Hot-mixed lime mortars

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A hot-mixed lime mortar is prepared using quicklime. Typically this involves a 'dry slake', during which the quicklime is mixed with naturally moist or slightly moistened aggregate (sand, stone dust, or subsoil). In the case of sand or stone-dust mortars, this initial dry slake is followed by the addition of water sufficient to produce a workable mortar for immediate or later use.

In our own observation and that of others,[1–3] the vast majority of lime mortars, and very many earth mortars, encountered in old buildings of traditional construction were 'hot-mixed'. Lime-stabilised earth mortars, with typically between 5 and 10 per cent addition of lime, usually in the form of quicklime, or more lime-rich earth mortars, where the subsoil effectively behaved as aggregate, were inevitably 'wet-mixed' and the heat generated by slaking would have been less intense and more localised. Depending upon their intended purpose, mortars would be used either hot or after cooling. For fine brickwork, or if the

quicklime had hydraulic potential and was not to be used immediately, the quicklime–aggregate mix would be taken to a dry powder for screening or storage for later use. For most uses, however, the hot mix was taken to a mortar for immediate or later use.

The use of earth mortars, with and without the addition of quicklime, for building and for base-coat plasters was probably almost universal in the British Isles at least until the 18th century. Building with earth also occurred in conjunction with lime used in plaster and limewash finishes. Where earth was common for walling, any arches and vaults within the same structure would have been laid in hot-mixed lime mortar. The use of lime and earth in separate or intimately associated combinations was part of the same masonry or timber-framing craft practice.

Fig. 1 Polished earth and lime plaster sample, York House, Malton, showing both quicklime and oolitic limestone content in the lime finish coat of lime and hair only, with naturally present aggregate within the burned limestone.

The position today

Very few lime mortars today are hot-mixed, even in the context of building conservation. Putty lime, mixed at a proportion leaner than in any historic precedent and used in situations where, historically, hot-mixed air-lime (i.e. pure lime) mortars were the norm, has been the common mortar of conservation and repair, and has often performed too sacrificially. Increasingly, natural hydraulic lime (NHL) mortars have been preferred, as well as heavily promoted, contradicting not only historic precedent and the principle of like-for-like repair, but risking clear incompatibility.

A plethora of designed and engineered NHL-based products have appeared in recent years, many of them to serve the 'eco-build' market. NHLs, as well as NHL-based eco-products, some of which also contain ordinary Portland cement in addition to NHL, are being increasingly applied to historic fabric constructed of much softer and more complex traditional materials designed by masons and not by chemists and engineers.

It would seem that the lime movement has led itself astray in various ways over the last forty years or so, and that conservators and other professionals have suffered a variety of forms of collective blindness, in two particular areas:

Fig. 2 York House, Malton: aggregated limewash and shelter coat, hot-mixed and applied while still warm.

- The almost universal presence of earth mortars in very many of our old buildings, of the highest to the lowest status, has been occasionally noted, but the implications for the necessary deployment of like-for-like and genuinely compatible repair materials have been insufficiently considered. It remains a revelation to most conservation and architecture professionals that earth mortars and/or hot-mixed lime mortars were so widespread.
- The fact that upwards of 85 per cent of historic lime mortars were hot-mixed has either not been noticed or, when it has been, has been declared impossible to match on the grounds that the preparation of hot-mixed lime mortars is unacceptably dangerous or impracticable, which experience tells us it simply is not.

When it is understood that a hot-mixed mortar delivers significant benefits in bond strength, advantageous pore structure, workability, and appropriate durability over a cold-mixed putty-lime mortar as well as over a typical NHL mortar, a straightforward question is begged: why are we not using it now for the repair and conservation of the buildings it typically inhabits?

Mixing proportions

There is a strong bond within a hot-mixed mortar between not only the lime and the aggregate but between both and the water content, which is managed very differently and 'locked in' in ways that are simply not the case with other forms of lime mortar.

Hot-mixed lime mortars are typically lime-rich. The lime revival has been based upon the use of putty-lime mortars at 1:3 and, increasingly, NHL mortars at a similar or greater lime proportion, though the addition of more NHL will generate even more compressive strength in a mortar that is already likely to be harder than a typical 1:1:6 (air lime : Portland cement : sand) mortar.

The 1:3 lime-to-aggregate mix has little, if any, historical precedent. Old mortars may be 1:1, 1:2, or 2:3, and this enhanced lime-to-aggregate proportion is critical to their successful performance and character. The perceived lack of durability of putty-lime mortars may be largely explained by the use of mortars gauged at 1:3, which may not even reliably contain a true quarter part of lime, depending upon the water content and bulk density of the putty lime used; but to mix even the most matured lime putty at a gauge of 1:2 or richer in lime is to produce a mortar that is too wet and sloppy for practical use, other than for plastering.

However, quicklime mortars were generally mixed at 1:3 before slaking. Quicklime typically doubles in volume upon slaking, so that a 1:3 mix will deliver a 2:3 mortar. Like-for-like, compatible mortars may therefore readily be achieved using hot-mixed air-lime mortars mixed to historic proportions.

Modern quicklimes – both high-calcium and hydraulic – are fired at higher temperatures than traditionally. This may have implications for their comparative strengths. In the case of NHLs, most certainly, the higher temperatures of modern firing deliver much more hydraulic activity, and more compressive strength, than would be the case were the same clay-bearing limestone fired at a lower, traditional temperature. The implications for higher-temperature-fired air-quicklime mortars have yet to be explored.

Historical precedent

> **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 ... so that 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 Morter much stronger than if you slack all your lime first, and throw on your sand altogether at last, as some do ...**
>
> (Joseph Moxon, 1703[4])

Apart from its more open and generally lime-rich character, the accepted indicator of hot-mixing is the presence within the mortar of typically small, angular lime inclusions. On this basis – and in the observation of materials analysts[5] – in excess of 85 per cent of historic lime mortars were hot-mixed. Some putty-lime use always occurred, but very much less than has been understood by the lime revival. Until the end of the 19th century, putty lime was generally reserved for fine plaster finishes and fine stucco-work. The use of hydraulic limes became much more common during the second half of the 19th century, but generally in association with civil and structural engineering works, below ground and under water. In some urban centres, the use of hydraulic lime mortar over traditional air-lime mortar became a matter of status, in much the same way as did the use of Portland cement mortars during the 20th century. In most places, the use of hot-mixed air-lime mortars continued at least until the Second World War.

This is not to say that hot-mixed air-lime mortars did not sometimes, or even routinely, enjoy quasi-hydraulic properties. The heat of slaking will promote reactivity with different sands and impure limestone or sandstone aggregates, as well as with granitic sands and, of course, with clays in earth mortars and added pozzolans. Very many historic earth mortars – particularly those used for plastering, but also frequently for bedding mortars – contained added quicklime, which stabilised the subsoil and reduced the shrinkage when clay content was greater than ideal. However, none of this promoted strength development comparable to that produced by modern NHLs.

Therefore, the widespread use of eminently hydraulic limes or putty limes has little, and only quite recent, historic precedent. Modern conservation and repair practice does not reflect this.

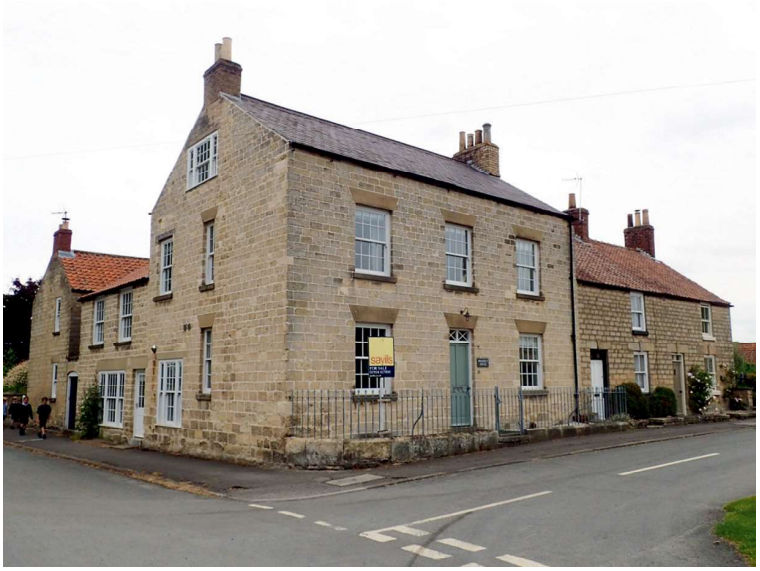
Performance of hot-mixed limes

Hot-mixed air-lime mortars at 1:2 or 2:3 ratio enjoy enhanced performance in terms of better bond strength, excellent vapour permeability, and an appropriate durability for most purposes. Durability may be improved where necessary by the introduction of traditional pozzolans in controlled and consistent volumes. These may be of brick, trass, oyster shell, or clay minerals within certain sands. It has been common practice in Scotland for hot-mixed mortars to be gauged with NHLs. The addition of linseed oil at no more than 2 per cent will also improve frost resistance. Calcined china clay, whilst more recent, offers similar advantages. In most cases, the addition of pozzolans will not be necessary, but where they are necessary their use retains the advantages of workability without seriously diminishing the benefits of an open-pore structure.

Practical advantages

Over the last seven years of regular and routine use, we have observed the following:

- Hot-mixed, lime-rich mortars are eminently efficient in the drying out of historic fabric.
- In use, hot-mixed mortars 'hold up' better during building and do not release lime on to the masonry below.
- For plastering, they may be applied at close to the liquid limit without slumping or undue shrinkage.
- They are exceptionally workable, a characteristic to which all practitioners respond very positively.
- Mortars may be used whilst still slaking and in a liquid state to fill the voids in rubble-core work, later stiffening and expanding slightly.
- Hot-mixed lime mortars are less vulnerable to rapid drying out and require less protection against this, as well as against frost damage.
- Quicklime is significantly less expensive than either putty lime or NHL and is generally available in all parts of the world.*
- Limewashing and shelter coating are more effectively executed – and pigments or other additives more efficiently engaged – while the material is still hot, which also allows the laying on of thicker coats of limewash. Pointing mortars might be used either hot or cold, often depending upon the time of year and the geology of the substrate.



Compressive strengths

The compressive and tensile strengths of hot-mixed lime mortars will surprise those familiar with slaked air-lime mortars mixed at 1:3, but this enhanced robustness is coupled with very efficient vapour permeability. Our own mixes have been observed to deliver similar strength to the older mortars we seek to replicate.

We are confident that they are generally like-for-like, though, as stated above, the implications of

Fig. 3 (Above) Prospect House, Slingsby, pointed with hot-mix mortar in 2008. The stone geology is the same as in the OPC-pointed buildings to either side, but the fabric is now so dried out that this would not be assumed at first glance.

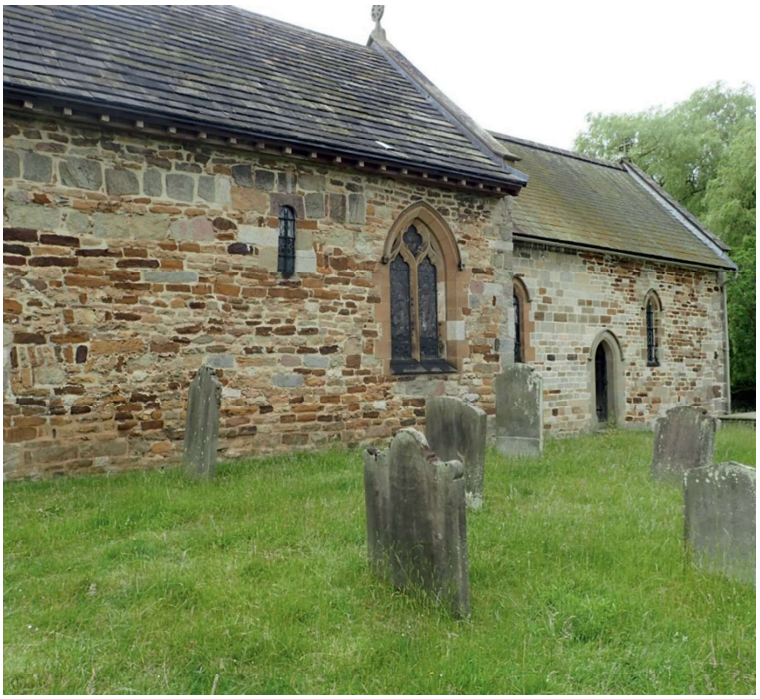


Fig. 4 St Michael's Church, Crambe. The stonework of the nave (left) was pointed with NHL 2.0 six months before the chancel (right) was repointed by ourselves with lime-rich hot-mix mortar. It is reasonable to say that the chancel fabric is now drier than that of the nave.

*Where it is not, but there is available limestone or quantities of seashell, small-scale lime-burning would be eminently feasible and economic.

higher slaking temperatures in modern quicklimes fired at between 900°C and 1300°C, compared with those achieved by quicklimes produced at traditional temperatures, need to be explored and understood.

The British Standard states that it should be enough for a mortar to be proven to have worked in the past.[6] We need to be confident that our own hot-mixed lime mortars are very similar to those which we see all around us as having worked very well historically. Historic England are in the process of commissioning a research project that will generate typical figures for tensile, flexural, and compressive strengths of hot-mixed limes, as well as for vapour permeability. An NHL research project, which will deliver similar figures for NHL mortars, as well as for controls of air-lime and hot-mixed air-lime mortars, is already under way.

As it is for NHLs, the standard 28-day test is inappropriate. It takes two years for an NHL to reach a strength close to its maximum, and this will typically be up to three times greater in compressive strength than at 28 days. Carbonation of air limes may also be expected to be relatively slow; however, hot-mixed air-lime mortars typically 'case-harden' in short order, protecting the interior of the mortar from rapid drying out and also from frost, and facilitating a steady and effective carbonation to depth. The presence of clays in the sand or aggregate, that may react due to the heat of the slake, will accelerate the setting time of hot-mixed air-lime mortars and assist early strength development without inhibiting carbonation.

Relevance to plastering

Whilst it is certainly true that the preparation of plastering mortars (at around 1:2) using putty lime had become common by the end of the 19th century (when practitioners began to write down their experience), it is our observation that the vast majority of plastering mortars before then were hot-mixed at an ultimate proportion of 1:2, or richer in lime than this. Putty lime was generally reserved for fine finish coats. Base coats and scratch coats for flat plastering and for mouldings run *in situ* were typically hot-mixed. In our experience, this works very well – hot-mixed plasters may be applied at the liquid limit without slumping and with acceptable or little shrinkage, depending upon the mix of aggregates and organic material (ox hair or fibre; hay or hemp shiv).

Earth plasters also were typically applied at the liquid limit, with added hay (rarely straw). The characteristics of an earth and a hot-mixed lime plaster are very similar in terms of bond strength and workability. Earth plasters seem generally to have included a gauge of quicklime (or of putty lime, which will have been still slaking when added, following the 'wet-to-wet' principle).

Although some external rendering (and certainly harling in Scottish practice) will have been applied hot, maximising a beneficial pore structure, most hot-mixed plasters will have been set aside for later use. Even a day after mixing, the elasticity of a hot-mixed plaster is improved. This would also have allowed for late slaking, particularly if the quicklime was used as lump. Some historic texts, however, speak of crushing down the quicklime before slaking.

A hot-mixed plaster is eminently workable and sticky and enjoys a strong and immediate bond with the substrate.

Fig. 5 Early English doorway at St Mary's Priory Church, Old Malton: hot-lime shelter coat to Hildenley limestone.

Health and safety

The risk assessment for the preparation and use of hot-mixed lime mortars differs in no way from that for the preparation and use of putty lime, NHLs, or, indeed, ordinary Portland cements.*

The high alkalinity of all of these is the primary hazard to be managed. The temperatures gained during hot-mixing are generally lower than those encountered every day in the average domestic kitchen, even allowing for the higher slaking temperatures of modern, higher-temperature-fired quicklimes.

Quicklimes fired at modern temperatures will be generally more reactive than those fired at traditional temperatures. The latter will fall to powder quite benignly, while the former will briefly spit and fire fragments of lime at some velocity unless covered with sand or other aggregate. The use of powdered quicklime eliminates this hazard, and its slaking with moistened sand (as little as 3 per cent moisture content) is generally benign and only a little volatile.

In our own experience, temperatures at the 'dry-slake' stage may reach 150°C during the summer months, and more like 105° during the rest of the year. Once a surplus of water is added, these temperatures will fall to around 58°. Short-term contact of the mortar

* Editor's note: there are additional hazards when preparing hot-lime mixes, which should only be carried out by those who are experienced and properly trained.

at the latter temperature will not burn the skin and will be immediately known by the mixer.

Hair or hemp or other organic materials may be added to the mortar at the dry-slake stage without incident; they do not even singe.

The primary hazard of all lime products is to the eyes. Eye protection should be worn during all work with lime mortars, as should gloves and, at certain times, such as when mixing any alkaline dry powder, face masks.

If any lime product enters the eye, saline eyewash should *not* be used, as this will amplify the potential damage. Sugar solution will neutralise the potential harm. Diphoterine eyewash is the readily available form of this, approved by the European Lime Association.

Lastly, if site-mixing is considered problematic (although it is entirely legal), pre-mixing for delivery of the cooled product to site is entirely feasible and involves no diminution in the primary performance benefits of a hot-mixed mortar. This was done in high volume in the UK by Tilcon as recently as the 1970s, albeit for gauging on site with ordinary Portland cement.

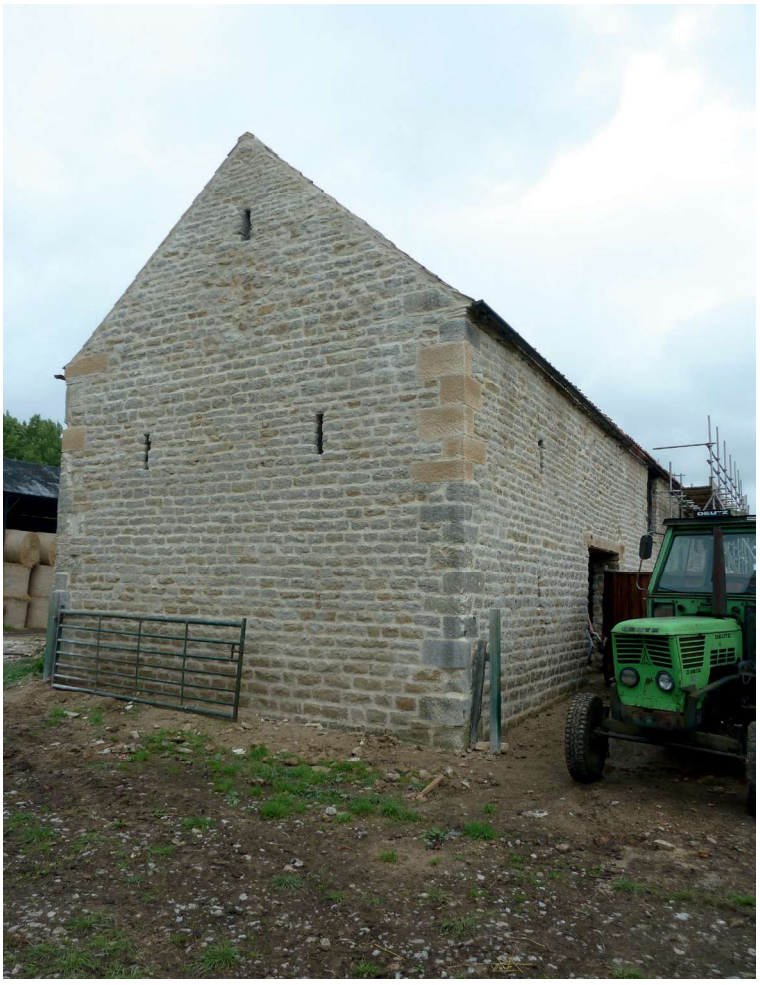
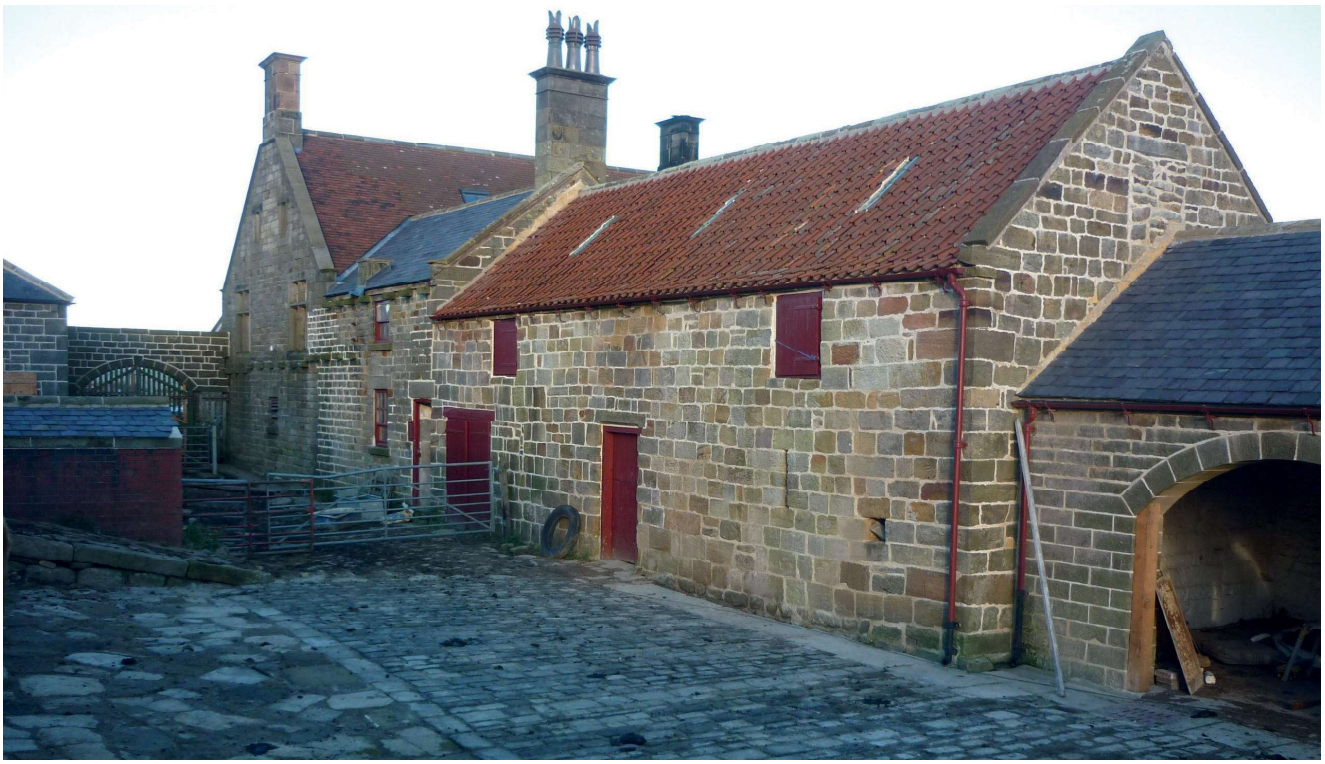
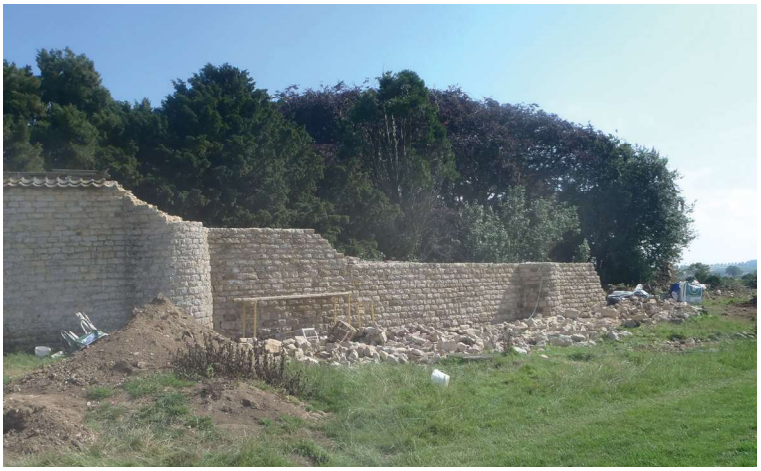
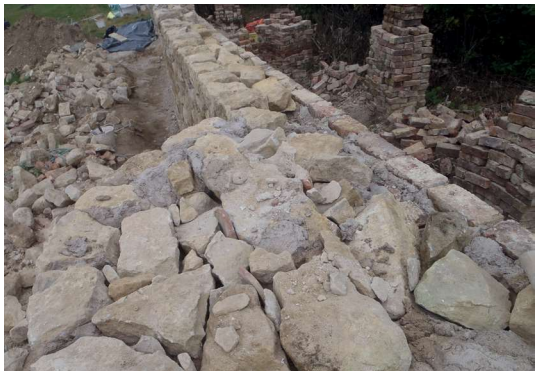


Fig. 6 (Right) Threshing barn, California Farm, Thornton Dale: hot-mixed lime mortars over earth and lime bedding mortars. (Contractor, Sam Baxter, to management plan prepared by the authors.)

Fig. 7 (Below) Threshing barn and other buildings, Swallowhead Farm, Fylingdales: hot-mixed lime mortars over earth bedding mortars. (Contractor, Stephen Straw, to management plan and specifications by the authors.)







Figs. 8 and 9 Rebuilding of a fallen 18th-century fruit-garden wall at Ryton, Malton, using hot-lime mortars. Work was completed in November 2014 and suffered no frost damage or disruption over the following winter.

Conclusion

There is rarely a good reason not to take into consideration any historical documentary and archaeological evidence on original mortars and to seek to reproduce their character and their performance, not slavishly, but in general and in principle. Historic lime mortars were not standardised, but variable according to circumstance and to the craftsmen involved. However, craft practices show remarkable consistency, according to the available evidence, in producing mortars that were very much richer in lime than those specified today and which were hot-mixed using quicklime. It is entirely unclear to us on what basis it was decided, over the last forty years, that we knew better than uncountable generations of building craftsmen, allowing even conservators to ignore not only the higher proportions of lime generally used but also the nature of the lime deployed and the general method of producing a suitable mortar.

In recent discussions with Santiago Gonzalez, a retired stonemason in Asturias, north-west Spain, a region of slate bedded in earth and lime mortars, subsequently pointed and rendered with lime mortars and plastered internally with both earth and lime mortars, the question as to whether the lime mortars were hot-mixed was met with a slightly baffled response: 'Why would we do anything else? It is all we ever did.'

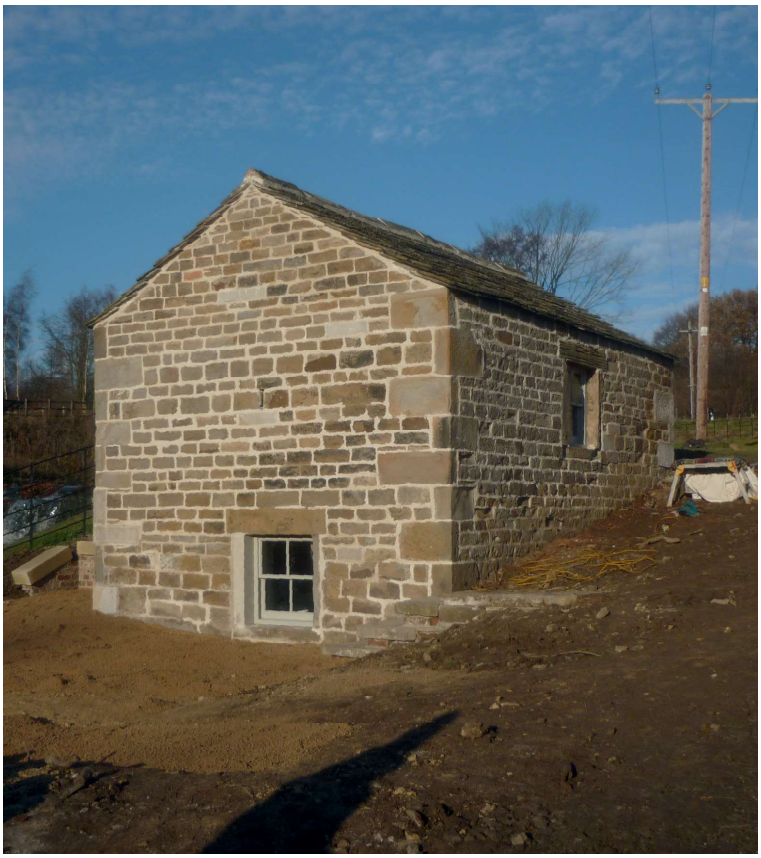


Fig. 10 Hot-mixed lime and sand mortar, Dam Head Pumphouse, Bretton Park, Yorkshire Sculpture Park.

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