering it with a good layer of sand and a roof that will keep the rain water away from it, the sand that covers the lime needing to be kept moist...

Cements are divided into prompt cements or roman cements, the set of which happens a few minutes after being mixed and slow cements or Portlands, in which the set takes several hours and the hardness is only complete after a few months.

The prompt cements are used for under water or underground works, they do not harden well in the air. Slow cements for masonry foundations, basins and reservoirs walls, coatings for humid walls and paving. Prompt cement mixed with fat lime in the proportion of 1 to 2 cement to 10 of lime (by volume) gives a mortier bâtard (mixed mortar to be polite) that has great hydraulic properties.

Half to one percent of sugar added to the cement promotes its hardness but delays its set a little...

We differentiate mortars thus: fat lime, used for raising walls, hydraulic lime for foundations, substructures, basement and works meant to be immersed. Slow or prompt cement for underwater works or in very humid places. Cement mortars with a slow set are greatly used for coatings, pavings and facing...

When we build, underwater masonry which will be submerged in a distant future, the mortar does not have to be very hydraulic. If, on the other hand, they will be subject to immediate inundation, they need to be very energetic.

In the first case, we make it with feebly hydraulic lime and sand or with fat lime mixed with energetic lime and sand (one method of his) or fat lime, lean pozzolans and sand. In the second case, we use energetic lime with sand, or fat lime, or feebly hydraulic lime or energetic pozzolans and lastly, we use sometimes a mortar of pure cement...

Special coating (render) for rammed earth wall: Make a clear but binding paste with one part of slaked lime, four parts of clay and some water. Add and mix into this paste, as much hair as it needs for the mix to be full of it. Use hair from tanners or from the sheet shavers (the people shaving the sheets made from teaseling as short as possible for a smoother finish).

The hair has to be well divided and beaten, so that it does not form clumps in the paste.

Apply the coating in the autumn on a well dried rammed earth wall with a big paint brush or by throwing it and then spreading it with a trowel.

Do not apply it during heavy rains nor during frost, which would prevent the drying out.

1911 – William Dibdin, Lime Mortar & Cement

Reference: Dibdin W J (1911) *Lime, Mortar & Cement: Their Characteristics and Analyses.* London. The Sanitary Publishing Company Ltd.

Table of the approximate composition of various limestones and the percentage of pure lime... in the burnt stone [balance is dolomite]:

Pure or Fat Limes	*Unburnt Stone Carbonate of Lime*	*Clay & Moisture*	*Burnt Stone CaO*
White Chalk	*98.5*	*1*	*98*
Oolite	*95*	*3*	*95.5*
Poor Lime			
Siliceous Oolite	*70*	*26.5*	*73.5*
Feebly Hydraulic			
Grey Chalk	*92*	*8*	*86.5*
Hydraulic			
Dolomite	*51*	*9*	*53.5*
Carboniferous	*86*	*14*	*81*
Grey Chalk	*83*	*17*	*73*
Strongly Hydraulic			
Blue Lias	*79*	*21*	*72*
Carboniferous	*71.5*	*27*	*60*
Scotch	*68*	*31*	*56.5*

To the practical eye there can be no manner of doubt as to the kind of mixture which is being employed for the purpose of binding bricks. If it is good stuff, made of well-burnt lime and clean sand or grit, the fact is patent at once to the expert; and, so far as he is concerned, there is no need for a chemical analysis.

Rough Test for Strength. Take a fragment of the mortar between thumb and forefinger, and try to break it. If it crumbles easily to dust it is at once known that its power of cohesion is slight, and that it will be wanting in binding power.

1912 – William Kemp, 'The Practical Plasterer'

Reference: Kemp W, The Practical Plasterer, Crosby, Lockwood and Son, London 1912.

Most of the lime used in London is prepared from chalk found largely in Kent; but lias lime, made from rock of the lias formation, is also a good deal employed in the metropolis, although its colour is less white than that of chalk lime. Dorking lime used to be in considerable demand for stuccoing, when that kind of work was popular; but there is not much lime produced at Dorking now.

Hydraulic Lime.
When lime of this character is used by the plasterer, he should bear in mind that there is apt to be in it, even when well ground, little lumps of unslaked lime, which, even if not larger than a pin's head, will materially injure the appearance of his work by 'blowing' or slaking, after the finishing coat has been applied. Want of proper attention to this point frequently results in a new ceiling or partition breaking out here and there in blisters, and thus injuring the plasterer's reputation as an able and conscientious craftsman.

"Fat" limes are principally employed for internal plastering, because of their readiness to slake into a fine powder, whilst they still 'set' or harden, with sufficient rapidity for general purposes.

Blue Lias Lime.
The hydraulic lime formed by calcining rocks of the blue lias formation is extensively employed for building operations at the present day, especially in the Metropolis. Beds of the lias are found over a considerable portion of Great Britain... Portland cement is manufactured from this stone at Rugby on a large scale. Despite its good properties, this lime is more uncertain in its behavior than chalk lime...

Coarse Stuff.
This is a rough description of mortar, composed of from 1 to 1 ½ parts of sand to 1 of slaked lime (by measure), with the addition of short animal hair, in the proportions given hereunder. Coarse stuff varies according to the proportion of sand which it contains, and may be classed, according to its quality, as No. 1, 2, and 3, the last being the finest and best. A bushel of this mixture should weigh from 14 lbs. to 15 lbs. The hair may be added in the proportion of 1 lb. to 2 cubic feet of stuff for superior work, and 1 lb. to 3 feet for ordinary work.

The hair should be that of the ox, clean, un- broken, and not too short. It should not be dirty or greasy, and if matted together when it comes from the tan-yard (as it usually is), should be well beaten with a lath or stirred up in water, to thoroughly separate the fibres. For some kinds of work white hair is to be preferred, although for first coats the colour of the hair is of no moment.

The sand is generally heaped up in a circular bank on the gauging-box, platform, or other surface where the plaster is to be mixed. The lime is mixed with water so that the liquid is of about the thickness of cream, and is then poured into the centre of the circle of sand. The hair is next added, and the surrounding sand drawn into the central with the "rake" liquid, and the whole mass well worked together until it is intimately amalgamated.

The mixture should then be left for several weeks to 'cool', as it is technically called, until the lime is thoroughly slaked, and its heating entirely killed.

Fine Stuff.
This is composed of pure lime, slaked with a small proportion of water into a smooth paste, and subsequently further diluted with water until it is of the consistence of cream. It is then permitted to remain until the slaked lime has subsided, and the superfluous water has either been run off or allowed to evaporate, so that the resultant mixture is of the proper consistency for use.

Rough Cast.
This is composed of sand, grit or gravel, well washed to remove clay or dirt, mixed with hydraulic lime and water in a condition of slaking...

Limewash.
Take well-slaked lime; dissolve 2 ½ lbs. of rock alum in boiling water and add to every pail of the limewash. This compound should be used very thin. As it begins to dry the alum will act as size and bind it to the wall, and the second coat will form a white smooth finish.

Stucco Whitewash.
Put half a bushel of un- slaked chalk lime into a cask and slake it with boiling water, and cover it over. Strain when cold through a fine hair sieve. Then dissolve 1 lb. of table salt in warm water and add to the lime solution. Then take 3 lbs. ground rice, 1 lb. glue, and ½ lb. Spanish brown; dissolve these in boiling water, put to former solution, add 5 gallons boiling water, stirring well, and let the mixture stand (with the cask covered) until cold. Make this wash quite hot before you apply it. This is for external work.

An Excellent Whitewash.
The following method of preparing whitewash has been strongly recommended. Take a clean, water-tight barrel, or other suitable vessel, and put into it ½ bushel of chalk lime, slake it by pouring boiling water over it in sufficient quantity to cover the lime five inches deep, and stir briskly until thoroughly slaked. When the slaking has been effected add 2 lbs sulphate of zinc dissolved in water, and 1 lb. of common salt. This will cause the wash to harden and prevent unseemly cracking on the wall.

1912 – Mitchell's Building Construction

Reference: Mitchell C F (1912) – Building Construction. Seventh edition, thoroughly revised and much enlarged. London. Batsford.

Rich Limes Limes are said to be rich or pure when the impurities insoluble in acids do not exceed 6% of the whole mass.

For plastering, rich, pure or fat limes only should be used, because of their readiness to slake, and their consequent non-liability to blister as compared with hydraulic limes.

Poor Limes are those containing from 15 to 30 % of impurities insoluble in acids. They possess the general properties of rich limes, but in less degree. They take longer to slake, and do not increase in bulk to such an extent as the rich limes. They do not take such a large ratio of sand, owing to the foreign matter they already contain.

Hydraulic Limes contain a quantity of combinable substances other than lime, such as silica and alumina, which on being burnt form calcium aluminate and calcium silicate, together with a portion of lime, the measure of these bodies up to a certain point being the measure of the hydraulicity.

Hydraulic limes only should be used as the matrix for lime concrete, and they are most suitable for constructional work…

Slaking is induced by adding water to quicklime… Slaking of the lime is an important process in the manufacture of mortar, and it is imperative that every particle of quicklime must be thoroughly slaked, for if any unslaked portions are built in the work it will, by its subsequent expansion, disturb the rest of the work. To obviate this failing, the mortar after mixing should always be left to temper, covered over sometimes with a layer of sand, for at least a week to one month before being used…

A long time elapses before pure limes harden, owing to their depending upon external aid to attain this state. If lime alone was used, the surface would set and form an impervious layer, and so check the CO_2 from acting on those particles below the surface, the moisture in which evaporates and leaves it in the state of a powder; and even when a large proportion of sand is used and the mass made porous, the supply of CO_2 must necessarily small; and a long time elapses before the material hardens… pure limes should be avoided for constructional work, and a lime or cement which does not depend on external aid to set, be used.

Hydraulic Lime Mortar. The strong hydraulic limes are usually ground into powder to facilitate the slaking. Slake the lime by sprinkling it lightly with water, then turn it up together in a heap, and cover it with sand. After 24 hours it may be made into mortar by adding the proportions of sand and water. One part of lime and 2 parts of sand make excellent mortar.

Selenitic Cement or Selenitic Lime is an invention of General Scott, and is made by adding to the limes of the lias formation (the best)… or to the magnesian limestones or any lime possessing hydraulic properties, a small proportion of calcium sulphate in the form of plaster of Paris, mechanically mixed and ground with lime.

Roman Cement is a natural cement prepared by burning at a low temperature nodules found in the London clay, and the shale beds of the lias formation. It contains about 40% clay, is of a rich brown colour… It is kept in barrels, as on exposure to the atmosphere it absorbs CO_2, and

moisture, and becomes inert. It should, therefore, be used fresh. It is about one third the strength of Portland cement (in 1912) and is much weakened by the admixture of sand, which should never be used in greater ration than 1 to 1... It is chiefly used for tidal and constructional work and where rapidity of setting is a necessity. It is now almost entirely supplanted by Portland cement for all works.

Mitchell. 1947 edition. Lime Mortar A suitable ratio of lime to sand for lime mortars is 1:3 (quicklime:sand). The lime should be semi-hydraulic; high calcium lime is unsuitable for mortar unless gauged with cement. Lime mortars should not be used for external work and in general it is preferable that, whether for external or internal work, lime mortars (other than hydraulic) should always be gauged with a proportion of cement. Mortar prepared with hydraulic lime may be unreliable and cannot be recommended for general use.

Cement-Lime Mortars Suitable proportions for cement-lime mortars vary according to conditions and requirements from 1:1:6 to 1:3:12, cement: lime: aggregate. A 1:1:6 mix should be suitable for use under most conditions of severe exposure; Mixes containing a larger proportion of lime become progressively more liable to suffer damage from frost and exposure, although the workability and plasticity of the mortar increases with the increase of lime content. A 1:2:9 mix should be suitable for all normal work except under conditions of severe exposure; but a 1:3:12 mix should be used for internal work only.

1914 – Jan Van der Kloes, A Trades Manual

Reference: Van der Kloes J A (1914) A Manual for Masons, Bricklayers, Concrete Workers and Plasterers, revised and adapted to the requirements of British and American Readers by Alfred B Searle. London. J & A Churchill.

Representing a summary of central European practice at the time.

In the opinion of the author, the deterioration at Cologne (Cathedral) of stones which are elsewhere found to be of excellent quality is largely due to the mortar employed. This is the more probable, as most of the buildings where such stones have proved satisfactory were built before the use of Portland cement became common...

Lime.
When… quicklime is brought into contact with water it 'slakes'. If lime is well-burned and the proper quantity of water is employed for slaking (with fat lime the amount of water required is about half the weight of the lime), the (p74) lump lime falls into an impalpable, perfectly dry powder (hydrated lime or slaked lime).

In dry-slaking, the lime is spread out on the ground in a layer 4 to 6 inches thick, and is sprinkled with water by means of a rose on a watercan. It is mixed with the aid of a shovel, and is then heaped up and left to itself for a day, so that it may be fulled slaked. It is advisable to cover the heap with sacks so as to retain the heat in it… The dry, slaked lime is sifted… so that all coarse particles are separated and a really fine, soft powder is obtained.

As the proper slaking of lime is a process requiring considerable skill, some lime manufacturers now supply properly slaked and sifted lime ready for use under the term hydrated lime. This method of slaking is termed 'dry-slaking' in contradistinction to 'wet slaking', in which the lime is mixed with three or four times its weight in water in a flat wooden trough, a liquid slurry being produced, which… is made to flow into a pit dug out of the neighbouring ground (this method only for fat or rich limes).

With both methods of slaking a considerable amount of heat is developed (P75)… To produce a building lime of good quality it is necessary to develop as much heat as possible, avoiding the addition of too much cold water to any part of the lump lime and screening the material from the wind and draughts… Both methods of slaking will produce an equally useful lime for masonry and plastering.

…there is always a risk of premature carbonation with dry slaked lime, which is bound to happen to some extent in ordinary dry-slaking with a suitable quantity of water, and is probably the reason (P76) why the use of lime putty has given better results than dry-slaked lime in tests with pozzalans… Wet-slaking is also the easier method and produces lime of better quality, as well as a durable lime paste. The use of rather more water than is strictly necessary does not do any damage in wet-slaking, providing that care is taken not to add too much cold water at a time and to regulate the supply of water (in Van der Kloes' method, water is still added to the lump lime, not vice-versa), so that the temperature in the slaking trough remains sufficiently high to retain the whole mass at a boiling heat for some time (must be properly mixed and stirred throughout process)… The provision of a grate at the outlet of the trough is superfluous and even harmful, because

it easily leads to the use of an excessive quantity of water and to the resultant cooling or 'drowning' of the lime…

Hydraulic Lime.
A lime of entirely different properties is made by burning limestone containing clay… It goes without saying that wet-slaking cannot be employed for hydraulic limes and that dry-slaking is the only permissible method. The manufacture of hydraulic limes is easier than that of fat limes, as less heat is needed to burn them, and they are usually supplied in a more completely burned state than are quicklimes… It is advisable to purchase hydraulic lime from the dealers in a ready-slaked condition, as this not only saves the trouble of slaking, but it is probable that the slaking has been carried out in a better manner and by specially-skilled labour.

Footnote: (Trass and lime mortars commonly used in Belgium and Holland in the past – for damp-proof courses, eg.). The reason why our ancestors did not experience the disadvantages of such mixtures as much as the builders of the present day is that they used an imperfectly burned lime and a coarsely ground trass, both of which introduced a certain amount of coarse stone powder (which acts like sand) into the mortar. At the present time, the demand is for very finely powdered trass and for lime which is purer and has been burned much better… The use of such strong trass mortars for structures which are intended to remain continuously under water merely results in a great waste of money, but if the structure is exposed to the air, the mortar shrinks and becomes loose and partially separated from the stones…

Lime Mortar.
In lime mortar the proportion of lime to sand may vary between 1:2 and 1:4 according to the nature and the properties of the lime and the purpose of the masonry. It is not advisable to use fat lime in a lime mortar. For this purpose hydraulic lime is far preferable… For building houses and other town buildings, on the contrary, the use of mortar made of hydraulic lime will produce dry masonry of excellent quality. Ordinary fat lime should… never be used without the addition to it of trass or some other hydraulic agent. Notwithstanding… there are many instances in different countries where not only is hydraulic lime used on a large scale for viaducts, retaining walls, etc, but such buildings are even constructed with mixtures of fat lime and hydraulic lime. This is foolish, as neither… should be used for such structures. The addition of lime to cement mortar has a two-fold purpose – a) to make the mortar cheaper and b) for the convenience of the workmen.

…the more the lime exceeds the cement, the more does it hinder the hardening of the latter and the damper will the walls remain (P151)… when the proportion of lime in a mortar is very large, such a mortar will never harden properly…

Choice of Mortar. Recapitulating… on choice of mortar:

1) *Lime mortar made of fat lime must be entirely discarded*
2) *Lime mortar made of hydraulic lime is a very useful material for ordinary buildings, but it must not be used for roadways, bridges, or masonry exposed to water such as marine work or reservoirs*
3) *Lime must not be added to cement mortar*
4) *Trass (or other pozzzolana) is in most cases, an excellent substance to add to cement mortar*
5) *When the choice lies between lime-trass mortar and Portland cement mortar, the trass mortar is preferable in most cases because*
    a) *it is easier to work;*
    b) *it is less liable to be spoiled if it is not used immediately after mixing. (trass mortar will not be spoiled if it remains a whole day after mixing before being used)*
    c) *it is usually cheaper*
    d) *it adheres to the stones almost, if not quite, as tenaciously as cement mortar.*
6) *For kiln, furnace and boiler work, clay mortar should be exclusively employed.*

The proper way to mix mortar by hand is as follows: The sand is first measured and shot out on a wooden floor or mixing board; the other solid constituents of mortar are also measured and added to the sand, the whole being mixed together in a dry state by means of the rake. After having worked through the heap several times, a hollow is made in its centre and a suitable quantity of water is poured on, but on no account must too much water be used. The mass is again turned over several times with the rake, and is then kneaded in such a manner that the workman pushes off a small quantity of the paste with the flat side of rake, rubs it flat over the floor, and fetches it back. He repeats this until the whole mass has been treated in this manner…

The mixing must not be stopped before the rubbed (P158) out surfaces show a uniform colour, quite free from white spots or ‘eyes’.

1914 – Building of the Bruce Hostel, Lerwick

Reference: Shetland Museum & Archives D11/225.
Mortar specification typed and edited by hand, by W. Laidlaw Macdougall*:*

"The mortar shall be composed of two parts fresh river sand to one part of fresh burnt lime mixed and used fresh each day."

1915 – Lazell, History and Uses of Hydraulic Lime

Reference: Lazell E W (1915) Hydrated Lime: History, Manufacture and Uses in Plaster, Mortar, Concrete; a Manual for the Architect, Engineer, Contractor and Builder. Jackson-Remlinger Pittsburgh. Facsimile by Filiquarian Publishing LLC.

The thrust of Lazell's treatise is clear and unambiguously promotes the use of dry hydrated lime for all building purposes and plastering. Advances in the industrialized production of reliable, good quality dry hydrate – both of high calcium and dolomitic – lime indicated to him that this was the most convenient, most economic and most reliable form of slaked lime. It was also obviating the need to either slake to stiff putty or to dry powder by traditional methods, which he considered more time consuming and more vulnerable to the inexperience or inattention of the masons or plasterers who carried out the operation, and with more variable and less reliably burned lump lime. At no point does he entertain the notion that this may be an inferior product, whether used as the only binder, or in combination with Portland cement. He does, however, in asides, show that hot mixing remained common in the trades at this time.

Classification of lime and lime products based upon the form in which they are supplied the trade:

a) *Run of Kiln Lime – the product as it comes from the kiln, without any sorting or further preparation*
b) *Selected Lump Lime – a well burned lime which has been freed from core, ashes and cinder by sorting*
c) *Ground or Pulverised Lime – lime which has been reduced in size to pass a ¼ inch screen*
d) *Hydrated Lime – a dry flocculent powder resulting from the treatment of quicklime with sufficient water to satisfy chemically all the calcium oxide present…*

Method of slaking: The ordinary method of slaking quicklime is to add sufficient water to produce a thick paste after the reaction of slaking is

completed... Sufficient water should be used in order that it may come into contact with all parts of the lime. If insufficient water is used some parts of the mass of lime become dry and are 'burned' in slaking. 'Burned' lime works tough and non-plastic in the mortar. If an excess of water is used, the slaking proceeds slowly and the resulting paste is thin and watery. Such lime paste is spoken of as 'drowned'... Too often the slaking is left to inefficient and ignorant labor, with the result that the mass of lime is not thoroughly slaked, being either 'burned' or 'drowned'...

"So late as 1851 an English architect, when sketching in the Campo Santo at Pisa, found a plasterer busy in lovingly repairing portions of its old plaster work, which time and neglect had treated badly, and to whom he applied himself to learn the nature of the lime he used. So soft and free from caustic qualities was it that the painter could work on it in true fresco painting a few days or hours after it was repaired, and the modeler used it like clay. But until the very day the architect was leaving no definite information could he extract. At last, at a farewell dinner, when a bottle of wine had softened the way to the old man's heart, the plasterer exclaimed, 'And now, signor will show you my secret! And immediately rising from the table, the two went off into the back streets of the town, when, taking a key from his pocket, the old man unlocked a door, and the two descended into a large vaulted basement, the remnant of an old palace. There amongst the planks and barrows, the architect dimly saw a row of large vats or barrels. Going to one of them, the old man tapped it with his key; it gave a hollow sound until the key nearly reached the bottom. There, signor! There is my grandfather! He is nearly done for.' Proceeding to the next, he repeated the action, saying, 'There, signor, there is my father! There is half of him left.' The next barrel was nearly full. 'That's me!' exclaimed he; and at the last barrel he chuckled at finding it more than half full; 'That's for the little ones, signor!' Astonished at this barely understood explanation, the architect learned that it was the custom of the old plasterers, whose trade descended from father to son from many successive generations, to carefully preserve any fine white lime produced by burning fragments of pure statuary, and to each fill a barrel for his successors. This they turned over from time to time, and let it air-slake in the moist air of the vault, and so provide pure old lime for the future by which to preserve and repair the old works they venerated. After inquiries showed that this was a common practice in many an old town, and thus the value of old air-slaked lime, such as had been written about eighteen hundred years before, was preserved as a secret of the trade in Italy, whilst the rest of Europe was advocating the exclusive use of newly burnt and hot slaked lime." (quoted in Hodgson, Concrete, Cement, Mortar, Plaster and Stucco, PP22-25)...

Compare the method of slaking recommended by Vitruvius and that of the skilled Italian plasterer with the modern method of slaking the lime in the middle of a ring of sand and almost immediately hoeing in the sand. In the present practice more often than not, the plaster is placed on the wall or the mortar laid between the bricks within a few hours...

Methods of dry slaking:

1. Lime, in comparatively small pieces about the size of an egg, is placed in a basket and immersed in water for a minute or two, until hydration has commenced, when it is withdrawn. The wet lime is generally put in heaps or silos in order to conserve the heat and prevent the escape of vapour. The material swells, cracks and becomes reduced to a dry powder.

2. Lumps of lime are placed in a heap and wetted at intervals so that the mass is equally moistened throughout. The slaking proceeds as in the first instance.

3. Small pieces of lime are exposed to the air for a number of months. The material absorbs both water and carbon dioxide from the atmosphere, falling to a dry powder. The powdered form consists of a hydrated sub-carbonate of lime containing about 10% to 11% of water.

The methods of dry-slaking lime are crude, and unless the greatest care is exercised, the resulting dry product will contain particles of unslaked lime. Further, the hydrates produced by these methods generally work short and possess poor sand carrying capacities...

In Circular No.30, 1911, of the Bureau of Standards:

"The proportion of impurities in hydrated lime is generally less than that in the lime from which it is made. In building operations, hydrated lime may be used for any purpose in place of lump lime, with precisely similar results. The consumer must pay the freight on a large amount of water, but the time and labour required for the slaking is eliminated and there is no danger of spoiling it either by burning or incomplete slaking... For all building purposes hydrated lime is to be preferred to lump lime. By its use the time and labor involved in slaking may be saved and the experience of the labourer is eliminated as a factor in the problem."

Hand-mixed mortars. (Best by mortar mixer but two methods if perforce by hand):

First: soak the hydrate with water so as to produce a thick paste, and allow to stand over night, then add the desired amount of sand and sufficient water to give the required consistency to the mortar. It is generally conceded that this method produces the more plastic mortar.

Second: Mix the hydrate and sand dry, the same as with cement mortar, then add the water to produce the required consistency.

Lime-cement mortars. In many cases where a mortar having a greater strength is required, or it is advisable to have considerable strength produced quickly, it is advantageous to use Portland cement in the mixture. Investigations by various authorities have proven that hydrated lime and Portland cement can be mixed in any proportion, from an addition of 10% of hydrate to the Portland cement for making a cement mortar, to an addition of 10% Portland cement to the hydrate for making a hydrated lime mortar. The addition of hydrated lime to a cement mortar improves the plasticity and water tightness, and the addition of Portland cement to a hydrated lime mortar increases the early time strength.

1916 – Williams Clough, Cob, Pise and Stabilized Earth

Reference: Clough Williams Ellis (1916) Building in Cob, Pise and Stabilized Earth. Shaftesbury. Donhead Re-print.

Limewashes: The basis of most lime wash recipes is the mixing of a quantity of tallow, which may be from 2 to 10 lb, into a bushel of quicklime to form an insoluble calcium soap. The tallow should be placed in the centre of the quicklime and the whole should be slaked together. If the quicklime is slow in slaking it should be covered with sacking, and hot water should be used. The addition of pigment may necessitate an increase in tallow, but a useful mean to remember is 5lb tallow to a bushel of quicklime. When tallow is not available, calcium stearate in powder form may be substituted, or linseed oil may be added... The pigments should be lime fast and should be added during slaking. If this is not possible the pigment should be mixed with alcohol and added to the strained whitewash...

There are several traditional formulae consisting of lime (not whiting) thoroughly slaked and thinned to a cream to which various additions are made, such as salt, alum, powdered glue, casein (skimmed milk), etc. The effect of salt is probably to hold the moisture and facilitate the carbonation of the lime, while the addition of a small quantity of alum improves the

of the lime, while the addition of a small quantity of alum improves the working qualities and is thought to increase the hardness of the surface. Caseins and glues give greater binding properties to the mix.
'Weatherproof' Whitewash (exteriors), for Buildings, Fences, etc

1. *62 lb (1 bushel) quicklime, slake with 12 gallons of hot water.*
2. *2 lb common table salt, 1 lb sulphate of zinc, dissolved in a gallon of boiling water.*
3. *2 gallons of skimmed milk.*

Pour (b) into (a), then add the milk (c), and mix thoroughly.

(3) 'Light House' Whitewash:

1. *62 lb (1 bushel) quicklime, slake with 12 gallons of hot water.*
2. *12 gallons rock-salt, dissolve in 6 gallons of boiling water.*
3. *6 lb of Portland cement.*

Pour (b) into (a) and then add (c).

Note - Alum added to a whitewash prevents it rubbing off. An ounce to the gallon is sufficient.

1920 – Blake's Building Repairs

Reference: Blake E G (1920) Building Repairs, Batsford, London.

Mason. ...Mortar for facework (in replacing failed stones individually) should be of good blue lias lime, and sharp washed sand (not too fine) and the back of the stone and the cavity should be thoroughly wetted, the mortar flushed all round and the stone pressed into the cavity so that the whole becomes a solid mass.

Plasterer. Hair Mortar. The mortar for plastering should be made exclusively with chalk lime. It should be made up roughly, at least a fortnight being being required for use, and should be allowed to lay in a heap, in order that the lime may become thoroughly slaked. If the lime is used too fresh, it is probable that many small particles of lime will remain unslaked after it is spread, and these in the course of time would absorb moisture and expand... commonly called 'blowing'.

The mortar should be gauged 1 of lime to 2 of sand, and the lime should be run before using in the following manner: A bay, or ring of sand is formed, and a barrowful of lime is placed in a tub and well-covered with water, which will generate sufficient heat to cause the water to boil. When this has subsided, it should be run through a fine sieve... into the bay, to separate

cores, stones, etc from the liquid lime, the sieve being supported on pieces of slate batten laid across the ring of sand from side to side. After standing overnight, any water which has risen to the surface can be run off if necessary, leaving the lime in a paste beneath. The hair should then be added, having been previously well beaten with sticks in order to free it from dirt and dust, and to bring it to a loose separated condition. This should be worked into the lime with a hair hook… after which the sand is distributed over the lime, and the whole mixed up with a larry or with shovels.

1920's – Lime burning in the Western Isles

Reference: MacIntyre M (1992) oral history recording of Domhnall Iain Monk speaking about traditional lime burning and slaking in Benbecula. Comainn Eachdraidh Nan Eilean Mu Dheas (Federation of Southern Isles Historical Societies) Newsletter No.4 June 1993 and reprinted in Lime News Vol 2 No.1 (1993).

"It was done on the ground, on a dry, flat piece. They used to put slabs down, and they would arrange them like 4 'feadain'. So that the draft would get in under the lime when they began to heat it. They would put big slabs to make these 'feadain'. The place where they would put the lime would be about 6 ft in diameter, and they would put the shells in the middle, and they would buid peat on the outside, and they would put wood amongst the peat, and they would build this up. The shells were built up into a big pile (rughan) and the peat was placed around the base. They would then kindle the fire which would burn right up to the top of the shells, and they maintained the peat on the fire, watching it to see that it was burning properly, and it would be going for a day anyway, starting early in the morning and continuing until the next morning.

They would then take the shells out from amongst the soot… if there was enough wind, the soot would blow off the shells. They would put them on canvas beside the loch until all the soot had gone. They then washed the shells (?) and put them in a bag, took them home and placed them on another slab, a big clean one, and again they used to build up the peat around the shells – right round – leaving a hole at the top through which they poured hot water. The lime would expand and the water would pulverise the shells. It was white just like flour and they would keep it there and use it when they needed it, taking a piece of peat when they needed it…

The lime had amazing power… Any white shell would do, (including razor fish, but mussels were not used… 7 canvas bags made ½ a barrel of lime for

building. When it was set it was hard as anything. It would last for years and years."

1920 – Kidder, Building Construction and Superintendence

Reference: Kidder F.E. (1920) Building Construction and Superintendence. Revised and enlarged by Thomas Nolan. Part 1 Masons' Work. Limes, Cements and Mortars Chapter by Thomas Nolan. William T Comstock Company New York.

P145. Importance of the Subject.
There is hardly any material used by the architect or builder upon which so much depends as upon mortar in its different forms, and it is important that the architect should be sufficiently familiar with the different kinds of limes and cements to know their properties, and to understand their adaption to and suitability for different kinds of work. He should also be able to judge of the qualities of the materials with sufficient accuracy to prevent any which are actually worthless from being used, and he should have some knowledge of mortar mixing.

There is considerable difference... in the limes of different localities, and before using a new lime the architect should make careful enquiries regarding its quality, and if it has not been much used it would be better to procure a lime of known quality, at least for plastering purposes; for common mortar it is not necessary to be so particular.

Classifications: Group A High calcium limes, limes containing less than 5% of magnesia... Group B Magnesian Limes – limes containing over 5% (usually 30% or over) of magnesia. These limes are all slower slaking and cooler than the high calcium limes... and they appear to make a stronger mortar. They are, however, less plastic or 'smooth', and in consequence are disliked by workmen.

In the Eastern cities lime is sold by the barrel, weighing for Rockland Me. lime 220lbs net; but in many parts of the country it is sold in bulk, either by the bushel or by weight. When shipped in bulk it is generally sold by the bushel of 80 lbs, 2 ½ bushels or 200 lbs of lime being considered equivalent to a barrel...

Good lime should possess the following characteristics: 1. Freedom from cinders and clinkers, with not more than 10% of other impurities; 2. It should be in hard lumps, with but little dust; 3. It should slake readily in water, forming a very fine, smooth paste without any residue; 4. It should dissolve

in soft water. There are some limes which leave a residue consisting of small stones and silica and alumina in the mortar box, after the lime is drained off. Such limes may answer for making mortar for building masonry, but should not be used for plastering if a better quality of lime can be procured.

P148. Slaking and Making Mortar.
…When quicklime is slaked at the building operation, the ordinary practice is to do the slaking either by putting the lime in a water-tight box and adding water through a hose, or by pails, or by forming on a plank floor or on a bed of sand, a circular wall of sand, shovelling into the ring thus formed, the lime, and turning on the water from a hose. When the process of slaking is complete, the slaked lime is covered with a layer of sand until wanted.

…finally the lime is reduced to a powder… In this condition the lime… is ready for making into a mortar. The best limes slake without leaving a residue. The mortar is made by mixing clean, sharp sand with the slaked lime in the proportion of 1 part of lime to from 2 to 5 of sand by volume. The New York Building Code requires that not more than 4 parts of sand to 1 part of (quick?) lime shall be used. Practically the proportion of sand is seldom, if ever, measured, but the sand is added till the person mixing the mortar thinks it is of the proper ***proportion.*** *For brickwork over a certain proportion of sand cannot well be added, for if there is too much sand in the mortar it will stick to the trowel and will not work easily. With stonework the temptation is always to add too much sand, as sand is generally cheaper than lime…*

Some limes when slaked leave a residue of stones, lumps and gravel, so that instead of mixing the mortar in the same box in which the lime is slaked, a larger proportion of water is added, and the slaked lime and water (about as thick as cream) is run off through a fine sieve into another box, in which the mortar is mixed. Such lime does not make as good mortar as that which leaves no impurities, but it is sometimes used in ordinary brickwork and stonework.

The general custom in making mortar has been to mix the sand with the lime as soon as the latter is slaked and to let it stand until required for use. Much stronger and better mortar will be obtained, however, if the sand is not mixed with the slaked lime until the mortar is needed (most would disagree).

P148a. Hydrated Lime.
When quicklime is slaked on the work, it is usually done by careless laborers in a very indifferent manner, and the slaked lime seldom reaches a condition of theoretical efficiency... ready-slaked lime, carefully prepared at the lime-plants, has been introduced during recent years. This is placed on the market under the names of 'new-process lime', 'hydrated lime', 'limoid' etc. Its manufacture involves grinding the lump quicklime to a fairly uniform, small size; the thorough mixing of the resulting grains of powder with the proper proportion of water; and the reduction of the slaked lime to a uniform fine powder by passing it through a sieve...

The product is generally sold in either heavy, closely woven burlap or duck bags containing 100 pounds, 20 bags to the ton or in paper bags containing 40 pounds, 50 bags to the ton.

P148b. Hydrated Lime and Portland Cement Mixed.
Very interesting tests have been made on the strength of a mixture of hydrated lime and Portland cement... Up to certain limits the addition of hydrated lime to Portland cement mortar makes the latter easier to work and more plastic... (and leads to) an actual increase in tensile strength when the addition does not exceed 10 or 20 %.

P149. Sand.
The reason sand is used in mortar is because it prevents excessive shrinkage and reduces the cost of the lime or the cement; and while its addition to cement mortar always weakens it, its addition to lime mortar in the proportion of 1 to 2 for example, adds to the latter's strength...

...the usual specifications for sand used in making mortar require that it shall be angular in form, of various sizes, and absolutely free from all dust, loam, clay, earthy or vegetable matter, and also from large stones.

Recent tests and experiments, however, seem to lead engineers to the following conclusions:

1. *It is not necessary to have the grains sharp*
2. *The coarseness of the grains governs largely the quality. In mortars loam or clay is sometimes injurious, and sometimes beneficial, at least in cement mortars*
3. *The pouring of water into sand does not accurately determine the voids, which can be found by weighing the sand and finding its moisture*

4. *Because of the effect of varying degrees of moisture, a study of voids does not result in a method of comparing sands*
5. *Dry sand measured loose is heavier than moist sand*
6. *When mixed with cement coarse sand makes a denser mortar and requires less water than fine sand*
7. *Fine sand with grains of uniform size and screened coarse sand when dry have nearly the same weigh, but with ordinary moisture fine sand is lighter and more porous than coarse sand*
8. *The weight of mixed sand is usually greater and the volume of voids smaller that that of coarse or fine sand…*

For rough stonework a combination of coarse and fine sand makes the strongest mortar. For pressed brickwork it is necessary to use a very fine sand…

Some masons attempt the use of fine sandy loam in their mortar, as it takes the place of lime in making their mortar work easily; but it generally tends to weaken the mortar, and it is better not to permit its use.

P150. White And Coloured Mortars.
To be used in laying face bricks should be made from lime paste or putty and finely screened sand. After the slaked lime has stood for several days the water evaporates and the lime thickens into a heavy paste, much like putty, from which it takes its name of 'lime putty'. By the time the putty is formed the lime should be well slaked and have no tendency to swell or 'pop'. Coloured mortar should never be made with freshly slaked lime, but only with lime putty at least three days old…

Clear lime putty may be kept for a long time in casks, for use in making coloured mortar, only a little mortar being made up at a time. Common lime when slaked and evaporated to a paste may be kept for an indefinite time in that condition without deterioration, if protected from contact with the air so that it will not dry up. It is customary to keep the lime paste in casks or in the boxes in which it was slaked, covered over with sand, to be subsequently mixed with it in making the mortar.

The Setting of The Lime.
Quotes Professor Clifford Richardson: "The setting of lime mortar is the result of three distinct processes which, however, may all go on more or less simultaneously. First, it dries out and becomes firm, Second, during this operation, the calcic hydrate, which is in solution in the water of which the mortar is made, crystallizes and binds the mass together… Third, as the per

cent of water in the mortar is reduced and reaches 5%, carbonic acid begins to be absorbed from the atmosphere. If the mortar contains more than five per cent this absorption does not go on. While the mortar contains as much as 0.7 % the absorption continues. The resulting carbonate probably unites with the hydrate of lime to form a sub-carbonate, which causes the mortar to attain a harder set, and this may finally be converted to a carbonate. The mere drying out of mortar, our tests have shown, is sufficient to enable it to resist the pressure of masonry, while the further hardening furnishes the necessary bond."

...Lime mortar... attains its strength slowly, and where high buildings are built rapidly the mortar in the lower story does not have time to get sufficiently hard to sustain the weight of the upper stories, and for such work cement should be added to the lime mortar...

For the brickwork of ordinary buildings, and for light rubble foundations, lime and natural cement mortar forms a suitable and frequently used mixture; and when a still superior quality and strength are wanted, lime and Portland cement mortar is used.

P154. Hydraulic Limes.
Hydraulic limes are those containing, after burning, enough lime to develop, more or less, the slaking action, together with sufficient of such foreign constituents as combine chemically with lime and water, to confer an appreciable power of setting under water, and without access of air... Hydraulic lime or cement should not be used after it has commenced to set, as the setting will not take place a second time and the strength of the mortar will be lost.

Mr Edwin Eckel states that: "theoretically, the proper composition for a hydraulic limestone should be calcium carbonate 86.8% and silica 13.2%. The hydraulic limes in actual use, however, usually carry a much higher silica percentage, reaching at times 25%, while alumina and iron are commonly present in quantities which may be as high as 6%... The hydraulic limes include all those cementing materials (made by burning siliceous or argillaceous limestones whose clinker after calcination contains so large a percentage of lime silicate... as to give hydraulic properties to the product, but which at the same time contains normally so much free lime that the mass of clinker will slake on the addition of water..."

Artificial hydraulic lime can be manufactured by mixing together, in proper proportions, soft chalk or thoroughly slaked common lime and unburnt clay,

then burning and grinding in much the same manner as the manufacture of Portland cement...

P158. Definition of Natural Cement.
Natural cement is the product resulting from the burning and subsequent pulverisation of a natural clayey limestone containing from 15 to 40% of silica, alumina and iron oxide. There is no preliminary mixing and grinding. The temperature of the burning is about that of the ordinary lime kiln, and not sufficient to cause vitrification. Almost all of the carbon dioxide is driven off, there is a combination of the lime with the silica, alumina and iron oxide, and the formation of a mass containing silicates, aluminates and ferrites of lime; or in case the original rock contains magnesium carbonate, the formation of magnesia and magnesian compounds. As this resulting mass, as it comes from the kiln, will not slake if water be poured on it, it is ground into a fine powder, which, when mixed with water, hardens or sets rapidly either in air or water. The property of hydraulicity, as in the case of all silicate cements, is due principally to the formation of tricacic silicate...

P164. The Uses of Natural Cements.
As the use of lime mortar is confined to dry places where it is exposed to the air, being usually employed only in construction of thin walls above ground and in the foundation coats of plaster; and as it loses its binding properties when exposed to dampness, as in basement walls, and when excluded from contact with air, as in thick walls; and as it sets too slowly to bear any immediate heavy weight; cements have to be added or cement mortars substituted to meet these conditions.

In mortar, natural cement is adapted to ordinary brickwork not subjected to high water pressure or to contact with water until about one month after laying; and for ordinary stone masonry where the chief requisites are weight and mass.

Natural cement mortar or concrete should never be allowed to freeze, should never be laid under water, nor in very exposed situations, nor in marine construction.

Natural cement may be substituted for Portland in concrete, if economy demands it, for dry unexposed foundations... and will not be exposed until three months after placing; for backing or filling in massive concrete or stone masonry where weight and mass are the essential elements; for subpavements of streets and for sewer foundations...

P200. Cement Mortars.
Cement mortar should be used for all mason work which is below grade, or situated in damp places, and also for heavily loaded piers and arches of large span. It should be used for setting coping stones, and wherever the mason work is especially exposed to the weather.

For construction under water, and in heavy stone piers or arches, and, for concrete, Portland cement should be used; elsewhere natural cement mortar will answer...

P202. Keeping Cement Mortars Moist.
Hydraulic cements set better and attain greater strength under water than in the open air; in the latter, owing to the evaporation of the water, the mortar has a tendency to dry rather than to set. This difference is very marked in hot, dry weather. If cement mortar is to be exposed to the air it should be shielded from the direct rays of the sun and kept moist.

P205. Cement-Lime Mortars.
Some constructions require quick-setting mortars, but do not need the strength nor warrant the expense of a 1 to 2, 3 or 4 mixture of cement and sand. A 1 to 5 or more mixture would give ample strength, but would work 'short'; that is, it would not work easily, rapidly and smoothly on the trowel. It would not adhere perfectly to the stone or brick and could not be safely used (this is the commonly used mix for new build in the UK in 2017). The addition of a limited quantity of slaked or hydraulic lime corrects these faults, results in a cheaper mortar and gives a mixture suited to a great variety of uses. It permits the use of Portland cement mortar for very many purposes.

The following are the principal advantages of Portland cement-lime mortar:

1. Cheapness in comparison with other hydraulic materials
2. Rapidity of setting and hardening
3. Marked hydraulic properties
4. Great strength on exposure to air
5. Remarkable resistance to the weather.

In making cement-lime mortar the sand and cement are thoroughly mixed dry, the lime putty is mixed with water and screened into a mortar box, and the whole is then thoroughly mixed and worked together until a proper consistency is obtained.

The following mixtures by measure that have been used with excellent results:

Cement 1 part, sand 5 parts, lime paste ½ part.
Cement 1 partm sand 6 to 7 parts, lime paste 1 part.
Cement 1 part, sand 8 parts, lime paste 1 ½ parts
Cement 1 part, sand 10 parts, lime paste 2 parts.

In regard to strength, a mixture of Portland cement 1, lime paste 1, sand 6, is as good as a mixture of Portland cement 1, sand 3, in this case one half the cement being replaced without loss of strength…

P212. Sugar In Mortar. Sugar has been employed for centuries in India as an ingredient of common lime mortar, and adds greatly to the strength of the mortar.

An addition of sugar or syrup equal to one-tenth of the weight of the unslaked lime, to lime mortar, adds 50% to the strength of the mortar and will cause the mortar to set more quickly. The addition of sugar to lime mortar is especially beneficial when used in very thick walls, as the lime mortar thus placed is never fully acted upon by the carbonic acid of the atmosphere.

1922 – Edwin Eckel, Cements Limes and Plasters

Reference: Eckel Edwin C. 1922 Cements Limes and Plasters, Their Materials, Manufacture and Properties. John Wiley and sons, New York; Chapman & Hall, London. Second Edition. Reprinted by Forgotten Books.

Eckel was an industrial chemist. He treats thoroughly with hydraulic limes, dismissing the feebly hydraulic limes as not worthy of the name, considered only and perforce ‘because the English use them’. He saw free lime in a hydraulic lime as an inconvenience, besides the economic advantage that the slaking of around 25% free lime broke all to a powder, thus saving the cost of grinding and grinding plant. He insisted that hydraulic limestones should not be fired at greater than 900 °C.

Methods of slaking lime in ordinary practice – When lime is used for making ordinary building mortar, the common practice is to add much more than the amount of water theoretically required. The result is not only to slake the lime, but to convert the slaked lime into a thin or thick paste, according to the amount of water used.

When ordinary laborers are slaking lime, it is evident that this method possesses the great advantage of being on the safe side. It is possible that the addition of surplus water weakens the mortar somewhat, but on the other hand, it ensures thorough slaking, or would insure it, if even reasonably good care were taken during the operation. The trouble, however, is that lime-slaking is not regarded as an art, but as a disagreeable necessity, and it is usually carried on by laborers who are not even supposed to know anything about the subject.

The result of these conditions is that the slaked lime used in mortar rarely even approaches its theoretical efficiency. Either so much water has been added that the strength of the product is impaired, or else the water supply or mixing has been insufficient and the product is not thoroughly slaked…

A realisation of these facts has caused the introduction of ready-slaked lime, prepared carefully at the lime-plants… Hydrated lime… In its preparation, particular care is given to insuring that the product shall be thoroughly slaked, and that this slaking shall be done with as little water as possible…

In ordinary practice, where quicklime is slaked on the work, only one general method is followed, though books on construction invariably list and describe several other methods. The process as actually carried out is to form, on a plank floor or on a bed of sand, a circular wall of sand. The lime is shovelled into the ring thus formed and water is turned on from a hose until the labourer considers the amount sufficient. The lime commences to slake more or less quickly, according to its composition, and when the process is completed it is covered over with a thin layer of sand until required for mortar [or is mixed with the sand for immediate use]. …In practice, sand is always added to lime mortars, the proportions for ordinary use being from two to four parts sand to one part lime paste.

Under the name of 'new process lime', hydrated lime', 'limoid' etc., a large number of lime-plants have within recent years placed a ready-slaked lime on the market. When this product is carefully prepared, it does away with all the trouble, waste and unsatisfactory results entailed by the old method of slaking lump lime on the work.

1923 – US Department of Commerce, Standards for Small Dwellings

Reference: Department of Commerce. Recommended minimum Standards for Small Dwelling Construction. Report of the Building Code Committee. 1923. Government Printing Office, Washington.

The committee does not feel justified in approving use of straight lime mortar for construction of walls of the minimum thickness herein permitted (8-inch), for the reason that its weakness in compression and slowness of set as compared with cement-lime mortar, coupled with its tendency to disintegrate under high temperatures, combine to unsuit it for this purpose.

Where walls of greater thickness are used or where 8-inch walls are used for a one-story building and where reasonable care is taken to prevent undue loads, the use of straight lime mortar should be made optional.

1924 – Graham and Emery Masons and Builders Guide

Reference: Graham F D & Emery T J (1924) Audels Masons and Builders Guide, Theo. Audel & Co. New York.

The principal mortars are: Lime mortar, Lime-cement mortar, Cement mortar: Portland and Natural

Lime mortar is recommended for ordinary house construction. It may be used except where very heavy loads have to be carried, as on brick piers, or walls much cut up by window or door openings, or in very exposed situations.

It should not be used for exterior basement walls subject to a great deal of dampness...

Cement-lime mortar has come in favour within the last few years. Tests show it to be stronger in compression and better than Portland cement mortar, when properly proportioned.

Lime Mortar.
...is composed of sand and either slaked lump lime or hydrated lime... Lump lime is slaked by pouring water on it... When water is added, it should slake into a fine smooth paste without leaving any residue...

Hydrated lime.
It sometimes happens that lime slaked on the job may, owing to carelessness or lack of skill, be burned or otherwise spoiled. (but more now being slaked at the plant in controlled conditions)... It should be used where experience labor cannot be had.

Apparatus for Mixing and Handling Mortar: Screen, Mortar box, Mortar platform, Hoe, Shovel, Hod. Mortar Box.

In suburban districts the mortar box is usually built on the ground or in the street at the most convenient place for water and use...
Mortar Platform.
In the preparation of mortar... a platform is usually provided for stacking a supply of the mortar for the hods, while additional mortar is being mixed in the mortar box...

Preparing Lime Mortar.
The various operations in preparing the mortar for use are: screening the sand, slaking the lime, proportioning & tempering. The sand should always be screened, or much time will be lost by the bricklayers in having to dig out the larger stones while they are spreading the mortar...

Slaking the Lime.
...Lump lime must be prepared or slaked at least one week before it is used for mortar... (laid, not mixed to mortar after one week).

In slaking the lime, form a shallow basin of screened sand in the mortar box. Place the lime in this basin and pour water over the lime until thoroughly slaked... In the sand basin it steams and boils... when the lime is properly slaked it is reduced to a slimey consistency by the labourer, using a hoe.

Proportioning the Sand.
As soon as the slaking process is complete, mix the sand with the paste and shovel it out onto the wood platform, to remain until tempered for use.

Tempering Mortar.
Working the mortar and adding water to bring it to a proper consistency for actual use is called tempering. Mortar should be tempered until it slides easily off the trowel... and should be worked until all white spots of lime disappear, otherwise they will swell and pop after the mortar is laid.

1925 – William Frost, The Modern Bricklayer

Reference: Frost W (1925) The Modern Bricklayer, a Practical Work on Bricklaying in all its Branches Volume I. London. Caxton Publishing Company.

...Hydraulic lime, such as Dorking grey lime, is a moderate hydraulic lime and is used extensively in London and the provinces for the making of mortar. It is very suitable for the purpose and attains a considerable degree

of hardness in course of time. Strong hydraulic limes which are sold in bags and ground into a fine powder, when mixed with sand in the proportion of 1 part of lime to 2 or 3 parts of sand, make a very fine mortar. Blue lias lime is an hydraulic lime and one of the best of the natural hydraulic limes. It is especially suitable for work under water or for foundations in damp situations...

Mortars.
Mortars vary according to the purpose for which they are required. In all cases accuracy must be observed in proportioning the various component parts, and great care taken in the mixing. As a rule not more mortar should be made than can be quickly used. This is of particular importance where cement mortars are concerned, as in these initial set begins fairly soon, and knocking up, unless the cement is slow setting and contains a certain admixture of hydrated lime, weakens the adhesive powers and the strength.

When lime mortars are used in large quantities it is always advisable to slake the lime on or near the job. For this purpose a pit is dug and boarded, into which quick, or lump lime, broken into convenient size, is tipped, and clean water run in. A ton of lime will require 75 gallons of water (340 litres or one third of a tonne). It is stirred vigorously to ensure the breaking up of the lumps and thorough slaking. Great heat and volumes of steam will be evolved during the process. The lime is only fit for use when all the heat has been given off. Good lime (lime putty as it is termed in this state) should be smooth and "fatty." If lumps are allowed to be unbroken, or the slaking otherwise imperfectly carried out, the mortar will be more or less hygroscopic and liable to "blow." When once slaked it should be kept protected from dust and rain.

Mortars can be mixed by hand or in a mill. By hand a suitable position should first be selected to place the materials upon. For this purpose a banker is usually laid upon the ground. This consists of a number of scaffold boards, about twelve in number and about 12 feet in length. Four stakes are driven in the ground. This keeps the boards in position and also keeps them close at the joints of the boards, which stop as much water as possible from oozing through the joints. Sand is placed on the banker and a large ring made. The lump lime should then be placed into the middle of the ring of sand, and the pieces of lime broken as small as possible. Sufficient water should then be put on the lime, using a watering-can or a hose with rose attached. The lime should then be covered with sand and the whole allowed to stand from twenty to twenty-four hours. It can then be mixed together

with the shovel or larry into a paste form ready for use. All the unslaked lumps should be taken from the bed of material and should not be used.

The mortar mill, or mortar pan, is a revolving iron pan with mixing paddles or arms into which the lime or cement, sand or crushed brick, are placed for mixing. The mill is first revolved with the materials in a dry state, water being added gradually. A mill ensures thorough mixing and is more economical than hand labour when large quantities are involved. Large mills are driven by power, small ones by hand but even with the latter there is a saving of time and labour.

1927 – Cowper, Lime and Lime Mortars

Reference: Cowper A D (1927) Lime and Lime Mortars. Shaftesbury. Donhead.

This was a literature review commissioned by the Building Research Station.

Traditional Indian building methods show an appreciation of pozzalanic additions, in the form of burnt clay; and a hydraulic mortar has long been in use in India, made from argillaceous limestone 'kankar'. Hydraulic mortars made with the Italian pozzolana and the German trass of similar properties, have also had a limited use for centuries...

A curious aspect of the history of the use of lime is afforded by the array of materials which have been added... to lime plaster and mortar, generally with a view to slowing down the setting and making possible a more extended manipulation of the material in artistic work. Thus fig and other fruit juice; elm bark (presumably in the form of an infusion), barley water, bullock's blood, cow dung, hot wax, white of egg, wort and beer, pitch, milk, gluten, butter-milk, cheese, saponifies beeswax, etc have been recommended... sugar is apparently a common addition to lime mortar in India; and the modern use of glue or size-water in the gauging of plaster is familiar...

Perhaps the most important recent development has been the marketing of mechanically hydrated or slaked lime, of uniform quality and in extremely fine powder, for preparing lime putty or mortar directly by the addition of the necessary water. This movement has made great headway in the United States.

The slaking of lime. Burnt lime or quicklime is seldom used as such in building operations, but is practically always slaked before use, and then mixed with sand, hair, etc...

With lean Class B limes, it is best to conserve the heat produced in the slaking process; therefore, after the water is added to the lime, the latter should be covered up with a layer of sand and left for some time for the process to come to an end. Any large unslaked particles of overburnt or under burnt lime should then be removed... As with plaster, the use of finely divided ready hydrated lime greatly simplifies the process of mortar mixing.

Slaked lime is to be prepared from hydraulic lime by sprinkling the requisite quantity of water on the lime, covering up lightly so as to retain the heat and moisture for 24 hours; and then thoroughly stirring and incorporating the sand, together with more water as required... All mortar shall be mixed to a uniform consistence with only sufficient water to attain a plastic condition suitable for trowelling; and hydraulic mortar shall be used within 10 days of slaking the lime.

1932 – Building Research Station report on the Weathering of Natural Building Stones

Reference: Schaffer R J, the Weathering of Natural Building Stones, (1932) Building Research Station.

The Effect of Dense Pointing. When a brick wall is pointed with a dense cement mortar, little movement of water can occur through the pointing, and practically no drying takes place from the mortar joints. If the wall becomes wet, most of the drying takes place by evaporation from the surface of the bricks and any soluble salts in the wall, whether originating in the mortar or in the bricks, will tend to be concentrated in the bricks, and considerable decay may result. As a rule, however, damage of this kind is frequently found to be limited to the softer kinds of bricks, or to those which possess a surface skin, but even Tudor bricks which have remained sound for hundreds of years have been observed to suffer decay after repointing with dense mortar...

Similarly, it has been observed that the use of a dense mortar for repointing the walls of medieval and other buildings is liable to accentuate the rate of decay of the masonry... In the experience of the Building Research Station, cement mortars are found to be somewhat more liable to cause efflorescence than lime mortars, although hydraulic lime mortars are not entirely immune.

1930s – Modern Building Practice in 40 volumes

Reference: Thomas P E (Editor) Modern Building Practice in 40 volumes, George Newnes London.

Volume 3, Cements, Limes and Mortars.
Limes.
Lime was once one of the most important of building materials, but its use is tending to become restricted on account of the employment of cement and the different makes of gypsum plasters that are today on the market. These substitutes are justly popular, on account of their more scientific manufacture and resulting standardised composition, which renders them easier to employ on modern constructional work where large quantities of material are mixed by mechanical means. Nevertheless, many builders of experience still hold that lime possesses a number of valuable qualities which up to the present have not been reproduced in other materials.

...When water is added to quicklime it immediately becomes hot, swells to nearly twice its original bulk, and finally falls apart into a powder. If more water is added until the mass becomes a pulp, it is known as putty. If slaking begins in less than 5 minutes, the lime is known as quick-slaking or fat lime; if between 5 and 30 minutes, it is called medium-slaking, but if no action takes place for half an hour, it is called slow-slaking or lean lime.

Quick-slaking lime should be just covered with water to begin with, and the mass carefully watched. At the slightest appearance of steam, more water should at once be added, and the heap hoed over with the special hoe.

Medium slaking should have water added so as half to cover the mass, and a little more poured on from time to time to prevent steam escaping and the mass becoming dry and crumbly.

Slow slaking lime should be thoroughly wetted at the outset, and then be allowed to stand until the slaking action begins. Water should be added sparingly from time to time, but not in sufficient quantities to overcool the mass, and in cold weather, hot water should be used. The lime should not be hoed until nearly slaked, as it is necessary to retain the heat as much as possible.

...Air-slaking, due to the lime absorbing moisture from the air, tends to weaken the setting properties of the material, as the lime has absorbed carbon dioxide from the air as well as moisture, and has therefore begun to carbonate.

Hydrated Lime.
Many modern manufacturers now supply hydrated lime in bags in a similar manner to cements... By using this lime, the risk of incorporating unslaked quicklime particles is removed, and with it the chance of work 'blowing' or 'popping' after completion... While (air) lime plastering will set in reasonable time as it has a large surface area exposed to the air in comparison with its thickness, several years will elapse before the lime mortar in a wall has been able entirely to carbonise.

Hydraulic Lime.
For ordinary builder's mortar it is best to use a hydraulic lime, which is one containing silica and alumina in addition to calcium oxide. These limes slake very slowly, but do not require exposure to the air to harden, depending for this largely on the hydration of the silicate. They are sometimes called Lias, and when very hydraulic are used in positions where the setting has to take place in water. The limestones which produce hydraulic limes contain in themselves the silica, alumina and iron oxide required, and have not, as has Portland cement, to be specially mixed before burning, and thus when ground are really of the nature of a natural Portland cement.

Mortars.
...For ordinary brickwork, mortar may be composed of 1 part grey stone lime [feebly hydraulic] to 3 parts of sand; and for quick-setting, and very heavy loads, 1 part Portland cement to 4 parts sand. The mortar should be prepared on a properly constructed deal platform or 'bank' and measured in boxes or moulds. If mixing is done by hand, this measured quantity of sand is piled over the slaking lime and left for sufficient time to complete the process before it is mixed. With lime already hydrated, all that is required is to mix the sand and lime dry, and then add enough water to render the mass plastic. A few days should elapse before using the mortar so prepared. A mortar mill should be employed whenever possible... as it minimises the danger of unburnt or unslaked lumps in the mortar.

Plaster and its Application.
Lime Plaster.
For centuries, in this country, lime has been the principal material used in plasterwork... The condition of this old plasterwork at the present time speaks well for the durability of the materials used, and for the workmanship exercised in their application.

...After calcination, the quicklime... is slaked in a large tub or cistern to prepare it for use in making mortar. Where the work is of sufficient magnitude, a large square pit is prepared, either by digging in the ground, or by building four sides with planks to form a reservoir... The cistern or lime box is mounted at one end of the pit and has a sluice covered with a sieve or fine grating at one of its ends; the box is so placed as to have a slope towards the pit. Water is run into the box until it is about half full, then the quicklime is placed in the water until the whole box is covered, care being taken to keep the lime under water [this contradicts all previous slaking procedure, 'drowning' the lime]...

When boiling has ceased, the lime has changed from a stone-like form to a thick paste; this is stirred with a paddle to ensure thorough mixing with the water; the sluice of the box is opened, and the liquid falls into the large pit, where it remains to cool off, and stiffen into what is known as lime putty.

This should stand in the pit for at least a month to ensure that all the lime is thoroughly slaked...

Hydraulic Limes
Lime is rarely found in a pure state... These hydraulic limes, as they are called, are not favoured by the plasterer, because although they attain great strength, their working qualities are inferior to the rich or fat limes, which also have a greater capacity for carrying sand. The ideal lime, therefore, for plastering purposes is one having the highest percentage of calcium carbonate, (such as is) found in Derbyshire, where the limestone is the purest in the country. The most important thing in lime plastering, apart from good materials, is abundance of time... Lime hardens very slowly, by a two-fold process – evaporation and carbonation...

There are no means of hastening this process without adversely affecting the quality of the finished work, and in all lime plastering, the more the natural processes are allowed to operate, the better the result.

Methods employed to hasten the hardening process. For many years it was the custom, when work had to be hurried, to mix plaster of paris with the coarse undercoating in order to speed up the hardening process and allow work to proceed without waiting for natural drying to take place. This was not always successful and much of this kind of work suffered from cracking and other weakness after the work became dry. It has to be realised that when plaster of paris or any other setting agent is added to lime, it is only

that agent which actually sets, not the mass of lime with which it is mixed, and that the moisture contained in the mass has still to be evaporated; also, until evaporation takes place, the lime cannot carbonate. The hardening of a mixture such as this is due to the power of the setting agent to hold or support – by a network of crystals interlacing the mass – the bulk of material with which it is mixed, but the hardening is not the same as that which comes from natural drying out.

1934 – National Lime Association

Reference: National Lime Association (USA) (1934) 'Masonry Mortar,' Bulletin 321. Washington DC.

Dry Walls With Lime Mortar.
A water-tight masonry wall has a neglible number of unfilled joints or open spaces where brick and mortar apparently meet but are not attached. The formation of such openings is influenced by the properties of the materials used and the class of workmanship employed. The presence of openings between units and mortar is the primary cause of excessive water penetration into the wall... This condition must be prevented if the masonry is to remain durable... The most effective method of preventing the condition... is to lay up the masonry in a mortar having properties which will permit the mason to completely fill all joints. The mortar should also possess properties which permit the formation of maximum extent of bond plus ability to maintain such bond.

The fact that openings exist is proved by the many instances of leaky walls wherein both units and mortars are comparatively impervious. Mortars of very low porosity are often associated with bad leaks...

Water that enters pores and voids of bricks, stones, mortars etc readily evaporates from the exterior surface. This is a normal condition offering no cause for concern.

To prevent excessive water penetration into a wall, one must use an adaptable mortar. This is a mortar that can be expected to adhere satisfactorily to all types of building units.

Lime promotes mortar adaptability and a mortar rich in lime is suitable for all types of units. An adaptable mortar is first of all workable. It has bonding power. It is characterised by low volume changes subsequent to hardening. It has good extensibility, produces good strength and has a rate of hardening compatible with modern methods of construction.

Properties Of A Mortar That Make It Adaptable And Suitable.

Workability.
Warren E Emley in Bureau of Standards Technologic Paper No. 169 states: "The ability to retain water, while the most important, is not the only factor governing plasticity." ...this property has been found to be always associated with plasticity, (therefore) it may be said that a measure of the water retaining capacity of a mortar provides a good index to its plasticity or workability...

The three known factors that control workability are:

1. *water retaining capacity*
2. *bulk density*
3. *good troweling properties*

...Water is the sole lubricating medium in mortar and the more retentive it is of water, the more workable is the mortar under practical working conditions. If the mortar loses water to the brick too rapidly, it stiffens so quickly that intimate contact is not made and as the mortar adheres to the brick only in spots... the extent of the bond is poor. If the mortar has high water retaining capacity the extent of bond is good.

Water-retaining capacity of mortars as related to the water-tightness of test walls

mortar composition Lime: OPC: sand Proportions by volume	*water retaining capacity (flow % after suction for 1 minute on a standard*	*maximum rate of leakage of 8-inch test walls made with dry-press bricks set dry (cubic centimetres of water transmitted thru walls per min*
0.15:1:3	*54*	*402*
1:1:6	*75*	*386*
2:1:9	*93*	*98*
3:1:12	*91*	*128*

NB these tests were "extremely severe, far more so than the conditions to which a wall may be exposed in the most severe rain storm. The extent of bond obtained with 2:1:9 and 3:1:12 was complete."

...It is difficult to get a satisfactory bond with a mortar deficient in water retaining capacity, no matter what the absorption of the brick may be. ...Bonding power involves general adaptability. Bonding power is that property of a mortar which gives it a tendency to adhere uniformly and completely at all points of contact where bricks and mortar meet, under widely different conditions and with various types of units, the intensity of its adhesion being such that the tensile strength of bond is either equal to or greater than that of the mortar (a 1:1:6 has much better bond that a 1:3 cement mortar)...

More recent data, published in Bureau of Standards Research Paper no. 683, "The Properties of Bricks and Mortars and Their Relation to Bond" show conclusively that mortars richer in lime than 1:1:6 have better bonding power than that mortar. As lime, either putty or dry hydrate, was substituted more and more for Portland cement, the bonding power was improved.

...Volume changes
Lime and rich in lime mortars have a high water retaining capacity and therefore tend to undergo a minimum of compacting when in contact with porous building units.

Shrinkage During Early Hardening

a. *This type of volume change is omnidirectional*
b. *It attends hardening through cementing action*
c. *It occurs but once during the lifetime of a mortar*
d. *Its magnitude is diminished when the mortar is in contact with an absorbent unit and is greatest when in contact with solids of zero porosity*
e. *A mortar which hardens slowly is more or less plastic when most of this type of shrinkage is completed*
f. *Any possible damaging effect of this type of volume change is dependent as much (and probably more) on the rate of hardening as on the magnitude of shrinkage*
g. *Data obtained during an extensive study at the Bureau of Standards show conclusively that this type of volume change is not damaging either to the mortar or to the bond between the mortar and bricks. This*

was found to be true regardless of the magnitude of the shrinkage of mortar during early hardening…

Volume Changes Subsequent to Hardening

a. *This type of volume change is characterised by expansion on wetting and shrinkage on drying*
b. *It is cyclic and frequently is rapid if the conditions for wetting and drying are favourable*
c. *It takes place in rigid mortar that has an elastic limit*
d. *High volume changes subsequent to hardening are characteristic of dense mortars of outstanding hydraulic properties. They are lowest for straight lime mortars. This type of volume change is reduced as lime is substituted more and more for Portland cement (Bureau of Standards Research Paper no. 321, 'Volume Changes in Brick Masonry Materials')*

…When the extent of bond is poor (less than 90% of the flatside area of a brick) there is a tendency for it to be destroyed entirely if the mortar is one that has high volume changes subsequent to hardening.

If the extent of bond is complete or nearly so, high volume changes in the hardened mortar tend to produce cracks in a direction more or less perpendicular to the plane of contact of brick and mortar. These cracks may heal slowly when the mortar is wet, but they occur again and again and tend to admit an excessive amount of water into the wall and, as a consequence, further occurrence of volume changes is accelerated. Usually, a mortar having low water retaining capacity is one that also undergoes relatively high volume changes subsequent to hardening…

Strength
A strong wall is one having integrity, ie., adhesion of mortar to units throughout. 'Mortar pancakes' that keep bricks apart and not together do not provide a strong wall, be the strength of the mortar what it may. A chain is only as strong as its weakest link… This weakest link is at the plane of contact of bricks and mortar when the latter has poor bonding power. All other things being the same, a water-tight wall is always stronger than a leaky one.

(Quotes National Bureau of Standards circular no. 30 as per Boynton and Gutschick.)

…These two undesirable properties, low water retaining capacity and high volume changes subsequent to hardening are usually associated. The same

holds for the desirable combinations, high water retaining capacity and low volume changes subsequent to hardening, and this desirable combination does more to promote strength in a wall of masonry than mortar strength per se. This fact should be appreciated and thoroughly borne in mind by all who are interested in improving unit masonry from the standpoint of both strength and water-tightness.

Weather Resistance

Two factors control the resistance to frost in unit masonry. These are:

1. *The extent to which the wall becomes saturated during its life history and,*
2. *The frost resistance of the building materials (units and mortar)*

The first of these two factors is much more important than the second. A comparatively dry wall is not exposed to weathering from severe climatic action. Water is the universal solvent and chief weathering agent. When water which saturates a wall is repeatedly frozen and thawed the masonry is disrupted regardless of the fact that the materials composing it may, in themselves, be frost resistance in the usual laboratory tests. The extent of bond between units and mortar in such a wall is poor to begin with, else the masonry would not be excessively saturated. A poorly distributed bond... soon fails entirely from frost action.

The freezing and thawing of moisture which, under the most severe conditions, only dampens or partially saturates the wall, does relatively little damage. In such a wall, the extent of adhesion between mortar and units is good. The bond is therefore relatively durable both because it is uniform and complete and because it is exposed to a minimum of exposure.

It so happens that those mortars which have the best freezing and thawing records in laboratory tests are usually associated with leaky masonry. The properties that enable them to endure severe freezing and thawing in the laboratory are not properties which cause them to bond completely and firmly to various types of building units. It also happens that those mortars of relatively less resistance to (these tests)... are usually associated with dry walls. They have properties which insure good adhesion at all points throughout the wall. It is more important to avoid excessive exposure of a wall than it is to have materials that are the most resistant when severely exposed... Excessive dampness in itself is damaging both to health and property.

Lime mortar has an enviable record for resistance to weathering in the oldest brick buildings in the history of this country. The walls in these fine

old buildings seldom if ever became completely saturated. Therefore the lime mortar did not decay and fall out.

Lime and rich in lime mortars attain their full strength at a rate less rapid than that of Portland cement mortars. Many of the natural cements and hydraulic limes also attain their strength at rates comparable to that of lime mortars. To subject specimens of mortars having a relatively slow rate of attaining strength to severe laboratory freezing and thawing tests at an early age is a procedure that can only add to an accumulation of 'misinformation' which is of no practical value. The number of cycles of freezing and thawing provided for in the usual laboratory procedure before specimens have aged a year is more than would be attained, even in a leaky wall, in half a century of normal exposure. The proof of this statement is found in the many examples of old masonry in both the United States and Europe made of materials which of themselves give negative results under prescribed laboratory tests, yet these buildings stand today in mute testimony of their endurance after centuries of exposure.

Rate Of Hardening
Some have expressed scepticism about the use of lime or rich in lime mortars for the reason that they believe that such mortars harden too slowly to meet the needs of modern construction. Let the facts dispel such an illusion.

Table 8
Rates of Hardening of Mortars on an Impervious Base as Indicated by Vicat Tests
(National Bureau of Standards Research Paper No.683)

Mortar composition Lime: Portland cement: sand (By volume)	*Rates of hardening. Average of 3 tests. Modified Vicat test after the mortar had been on an impervious (steel) base for 2 hours. Millimetres penetration in 30 seconds.*
0:1:3 (opc no.1 - grey)	*5.2*
0:1:3 (opc no.2 – white)	*0.8*
1:1:6 (opc no.1)	*1.8*
2:1:9 (opc No.1; quicklime)	*3.8*
3:1:12 (opc no.1; quicklime)	*4.0*
1:1:6 (opc no.2; hydrated lime)	*1.0*

2:1:9 (opc no.2; hydrated lime)	*2.5*
3:1:12 (opc no.2; hydrated lime)	*3.5*
0.15:1:3 (opc no.1: quicklime)	*1.8*
1:0:3 (quicklime)	*30*
1:0:3 (hydrated lime)	*22.7*

Table 9
Mortar Mixes for Various Types of Masonry

Masonry Type	*Construction Type*	*Loading*	*Proportions*
Common and face Shale or sand-lime Brick	*Dwellings, garages and similar*	*Any for such types*	*1:0:3*
Clay or shale Brick	*Walls and piers below grade continuously ex-posed to wet or damp conditions*	*Ordinary distributed*	*1:1:6*
		Heavy concentrated	*1:1:6*
		Eathquake tremors	*1:1:6*
Granite, limestone, Marble, sandstone, Terracotta facing and trim	*exterior walls and piers above grade*	*Ordinary distributed*	*2:1:9*
		Heavy concentrated	*2:1:9*
		Earthquake tremors	*2:1:9*
Common and face clay, shale or sand-lime brick, concrete brick	*Interior walls and piers above and below grade*	*Ordinary distributed*	*2:1:9*
		Heavy concentrated	*2:1:9*
		Earthquake tremors	*2:1:9*

Hollow clay tile, Concrete block, Concrete tile, Cinder block Gypsum block	*Exterior walls above grade and interior partition walls*	*Non-bearing partitions, exterior and bearing walls and partitions*	*2:1:9*

(NB Portland cement circa 1934 has much less strength than after WWII and since - around 500 psi/3.4 Mpa. A modern 2:1:9 would be stronger (3.8 after 28 days; 4 Mpa after 90 days) but still less strong after 2 years than most currently available NHLs. (HE/BLF/Figuieredo 2018) and with a higher free lime content). Similar – and beneficially lesser – strengths, but with earlier initial set may be achieved with a hot mixed lime mortar and up to 10% pozzolanic addition, without any sacrifice of workability and, if 10%, with 80% free lime content, offering excellent effective porosity).

Lime mortar containing no cement does harden slowly on an impervious building unit. With more porous units such as dry-press bricks, there should be no difficulty whatsoever. Lime mortar is particularly suitable with very porous units set dry in winter construction. The bulk of the water is out of the mortar and in the brick before it can be frozen. At the same time the lime mortar is sufficiently retentive of water to make the necessary intimate contact with the highly porous units without necessitating wetting such units to any extent whatsoever. Bricks should never be wetted when laid in freezing weather...

Mortar Recommendations
From the foregoing study of essential mortar properties it is apparent that lime mortar meets all of the requirements, including strength of masonry, for most purposes.

However, in order to avoid delay, where rapid methods of modern construction are employed, the addition of Portland cement to lime mortar is recommended, even though this practice adds to the cost of construction and often results in considerable sacrifice in quality of the finished masonry. When cement is so added it replaces an equivalent volume of lime in the mortar mixture.

It must be remembered that as Portland cement is substituted more and more for lime, there is a greater and greater sacrifice of the essential properties – water retaining capacity, workability, adaptability, bonding power, and low volume changes subsequent to hardening.

Laboratory and service tests have both shown that a mortar consisting of 2 volumes of lime, 1 volume of Portland cement and 9 volumes of sand is well adapted for use with a wide variety of units and under a wide variety of conditions, it is therefore recommended for general use where a mortar having a rapid rate of hardening is required. If it is desired that the mortar strength is increased, it is recommended that the sand content be reduced to 7 or 8 volumes but that the ratio, 2 volumes of lime to 1 volume of cement, be maintained. This procedure will increase mortar strength with no sacrifice of the more essential properties...

1935 – Searle on Limestone and its Products

Reference; Searle A B (1935) Limestone and its Products, Their Nature, Production and Uses. London. Ernest Benn Ltd.

Hydraulic limes are prepared by calcining an argillaceous limestone, the clay present entering into combination with a portion of the lime and forming what may be regarded as a mixture of Portland cement and quicklime.

The chief raw material in this country for hydraulic limes is the blue Liassic limestone of Warwickshire, South Wales, etc., but other argillaceous limestones may be used... A much superior cement is obtained when the composition of the material is adjusted so as to give a product of approximately the same composition as Portland cement.

The composition of the limestones used for making hydraulic limes must lie between (1) pure limes with 3 per cent, of clay, and (2) marls or mixtures of clay and chalk which contain no excess of lime. It has been found that argillaceous limestones with 70-80 per cent, of calcium carbonate, 10-17 per cent, of silica, and not more than 3 per cent, of iron and alumina are best, as, in the hydraulic limes made from these, most of the clay is combined with lime, yet there is sufficient free lime present to cause the material to slake satisfactorily. Hydraulic limes may also be produced by under-burning a rock which would, at a higher temperature, produce an excellent natural cement, but these are very inferior and unsatisfactory.

Hand Slaked Lime.
Until a few years ago, all slaked lime was prepared by hand. The essential feature of the slaking is the addition of water to the lime in such proportions and at such a rate as to produce either a dry powder or a plastic paste, according to what is required, if a dry powder is desired the

process is often known as dry slaking, but if a paste or putty is to be produced the term wet slaking is used. If a large excess of water is added rapidly the slaking tends to be... so seriously retarded that the lime is said to be "drowned"; ...the wet surface of the lime becomes impervious to water so that the latter does not reach the interior of the lumps. If "drowned lime" is used for plastering, the pieces of quicklime... gradually absorb moisture from the air, swell, and cause objectionable... "blisters" on the surface of the plaster.

In slaking a fat lime by hand, the water should be sprinkled over the surface of the lime, the weight of water required being about half that of the lime... If the lime were perfectly pure, the quantity of water which would combine with it would be exactly 32.1%, but so much heat is generated during the slaking that a considerable quantity of water is driven off as steam, so that more... water must be added.

When slaking a fat lime it is preferable to add the water slowly, but all at once, as when it is added in two or more successive portions, water is lost by evaporation and too little may remain in combination with the lime. The workman should place a convenient quantity (say 100 lbs) of lime on a concrete or stone surface and sprinkle water on it—preferably through the rose of a watering can—and then turn the material over repeatedly with a spade until the slaking is sufficiently advanced for it to be completed without further attention.

If insufficient water is used some parts of the lime will remain unslaked and this may cause serious trouble when the slaked lime is used. Incompletely slaked lime is said to be "burned." ...It appears to be due to the addition of too much water at first and too little at a later stage of the hydration, or to the use of too little water through the slaking. The excessive heat developed appears to cause the colloidal hydroxide to become hard and, therefore, non-plastic so that the "workability" of the lime under a trowel is diminished...

If too much water is used, however, the lime is said to be "drowned" and the resultant produced is a thin watery paste of little or no value. When the slaking is properly conducted the product is either a light, dry and fine powder or a moderately soft paste according to whether hydrated lime or lime putty is required. The men engaged in slaking lime by hand should have their mouths and noses carefully protected by means of respirators.

Unless the source of lime is changed... a man will usually be able to judge

fairly accurately the amount of water required and the best rate at which to add it. Unless exceptional care is used, however, lime slaked by hand tends to be too moist and, therefore, "sticky," hence, the custom of making it into a putty or paste. The slaked lime should be carefully examined and any unslakable materials such as unburned limestone, pebbles, or flints, removed...

For some purposes the slaked lime is passed through a sieve with 24 holes per running inch, and, occasionally, a much finer sieve is used. Hand slaked lime, is, however, regarded as a crude product... [but] hydrated lime of first-class quality can be obtained by careful hand slaking followed by suitable screening or air separation.

Some men, when slaking lime by hand, add most of the required water to the lump lime and after a suitable time, place the product on a sieve with ½ - ¾ in. holes; the finer material which falls through the sieve is used as slaked lime, whilst the coarser pieces are treated separately with more water to see whether they then fall to powder...

If the process is carried out properly and suitable lime is used, the lumps will evolve much steam and will gradually fall to a moderately fine powder free from lumps. If an impure lime is used, or the process has been badly controlled, an unsatisfactory mixture of lumps and powder will be produced. Notwithstanding the apparent crudity of the method of slaking by hand, some of the best commercial hydrated lime on the market is obtained by this method.

In dry slaking by hand the lime is spread on the ground in a layer, 4-6 in. thick, and is sprinkled with water by means of a rose on a watercan. It is mixed with the aid of a shovel, and is then heaped up and left to itself for a day, so that it may be fully slaked. It is advisable to cover the heap with sacks so as to retain the heat... [and] to watch the heap during the first few hours, as the temperature... is often sufficient to set cloth or wood on fire.

In an alternative method, the lumps of lime, in a basket, are immersed in water for a short time and are then withdrawn and placed in heaps or silos to prevent the escape of water. The lime slakes and falls to powder but is very liable to contain some unslaked lime. The dry, slaked lime is sifted... It is much better to employ sieves with 36 or more meshes per linear inch, so that all coarse particles are separated and a really fine, soft powder is obtained. Indeed, the present tendency is to require all dry-slaked lime to leave less than 6 per cent, of residue on a 200-mesh sieve...

During the slaking of lime a considerable amount of expansion takes place. One bushel of lump lime... which contains little or no non-volatile impurities will produce 3-3 ½ bushels of dry powder. This is the case with the best limes made from blue or grey limestone. The colour of these stones... burns away, leaving a pure white lime. The amount of swelling depends partly on the purity and porosity of the lime and partly on the manner in which the water is added, the swelling being less if the water is added very slowly. This is particularly noticeable with magnesian limestone. Dry slaking is not suitable for hydraulic limes.

In-wet slaking by hand the lime is mixed with three or four times its weight of water... in a shallow tub or trough, the mixture being well stirred with a wooden rake so as to produce a milk or slurry; this is run off into another vessel or into a pit, as desired. This process ensures the complete hydration of the lime, which is uncertain with dry slaking, and produces a stronger mortar when such lime is mixed with sand or trass.

Care should be taken not to "drown" the lime in an excess of water, and it is desirable not to add too much water at a time. When the slaking is skillfully done the mixture remains at a boiling heat for some time. Wet slaked lime should not be run through a grate or sieve, as this creates too great a temptation to use a large excess of water. Any pieces which cannot be slaked soon settle and remain behind when the slurry is run off. If a paste or putty is required it is sometimes better to dry slake the lime first and obtain a dry powder to which can afterwards be added the water necessary to produce a paste. If all the water needed is added at once, some parts of the lime may be "drowned."

The use of mechanically hydrated lime is increasing so rapidly that the production of hand slaked lime is quickly diminishing. This is unfortunate, because a skilled lime slaker can adjust the quantity of water added to suit each batch of lime, whereas a machine must be adjusted in order to produce slaked lime of "average" quality. Hand slaking is very slow and, therefore, costly, but hand slaked lime is, for some special purposes, superior to mechanically slaked lime...

Hydraulic lime is slaked in a different manner because such lime is really a mixture of two materials: [a) quicklime, and [b) a hydraulic cement. The slaking relates only to the first constituent, the resulting product being a powder containing unslakeable lumps (grappiers) which must be separated by screening unless the original lime has been ground to powder, prior to

slaking. Unless a hydraulic lime is to be used at once it is important not to add any more water than is needed to slake the quicklime present. Any excess of water will cause some of the "cement" to harden and will render it useless.

Unlike quicklime, hydraulic limes do not swell appreciably when slaking, and they develop far less heat. A hydraulic lime may, therefore, be mixed with a limited amount of water with little or no risk of spoiling it...

About 10-15 per cent, of water is usually required for slaking a hydraulic lime, but the optimum proportion should always be found by trial as imperfectly slaked lime can cause serious trouble when in use. The water should be supplied in the form of a very fine spray so that no part of the lime receives an excessive quantity of water...

A good hydraulic lime should fall to powder when immersed in water for 24 hours, or when sprinkled with a suitable quantity of water, and at the end of this time should not leave more than 5 per cent of residue on a no. 24 sieve. A properly hydrated hydraulic lime will usually require only 7-8 per cent, of its weight of water, but 10-11 per cent, is usually added to allow for loss by evaporation. A dry slaked hydraulic lime usually contains a considerable proportion of lumps (grappiers) of harder material; these should be removed... [and] can be ground and made into cement...

It may seem strange that hydraulic lime requires so long to slake completely because all movement ceases within 48 hours of adding the water and no vapour appears to be set free! The true test is that mortars made with hydraulic lime which has only been slaked for 48 hours, crack and show other signs of incomplete slaking, whilst mortar made of the same lime which has been slaked for a fortnight will be excellent...

Ample time must be allowed for slaking hydraulic cements, both when neat and when mixed with sand, but care must be taken to avoid re-working a material which has been slaked with too much water and has begun to set. If the lime is slaked whilst warm, as it comes out of the kiln, or if hot water is used, the time of slaking may sometimes be reduced to three hours.

Hydraulic limes should always be sifted after slaking, in order to remove any imperfectly slaked lumps (grappiers) and it is preferable to grind the lime to powder before slaking so as to avoid inconvenience caused by the formation of these lumps.

When large quantities of hydraulic lime are to be slaked, as in France where the slaking is done at the lime works, the lime is spread out in layers on large floors, sprinkled with just sufficient water to slake the free lime, and then shoveled into heaps or placed in bins where it is kept for about ten days, during which the slaking is completed. The product—which should chiefly consist of a fine powder—is then sieved or screened... or passed through an air separator to remove the lumps (grappiers) and is then ready for sale or use. A portion of the grappiers is usually ground to powder and added to the sieved product so as to increase the hydraulicity of the latter. The process used is described under "Ground Lime". In slaking prior to sale, an excess of water should be avoided, or some of the cementitious part of the lime will be spoiled.

Grappiers
The coarse material separated when hydraulic lime is slaked is known as grappiers. It is a highly cementitious and hydraulic material, though inferior to Portland cement. It is obtained as a by-product when hydraulic cement is hydrated at the works... and requires to be ground... in order to be of the same fineness as Portland cement, for which it is used as a substitute. To be useful, the grappiers must be free from more than about 15 per cent of unburned limestone and the more nearly their composition resembles that of Portland cement, the more valuable...

In France, where the grappiers industry is more extensive, there is an increasing tendency to simplify the procedure by grinding the lumps of grappiers as finely as possible and adding them to the hydrated lime, thereby increasing the hydraulicity and cementing power of the latter...

The Use Of Lime In Building Construction
For most building purposes, a somewhat impure lime is often preferable, because the argillaceous material present, or the siliceous material introduced by burning the stone in contact with the fuel, produces feeble hydraulic properties which make a stronger joint or surfacing material.

A rough distinction exists in the building trade between "fat" or "rich", and "poor" or "lean" limes. The former slake rapidly with high rise in temperature; the latter slake slowly and without much rise in temperature. Fat limes set only by absorption of carbon dioxide, but lean limes are hydraulic and set like diluted cements.

Lime For Use In Mortar
Mortar is a mixture of sand and water with some binding material, such as

lime or cement or both. A fibrous material, such as hair, is often added to increase the strength. In lime mortar the lime forms a colloidal gel with some of the water and this gel coats the sand grains. As the mortar dries, the colloidal gel dries and shrinks and so holds the particles together. A small proportion of crystalline calcium carbonate is also formed and the interlacing of the crystals increases the strength of the mass. The mixing of the various ingredients must be thorough; all fat lime mortars are improved by prolonged mixing, but in those containing hydraulic lime cement the mixing must not be continued after the cementitious portion has begun to set. The mixing may be by hand or machinery; the use of the latter is generally known as grinding, but no actual grinding should occur with properly prepared materials. Mortar made with fat lime should not be used for 24 hours or more as storage greatly improves its workability.

For the production of ordinary mortar for general use by builders, either a fat lime, a lean lime, or a hydraulic lime (Lias lime) may be used. Fat limes are preferred, but lean limes can be employed if they do not slake too slowly; they are regarded less favourably by some builders, because they have a much smaller sand carrying capacity, and-the resulting mortar does not "work" very smoothly. Hydraulic limes are stronger in cementing power, and behave like a mixture of fat lime and Portland cement.

Magnesian limes are generally suitable for mortar and sometimes exceed calcium limes in smoothness, working, sand carrying power, and resistance to weather. There is also evidence that magnesian limes give mortars that eventually give greater strength than those made of high calcium limes. They slake more slowly than calcium limes, and, unless care is taken, the mortar may prove to be unsound by a steam pat test. The slow slaking is often due to partial over-burning of the lime.

Greystone limes are highly appreciated for the strength of the mortar which they produce as a result of being feebly hydraulic, though this reason is seldom realized. Ground greystone lime requires about one month after being mixed with water before it develops appreciable hydraulic strength. It loses this property if the lime is stored in the form of putty or if it is soaked and kept for a long time before use.

Mortar made with fat lime or a lean lime with a low silica-content does not "set" in the same manner as hydraulic lime or concrete. Such lime merely dries, and by gradual absorption of carbon dioxide on its surface it becomes moderately hard externally, but the interior of the mass may remain soft for several hundred years (really?). The purer the lime and sand

used in the preparation of the mortar, the softer will be the mortar, no matter how long it has been in use. The carbon dioxide absorbed from the air combines with the lime at the surface of the joints, and, by closing the pores, prevents a further penetration, so that most joints in old masonry are only hard for a very short distance below the surface (this is prejudice, certainly not observation).

Hydraulic lime, on the contrary, undergoes a complex chemical change when in contact with water and "sets" to a hard mass. It does this equally well in air or under water, provided the mortar is supplied with sufficient water to ensure its adequate setting and subsequent hardening. If the supply of water is insufficient, the hardening will be incomplete.

Fat limes can be caused to harden like hydraulic lime and cement, by adding a suitable proportion of a material which will combine with the lime, forming a compound somewhat resembling those in hardened cement concrete. Such material is known as pozzuolana; the commonest variety is trass, which is extensively used on the Continent...

Pure limes to which no pozzuolana has been added should not be used for work in contact with water, but only for structures above ground level.

High calcium limes are generally regarded as preferable, because they slake readily and completely in a short time whereas magnesian limes slake more slowly and uncertainly and may, therefore, cause trouble...

In limes used for building construction, the physical characteristics, such as plasticity, time of set, colour, hardness, and strength, are of great importance, whereas chemical composition is immaterial except indirectly, inasmuch that limes made from limestone of different purity and composition usually have different physical characteristics... The lime which can carry the largest quantity of sand should be the best for mortar.

A useful indication of the quality of a lime is to measure its volume before and after slaking. All good limes will increase in volume, but a fat one should increase to three times its original size. Limes which produce less than twice their volume of slaked lime are described as lean or poor.

Before mixing it with sand or any other solid material, a quicklime should be slaked and made into lime putty; the hydrated lime merely requires to be mixed with water, and the hydraulic lime should be slaked by sprinkling it with water, avoiding an excess, and finally passing it through a no. 5 or finer

sieve.

The chief disadvantages of lump lime for use in mortar are:

(i) It requires slaking, which is troublesome and tedious.
(ii) It frequently contains much core and useless material.
(iii) The quality varies greatly and cannot easily be checked by the builder; consequently, the quality of the mortar also varies.
(iv) It soon spoils if kept before being used.
(v) It is inconvenient to keep on account of its caustic properties.

In short, it has all the disadvantages of a crude material. In the United States, it has been replaced almost completely by hydrated lime, which is free from all these objections.

In some localities, the quality of lime, as compared with that made fifty years ago, has deteriorated seriously. This is due to the skilled burners having left or died and other men with less care and skill having taken their places...

The advantages of hydrated lime in making mortar are:
(i) It can be stored indefinitely and easily.
(ii) It requires no slaking.
(iii) It is more uniform in quality.
(iv) It contains less "core" or useless material and so can be used without waste.
(v) It avoids the production of bad putty through carelessness or ignorance of the man in charge of the mortar.
(vi) It avoids the loss otherwise caused through having to make more putty than is needed to allow for useless material in the lime.
(vii) It is particularly easy to measure and use.
(viii) E. W. Lazell has shown that mortar made with hydrated lime is stronger than that made with hand slaked lime and used immediately. The reason is that mechanical slaking under proper control ensures complete hydration, whereas, with hand slaking, the paste must be left for some weeks before the hydration is complete. Moreover, in hydrated lime, the coarser, unaltered particles are separated, so that the risk of caustic lime in hydrated lime from a good firm is negligible. Much of the hydrated lime on the market is not as good as a hand slaked lime putty about a year old, because the plasticity of lime can only be developed in the presence of more water than is permissible

in hydrated lime. For most building purposes, however, hydrated lime is as good as need be desired.

…The advantages of fat lime—either lump or hydrated—are:

(i) It enables bricks to be laid more rapidly and more easily than when cement is used, as lime is more plastic than cement. A greater strength can be used by replacing some or all of the lime by Portland cement, but where such additional strength is wholly unnecessary there is no object in securing it, and lime mortar has ample strength for all ordinary buildings.

(ii) Fat lime produces the only mortar that can be prepared in large quantities in advance, i.e. that made from either quicklime or hydrated lime. All the lime mortar needed for a structure can be mixed before the walls are started. It may be stored, either in a stack or pit, until required, and, in fact, is actually better and more easily worked because of the ageing. This feature of lime mortar affords a good chance for economy, as machine mixing is particularly suitable and satisfactory. As the mortar is required, it may be re-tempered to the desired consistency and used with full confidence.

(iii) Fat lime makes the most economical mortar. The cost of the materials is low, because of the high sand carrying capacity of the lime. The strength of the mortar is ample, thus permitting it to be used under practically all conditions. The natural plasticity of the lime decreases the cost of mixing the mortar, of spreading the mortar bed, and of placing the bricks. No mortar is wasted. If the mortar is mixed as needed, any left over at the end of a day, or not used, because of a sudden shut down on the job, can be stacked and used when work begins again. If cement mortar works short, the droppings are excessive, 10 per cent, being sometimes wasted. This is not the case with lime mortar, for the only droppings are due to trimming the joints, and these are negligible.

(iv) Fat lime mortar avoids delaying the bricklayers, who, when cement mortar is used, have to wait for mortar to be mixed. Lime mortar is always ready for use and so increases the efficiency of the entire force and makes maintenance of construction schedules easy.

Some builders add a small proportion (15 per cent) of Portland cement to lime mortar in order that it may set quickly enough for the bricklayers to work rapidly, as in many modern steel skeleton structures with brickwork panels.

In order to secure the best results, the lime must be properly treated. The best method is to prepare a lime putty by slaking the lump lime or by mixing the hydrated lime with water. The modern desire for speed makes most builders unable to keep the putty for a long time, and, consequently, the full plasticity of the lime is seldom developed in modern mortar. This is wasteful of lime as old lime putty will carry more sand, than newly made putty...

Hydraulic limes can be purchased-in the lump or ground form, the latter being far more convenient. They are... divided into three classes: (i) feebly hydraulic; (ii) moderately-hydraulic; and (iii) eminently hydraulic...

Hydraulic limes are chiefly used where a mortar is required to have a greater strength than can be produced with a fat lime. At one time they were widely used, but since the use of Portland cement has become so popular the latter is usually preferred, as it is stronger and more regular in composition and properties.

Hydraulic limes are also used in foundations and in locations where the brickwork or masonry may be in occasional or constant contact with water. When slaking hydraulic lime, the use of too much water must be avoided; too little will do no harm. It is usually better to buy the hydraulic lime ready-slaked.

Lime For Winter Mortar
When brick laying must be carried out in very cold weather, the most satisfactory mixture consists of one measure of Portland cement, two of fat lime, and nine of sand. This is much cheaper than a cement-sand mortar, is less sensitive to frost, and is easier to work. Mortar must not be used during actual frost, and bricks laid just prior to a frost must be covered, or otherwise protected until the mortar has hardened.

Lime In Cement Mortar
The addition of a little lime putty or hydrated lime to cement mortar makes the latter spread more easily and work more smoothly. It also increases the adhesive properties of the mortar.

The lime putty, or a paste made by mixing hydrated lime with water, should be added to the dry mixture of cement and sand, any additional water required being then added and the whole mixed thoroughly.

On work frequently exposed to water, the addition of lime is undesirable as it tends to be washed out and leaves a porous mortar.

The best lime is a fat, high calcium lime, such as is used for fine stuff in plastering. Hydrated lime is more convenient than lump lime.

Lime Cement
Lime cement is a term applied to lime when mixed with sand so as to form a mortar or plaster which is used as a cementing agent. Before the invention of Portland cement, lime was extensively used as a cement, and today when speed of hardening is not important, it is still useful for many purposes. Unfortunately, the tendency to require rapid hardening materials for all purposes, even under conditions where time is of minor importance, has led to an increasing failure to recognize the advantages of lime as a cement.

For this purpose, two kinds of lime are available: (a) a fat lime, and (b) a hydraulic lime.

The fat lime should be high in calcium oxide and very low in magnesia. In course of time, magnesian limes form products which are as hard and strong as those in which pure calcium oxide is used, but magnesian limes slake very slowly and somewhat uncertainly, so that they are generally less suitable than calcium limes.

The lime should contain at least 95 per cent, of lime and magnesia (on the ignited sample).

Lime cement of the kind described is merely a good quality of lime, but lime cements composed of lime and casein or similar materials are quite different; they are described later.

Lime cements composed solely of hydraulic limes resemble a mixture of fat lime and Portland cement, but are somewhat uncertain in their behaviour. For structures requiring a material stronger than ordinary mortar, but not so strong as a cement sand mortar they are excellent and cheap.

Fat lime is particularly suitable for interior plaster, because:

(i) It is more plastic than any other, can be spread with less effort, and covers a large surface.

(ii) It is cheaper than cement or plaster of Paris, both in first cost and in sand carrying power.
(iii) It does not spoil (like cement) if used slowly.
(iv) The plaster can be prepared some time before and used when required.
(v) There is less waste than with other materials.
(vi) It is an ideal base for colours and decoration.

Lime for use in plastering must not crack when in use. The shrinkage of fat lime is overcome by the use of a suitable proportion of sand. It is a common mistake for plasterers to use too little sand; the result is that the plaster shrinks, cracks, and may fall away. For ceilings, the addition of a little plaster of Paris is an advantage which is well worth the extra cost.
For Exterior Plaster, including rough-cast and stucco, lime is the most suitable binding agent. It has a greater covering power than Portland cement. It is a mistake to use too little sand with the lime, as both "rough cast" and "stucco" should be as lean as possible.

The most suitable lime is a fat lime, such as that specified for interior plaster ("fine stuff") and, whilst an inferior lime may be used, it is not recommended.

The advantages of lime for exterior work are:
(i) It is cheaper and "goes further" than Portland cement.
(ii) It is equally durable.
(iii) It has a greater sand carrying power.
(iv) It is more plastic and so is easier to use.
(v) The slow hardening enables the material to adjust itself to the background better than cement plaster can do.
(vi) The waste is much less.

Lime Putty
Lime putty or Plasterer's putty is made by slaking a fat lime with as much water as will produce a soft plastic paste. All lump lime must be converted into this form before it can be used satisfactorily for plastering. The putty must be kept for at least a week and preferably for several months before it is used, so as to ensure every particle of lime being fully slaked... Lime putty does not spoil appreciably on storage.

Lime putty is made by placing the lime in a tub of water in which it is stirred and slaked. The slaked lime is then carefully sifted through a fine sieve into a wooden bin; the residium which does not pass is rejected for plasterer's work.

A considerable excess of water is added and the surplus is allowed to drain away from the bottom or through the sides of the vessel in which the putty is stored.

The finely sifted calcium hydrate with excess of water may be left with safety for a year or so to mellow, the water which rises to the top drains away through the joints of the wood-bin, or it evaporates, leaving the pure slaked lime putty as a creamy mass; only the thin outer crust exposed to the air will set. For the setting coat of plaster work, putty should not be used until it has mellowed for at least three months... The long time required for ageing the best lime putty has caused hydrated lime to be used wherever possible, but even hydrated lime should be mixed with water to form a putty and kept for at least 24 hours before it is used.

Lime In Wall Coatings
Under the term limewash, whitewash, distemper, etc. is included a milky suspension of slaked quicklime or hydraulic lime or hydrated lime in water. No definite proportions of lime and water are used, the user judging by the appearance of the wash when applied to a surface. Equal weights of lime and water usually produce an excellent lime wash, but much depends on the nature of the lime.

The addition of 30 lbs of common salt or 10 lbs of dry calcium chloride to 100 lbs of the slaked lime or hydrated lime produces a superior lime wash. The addition of a little glue is also advantageous and prevents earlier work from being rubbed off. A mixture of 6 lbs of glue, 4 gallons of water, and a cream containing 100 lbs of slaked or hydrated lime is generally quite satisfactory. Instead of common salt, a mixture of 4 lbs of zinc sulphate and 2 lbs of common salt per bushel of lime is preferred by some architects. The zinc sulphate combines with the lime, forming a substance similar to plaster of Paris and rendering the whitewash more durable.

Some users find that the addition of linseed oil or melted tallow lessens the tendency of the material to be "rubbed off," and one well-known builder uses milk instead of water for the same reason.

A more elaborate whitewash is made as follows:

Add enough water to 12 lbs of hydrated lime to make a thick cream. Dissolve 1 lb of washing soda in 1 gallon of boiling water, and add this to the lime. Dissolve 1 lb of glue and 1 lb rice flour in 3 quarts of water. Add this to

the above mixture and apply. The above quantities will make enough whitewash to cover about 600 square feet.

Hydraulic lime must be carefully selected or the wall or other surface will not be sufficiently white. It will, however, be more durable than when quick-lime or hydrated lime is used.

The mixture of lime and water (with or without other ingredients) should be made fairly thick, passed through a no. 50 or finer sieve, and then diluted with water as required. If the screening is omitted, the wash may not have a sufficiently smooth surface.

Whitewash is the cheapest of protective paints, but it requires frequent renewal. Its slight disinfectant power adds greatly to its value.

1946 – The Royal Institute of British Architects (RIBA) Committee on the Architectural Use of Building Materials

Reference: RIBA Committee – The Architectural Use of Building Materials - Post-War Building Studies No.18 1946 London HMSO for the Ministry of Works.

The technical evidence does not point to short cuts in the achievement of good building; it points consistently to the discovery by scientific means of the rationale of established building traditions, which should be altered only with the full knowledge of the consequences…

Dense cement mortars have disadvantages when used in association with common bricks for ordinary building purposes, and it is now emphasized that lime, although not yet in all forms the subject of exact specification, has valuable uses in joints and rendering… Good workmanship requires adequate time for the various building processes to mature… Also the bad standards set by false economies arising out of ill-considered competitive costing, which make qualitative specification difficult, ought to be recognized and guarded against in post-war building…

A dense cement mortar is usually cold and dismal, and tends to produce capillary cracks in the joints. Pointing with black mortar should always be avoided and, as a rule, any brickwork where the joints are darker than the bricks will look heavy and dull. Non-hydraulic, or semi-hydraulic lime (conforming to B.S. 890-1940) gauged with cement and sand usually adheres to the bricks better than cement mortar and is less liable to shrinkage cracks. The composition of the mortar should be selected to suit

the particular characteristics of the brick. The type of lime known as 'hydraulic' often makes excellent mortar, but this lime is not produced in large quantities, and as it is not the subject of any specification, it varies from one works to another. Some definition and specification of hydraulic lime would be helpful to architects.

1950 – Newbold & Edgar, Modern Practical Building

Reference: H B Newbold & Edgar Lucas (1950) Modern Practical Building Volume 1 Third edition Hazell, Watson and Viney Aylesbury and London.

Limes. …There are various kinds of lime, each requiring different treatment. The manufacturer's instructions should be carefully followed in slaking and mixing.

Limes may be divided into three types: 1) non-hydraulic, 2) moderately hydraulic, 3) strongly hydraulic.

Lime Mortars – Lime mortars are usually prepared in the following proportions: one part lime to three parts sand, by volume.

For hand-mixing [hydraulic limes], the sand is placed in the shape of a ring on a clean, water-tight platform. The lime is placed in the centre, water is added, and the heap left to slake for about twelve hours… After mixing, the heap should be smoothed over the exterior with the spade, so that air cannot readily penetrate the interior. Non-hydraulic lime mortar so treated will keep in good condition for a period of up to seven days. It should be knocked up as necessary to bring it to a suitable condition. Non-hydraulic lime mortar is not recommended for permanent walls, as it has little strength.

Moderately hydraulic lime mortar should be used if possible on the day of mixing, or within 24 hours at the outside. If allowed to stand longer, the setting and hardening action will take place in the heap, and much of it will be lost when the mortar is used.

Strongly hydraulic lime mortar, such as mortar made with blue lias lime, has a strong setting and hardening property. It makes a durable mortar if properly prepared, but must be used within a few hours of mixing. If allowed to stand for long, the setting action takes place before the mortar is used… Ground hydraulic limes should be slaked by mixing with damp sand to make a stiff mix. The finished mix is then prepared by adding

further sand and water. The mortar should then be used within about 4 hours.

Mill mixing. On large jobs mill mixing is usual. It is efficient, especially in breaking up the small lumps to a fine powder. Furnace ashes, clinker, and crushed bricks are often used as aggregate, instead of sand. Ashes and clinker make a black mortar of good strength, provided that the aggregate is free from partially burnt material and chemical impurities. If crushed brick is used, the old bricks must be clean and old mortar or plaster cleaned off.

Hand mixing. The Mixing Operation is carried out either in a pit or on a close-boarded platform of wood. The sand and lime are measured into the correct amounts to give the required proportion, and the sand is formed into a circular bank on the platform. The lime is then placed within this bank, or ring, and water is sprinkled on with a hose-pipe, which is best suited to the purpose when fitted with a rose or some form of sprinkler. Steam will be generated during this sprinkling operation, and when this has ceased, the lime is stirred with a 'larry'... The sand is then shovelled, starting from the outside of the ring first, on to the lime, the larrying operation being continued the while. When thoroughly mixed, the mortar is left to stand for a week or so before being used, when it should be 'buffered', or beaten up again with the larry and shovel. For use, it is customary to add more water, as the wetter it is, up to a point, the easier it is to handle, but this should not be over-done.

Hydralime is made from quicklime and water in the requisite proportions. It is supplied grey for mortar and white for plaster, and where rapid setting is required, Portland cement is mixed with it in the proportion of hydralime 2 parts, Portland cement 1 part and sand 8 parts. For ordinary plasterwork it is mixed... 1 part hydralime to 4 parts sand.

Lime Putty is run into a box, or a pit lined with plaster, and then left to stand for at least 3 months. In preparing this, the lime is slaked in a similar manner to that employed in preparing coarse stuff for plaster, and then the paste is run through a sieve. The water should be drained (P334) off after it is run into the tub or pit, and the putty should be covered up from the air or it will lose its setting properties.

Lime-cement mortar. This is sometimes called 'compo' or 'gauged' mortar. It combines the advantages of lime and cement mortars, and for all ordinary work, it is preferable to either. Setting and hardening of compo is superior to lime mortar, and, though the strength is not so great as cement

mortar, it is adequate for walls and piers bearing normal loads. A great merit of lime-cement mortar is that it is not likely to develop shrinkage cracks. It works easily off the trowel, and sound work can be done at a higher speed than with cement mortar… The Building Research Establishment recommends that at least 20% of the total volume of lime-cement should be cement.

Lime [for plastering]
(Lump lime) must be slaked in pure water, about 32% by weight of the lime being required for this purpose. This is usually done in a mortar box, or for large quantities in a pit, the sides and bottom protected by planks, on a platform within a ring of sand or on a base of sand with a ring of sand round it. The lime and water has to be well-stirred to break up the lumps. It swells, becomes hot and throws off steam. Stirring must be continued until little steam arises. It may then be left alone, when it gradually dries. For plastering purposes, the slaking must be very thorough, all lumps being broken up during the process. If this is not done some caustic lime will remain… causing blowing.

To ensure perfect slaking after the first process the lime is broken down and once more mixed with more water to form a thick cream, which is allowed to stand for from two to four weeks to 'cool'. This long running produces what is known as 'plasterers' putty'.

Fat or rich lime… works smoothly and easily, improves for being mixed some time before being used, but lacks strength. It is essentially for interior and fine work…

Hydraulic limes… the lias or blue lias limes belong to this class. They are feebly hydraulic if containing no more than 10% of silicate of alumina, ordinarily or medium hydraulic if over 10 and under 20% and strongly hydraulic if up to 30%. Such limes are only suitable for exterior rendering in positions exposed to water…

Rendering mixes – the old stucco mixes consisted of 1 part hydraulic lime to 3 parts sand, with 1 lb cow hair to the cubic foot of stuff. It was necessary to protect this stucco with oil paint. Modern rendering consists of a Portland cement and sand, or a Portland cement-lime-sand mix…

The Building Research Station recommend the following:

- *Under coat (parts by volume): 3 parts white hydrated lime or stiff lime putty* 1 part Portland cement, 10 parts clean sand or crushed stone aggregate.
- *Finishing coat: 3 parts lime, as above, 1 part Portland cement, 12 parts sand or crushed stone, according to colour and texture required.*

1950 – Ministry of Works Advisory Leaflet on Limes for Mortar

Reference: Ministry of Works Advisory Leaflet No.6 (1950) Limes for Mortar. London HMSO.
This leaflet summarises mortar uses as understood after WWII, notably the routine running of fat quicklimes to putty by this time (often to be gauged with cement or gypsum) and the continued dry-slaking of hydraulic quicklimes. This is transcribed in its entirety.

How to Use Lime When Mixing Mortar.
The Kinds of Lime. All limes start as lump lime, or quicklime, which is obtained by burning chalk or limestone in a kiln.

Blue Lias, and similar limes, which come from limestone containing clay, have the property of setting under water soon after slaking; they are therefore known as hydraulic limes, and are used mainly for mortar.

Greystone Limes come from chalk containing only a little scattered clay minerals – not enough to make them fully hydraulic – but they will harden under water or when moist in two to three weeks after slaking. These limes are classed as semi-hydraulic; they can be used for both mortar and plastering.

White Limes (mountain limes, chalk lime etc) come from rocks which are practically pure limestone or chalk. They do not set hard under water, and are therefore classed as non-hydraulic limes. They are used for plastering and making cement-lime mortar.

Magnesian Limes are made from dolomitic limestone. They are in a class by themselves and are used mainly for mortar, but they must not be used with bricks containing sulphates. They are mostly non-hydraulic.

Lime Putty.
Quicklime must be slaked before it can be used. In the old days all builders used to slake their own lime, running it to a paste known as lime putty (this is true only of the 20th century, for the most part).

Lime putty run from quicklime is still used in some parts of the country and for special jobs, since one of its chief characteristics is good workability.

Slaked non-hydraulic limes improve with keeping, so they should stand for at least two weeks to fatten up before use. They should be kept moist and undisturbed until they are needed. Semi-hydraulic quicklimes are usually slaked as non-hydraulic limes, but the wet putty must not be stored. Slaked hydraulic limes do not keep – the quicklime is usually slaked on the building site by spraying it with water on a clean wooden platform until thoroughly moist: it is then heaped together, covered with sand and left for about 36 hours. The material is then put through a sieve before use, to remove any unslaked particles which might slake later in the hardened mortar and cause unsoundness or even cracking. Magnesian limes are also slaked in a heap.

Dry Hydrated Lime.
Nowadays most lime used in building is dry hydrated lime – a ready-made form of slaked lime, which is a white or greyish powder supplied in paper bags like cement. It is usually manufactured from white lime or from greystone lime, and is therefore non-hydraulic or semi-hydraulic. Hydraulic limes are also available in dry hydrated form – they set in the same way as cement, but not quite so quickly.

Lime Putty from Dry Hydrated Lime. Dry hydrated lime is often mixed and used at once as a mortar or plaster. If it is not of the quick hardening or hydraulic type, it is better to soak it in water for 24 hours before adding the sand. This will give a much more workable mix. Stir the hydrated lime into the water until a putty-like mixture is obtained. Don't add the water to the lime or you will get a lumpy putty.

Lime Mortars.
Lime mortars are usually of a 1:3 lime: sand composition. For external brickwork it is usually best to use hydraulic lime mortars because other lime mortars do not stand up well to frost. Semi-hydraulic and non-hydraulic lime mortars, however, are used for bedding limestone and sandstone.

Mixing Lime Mortars.
To make mortar from non-hydraulic lime putty or soaked hydrated lime, mix the sand and lime putty on a clean platform until an even consistency is reached. Round off this 'coarse stuff' into a heap, smooth the sides and leave undisturbed until required for use, but don't let it dry out if you keep it for any length of time. The coarse stuff will stiffen up on standing, but

with vigorous beating and stirring it can be knocked up to its original plastic state. If possible, don't add any water when knocking up – working the mortar vigorously will give a better material than the addition of water. Semi-hydraulic putties are mixed in the same way – but when using them, don't make up any more mortar than is sufficient for one day.

To make mortar from hydraulic quicklime which has been slaked on site, mix the sand and the lime thoroughly, adding more sand and/or water if necessary to get the right proportions and consistency. Magnesian lime mortar is also prepared in this way. Hydrated hydraulic lime must not be soaked overnight. Mix it dry with the sand, then add water, and use within four hours.

Cement-Lime Mortars.
Lime gives a mortar good working properties. The more lime in the mix, the better the workability. A fat lime slaked to a putty gives the best working properties, and an unsoaked hydrated lime the poorest.

Cement gives a mortar strength and durability. Not only is the hardened mortar strong, but it hardens quite quickly. Without lime, a high proportion of cement to sand is needed to make a workable mix, but this is wasteful and may easily cause cracking due to too much shrinkage. Unlike a lime mortar, a cement mortar will readily lose water to a thirsty brick and thus give loss of adhesion.

A mortar containing both lime and cement will normally possess a desirable combination of both properties. It will be workable, will set reasonably quickly, and is adequately strong for all purposes in small housebuilding. Hydraulic limes should be used with sand alone and not with cement...

For normal types of brickwork under normal conditions use a 1:2:8-9 cement: lime: sand mortar. If, however, brickwork has to withstand severe weather, or for bricklaying during winter where earlier strength may be demanded, use a 1:1:5-6 mix; a 1:3:10-12 mix is only suitable for internal work when there is no danger of frost affecting it.

Cement-lime-sand mixes are also very good for external renderings; a 1:2:8-9 mix is suitable for normal use, but where a wall has to stand up to severe weather conditions, a 1:1:5-6 mix is better.

Mixing Cement-Lime Mortar. These are usually prepared by first making up a wet mix of lime and sand usually known as a coarse stuff. If the lime is

added as putty the coarse stuff may be used immediately, but if you use dry hydrated lime, mix up enough coarse stuff for the day's work and let it stand overnight to improve its properties. Immediately before use, mix the cement thoroughly into the coarse stuff, adding more water if necessary. Don't mix up all the mortar at once. Do it in batches so that each batch can be used up within tow hours of adding the cement; throw away any left after this. Cement-lime mortar may also be prepared by mixing dry hydrated lime, cement, sand, then adding the water, and using straight away. This often speedy and convenient, but remember that such a mortar does not have good working properties.

Type of lime; other names; source; type of slaking; expansion of slaking; method of slaking; maturing time; mixing mortar; when to use mortar; knocking up: use of hydrated lime.

Non-hydraulic limes; (fat lime, high calcium lime, Mountain lime, chalk lime; limestone lime; white lime; white chalk-lime); chalk, mountain limestone; and other almost pure limestones. Slake rapidly with much heat; considerable expansion; gradually stir quicklime into excess of water; mature for at least 2 weeks, but as long as possible; mix putty thoroughly with sand; must be kept moist if not used at once; can be knocked up if it stiffens; as hydrate, stir into water and leave for 24 hours, then use as lime putty.

Magnesian limes; dolomitic lime; dolomitic limestone; slakes very slowly; variable expansion; slake as hydraulic lime or add (hot) water to the lime, sieve; mature 36 hours; mix putty thoroughly with sand; use within 24 hours; can be knocked up if it stiffens.

Semi-hydraulic limes; grey lime, greystone lime; source: grey chalk; slow slaking; moderate expansion; to slake for putty, stir into excess water; for mortar, soak with water and cover with sand; mature 36 hours. Mix putty thoroughly with sand; use within 24 hours; can be knocked up within 24 hours; as hydrated lime, stir into water and leave for 24 hours, then use as lime putty.

Hydraulic limes; Blue Lias lime; blue lias limestone; slakes very slowly, requires fine grinding; small expansion; spray with water and cover with sand, sieve; mature 36 hours; mix covering sand with the slaked lime, adding more if required; use within 4 hours; should not be knocked up after it stiffens. If hydrated: mix dry with sand, add water and continue mixing, use within 4 hours.

1951 – British Standard Code of Practice CP 121.201

Reference: British Standards Institution (1951), Masonry walls ashlared with natural stone or with cast stone (British standard code of practice general series; no. CP 121.201).

Cement. Cement should be stored on a wooden floor, well above ground level, in a perfectly dry structure. Consignments should be placed in a manner that permits inspection and use in rotation of delivery. Cement affected by dampness should not be used. Cement delivered hot need not be aerated to cool before use.

Quicklime. Quicklime should be delivered to the site as soon after manufacture as possible.

Semi-hydraulic (calcium) quicklime and non-hydraulic (calcium) quicklime deteriorate rapidly on exposure to the atmosphere and are liable to cause fire if stored in an unslaked condition adjacent to combustible materials. Quicklime should, therefore, be slaked immediately.

Hydrated lime. Hydrated lime, hydrated or pre-treated hydraulic lime and quick-hardening lime (Roman cement) should be stored in the same manner as cement.

Lime Putty. Lime putty may be prepared from the quicklime or dry hydrate of either non-hydraulic or semi-hydraulic lime.

Preparation from quicklime. The slaking vessel or pit should first be partly filled with water to a depth of about 1 foot and enough quicklime should then be added to cover the bottom and come about half-way to the surface of the water. Stirring and hoeing should begin immediately, and the quicklime should not be allowed to become exposed above the surface of the water.

Should the escape of steam become too violent or the quicklime become exposed, more water should be added immediately. The mix should boil gently and, as it thickens, more water should be added. Water and then quicklime should be added alternately until the requisite quantity of milk of lime is obtained.

The stirring and hoeing should continue for at least five minutes after all reaction has ceased. The resulting milk of lime should then be run through a

sieve of 1/8-inch mesh into a maturing-bin. It should be protected from drying out and remain undisturbed for a period of at least two weeks to permit it to fatten up to lime-putty.

Preparation from dry hydrate. The hydrated lime should be mixed thoroughly with water until a mixture of the consistence of thick cream is obtained; this should then remain undisturbed for not less than 16 hours.

Mortar Mixing
General. Mortar may be mixed on the site, either mechanically or by hand. Mechanical mixing may be carried out by any suitable mixing machine. Hand mixing should be done on a clean watertight wooden platform or other clean surface. If coarse-stuff is to be used, the lime-aggregate mix (coarse stuff) may be delivered ready-mixed...

Portland Cement/Lime Mortars
Cement/dry hydrate lime/fine aggretate mortar
Cement, hydrated lime and fine-aggregate should be thoroughly mixed, in the required proportions, first dry and then with the addition of water until the required consistence is obtained. The mortar should be used within two hours of the addition of the water, and mortar not then used should be discarded. Under no circumstances should re-tempering of dried or partly set mortar be carried out.

Coarse stuff gauged with cement
Cement should be thoroughly mixed with the coarse-stuff in the correct proportions immediately before the mortar is required. Water should then be added to bring the mix to a workable consistence. The mortar should be used within two hours of the addition of water and mortar not then used should be discarded and not re-tempered.

Lime Mortar
Hydraulic Lime Mortar

Preparation from quicklime
Slaking. Hydraulic quicklime should be fresh and should be slaked as soon as possible after delivery. The quicklime should be slaked upon a clean platform or in a suitable container.

Lump quicklime should be piled into a heap, any lumps larger than 6 inches being broken down. Water should be thrown on or sprayed on as the heap is formed.

Ground quicklime should be piled into a heap. Water should be sprayed on, and the heap turned over three times to mix the lime and water thoroughly.

Care should be taken not to use too much water; approximately 70 gallons is required per ton of quicklime.

The heap of lump quicklime or ground quicklime should be covered with fine-aggregate, banked down to retain the heat and left undisturbed for at least 36 hours or longer, until required. The heap at all times should be protected from the rain.

Mixing. The requisite quantities of slaked lime and fine-aggregate should be mixed with sufficient water to give a mortar of workable consistence. When prepared from lump lime, the slaked lime should be passed through a sieve of ¼ inch mesh before use, in order to remove any unslaked lumps. The mortar should be used within four hours of mixing…

Preparation from hydrated or pre-treated hydraulic lime. Hydrated or pre-treated hydraulic lime and fine-aggregate in the required proportions should be thoroughly mixed, first dry and then with water until the necessary consistence is obtained. The mortar should be used within four hours.

Magnesian Lime Mortar
Slaking. Magnesian quicklime should be slaked in a manner similar to… hydraulic quicklime in lump form, but the heap should remain undisturbed for at least two days. Approximately 90 gallons of water is required per ton of quicklime…

1951 – Sawyer on Plastering

Reference: Sawyer J T (1951) Plastering. London Edward Arnold. Also 2007 Reprint by Donhead, Shaftesbury.

Blue Lias Lime is a well known eminently hydraulic lime that has so little slaking power that it has to be machine ground to fine powder. Lime of this nature possesses setting and hardening properties closely associated with those of Portland cement…

The increasing use of hydrated lime for plastering is due to the fact that it is easily and quickly prepared; it takes up less space than lump lime, and it is reliable. The erection of putty bins or the digging and lining of pits in the

ground, the slaking and 'running' of the lump lime, the 'popping' or 'blowing' on finished surfaces due to particles of unslaked lime in the plastering material, are all largely or wholly eliminated by the use of hydrated lime...

Lime Finish. The traditional finish was carried out with raw (ungauged) coarse stuff for the rendering and floating coats and raw lime setting stuff for the finishing coat. This is seldom used today on account of the long waiting time necessary between the application of the various coats. Where a lime finish is specified, coarse stuff is usually gauged with Portland cement to the extent of 15 or 20 to 1 respectively on backgrounds of brick or slab...

Lime Putty. This consists of slaked, sieve-run lime matured for at least two weeks, or hydrated lime and water mixed to the consistency of milk, left overnight to fatten for use. Lime putty with added plaster is used mostly for running interior mouldings in situ, the usual strength being 2 parts of lime putty to 1 part of plaster.

1952 – Alfred Geeson, Building Science Materials

Reference: Geeson A G (1952) Building Science Materials for Students of Architecture and Building Volume II (Lime). English Universities Press London.

Quicklime – Quicklime is sold in bulk as lump quicklime, or more rarely in bags in the form of a powder, ground quicklime... Both types of quicklime are slaked on the job or in the yard by the user, and the operation calls for great care and experience. The lime should be fresh and should be screened to remove any unsound particles. If more water is used than the minimum necessary for hydration, a lime putty is obtained. This is left for about two weeks before use in order to develop plasticity or 'workability' and also to permit the slaking of any extremely small, slow-slaking particles that may have passed the sieve.

Hydrated Lime – Hydrated lime is quicklime treated at the works with the correct amount of water (steam) for the chemical process of slaking... there is little possibility of incorrect slaking, and the material merely requires the addition of the necessary sand and water to bring it to the correct consistence for use. Alternatively, it may be 'soaked' ie. added to water some hours before mixing with the sand. This enables it to develop workability, though at the expense of any hydraulicity it may have possessed.

Non-hydraulic limes – These include limes entirely devoid of hydraulic constituents… and those containing only a negligible percentage of such constituents but an appreciable proportion of inert constituents (the 'lean' or 'poor' limes). They set only (P7) by carbonation, and thus are capable of developing little strength unless gauged with other materials such as a cement or a pozzolana.

Rich limes contain no hydraulic constituents; and only a small proportion of inactive impurities (up to 20%, but usually 5%, or less)… white chalk… the oolitic limestones of the Jurassic system… although these are more largely used as building stones… from the Carboniferous system… called 'mountain' limestones when occurring in massive deposits to distinguish them from the thinly bedded deposits common to northern England and southern Scotland.

The composition of a semi-hydraulic lime depends upon the relative proportions of clay to carbonate in the stone from which it is produced. It also depends upon the degree of burning. A semi-hydraulic lime consists… of a mixture of calcium oxide and calcium silicate, and on adding water slaking takes place in the usual way by its action on the oxide. Complete slaking is much slower, however, than for non-hydraulic limes, because of the much longer time necessary for hydration of the silicate… A semi-hydraulic quicklime run to putty should be used within a week.

Eminently Hydraulic Limes – These are rather similar in chemical composition to Portland cement, but contain free lime. They do not harden so quickly, however, and they do not reach such a high strength [as cement-sand mortars we would now say], but for mortar and concrete in ordinary building work they are quite satisfactory – in fact, they have certain advantages. They are obtained from a few distinct localities in the blue lias formation… notably Barrow-on-Soar in Leicestershire, Rugby, Aberthaw in South Wales and Lyme Regis in Dorset…

The degree of burning is more important than with other types of lime, for clinkering and fusion occur more readily and a much higher proportion of clinker may be formed. This clinker is comparatively inert unless the particle size is reduced by grinding; if it is extremely finely ground, a 'natural' cement results. It is unusual for an eminently hydraulic lime to be supplied in the hydrated form, because of the difficulty in ensuring the complete hydration of the oxide whilst at the same time retaining the efficiency of the hydraulic components…

Natural Pozzolanas - …the principal one is volcanic ash, rich in silica and alumina, found in extensive deposits around Mount Vesuvius – notably at Pozzuoli… Another… is Trass, a similar volcanic deposit found in the upper Rhine district and used extensively in many parts of Europe, whilst others are found in the Azores, the Canaries etc. Many other natural minerals are pozzolanic in lesser degree, notably sands derived from the decomposition of igneous rocks… In some countries pozzolana mortars and concretes are used on a large scale and have been extensively developed. In Britain, however, [their use]… has been precluded by reason of the great popularity of artificial cements such as Portland. But for much ordinary building work the very great strength of Portland cement is not necessary, and lime-pozzolana mortar, in which the pozzolana replaces some or all of the sand, gives ample strength and durability. [and considerably more breathability, probably]. It also possesses certain advantages, amongst which are superior workability, better adhesion and a far more pleasing colour.

Lime Mortars. …Nowadays lime mortar is seldom used without additives, eg cement, to give strength, but in districts where hydraulic limes are produced, these may be used in preference to cements, except for structural work, where the highest possible strength is needed. For brickwork mortar for all normal building work it has the advantage of better workability, less shrinkage and therefore better adhesion, and also a more pleasing colour whatever the type of brick used.

Non-hydraulic lime mortar – The proportions of lime to sand are usually 1:2 to 1:3 by volume of the dry materials, depending chiefly upon the grading of the aggregate. Since carbonation is the only form of setting, this type of mortar is comparatively useless without the addition of a cement or pozzolana, or the use of an aggregate having pozzolanic properties. The former will be referred to later as 'compo'. The latter (with pozzolana) is not usual in the case of mortars mixed by hand or in a mixer, but is common in mill-run mortars, the reason being that this type of aggregate (clinker, broken brick etc.) is not sufficiently fine without grinding. The aggregate and lime are therefore ground together or 'run' in a mortar mill, and this (P151) method has the advantage that any unsound lumps of lime are reduced and well distributed…

Eminently Hydraulic Lime Mortar – As has been said, the use of 'straight' lime mixes, for mortars, renderings and even concrete, is usual in certain districts (those producing the right type of limes eg the blue lias). Since such limes are eminently hydraulic and are used on account of the strength developed, great care is necessary in their slaking and use. They are also in

the form of quicklime, which increases in volume on slaking, which increases in volume on slaking, the proportion may be rather lower than when hydrated limes are used.

The lump quicklime is slaked by adding only sufficient water to break it down, and covering with sand for 2 or 3 days, after which it is mixed with the correct quantity of sand and sufficient water to give the required plasticity, and used immediately.

Ground quicklime is usually mixed with moist sand and left until required, when it is mixed immediately before use with the remainder of the sand and sufficient water. The usual proportions are 1:2 to 1:4.

Compo – This is the name usually given by the user to cement-lime mortars. These can be considered as cement mortar, the workability of which has been improved by the addition of lime; or lime mortar, the setting and strength properties of which have been improved by the addition of cement. The usual proportions are 1:3:12, but for higher early strength, such as might be advisable in cold weather or for ½ brick walling (eg. cavity work), the proportion of cement is often increased to 1:1:6...

Internal Plastering – Plastering to internal surfaces is carried out with sanded mixes of a) lime, b) plaster or c) lime gauged with either plaster or cement... Under more leisurely conditions than those prevailing today, lime and sand were used, with a proportion of hair to facilitate application. Applied in several coats, each was permitted to dry and attain a certain strength before applying the next. On completion, too, ample time was given for hardening without disturbance by vibration, etc. and the result was highly satisfactory, as can be proved by inspection. Nowadays, plastering is hurriedly done on walls, etc. that have not properly settled down, subjected during application and afterwards to jarring and other disturbance from other tradesmen working on the completion of the building. These conditions have led to certain modifications in practice, with the idea of facilitating application earlier in the building programme, and in a shorter time; also to give the sufficient early strength to enable the work to withstand vibration etc., without weakening the bond...

Lime mixes - Quicklime for plastering is run to putty as follows: the tub or other slaking vessel is half-filled with water, the lime added slowly (P154) and stirring carried out continuously, more water and lime being added alternately so as to keep the boiling action from becoming too violent. After the slaking has finished and the slurry cooled, it is poured through a 1/8

inch sieve into a tank or tub for maturing. This takes from 2 to 3 weeks, and the slurry thickens as it fattens into putty.

If hydrated lime is used, it may be soaked overnight by placing it in water and stirring thoroughly, giving a putty similar to that produced from quicklime. Alternatively, it may be mixed dry with the sand, then mixed wet and used right away... There should be no excess of lime between the sand grains. 1:2 ½ is the usual proportion for coarse stuff for undercoats, but if the sand is very fine the lime will carry less of it, and if the sand is coarse, the proportions may be 1:3. For finishing coat less sand is used, often equal proportions of sand and lime, but it is usual nowadays to make additions to this coat so as to secure quicker set, greater strength and smoother finish.

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Historic Environment Scotland
Longmore House, Salisbury Place
Edinburgh EH9 1SH
T. 0131 668 8600

Scottish Charity No. SCO45925
VAT Number: gb 221 8680 15