Conservation of Heritage Structures & Older Buildings

Repointing Masonry Walls – Matching the Techniques for Success or Failure

By Paul Jeffs, PJ Materials Consultants Limited

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Introduction

Repointing can be described as the process of removing deteriorated mortar from the joints of masonry walls and replacing it with new mortar. The process is often referred to as "tuckpointing", although this term generally describes a particular method of mortar application.[1] When repointing is considered necessary, the major objective should be to restore visual and physical integrity of the masonry.

There is no doubt that the selection of incorrect repointing materials and techniques can lead to poor results - either from an aesthetic or a durability perspective. Of course, the same claim can be made for the original pointing work, although the evidence is overwhelming that good practice has produced masonry walls that have stood the test of time, or at least have provided a reasonable service life before restoration work became necessary. Conversely, there are many examples where materials and techniques were not sufficiently durable - most likely due to a lack of appreciation of the critical role that repointing has to play. (See Photograph 1.) This presents a problem to the designer of a restoration strategy for a heritage structure, as the re-use of the original concepts of mortar and/or jointing style may achieve an historically correct appearance - but further work may then be soon required to arrest ongoing deterioration. An awareness of the key factors that affect durability can assist the designer in deciding whether it is possible to achieve that which should be every conservationist's goal - the retention of architectural elements and style. It can also ensure the avoidance, where possible, of those strategies that could alter the historical appearance of heritage structures.

Photo. 1. This hard cement based repointing mortar was applied without cutting out the old mortar and is now causing deterioration to the stone masonry units.

[1] The U.S. Masonry Advisory Council defines "tuckpointing" as being the process which points masonry with a flush mortar joint that approximates the colour of the masonry units and uses a mortar of contrasting colour that is shaped into a thin strip. (See Glossary of Terms for more information.

In this topic, we will evaluate some of the practices that can be considered to be incorrect, as well as those that are accepted as preferred methods. However, it is readily admitted that the focus is on preservation of structures for the long-term future, rather than short-term authenticity. In presenting the recommended preferred practices for repointing, it is acknowledged that the work should be preceded by a thorough and expert investigation that reveals any causes of accelerated deterioration and identifies any other factors that may influence the selection of repointing materials and techniques. This particularly applies if structural damage has occurred.

The Function and requirements of Masonry Mortar

It is a common but misguided conception that mortar is only used to "glue" the masonry units together and therefore the mortar should be as strong as possible. However, although it is important that individual masonry elements should become a monolithic component of a structure - and obviously this is unlikely to be achieved by dry-laying brick or block units - structurally adequate free-standing stone walls can often be constructed without any mortared joints at all. Unfortunately, this can lead to damage of stones due to uneven loading conditions and poor lateral restraint as stresses develop from the natural accommodation of movement caused by temperature change, wind loading, snow, vibration, differential settlement, etc. The major function of mortar, therefore, is to uniformly distribute these stresses and provide restraint against lateral movement. (see Figures 1 and 2.)

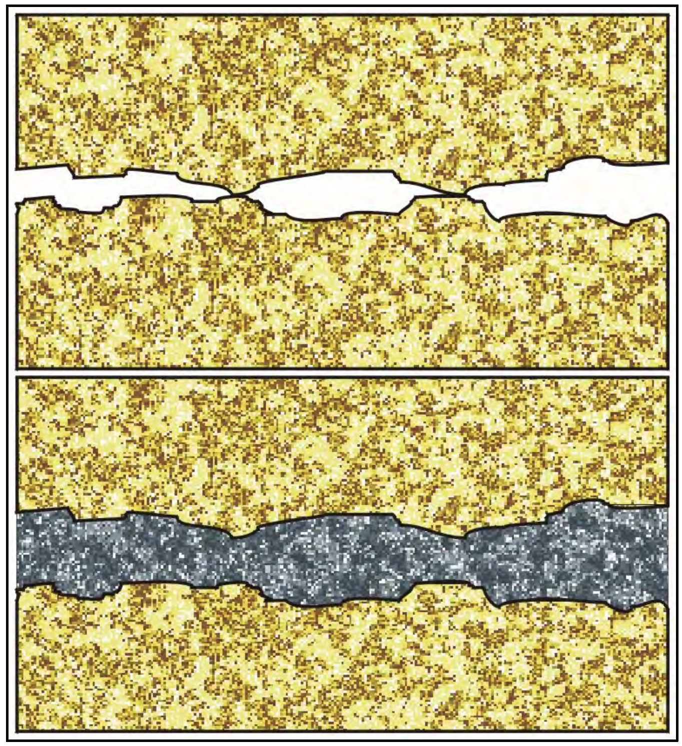

Figure 1& 2: Dry-Laid stones (top) provide point-loading and poor lateral restraint; Mortared joints (bottom) provide uniform load distribution and good lateral restraint.

In addition to providing uniform support and the avoidance of point-loading conditions, it is important that the mortar absorbs stresses as they develop. If the hardened mortar is too strong, stresses can be transmitted to the weaker units which would then suffer deterioration from cracking or spalling. Additionally, hard mortar will generally have a dissimilar coefficient of thermal expansion to masonry units and, as the two materials change their volume differently as temperatures rise and fall, the weaker units can undergo quite severe stresses. It therefore follows that, for repointing work, the masonry mortar should also be designed to be equal to or somewhat weaker than the remaining mortar within the joints.

A further major function of mortared joints is to prevent or reduce the ingress of moisture. However, it is important that the mortared joint also permit moisture to "breathe" out from the interior of the masonry, in the form of vapour, at a similar rate to the masonry units. This means that the two materials - the masonry unit and the mortar - should exhibit similar "moisture vapour transmission rates". (see Figures 3 & 4.) Deterioration from the action of freeze/thaw cycles can only become severe if the masonry remains saturated between cycles. If masonry can dry quickly after rainfall, before freezing temperatures occur, then damage is unlikely to occur or become severe. It is therefore very important that the mortar should "breathe" easily and not trap moisture within both materials at the interface between the mortar and the masonry unit.

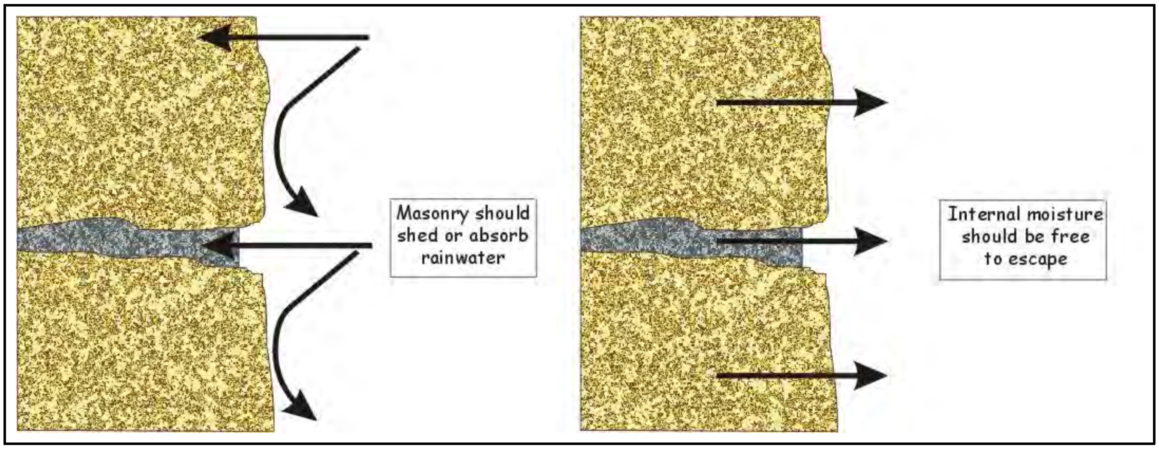

Figure 3 & 4: There are usually no problems with masonry absorbing rain-water - as long as both the mortar joints and the masonry units can uniformly dry before freezing and thawing conditions prevail.

It is also equally important that the hardened mortar should exhibit low shrinkage properties. As evident from later illustrations, excessive shrinkage of hard mortar that is well bonded to the masonry unit can cause stress cracking of the weaker material. Alternatively, when poorly bonded mortar shrinks, gaps can open up at the interface with the masonry unit which can produce paths for the rapid ingress of moisture.

Repointing Strategies

At the current level of technology, it is not possible for mortar joints to be designed to last the full life of a structure. Therefore, they should be considered a maintenance item and repointing planned as necessary, in which event very little damage should occur to the masonry units. In fact, as will be seen later, most of the damage to masonry units occurs because joints are not repointed soon enough - or the wrong techniques are used. However, it is important that the causes of any accelerated deterioration of masonry joints be investigated and fully understood, before the final development of a repointing strategy. If deterioration of areas of masonry is mainly due to poor drainage or the absence or deterioration of gutters, these problems must be corrected - before any repointing work commences. The phasing of repointing work is also important in conjunction with other restoration work. For example, consideration should be given to completing any cleaning work after old mortar removal work but before joint filling. In this event, should water cleaning techniques be used, consideration should be given to any undesirable effects from saturating the masonry through opened joints.

An important part of the repointing strategy should be an evaluation of the time of year when the work will be carried out and the effect that anticipated changes in temperature could have during the early strength development of the mortar. Ideally, to reduce the potential for freezing or rapid drying, the actual repointing work should be carried when the masonry wall temperature is between 5°C (41°F) and 25°C (77°F). However, consideration should also be given to the effect that a rise or fall of temperature outside that range can have on the immature hardened mortar. The selection of the mortar constituents will be important in this regard (discussed later) and the specification for the work must address the requirements for providing adequate protection.

The Deterioration Process

If we are to develop effective repointing strategies, it is important that we learn from past mistakes and avoid repeating them. Figure 5 illustrates a typical sequence of deterioration that can take place over the years.

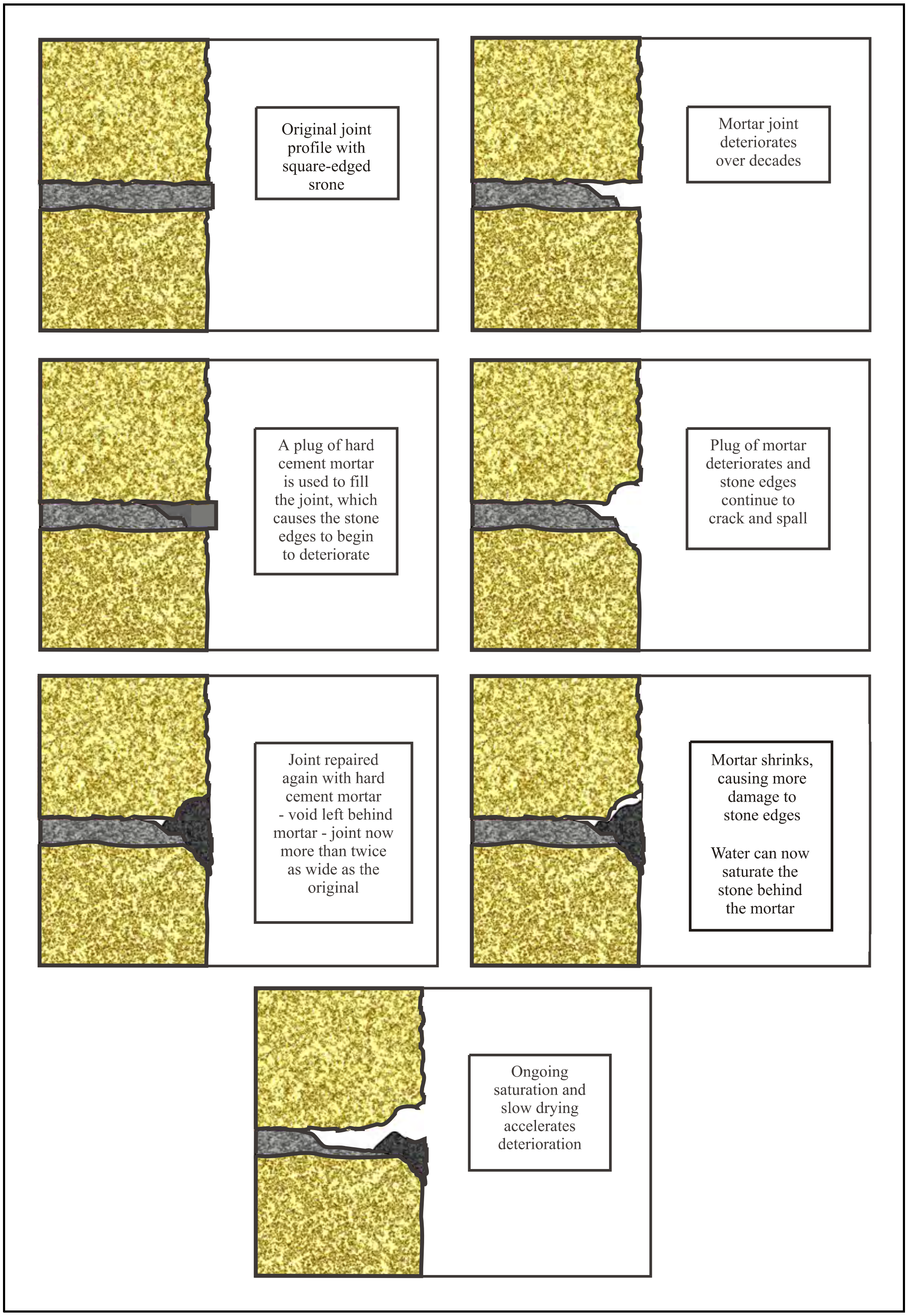

Figure 5

A structure that exemplifies the illustrated sequence of progressive deterioration is shown in Photos 2 and 3. The first photograph shows a section of stone masonry 16 years after major repointing work was carried out in 1961.

A close examination reveals that the ribbon-jointing style using a cement mortar is deteriorating quite badly, along with the stone edges.

It can only be supposed that this advanced rapidly, as major repointing work was carried out again in 1993 and Photograph 3 illustrates the extent to which a hard cement mortar has been used to maintain a flush joint, increase the joint widths and thereby reduce the visible area of stone.

Photo.2: A section of mortar 16 years after repointing in 1961
By kind permission of the Wellington County Museum Archives, Ontario

Photo. 3: After major repointing in 1993

Repointing Techniques

With good maintenance practices, it should be possible to repoint a structure to last for more than fifty years. Indeed, many heritage structures can be found with the original mid-to-late-nineteenth century mortared joints still performing well, even though they have been exposed to quite hostile weathering actions. (see Photographs 4 & 5)

Photo.4: (Top) Original mid-eighteenth century mortar in 1974 (By kind permission of the Wellington County Museum Archives) Photo. 5. (Bottom) 34-years later, there is little sign of additional deterioration.

Photograph 4 shows a section of masonry constructed from ashlar limestone in 1853. The original mortar is clearly visible and - apart from some localised repointing work that is required - in general, the condition of the mortar is very good. The photograph was taken in 1974 and, if it is compared with Photograph 5 - which was taken in 2008 - it can be seen that very little deterioration has taken place since that time. While it is fair to state that some partial repointing work is required in other areas of the masonry full joint restoration work is still not required - even after more than one hundred & fifty years.

Experts generally recommend that the preferred way to tackle the repointing of traditional masonry is to only remove the deteriorated mortar, use similar coloured and strength mortar and adopt a similar pointing style to blend with the remaining mortar. In fact, complete repointing of all mortar joints is rarely necessary, unless the entire mortar is badly deteriorated or previous repointing work is contributing to accelerated deterioration. By careful selection of only those areas that are badly deteriorated the high cost of effective repointing can often be kept to a reasonable level.

In order that progressive deterioration already illustrated by Figure 5 can be arrested or slowed, the restoration strategy should consider the technique detailed in Figure 6. This generally preferred technique removes old deteriorated mortar, using the methods described later, and replaces it with a carefully designed mortar (also discussed later). The original joint width is almost restored by recessing the mortar and any lower projections are chamferred to assist in shedding rain water.

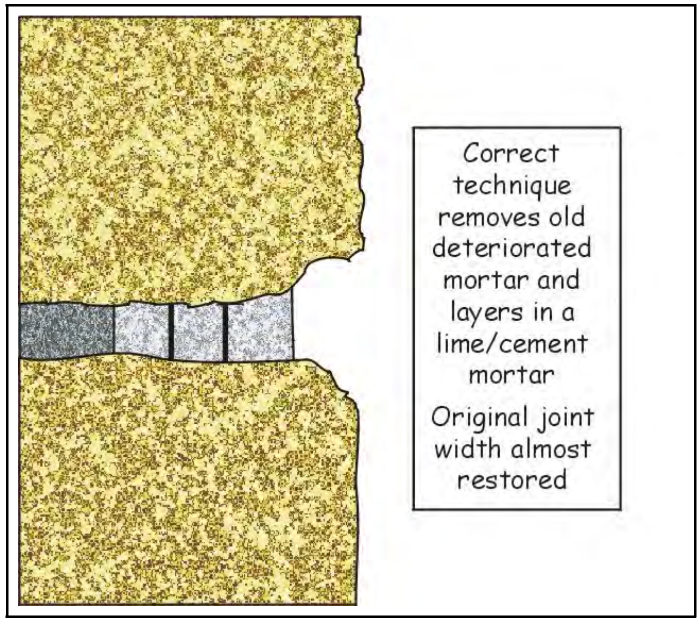

Figure 6

If a return to a straight edged joint is considered essential for authenticity, then a purpose-designed mortar - not the repointing mortar - should be used to re-profile the deteriorated masonry unit. The re-profiling mortar should preferably consist of a lime/sand mortar containing very little cement, if any. A clean, concreting sand chosen for its size distribution and colour can be used to resemble the masonry unit. Alternatively, a proprietary, custom-matched product can be used. In either event, it is essential that the strength of the re-profiling mortar be weaker than the stone and have similar "breathing" properties.

Jointing Style

If significant repointing work has been carried out over the years, and/or significant deterioration of the masonry units has occurred, the selection of a pointing style becomes more difficult. In an ideal world, as already discussed, the most obvious style to adopt would be that used at the time of original construction. (See Photograph 6.) However, if the original style has obviously contributed to early deterioration, and/or the repointing materials and techniques have further accelerated damage, it may be more prudent to design the style to provide greater durability.

Photo. 6. The repointing of this 100-year old brick masonry attempts to match the original pointing style.

The following five photographs further illustrate how the selection of a pointing style and hard mortar can accelerate deterioration. Photograph 7 was taken in 1974 and shows the results of numerous attempts at repointing over at least a forty year period. At one time - or perhaps originally - mortar was used to change the appearance of the random sized rubble stone to a more expensive, uniform ashlar stone. (A form of the technique originally known as “tuck-pointing”.)The repointing techniques applied mortar over the faces of the stone and then used a "tape" or "ribbon" style for repointing. (This is a technique that has been widely adopted in the Wellington County area in Ontario and appears to have grown and spread in popularity during the 1930 - 1940's) Photograph 8 shows the extent of deterioration caused by the poor techniques in 1994.

Photo.7: The effects of numerous attempts at repointing (1974)
By kind permission of the Wellington County Museum Archives

Photo. 8: Further deterioration is evident after 20 years

Taken about 1993, Photograph 9 shows an area of the church masonry which more clearly reveals the extent of previous repointing and the deterioration. Photograph 10 further illustrates the extent to which the technique, style and selection of hard cement mortars has accelerated deterioration and damaged the masonry units. In particular, water has soaked into the stone behind the "feather-edged" mortar which covered the stone face. The water has been unable to "breathe" as naturally through the hard mortar as it could through the stone. This has repeatedly caused the development of stresses within both the mortar and the stone during periods of freezing and thawing, until progressive damage occurs to both materials - but the "softer" natural stone suffers more.

Photo.9 through 12.(Upper Left) Natural stone masonry that has been repointed many times - incorrectly, and (Upper Right) a close up view of accelerated deterioration caused by the incorrect repointing techniques - note the damage caused to the natural stone. (Lower Left) The same area of masonry some 10-years after restoration, and (Lower Right) the omission of inner core rubble grouting has resulted in further deterioration.

However, of equal concern is the fact that water has penetrated through to the inner rubble core and signs of leaching out of the binder are also apparent. This raises concerns that the masonry may not be acting completely as a composite structure and loads may not therefore be uniformly distributed and stresses evenly absorbed. Part of a restoration strategy, under similar circumstances, should investigate the seriousness of any inner core deterioration and evaluate the need for grouting techniques to ensure structural stability of the masonry.

Unfortunately, when restoration was carried out about two or three years after Photograph 9 was taken, the work did not include grouting of the inner core rubble. Photograph 11, taken in 2008, indicates that this omission is resulting in further evident deterioration. A close-up inspection of the masonry confirms multiple areas where water which obviously enters the core rubble at higher levels, then gravitates and collects to cause freeze/thaw damage - which subsequently permits the binder from the inner core to percolate and exit the masonry through deteriorated joints. (See Photograph 12.) An unfortunate result of the original poor repointing practices (illustrated in Photograph 9.) is also the damage caused to the masonry units by the subsequent cutting out operations required to remove the hard cement mortar from the face of the stone.

When faced with the deterioration illustrated by the previous few photographs, the selection of the repointing style requires careful evaluation. It is essential that all the hard mortar be removed from the face of the stone, as well as the deteriorated mortar from within the joints. This means that the choice of durable styles is limited and the preferred choice would be to recess the joints as previously described. It should be appreciated that this compromise changes the current appearance of the structure and may not necessarily represent the original style of pointing.

Photos 13 through 15 illustrate repointing a foundation wall that had been poorly repointed over many years.

Photos. 13 through 15: A badly repointed foundation wall before, during and after restoration.

Test Panels

An essential part of a repointing strategy should be the construction of a small test panel within an area of masonry requiring restoration. The panel should be constructed in order that the techniques and style of repointing may be determined for uniform bidding purposes. This will also ensure that all parties, including the client, are fully aware of any likely changes to the then existing appearance of the structure. The site for the test panel, usually 10 - 20 square feet in area, should preferably be positioned at an inconspicuous location. The mason carrying out the work should be made aware of the style required by the restoration strategy and should only use practices that will be permitted for use during the actual work. The various stages of the work on the test panel should be approved as they proceed and, once accepted, used as a standard reference for the entire project.

Before the test panel is constructed, it is recommended that small size batches of mortar - and stone re-profiling mortar, if required - be made to evaluate strength and colour. If possible, the batches should be made some while ahead of the test panel construction work in order that the mortar can gain sufficient maturity for adequate comparisons of colour to be made. In view of this, as well as the fact that the test panel may be required to provide information prior to finalizing the repointing strategy, it makes good sense for an experienced mason to be employed to carry out the on-site test work even before the development of a specification and the invitation for bids. Although this will obviously incur an additional cost, there is usually great value as it will permit the bidders to inspect the test panel and fully understand their responsibilities and liabilities in providing the desired quality and appearance of masonry.

The Repointing Process

Once the repointing strategy has been designed, the specifications for carrying out the restoration should be developed. The specifications should stipulate the requirements for the following:-

Preparing a Joint for Repointing

Effective joint preparation requires a considerable amount of work, often resulting in the removal of mortar that may not necessarily be deteriorated, but it is extremely important if long term durability is to be achieved. All excessively soft, loose and crumbling mortar should be raked out to a uniform depth and for the full width of the joint. In order that a good bond between the mortar and the masonry unit can be achieved - and to combat the potential for shrinkage of the mortar by maximising the bond area - it is generally recommended that joints should be raked to a depth equal to between 2 and 2½ times the width of the vertical joint. Obviously, for most brick masonry, this means that the mortar should be removed to a depth of about ¾ to 1-inch (20 to 25-mm). However, for random coursed stone masonry, this can often require removal of around 2-inches (50-mm), but even more will be required if deterioration goes beyond that depth. (Temporary support of some masonry units may therefore be necessary on occasions.) The mortar remaining in the joint should be left square cut and flat before final removal of dust and debris.

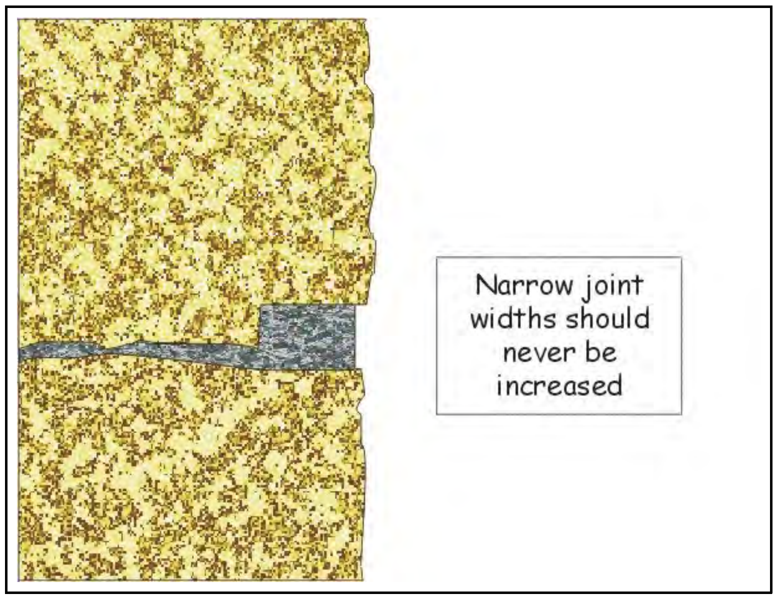

Figure 7

Joints should never be widened to facilitate easier repointing. (see Figure 7.) Very narrow joints can often be raked using pointed industrial hack-saw blades or other suitable instruments. The use of grinders to open up a joint or remove mortar is difficult to control and, whenever possible, should be avoided to prevent damage to masonry units. In fact, on heritage structure restoration projects, it is generally recognized that power tools should only be permitted for mortar removal work in exceptional circumstances, and then only used by experienced operators. (See Photograph 16.) In particular, grinders should never be used as the only means by which mortar is removed - nor should they be permitted to be used on head (vertical) joints (see Photograph 17) Apart from the potential detraction from the visual character of the masonry, damage caused to the masonry unit may increase the potential for accelerated weathering.


Photos.16 & 17: Damage caused by use of a grinder to remove previous mortar.

If joints are uniform and sufficiently wide, the use of grinders with small diameter blades is often permitted to remove the central portion of mortar in order that easier use of hand tools can be achieved. In this case, the thickness of the grinder blade must be less than half the width of the joint. In addition, removing deteriorated lime mortar is usually no problem using hand tools, but removal of hard cement based mortars is generally more difficult and the avoidance of power tools may not be possible. Unfortunately, when previous repointing work used inappropriate mortars, the use of inappropriate tools (grinders) is often the only solution.

Ironically, in some rare cases, the use grinders will in fact create less damage to some stone masonry units than carving tools or chisels - particularly if the units are under high compression loads due to unusual circumstances, and/or the stone was face-bedded. This latter condition can often cause fracturing or scaling of the joint edges from the release of energy during the cutting out of joint under severe compression. (See Photographs 18 & 19.)

Photos.18 & 19: Cutting out over-loaded face bedded stone mortar joints using hand chisels (left) caused damage to the masonry which was not created when grinders were used. This was due to unusually high loads imposed on the outer wythe of masonry following roof reconstruction work carried out 30-years previously.

However, damage to masonry units can usually be better controlled by use of hand tools. (see Photographs 20 through 22) Chisels should be used that have point thicknesses that are no wider than half the width of the joint.

Photo.20, 21 & 22: Removing deteriorated mortar with chisel (left) rake (middle) and lightweight stone carving tool (right).

A reasonably recent innovation within the masonry restoration industry is a power tool that is claimed to be more controllable than a grinder - and has a purpose designed dual blade configuration that can be used for a variety of circumstances - including cutting out head joints. (See Photographs 23 through 25.) However, the correct use of the tool should be assured with trials and training - particularly when hard mortars are present. The formation of a short length of a centre slot using a grinder is typically advisable to ensure the blades can get a 'purchase' into the mortar within horizontal courses. The dual blades can then be inserted into the slot and moved horizontally. This technique will typically avoid potential damage to masonry units from 'chattering' of the blades on the surface of the mortar. At the moment, there is only one manufacturer supply a proprietary tool of the type described and illustrated.

Photos.23 through 25.A new cutting out tool (left) that can be used for stone (centre), brick (left) and other types of masonry unit - and can be used for head joints (left inset). The dual blade configuration (right inset) reduces the possibility of causing damage to masonry units during cutting out operations.

Cut out joints should finally be cleaned of dust and debris by gentle flushing with clean water. If it is possible for this to be carried out just prior to filling the joints, the dampness will prevent the rapid loss of mixing water from the new mortar which could otherwise reduce bond. However, the joints should not be wetted with free water at the time of application as this may cause undesirable reductions in the strength of the bond or an increase in shrinkage. It is also important that the face of the masonry units be damp to dry - not wet - at the time of repointing work, or mortar runs and "streaking" may occur. (See Photograph 26.) This also means that repointing work should be suspended during rainfall and freshly applied mortar protected from getting wet.

Photos.26. The result of repointing while the face of the masonry is wet.

Repointing Mortar Selection

Canadian Standard CSA A179[1], which specifies requirements of mortar for use in bedding, jointing and bonding in masonry unit construction, does not specify mandatory requirements for repointing mortars - although the latest edition (2004) now includes information within an appendix. In general, weaker strengths and lower flows are typically required for most repointing mortars - particularly for historic masonry projects - compared to conventional bedding mortars.

The selection of a repointing mortar is currently a controversial topic with many experts not in total agreement. The major disagreement concerns whether or not the mortar should contain hydraulic lime as the sole binder.[2]

Most experts involved with the restoration and conservation of older heritage structures argue that the original mortar on many 19th century buildings generally used lime as the sole binder and whenever possible should therefore it should be used again for the repointing work - without including Portland cement.[3,4] However, many experts argue that these mortars are not necessarily well suited for the Canadian weather conditions, mainly due to the need to provide exceptional protection during cold temperature working and their vulnerability to freezing through their early periods of hardening. There has been a relatively recent trend for some restoration professionals to use mortars containing hydraulic lime as the sole binder on architecturally significant heritage structures and there are some experts who claim that inadequate testing of these mortars has been carried out.[2] (Hydraulic lime is not currently available from Canadian lime manufacturers.) However, since the first modern use of these mortars during the mid-1990's, there is evidence that to date they have performed well on several of Canada's most important historic buildings - a hydraulic mortar was used on the Peace Tower and the Library of Parliament, both part of the Parliament Hill complex in Ottawa,[5] and it was used on the Manitoba Legislative Building in Winnipeg.[6]

We will re-visit some further concerns on the topic of binder later in this section, but it is the author's opinion that the selection of the repointing mortar ingredients will depend on many factors that will vary from structure to structure. Indeed, on rare occasions the ingredients may need to be varied on one structure depending on variations in the durability of the masonry units and the severity of exposure from one elevation to another - although this may be difficult to control in practical terms. However, the author believes that the major objective should be to match as closely as possible the original mortar for appearance and performance - *provided that the original pointing has proven to be sufficiently durable.* When the original mortar was pure lime and sand - and it has proven to be sufficiently durable - the decision to repoint the masonry units with a similar material should be relatively straightforward. (Except that experts do not necessarily agree which type of lime should be used - hydrated or hydraulic, how much lime should be used and whether the mortar should be air-entrained or not.) However, the decision-making process becomes much more complicated when the mortar has deteriorated badly to cause accelerated deterioration concerns. When pure lime/sand mixtures are selected, then repointing must be completed before the end of August to permit sufficient hardening of the lime by carbonation before the onset of freezing conditions.

When considering the selection of a masonry mortar for a repointing project, the available options are numerous. The combinations of the main components most likely to be currently used for masonry mortar may be summarised as follows:-

- White or Grey Portland Cement and Sand
- White or Grey Masonry Cement and Sand
- White or Grey Portland Cement, Hydraulic Lime and Sand
- White or Grey Portland Cement, Hydrated Lime and Sand
- Hydraulic Lime and Sand
- Hydrated Lime and Sand
- Proprietary Pre-Blended Mortars for historic structures

In addition sulphate resistant cement may be used on some occasions and, as discussed later, there are three classifications of hydraulic lime. Apart from repointing operations for heritage structures, the most commonly used mortars are based on combining cement and hydrated lime as the binder.

Scientifically analysing the original mortar to match the ingredients may be of interest from a historical viewpoint, but rarely is it possible to match the weathered appearance of the mortar today by using similar proportions of similar materials. Indeed, a mortar designed to match the existing weathered appearance of the original mortar may very well change within a few years due to its own weathering. However, evaluating the likely original gradation of sand can be important in matching texture. This can be achieved by breaking down a representative sample of the known original mortar using a wooden mallet. A pure lime/sand mortar is easier to evaluate as the lime constituent can generally be removed by using a dilute solution of hydrochloric acid (also known as muriatic acid). A 5 to 10% strength solution should cause a rapid bubbling action with the lime portion being dissolved within a short period of time. Washing and drying the remaining portions may then assist in the evaluation of the size distribution and colour of the sand.

Colour matching can often be achieved by the selection of a particular sand or by blending various combinations of sand. Apart from white cement (discussed later), the use of artificial colouring admixtures should be avoided unless absolutely necessary. They often do not weather well, the colour match may be lost within a short time and weathering throughout the masonry may vary depending on local exposure conditions. A good technique is to mix several small batches of mortar using different formulations of the selected materials. Some of the mixtures can be used to check strength development, but a few cured samples should be made about the same thickness as the mortar within the joints to be filled. After at least a three day period of natural setting and hardening, accelerated drying can then take place by use of a ventilated oven, avoiding high temperatures. In addition, weathering can sometimes be artificially simulated by storing the samples for a period within a carbon dioxide rich chamber until a uniform mature colour has been achieved. This technique may help, but there is still no guarantee that an accurate match will be achieved when the selected mortar is used. The only method that assures good comparison uses natural maturing of the samples over a reasonable period to make the evaluation.

For better colour matching on historical structures, the U.K. Society for the Protection of Ancient Buildings recommends replacing up to one-half of the quantity of coarse sand with the old mortar that is removed during cutting out operations.[7]

It is essential that the test sample surfaces used for comparison should be tooled in the same manner as that to be used on the project. Another method that may be used is to carefully break down a sample of the original mortar and mix the powder with a small quantity of water. The unweathered appearance can then be compared to the test samples.

Binder Materials

Until the late 1800's, pointing mortars used lime as the only binder, and this largely acquired its hardened properties by a slow process known as carbonation. (See Figure 8 for an explanation of the chemical and physical cycles of lime.) Traditionally, the quicklime was delivered fresh to the construction site in a sealed wooden barrel. The quicklime was then transferred to a pit or a large wooden box and mixed with water - a process known as slaking - to produce a lime putty which would be left to mature for several months.[8] Once the slaked lime reached maturity, the excess surface water was then removed and sand mixed to produce the mortar at the proportions 1-part lime putty to 3-parts sand by volume.

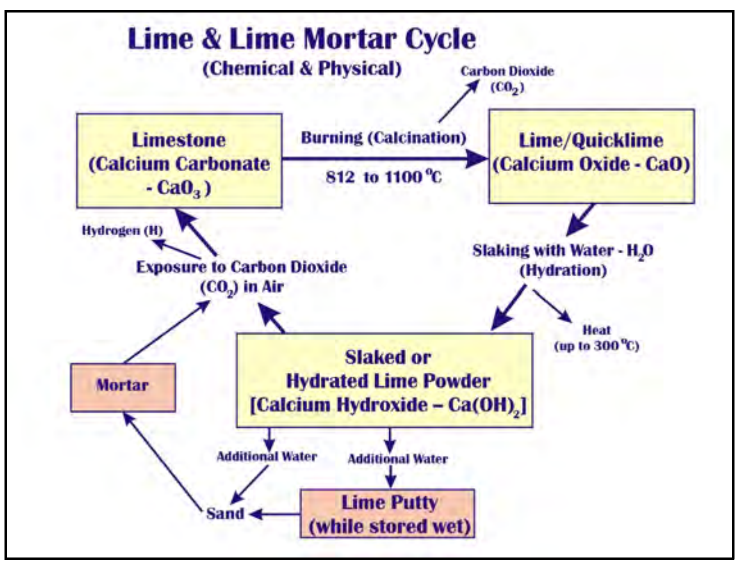

Figure 8. Lime and lime mortar cycle

If the quicklime contained clay impurities, some hydraulic properties resulted - the speed and degree of set and strength development depending upon the amount of reactive aluminates and silicates available to react with the lime. The materials that were deliberately produced to have hydraulic properties were - and still are - described as “feebly”, “moderately” or “eminently” hydraulic, after a classification developed by Louis Vicat in the 19th century. On some occasions, crushed brick - or other pozzolanic materials - were added to lime putty to provide some hydraulic properties - until the introduction of Portland cement, around 1870.

After the introduction of Portland cement, the production of hydraulic limes almost disappeared - although the benefits of blending lime into cement mixtures assured its availability and use in the form of lime putty. The advent of pressure hydration technology during the 1930's moved the slaking process from the job site to the lime plant where the water could be precisely controlled to produce a dry powder that could be subsequently supplied in bags. (Lime putty can still be obtained in North America - typically supplied in drums or pails.) The advent of the pressure hydration technology also almost completed the demise of hydraulic lime - until a revival in Europe lead to the importation of materials from that continent, as well as the U.S.A., from the late 1990's.

The advantages of lime mortars may be summarized as follows:-

- Low strength
- Low shrinkage
- Good adhesion
- Good compatibility with most masonry unit materials
- Good "breathability"
- Provides autogenous re-healing of minor shrinkage cracks

These properties reduce the likelihood of stress-related damage being caused to the masonry units and improves durability. However, lime-based mortars are very slow-setting and develop their strength over several months.

The practice of incorporating Portland cement to masonry mortar did not necessarily improve the durability of repointed masonry - particularly older buildings. However, when used properly, it did improve some of the less desirable properties of lime mortars, such as slow setting and strength development. The main disadvantages of cement, compared to lime, may be summarized as follows:-

- Higher strength than often desirable
- Potentially high shrinkage
- Stronger adhesion
- Potential incompatibility with masonry units
- Low "breathability"

With certain “weak” masonry units, the use of Portland cement can therefore potentially lead to a “rigidity” that may transfer stresses from differential movement to the masonry unit - causing cracking or spalling problems. Additionally, cement mortars typically maintain moisture for longer periods than lime based mortars - potentially leading to problems associated with freezing and thawing. A further disadvantage with grey normal Portland cement is that it contains soluble salts that may subsequently leach to the surface to create efflorescence. However, similar problems can also apply to the use of lime should inadequate protection cause surface leaching of lime under damp or wet conditions.

It can therefore be seen that the incorporation of too much cement can often do more harm than good. However, as indicated later, a carefully chosen combination of lime and cement can create effective, durable mortars. If cement is to be incorporated into a mortar, it is recommended that only white cement be used, as this material contains less soluble salts and will lessen the risk of the development of efflorescence. The incorporation of a limited quantity of grey cement, in conjunction with the white cement, may be useful in producing a required colour match, but trials should be carried out to evaluate the potential risk of efflorescence.

Proprietary pre-blended masonry cements entered the North American masonry market during the late 1920's. They typically contain Portland cement or blended hydraulic cement; a plasticizing material such as finely ground limestone, or certain clays or shales; air-entraining agents; and sometimes water-repelling agents.[9] White masonry cement and coloured masonry cement containing premixed mineral oxide pigments are also available in some areas. Many masonry experts consider that the high strengths provided by masonry cement mortars make them unsuitable for use with older masonry units.[10] Masonry experts are also not in general agreement with regard to the benefits of masonry cement mortar, particularly with regard to shear strength, flexural bond strength and water penetration resistance.[11,12] However, a major advantage of masonry cement is that its selection will reduce the number of ingredients required on site.

Mortar Admixtures

There is often a misconception that admixtures that may be effective with cement based mortars and/or concrete are also suitable for use with lime based mortars. Apart from general purpose materials such as pigments, this is rarely true and, in almost all cases, their use is not recommended. In particular, "anti-freeze" compounds do not provide lime mortars with adequate protection from freezing conditions and can have a deleterious effect - particularly on colour and efflorescence.

Air entraining admixtures added to a mortar mixture on site also may not react in the same way that they react with cement based materials - and should be avoided, unless a comprehensive laboratory study is carried out to determine any benefits. In fact, they may entrain the wrong size and spacing of air bubbles for adequate protection from the cyclical action of freezing and thawing, and may reduce compressive strength as well as adhesion of the mortar to the masonry units. Experts' opinions vary regarding whether or not to entrain air into lime-based or lime/cement mortars, but there is growing evidence from both laboratory and field research that benefits are available to improve freeze-thaw durability - provided that adequate expertise and control is provided for both types of mixtures.[13,14] Manufacturers of prepackaged repointing mortars are now able to supply them as air-entrained mortars and, certainly, these are proving to provide excellent properties and appear to be suitably durable. However, some masonry experts recommend that air entrainment not be used for brick masonry in view of concerns regarding the development of adequate bond strength and resistance to water penetration.[14]

Site-blended colourants are not usually recommended, unless it is known that pigments were used in the original mortar, or on the rare occasions when colour matching is not possible using alternative techniques. If considered essential, they should be chemically pure, synthetic oxide pigments which have been proven to be alkali-resistant as well as colour-fast under exposed sunlight. No more than 10% by volume of the binder should be used unless carbon black is required, in which event it should be limited to no more than 3% by weight. Organic dyes should not be used as they tend to fade rapidly under exposure to sunlight. Manufacturers of prepackaged repointing mortars can supply their products pigmented to match or blend with a pre-determined colour.

There is virtually never a good justification for using bonding agents to improve adhesion between the repointing mortar and the masonry units. Polymer/latex-modification is rarely recommended as it reduces compatibility - particularly with regard to moisture vapour transmission - and excessively increases strength. However, there are some rare occasions when its properties may be beneficial and certain restricted use has occurred - for example on large stone buttresses.

Sieve Size	Percent Passing	
	Natural Sand	Manufactured Sand
No. 4 (4.75-mm)	100	100
No. 8 (2.36-mm)	95 -100	95 -100
No. 16 (1.18-mm)	70 -100	70 -100
No. 30 (600-µm)	40 - 75	40 - 75
No. 50 (300-µm)	10 - 35	20 - 40
No. 100 (150-µm)	2 -15	10 - 25
No. 200 (75-µm)	-	0 - 10

Table 1- ASTM Sand Grading
(Source: Reference No. 15)

Mortar Sand

The importance of the role that sand plays on a mortar mixture is often not appreciated. The selection of the sand can have an affect on the workability and board life of the fresh mortar - as well as the appearance, compressive strength, bond strength, drying shrinkage and moisture vapour transmission properties of the hardened mortar. As already indicated, it is generally acknowledged that a repointing mortar should contain a well-graded, washed sand that matches the texture and range of sizes found in the original pointing mortar.

For historic structures, many authorities and masonry consultants will require the use of a grading which complies to ASTM [15] (See Table 1.) although the slightly different CSA 179 grading is also used.[16] (See Table 2.) Some consultants will specify a variation based on previous experiences. Generally, the specified variation of the ASTM grading will require a higher proportion of the mid-range mesh sizes, as this usually produces a better texture of mortar and improves moisture vapour transmission properties. A customised blending of two or more sands is often the only way to produce a grading that meets some specified grading requirements and this will typically be carried out using dry sands with the subsequent blend being bagged prior to shipment to site. Obviously this will significantly increase the cost of the mortar, but the extra expense will generally not play a large part in the overall cost of a repointing project - particularly since the volume of mortar is far less than that required for new masonry construction projects.

Accurate batching by volume can be best achieved by batching with dry sands - or by making allowance for the "bulking" of damp or moist sand. A simple bulking test consists of measuring a sample of sand in a cylinder, transferring it to another container and half filling the cylinder with clean water. The sample of sand is then added to the water, rodded well and levelled off. The difference in level is then measured and a calculation made to determine how much more sand to add to allow for bulking. If the final level was 130-mm, for example, and the original damp sand was 110-mm, then the calculation would be:-

ISO sieve Size	Fine Aggregate (Sand) percentage passing
5-mm	100
2.5-mm	90 -100
125-mm	85 -100
630-µm	65 - 95
315-µm	15 - 80
160-µm	0 - 35

Table 2- CSA Sand Grading
(Source: Reference No. 16)

$\frac{130 - 110}{110} \times 100 = 18.2\%$. (ie: 18% more sand should be added to allow for bulking)[17]

Mix Proportions

Depending upon the particle shape and grading, the approximate void space within sand is generally about one-third - hence the most common binder to aggregate ratio of 1:3. The most effective ratio of aggregate to binder should provide the optimum water retention and workability, while minimising strength and shrinkage. Higher ratios of aggregate can improve durability by improving "breathability" - but can reduce bond within the masonry joints.

Mortar Type	Parts by Volume			
	Portland Cement	Masonry Cement	Hydrated Lime or Lime Putty	Sand
M	1	1	--	$4\frac{1}{2}$ to 6
	1	--	$\frac{1}{4}$	$2\frac{13}{16}$ to $3\frac{3}{4}$
S	$\frac{1}{2}$	1	--	$3\frac{3}{8}$ to $4\frac{1}{2}$
	1	--	$\frac{1}{2}$	$3\frac{3}{8}$ to $4\frac{1}{2}$
N	--	1	--	$2\frac{1}{4}$ to 3
	1	--	1	$4\frac{1}{2}$ to 6
O	--	1	--	$2\frac{1}{4}$ to 3
	1	--	2	$6\frac{3}{4}$ to 9
K	1	--	3	9 to 12
	--	--	1	$2\frac{1}{4}$ to 3

Note: CSA 179 sand is proportioned on a dry basis and adjusted for bulking; Mortar should not contain more than one air-entraining material

Table 3: Interpretation of CSA 179 details for mortar ingredient proportions

Source: Reference 9.

An interpretation of CSA 179 - adapted from Reference 9 - details for mortar ingredients is detailed in Table 3. However, the mandatory part of the standard only covers types S and N mortars and requires the sand to be measured in a damp, loose state.

The Ministry of Culture, Tourism and Recreation recommendations regarding mix proportions for various masonry materials are shown in Table 4. The recommendations are considered to be conservative and one grade weaker mixes should be used for valuable heritage masonry. They are based on the use of lime putty and white Portland cement.

Most specifications that require the use of masonry cement will call for proportions of by volume ranging from 2¼ to 3½ parts of damp, loose mortar sand.[9]

Cement : Lime : Aggregate Proportions

Masonry Material	Selected Exposure		
	Sheltered	Moderate	Severe
Highly durable: granite, hard brick, etc.	1 : 2 : 8 1 : 2 : 9	1 : 1 : 5 1 : 1 : 6	1 : 0.5 : 4 1 : 0.5 : 4.5
Moderately durable: most, limestones, bricks, etc.	1 : 3 : 10 1 : 3 : 12	1 : 2 : 8 1 : 2 : 9	1 : 1 : 5 1 : 1 : 6
Poorly durable: soft brick, friable stone, etc.	0 : 2 : 5	1 : 3 : 10 1 : 3 : 12	1 : 2 : 8 1 : 2 : 9

Table 4: Recommended Repointing Mix Proportions
Source: Ministry of Culture; "Historic Masonry" (see Bibliography)

Figure 9 - adapted from Reference 1 - provides a further selection chart which also provides assistance for the selection of the appropriate binder for historic masonry structures.

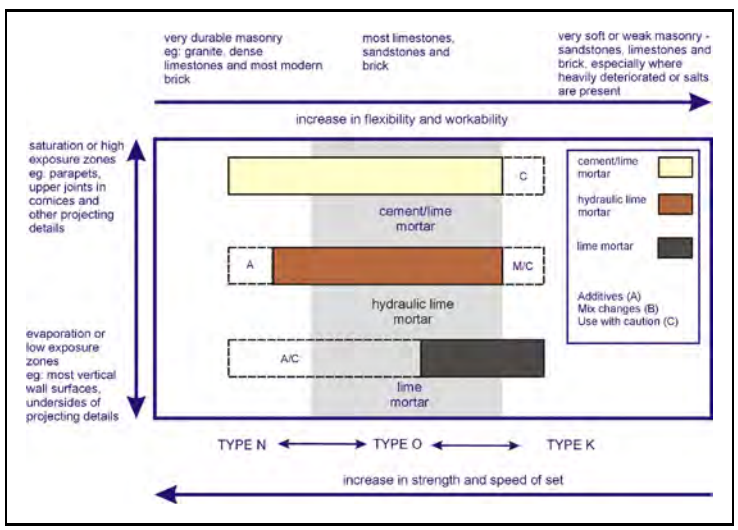

Figure 9. Mortar Selection Chart for Historic Masonry Structures

Mixing the Mortar

Experts' opinions vary regarding the most desirable mixing procedures - although most agree that, to prevent low strength development and excessive shrinkage, the minimum amount of water should be used to produce a desirable workability. Fortunately, stiffer mixes are more desirable for repointing work.

For reasonable sized projects, mechanical mixing techniques should preferably be used to produce a uniform mix and an even colour, without streaks of unmixed materials or lumps. The preferred method for mixing masonry cement or cement and lime mixes is typically to briefly mix about 75% of the required water, all of the binder and 50% of the sand; the balance of the sand is then added with the remaining water. Mixing should then take place for about five minutes. (Over-mixing should be avoided when using air-entrained mixes to avoid producing excessive air and/or an inadequate air void system.) This will ensure that adequate wetting out and absorption takes place to help prevent rapid loss of workability - sometimes referred to as "false-setting". Only sufficient water should be used to produce a consistency that will stick to a trowel held upside-down. The mortar should then be used while it is still workable, usually up to two hours after final mixing. Retempering by adding more water is generally not permitted.

The preferred method for mixing lime mortars is to introduce about 50% of the required sand and blend this dry with all of the lime for about 2-minutes or until a uniform colour is achieved. The remaining sand is then added and dry mixing continued for about another 1 to 2- minutes. Water is then introduced slowly and final mixing continued for about 10-minutes to produce the optimum workability. Hydrated lime mixtures are often allowed to stand for a while before use and can in fact be kept in storage for extended periods, provided they are kept damp within air-sealed containers. Hydraulic limes have a limited storage life after mixing - the period being determined by their hydraulicity.

On many projects, a hydrated lime and sand blend is pre-mixed with water in advance of preparation of the final mortar and stored in airtight containers until required; the correct quantity of cement is added only when the mortar is required.

Photos.27 & 28 (Left) Mixing a prepackaged repointing mortar. (Right) A drill and inserted mixing head.

When using prepackaged repointing mortars, it is essential that the manufacturer's recommendations be followed for mixing. Many products have different peculiarities that may require some training to overcome potential problems. In particular, if a mixing head within a drill is the chosen method, the power and adjustable speed range of the drill is important. (See Photographs 27 & 28)

Filling the Joint

As discussed earlier, before the actual repointing work begins, cut out joints should first be cleaned of dust and debris and then conditioned to the right degree dampness.

Photo.29: Applying the final layer of mortar

The deepest joint areas should be filled first to produce a uniform remaining depth to be filled. The preferred method is to fill the joint with successive layers, allowing each layer to harden before application of the next - it should not be possible to leave a thumb-print impression. This will help to minimize the shrinkage that could otherwise reduce joint water-tightness. Each layer should be well compacted to a depth of no more than10-mm. If deep filling is permitted in one layer, the mortar should be produced with a stiff consistency and well compacted. The final layer is usually left flush or slightly proud of the final required finish and a period allowed for the mortar to stiffen to the desired degree for final joint finishing. (See Photograph 29.)

Narrow joints can be filled without contaminating the masonry units by use of masking tape. Alternatively, two strips of waxed paper between which the mortar is sandwiched can be inserted into the joint.

Joint Finishing

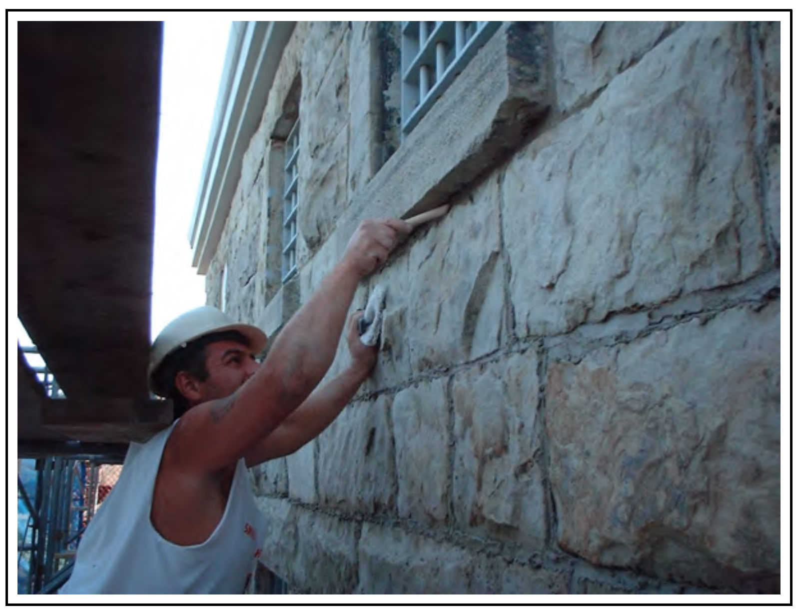

Photo. 30. “Slicking” the stiffened mortar to the desired profile.

Simply using the trowel to smooth the filled joint is not a recommended practice. The preferred practice is to "tool" the filled joint with a purpose-designed finishing tool, known as a "slicker" to the finished profile. (See Photograph 30.) Pulling the slicker over the surface compresses the filled joint to improve durability and strength. The process usually brings binder to the surface and this is often removed by gently brushing with a soft-bristled paint brush. (See Photograph 31.) This helps to produce a more weathered appearance, but care should be taken to avoid dislodging or loosening embedded aggregate particles.

Proper timing is important or colour changes can result. Also, hairline cracking can occur if the mortar is too soft. Dark streaks, known as "tool burns", can be caused should the mortar be too hard when tooled.

In the event of delays, or on completion of each day's work, repointing should end at an appropriate location that will avoid colour differences from being noticeable when repointing continues.

Photo.31: Brushing the joint to remove binder and to produce final finish

Photo.32. The finished joint

There are a variety of different pointing styles that can be adopted, but obviously the first consideration should be to reproduce the original joint profile. However, as has already been discussed, there are occasions when this may not be desirable for reasons of poor durability. There is no doubt that the most durable style is a flush, concaved profile. (See Photograph 32.) The least durable style is a joint that projects from the masonry, exposing a wide surface of mortar and/or does not adequately shed water.

Cleaning the Masonry

While there will always be a need to clean the masonry prior to completion of the restoration work, one of the largest challenges facing the consultant or inspector is to ensure that mortar droppings, splatters, smears, etc., created during the repointing operations are removed and the face of the masonry washed to prevent the residue from hardening. A modern trend in masonry construction - particularly for bricklaying operations - is to permit the use of a “brick cleaner” or other cement-removing solution to remove hardened mortar deposits at the end of the work. Although modern masonry units may be able to withstand the chemical reactions that have to take place to remove the cement mortar, this may not be the case with traditional masonry, particularly limestone and sandstone. Specifiers are cautioned to ensure specifications require cleaning residual mortar immediately they are created - and inspectors/consultants should rigidly enforce this during repointing operations. Preventing repointing mortar smears over the face of the masonry units from the joints must also be discouraged, but the occurrence or otherwise of this will depend on the skills and diligence of the mason. (See Photographs 33 & 34.)

Photos. 33 & 34. The difference between the degrees of skill and diligence exhibited by the two masons requires no comment!

Curing and Protection

As with most of the procedures covered under this topic, experts are not always in agreement regarding the best curing practices for freshly repointed joints - particularly during cold weather conditions. However, it is generally recognized that rapid evaporation of the mixing water within freshly mixed cement/lime mortars should be avoided - since this could lead to desiccation of the binder components. (Excessive loss of water into the masonry units can have a similar effect and, as discussed earlier, conditioning the substrate prior to filling the joints is therefore essential.)

Photo.35. Curing repointed joints using mist-spraying techniques.

The result of desiccation is typically a weak, friable hardened mortar which has lower strength than desirable. Generally, hardened mortar that has become desiccated will also be more porous, leading to less resistance to the actions of freezing and thawing. The "sucking" action of water into dry masonry units, combined with excessive evaporation of mortar after repointing, can also lead to a reduction in bond of the hardened mortar to masonry units. Rapid drying can also lead to lime becoming concentrated at the surface and this can increase the potential for shrinkage cracking and subsequent leaching of the lime under wetting and drying conditions.

Typically, recommendations to prevent rapid drying include a two to four day damp cure for cement/lime mortars and three to seven days for pure lime mortars.

Curing is typically best achieved using plastic covered wetted burlap, with re-wetting taking place prior to drying - although this can often be difficult to achieve in practice. (A proprietary curing sheet has recently become available which consists of an absorbent fabric to which a plastic sheet is bonded - the plastic sheet contains small diameter holes which permit saturation of the fabric to be repeated over time.) Alternatively, mist-spraying is often employed (see Photograph 35) although this is less effective during long, dry periods. Care should also be taken to limit the degree of saturation of freshly repointed masonry that could otherwise cause staining from the effects of lime-leaching. Freshly repointed joints should be protected from direct rain-fall for similar reasons.

A major concern when using weaker mortars, and particularly pure-lime mortars, is the provision of adequate protection during freezing conditions - at least seven-days being typically recommended, although longer periods of protection may be required under severe exposure conditions. Carbonation of lime is a slow process and, although the exterior portion of the repointed joint will harden quite quickly, this may not be adequate to protect the underlying non-carbonated portion under some conditions. Avoiding repointing work using pure-lime or weak mortar mixtures is therefore desirable with expensive heated enclosures being preferred if this is not possible.

Conclusions

By necessity, this presentation has examined some of the more critical factors that affect the durability and appearance of repointing masonry. It should not be regarded as a comprehensive study - there are many more factors not included here that are worthy of consideration.

Although it is recognized that retaining or restoring the original appearance of a mortared joint must be an essential part of any repointing strategy, it is hoped that it has been illustrated that the continuing accomplishment of this may become impossible if the wrong techniques are used.

A final point; if weak mortars are considered essential for certain applications - particularly historically significant structures that are constructed using soft or weak masonry units and which are exposed to severe environments - then the industry, and owners, should be prepared to accept a shorter service life and implement regular, routine inspections to ensure that appropriate speedy maintenance and further repointing can be carried out.

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"Masonry - How to Care for Old and Historic Brick and Stone" - Mark London for the U.S.A. National Trust for Historic Preservation, Washington, DC.

"The Repointing of Historic Masonry Buildings" available from ServiceMaster Industries Inc., Illinois. (An excerpt titled, "An Introduction to Repointing" was published as an APT Bulletin in 1979 Vol.XI no:3.)

ACKNOWLEDGEMENT

The author would like to thank Bonnie Callan at the Wellington County Museum, Ontario, for her help and patience during his archival research. The referenced photographs used in this presentation are from the Gordon Couling Collection, which provides a useful record for the assessment of the level or lack of deterioration that some heritage structures experienced over twenty to thirty years.

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