Standard Guide for Repair and Restoration of Dimension Stone[1]

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1. Scope

1.1 This guide describes materials and procedures for restoring facades constructed of or finished with dimension stone. All of the materials, procedures, and principles are suitable for restoration of historic and nonhistosric structures.

1.2 This guide is not intended to address restoration of interior dimension stone, although many of the materials and procedures may be suitable for interior use.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C5 Specification for Quicklime for Structural Purposes
C10 Specification for Natural Cement
C91 Specification for Masonry Cement
C119 Terminology Relating to Dimension Stone
C141 Specification for Hydraulic Hydrated Lime for Structural Purposes
C150 Specification for Portland Cement
C207 Specification for Hydrated Lime for Masonry Purposes
C270 Specification for Mortar for Unit Masonry
C1180 Terminology of Mortar and Grout for Unit Masonry
C1242 Guide for Selection, Design, and Installation of Dimension Stone Attachment Systems
C1324 Test Method for Examination and Analysis of Hardened Masonry Mortar
C1329 Specification for Mortar Cement
C1489 Specification for Lime Putty for Structural Purposes
C1515 Guide for Cleaning of Exterior Dimension Stone, Vertical And Horizontal Surfaces, New or Existing
C1521 Practice for Evaluating Adhesion of Installed Weatherproofing Sealant Joints

2.2 *OSHA Directive:*

STD 1-12.026 Abrasive Operations Using Cut Off Wheels and Masonry Saws

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, other than those listed below, refer to Terminology C119 and Terminology C1180.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *defect*—naturally occuring flaw in the stone.

3.2.2 *dimension stone restoration consultant*—one who is knowledgeable and experienced with the care, restoration, and repair of building dimension stone.

3.2.3 *distress*—localized damage of stone units such as cracks, chips, holes, deterioration, bowing, and projections that have been broken off or worn down caused by wear, erosion, settlement, displacement, or other adverse chemical or mechanical actions.

3.2.4 *dutchman repair*—a stone repair method whereby a portion of a stone unit is cut out and replaced with another piece of stone (called a dutchman). The dutchman is usually rectangular or square in shape, but may also be rounded, and is usually at a corner or edge of the stone unit.

3.2.5 *pointing*—placing mortar in the outer portion of the joints between stone units. To point stone joints, the outer portion of the joints must either be left open during installation or cut or ground out, i.e. have the mortar removed from the outer portion of the joint. New mortar is then pressed into the joint with a pointing tool. The increased compaction of the new mortar provides an improved resistance to water penetration at the joint compared to the primary stone setting mortar.

3.2.5.1 *repointing*—the removal of existing mortar from the outer portion of the joints between stone units and the subsequent pointing of the joints.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.5.2 *tuck pointing (tuckpointing, tuck-pointing)*—this term is intentionally not used in this standard, because it is often used inconsistently. It is variously used to mean repointing, simply pointing, or applying a raised bead of mortar (often of a different color) down the middle of mortar joints.

3.2.6 *proprietary repair mortar*—an exclusively manufactured product formulated from cementitious compounds, fine aggregates, mineral pigments, possibly bonding agents, and other additives. It is used for filling cracks, holes, and other depressions in stone units or for rebuilding the surface of damaged stone units to their original profile.

3.2.7 *repair mortar, cement-based*—repair mortar utilizing portland cement, masonry cement, blended cement, mortar cement, or natural cement as the primary binder.

3.2.7.1 *repair mortar, polymer-modified*—cement-based repair mortar incorporating a dry or liquid polymer modifier as a secondary binder, to alter the performance properties

3.2.7.2 *repair mortar, polymer-based*—repair mortar consisting of a polymer binder and aggregates, without cement or hydraulic components.

4. Significance and Use

4.1 The purpose of this guide is to assist those who wish to restore facades constructed of or finished with dimension stone. It is an aid to owners, building managers, architects, engineers, contractors and others involved with restoring dimension stone.

4.2 This guide is not meant to supersede manufacturers' directions and recommendations for the use of their specific products, or written directions from the architect or building owner. When manufacturers' directions are in conflict with this guide, follow their recommendations or consult with their technical staff for further direction.

4.3 Prior to undertaking a full-scale repair or cleaning procedure, the methods under consideration for repair, patching or cleaning should be tested on an area not easily visible or on sample stones. The test will assist in judging the effectiveness of the chosen method and permit assessment of potential damage to the building stone. Completely evaluate the success of the sample repairs before undertaking the full-scale cleaning or repair procedure.

5. Condition Survey and Restoration Plan

5.1 The first step in a restoration project is to conduct a project survey consisting of a review of existing original architectural drawings and specifications and any original stone shop drawings that may be available. The stone shop drawings contain detailed information on stone and anchoring that is not always found in the architectural drawings. The shop drawing review is followed by a thorough examination of all exposed stone surfaces and related elements of the building envelope. Document distressed areas and existing repairs. Determine the causes of observed distress to avoid performing cosmetic repairs while failing to correct the underlying problems. As an example, if problems result from water damage, the source of water penetration must be found and corrected if the repairs are to be successful and long lasting. If the damage to the stone is a result of structural instability, that structural issue must be addressed before repairs are made.

5.1.1 A dimension stone restoration consultant experienced in natural stone facade design and construction should participate in the condition survey. If structural distress is observed, consult with a qualified engineer with stone facade design experience. For stone displaying deterioration with an unknown cause, a petrographer specializing in dimension stone analysis can be consulted to determine whether a failure is related to inherent properties or mineralogical composition of the stone.

5.1.2 During the condition survey, identify and document repairs performed during previous restorations. The condition of existing repairs should be assessed to determine if they are stable, if they have failed, if they are a potential threat to the building fabric, or if they are posing a safety risk. Existing repairs can be made more apparent or can be damaged by cleaning or other restoration processes. The restoration consultant will be able to help with the proper procedures concerning previous repairs.

5.1.3 When necessary, appropriate field or laboratory testing, or both, is normally included with the condition survey to verify the nature of existing materials and the extent of the work needed to restore the project to the desired condition. Cleaning compounds and repair materials under consideration should be evaluated and tested to confirm that they will be effective and will perform without detrimental effects to the stone for the life of the building.

5.2 Once the condition survey is complete, prepare a restoration plan describing the repair and restoration work to be done. Perform the repairs and cleaning in a systematic, sequential order that will avoid damage to previously completed phases of the project.

5.2.1 Structural repairs must precede cosmetic repairs. For example, if expansion from rusting anchors is causing the stone to crack, the anchors must be replaced or treated before repairing cracks.

5.2.2 Perform testing of existing materials sufficiently in advance of restoration work to allow suitable cleaning, patching, repair, and replacement materials to be identified.

5.2.3 When chemical cleaners are used, perform the cleaning before the patching. Some cleaning compounds adversely affect the color and strength of the installed patch. Performing the cleaning first will help prevent damage or discoloration of the patching materials and will also allow the patch materials to be matched to the cleaned surfaces of the original material.

5.2.4 If mortar in the joints is missing or deteriorated to the extent that water intrusion will occur, the joints must be repointed and allowed to cure before using a wet cleaning method. This is especially important if a water soak preparation or pressure water spray cleaning method is specified.

5.3 The National Historic Preservation Act allows qualifying historically significant buildings or structures to be restored using federal funds set aside for historic preservation. The permitted type and extent of restoration work may be limited by government regulations. A formalized Historic Structures Report is used in these cases to outline the property's history, existing condition, goals for the use of the property, and provides a recommended treatment approach and scope of work for restoration. The Historic Structures Report is a multidisciplinary task and a team of several consultants consisting of historians, architects, engineers, materials scientists, and conservators is usually required to complete the report.

6. Stone Patching

6.1 *Patching, General*—Patching small areas of distress is commonly performed in order to avoid replacing full stone units. This may be preferable in certain situations to preserve as much of the historic fabric of the structure as possible. However, areas of distress that do not impact the overall integrity of the stone unit and will not lead to further degradation of the stone, or do not detract significantly from the stone's appearance, are often left untreated.

6.1.1 Patching compounds must properly adhere to and match the stone as closely as possible, not only in appearance, but also in physical properties. Patching materials must be compatible with original stone.

6.1.2 The original stone may be repaired with a patch, in lieu of replacement, because of historic value, a lack of availability, or difficulty replacing whole pieces. For these reasons, it is very important that the original stone being repaired be carefully protected from further damage. The physical properties of patching compounds should be verified so the resulting performance characteristics of the patch do not conflict with the performance characteristics of the surrounding stone. It is generally agreed that it is better for the patch (which can be easily replaced) to fail than to cause any further damage to the existing, historically valuable, irreplaceable, facade. In the following paragraphs, there are specific examples of physical properties and how they affect the viability of the patch with a specific stone.

6.1.3 The combined compressive strength and modulus of elasticity of the patching material should produce similar or lower performance characteristics to the analogous properties of the original stone for a non structural repair. Consult an experienced stone restoration consultant to confirm that the combined properties of the patching material do not result in performance characteristics that could damage the particular stone for a specific project.

6.1.4 Patching compounds should also have a comparable coefficient of thermal expansion to that of the stone being patched. This is desirable so that the differential thermal expansion will not stress the patch and cause a loss of bond.

6.1.5 Water absorption and water vapor transmission characteristics of the stone must be considered when selecting a patching compound. This is especially important when patching an absorptive stone. If the patch does not transmit water vapor at a similar rate as the surrounding stone, it may trap moisture and dissolved salts behind it, which can cause the patch to lose bond or deteriorate. This can also cause deterioration of the surrounding stone. Polymeric bonding agents, such as high solids epoxy, may also inhibit water vapor transmission. These are generally not recommended and should only be used if they can demonstrate proper water vapor transmission by testing or exemplars.

6.1.5.1 A patch, whether cementitious or polymer-based, will normally be more obvious after wetting by rain or during cleaning. This phenomenon occurs with most patching materials and is not necessarily a sign of badly matched properties. Patching material is designed to match dry stone. Once the wetted stone returns to the dry condition, a properly installed patch will return to its original state, matching the surrounding stone.

6.1.6 Ground stone, crushed stone, or stone dust of the same variety as the stone being patched is sometimes added to the patching compound to help match the patching material properties to the stone properties. Mixing these additional materials into the patching compound can cause the patch to lose strength, lose bond, or cause difficulty in finishing. Therefore, adding material to a manufacturer's patching compound is generally not recommended but sometimes cannot be avoided. For example, it is sometimes necessary to use ground or crushed stone added topically to replicate finishes such as exposed aggregates, granite crystals, contrasting colored crystals, etc. When a patch is deep, the manufacturer sometimes recommends adding matching stone aggregate to prevent excessive shrinkage. When necessary, additional materials should only be added under the guidance of the manufacturer of the patching compound.

6.2 *Cementitious Repair Mortars*—Repair mortars are generally suitable for patching unpolished stones and are especially suitable for porous stones. Simple job site mixes of portland cement, sand, and pigments have been used but are inconsistent and often fail within a short time. Proprietary repair mortars often contain polymeric additives to improve bonding and increase flexibility Suppliers of proprietary repair mortars should provide manufacturers' data to show that the physical properties and the rate of the water vapor transmission for their product are similar to the stone being repaired. Proprietary repair mortars that are custom blended to match the color and texture of the original stone are available. For stone that exhibits a range of colors, repair mortar will generally have to be prepared at the site by mixing two or more of the manufacturer's standard or custom colors, allowing the proper color to be achieved without changing the properties or the bond of the repair mortar.

6.2.1 *Patching Stone with Repair Mortars*—The following guidelines represent accepted industry procedures for patching using cementitious repair mortars. These guidelines will assist the installer and specifier in planning the repair and selecting the proper mortar for their particular need. Every manufacturer should provide directions for the proper use of their mortar. Users should understand and follow the manufacturer's written directions.

6.2.1.1 *Preparation*—Remove deteriorated and loose material from area to be patched to uncover solid, sound stone. Remove additional material to sufficient depth, especially at edges of area to be patched, so that patch will be at least ½ in. (12 mm) thick but not less than that recommended by mortar manufacturer. Some repair mortar manufacturers recommend ¼ in. (6 mm) minimum thickness. Prepared area is to have square edges. In some cases, undercut edges are specified to improve mechanical bond, but the resulting thin, tapered edge increases the risk of damage at the edge of the final patch. If the patch abuts the edges of an adjacent stone unit, provide forms to shape the perimeter of the patch and prevent it from bridging mortar or sealant joints. Alternatively, cut the extra material out of the joint after curing per manufacturer's directions.

6.2.1.2 After unsound material removal and edge preparation are completed, clean the entire area with potable water and a bristle brush to remove dust and loose material. Rinse the area to be patched, allowing the adjacent stone to remain damp. The bond of the patching material to the stone is directly affected by the moisture content of the stone being patched. The amount of water in the stone affects the absorption of the bonding agents into the original sound stone. If the stone is wetted incorrectly (too dry or too wet) the bond will be adversely affected. Manufacturers' directions vary regarding the amount of water that should be on the stone when applying the patching mortar. Be sure to completely understand and follow manufacturers' recommendations for wetting stone prior to applying patching material.

6.2.1.3 Generally, larger patches and patches on the underside of projecting courses require the use of threaded rods to hold the patching material in place. The threaded rods must be made of a corrosion-resistant metal, typically type 304 or 316 or stainless steel. The threaded rods must be securely fixed to the existing stone. Usually this is done by epoxying the pins in holes drilled into the sound stone. The epoxy manufacturer will recommend the proper size hole for the diameter dowel being used. Good practice dictates that the threaded rods be installed in tandem at opposing angles to create a mechanical bond with the patching material. Stainless steel helical anchors are also used for this purpose. Nylon pins are not acceptable because they shear easily, have unfavorable thermal expansion characteristics, and do not hold their shape over long periods of time. Consult a stone restoration consultant on the proper application of threaded rods.

6.2.1.4 *Bond Coat*—Before applying the main patch material, apply a thin, specially mixed coat of repair mortar to the patch area per the manufacturer's recommendations. This bond coat is mixed to a thinner consistency than the final repair material. The actual consistency varies a great deal between the different manufacturers. Apply the bond coat to wetted stone and work material into crevices and depressions, maximizing its contact with the stone. Always review the manufacturer's directions for proper bond coat consistency and application.

6.2.1.5 *Application*—Apply repair mortar while bond coat is still wet. Apply the mortar in one or more layers of thickness as recommended by mortar manufacturer, but not less than ¼ in. (6 mm) nor more than recommended by mortar manufacturer. Roughen the surface of layers that are to receive another layer. Forms are used to keep patch material out of the joints. If the repair mortar gets into joint space, scrape the repair mortar out of the joint while it is still pliable or cut the mortar out of the joint after it is fully cured. Do not leave repair mortar in the joint space.

6.2.1.6 *Temperature*—Only apply the repair mortar in the temperature ranges recommended by the repair mortar manufacturer (typically between 40 and 90°F, 5 and 32°C). Cold temperatures can freeze the repair mortar or inhibit its cure. Temperature above 90°F, low humidity, high wind, direct sunlight, or a combination of these factors will cause the mortar to dry too fast, causing color changes, excessive shrinkage and cracking, and weakening of the patch. Colored repair mortars may exhibit color differences when cured at a lower temperature range.

6.2.1.7 *Finishing*—Work should be performed by skilled craftsmen using methods recommended by the repair mortar manufacturer. An evaluation sample should be prepared for the particular stone being patched. The sample patch should be approved before full-scale work is undertaken. Trowel, scrape, tool, or carve surface of patch to match surface of surrounding stone. Make samples using different finishing methods to see which works best for the particular stone being patched. Samples applied to the actual masonry should be approved before beginning work. Test samples applied to plywood or other materials different than the original may affect the final color of the mortar. Sometimes, during application, the patching material gets on the surrounding stone. The residual patch material must be cleaned off the face of the surrounding stone with clean water and a sponge as soon as possible. If the residual patch material is allowed to cure, it will cause a permanent discoloration of the stone.

6.3 *Polylmer-Based Materials*—Polymer-based patching materials typically possess excellent adhesion and flexibility but may deteriorate from exposure to sunlight or exterior use. Polymer-based patching materials are most suitable for use with polished stone, since they can be finished to a similar gloss. Available materials are generally either a polyester or an epoxy. Epoxies may tend to chalk or yellow on exposure to sunlight. The appearance and some physical properties of epoxy patching materials can be made to better match that of the stone being patched by mixing them with ground or crushed stone of the same variety. (See 6.1.3 for additional information on the use of fillers.) Even though products containing polyester resins are marketed for use on stone, polyester resins possess poor thermal compatibility and very low water vapor transmission compared with stone. This, when combined with a high level of brittleness, makes polyester resin-based materials poorly suited for exterior stone repairs.

6.3.1 *Patching with Polymer-based Materials*—The guidelines below are to illustrate general proper procedures for patching stone using polymer-based materials. These guidelines will assist the installer and specifier in planning the repair and selecting the proper polymer-based materials for their particular need. Every manufacturer provides directions for the proper use of their material. Users should understand and follow the manufacturer's written directions.

6.3.1.1 *Preparation*—Remove deteriorated and loose material from the original stone to be repaired until solid, sound stone remains. Remove enough additional material to sufficient depth, especially at edges of area to be patched, to allow a patch that will be at least ⅛ in. (3 mm) thick with square edges. If the patch abuts the edges of a stone unit, forms must be provided to shape perimeter of patch and to prevent the patch from bridging a mortar or sealant joint. Clean the prepared area with compressed air or water and a bristle brush to remove dust and loose material; remove oils, paints, and other materials that might interfere with bond. If water or solvents are used, allow the stone to dry thoroughly before applying patching material.

6.3.1.2 *Application*—Apply a thin coat (as defined in manufacturers' recommendations) of polymer-based material to the area to be patched. Work the material into crevices and depressions. Apply polymer-based patching material in one or more layers ⅛ in. (3 mm) or more in thickness but not exceeding manufacturer's recommendations; allow each layer to cure before applying the next layer as recommended by manufacturer. Slightly over-fill patched area to allow for finishing.

6.3.1.3 *Finishing*—After the patch has cured, remove the excess material and finish to match surrounding stone. For large patches, use stone finishing tools and methods used in fabrication shops. For small patches in honed-finished stone, finish with fine sandpaper used with a hard sanding block. For small patches in polished-finish stone, finish by fine sanding using a hard sanding block, then successively finer sanding using a soft backing followed by buffing with a hard felt pad with polishing compound.

7. Whole Stone Replacement

7.1 The choice of repair or replacement for any building is often dictated by the condition of the stone and its location on the building. If the historic stone facade is in good overall condition, but just a few stone units are severely deteriorated, replacement of those few stones could be appropriate. Stone replacement does become necessary when a majority of the stone on the building is deteriorated or damaged. The deterioration can be from many issues including, efflorescence, previous chemical cleaning, or a harsh climate. Malleable iron or carbon steel stone anchors that have corroded can also cause damage to stone on a building. If a large enough quantity of the stone is deteriorated, it becomes more feasible to replace the stone with new stone of the same type. Stone replacement in kind is often avoided for historic restoration because new stone simply does not match the weathered patina of the existing stone. Usually a stone restoration consultant will try to save or stabilize the existing stone because the wear, deterioration, and cracks have historical significance. Also, removal of an existing stone could damage surrounding stone. If the existing stone is deteriorated to the point that it is structurally unsound, the best option then is to replace the damaged stones. However, stone replacement in kind is often used to repair non-historic stone facades when matching replacement stone is readily available and the damaged stones are easily removed.

7.1.1 When stone replacement is used for restoration of historic facades, every effort should be made to use replacement stone that is as similar as possible to the original stone. For minor replacement, stone salvaged from an inner wythe of the wall may be available for reuse on the exposed surface. Similarly, stone may be salvaged from new wall openings made necessary by functional adaptations of the building. Another technique that is similar to replacement involves removing a stone unit and replacing it in its original position after refinishing and possibly reversing it. Unfortunately, these replacement stone sources may be less practical than they seem due to the difficulties in removing the stone without causing substantial damage.

7.1.2 Recommendations for the removal process, stone bracing, and design of replacement anchors should be specified by a qualified stone engineer. In mortar-set building facades, removal of damaged stone for replacement may result in adverse consequences that are not obvious. Replace one stone at a time letting the setting mortar harden before any further work in a specific area. Removing too many stones at one time can lead to a total wall failure. In some cases, it may be necessary to anchor or temporarily brace the facade prior to stone replacement. Employ a qualified, experienced restoration contractor to perform the bracing, stone removal and replacement.

8. Partial Stone Replacement (Dutchman Repair)

8.1 For historic stone facades, partial stone replacement is often the preferred method for repairing stones that are generally in good condition, but have localized damage. With newer construction, the matching stone is more readily available and the decayed or damaged stone is usually easier to remove than that found on an older building. For these reasons, complete stone replacement is typically more viable with newer construction. Even so, partial stone replacement is sometimes the best alternative, even in newer buildings because of the possibility of damaging surrounding stone during removal of damaged stone.

8.2 Dutchman repairs involve cutting out damaged areas of a stone and replacing these areas with new pieces cut from matching stone bonded to the original with an adhesive. These can occur anywhere on a stone, yet are easier to address on the edge or corner of the stone unit. Typically, the area is cut out in a rectangular or square-like shape and the work can proceed relatively quickly. These repairs are usually not noticeable to casual observers. However, if aesthetics are critical, the repair is less noticeable but takes more installation time if the shape of the dutchman is irregular with rounded or odd shaped edges. In some cases, stone panels are core drilled to access the backup structure for remediation. A dutchman can be used for core drilled holes by making a round plug out of matching material and securing the plug into the core hole with an adhesive. In any dutchman repair, the adhesive joint between the original stone and the replacement should be kept as small as possible. The creation of a dutchman repair requires very specific craftsman skills and a qualified, experienced stone mason should be employed. The adhesive used is usually matched to the color and properties of the stone as closely as possible. For larger sizes or difficult orientations, mechanical attachments such as stainless steel threaded rods may be required to properly support the weight and lateral loads of the stone dutchman. Do not rely solely on the epoxy to support the weight of any stone component. The threaded rods must be oriented so that a mechanical bond is created and the weight is supported in shear on the threaded rods in lieu of tension.

8.2.1 Dutchman repairs at or adjacent to gravity or restraint anchors should be avoided. If repairs at these locations cannot be avoided, additional or alternate anchorage, as determined by the responsible design professional, may be required prior to commencement of the Dutchman repair.

8.3 Adhesives used for partial replacements may need to be supplemented with mechanical anchoring, such as stainless steel pins set in adhesive. The dimension stone restoration consultant should specify the number and size of the pins required.

8.4 The stone selected for a dutchman repair should match as closely as possible in color and finish to the original stone. One very good source for repair stone to use in a dutchman repair is existing stone on the building that is no longer used, i.e. stone removed for an addition. This provides for a good match of finish color and even weathering effects.

9. Stone Consolidation

9.1 Where entire stone facades are deteriorating, especially sandstones that are deteriorating due to loss of cementing minerals, stone consolidation may help to preserve the stone façade. Stone consolidation consists of chemical injections or surface applications of chemicals that are absorbed by the stone and then harden within the pores of the stone. Consolidation treatments are irreversible and should only be used after extensive testing and evaluation to determine the treatment''s suitability, necessity and durability (length of life).

9.2 Consolidation treatments are controversial in some segments of the stone industry. Little, if any, data exists as to their long-term effectiveness, and their use in certain stones and environmental conditions can cause even further harm in the form of discoloring, delamination and reduced durability. Potential users should seek sound technical advice from experts knowledgeable with the stone in question before the application of any consolidants.

10. Anchor Replacement

10.1 *Need for Replacement*—Stone anchors may need to be replaced for any of several reasons. For example, the original anchors may have been improperly installed causing stone displacement or anchor failure. Where stone is installed with anchors that are not corrosion-resistant, the anchors may have deteriorated to the point where stone is in danger of falling off the building. Also, the expansion that results from rusting of iron or steel anchors may cause displacement, cracking, or spalling of stone at the anchor slots. Rusting of iron or steel anchors will also often lead to rust stains.

10.1.1 Refer to Guide C1242 for information on design, selection, and installation of exterior dimension stone anchors and anchoring systems. Whenever anchor replacement is under consideration, it is strongly recommended that a qualified dimension stone restoration consultant be retained to evaluate the existing anchors and, if necessary, design the replacement anchors.

10.2 *Replacement Anchors*—In general, replacement anchors should be of the same design as those being replaced, unless the design of the existing anchors is inadequate or it is not possible to use them for other reasons. Replacement anchors should always be made of corrosion-resistant material such as stainless steel.

10.3 *Replacement Methods*—In most instances, stone units must be removed and reset in order to replace the anchors. When a large number of anchors must be replaced, or when the failed anchors cannot be left in place, removing and resetting of the stone is necessary. Alternatives to removal and resetting generally require drilling through the face of the stone to install supplemental anchors while leaving the failed anchors in place. This alternative requires patching the face of the stone at the new anchor locations, which can be objectionable. Where only a few anchors have failed, drilling new anchors through the face and patching may be preferable to disassembling the entire facade. Depending on the type of anchor, cores may be drilled through the stone to expose the existing failed anchor for removal and installation of the new anchor. The core holes should then be repaired as appropriate.

11. Joint Remediation

11.1 *Removing Deteriorated Mortar and Sealants:*

11.1.1 *Mortar Removal Depth*—Recommendations vary about the depth to which existing mortar should be removed for repointing. Some recommend removing mortar to a depth of 2 to 2 ½ times the joint width, while others contend that ⅛ in. (3 mm) more than the joint width is adequate to develop a good bond between the pointing mortar and the substrates. Deep removal of mortar in walls of relatively soft stones and a portland cement based mortar in the joints risks damage to stone edges. With lime mortar joints between relatively hard stones, little damage is likely to occur, even with deep removal. All loose and deteriorated mortar must be removed, even if the recommended depth is exceeded.

11.1.1.1 Where loose material of a sand-like consistency is found throughout the joint depth or voids are encountered, the stone restoration consultant should be consulted to provide direction on how to proceed. The loose sand mass may have to be removed and the joint or void regrouted. In extreme cases, stone units may have to be removed and reset.

11.1.1.2 *Mortar Removal Methods*—It has been generally recommended that only hand tools (ie. hammer and chisels) be used to remove old mortar from the joints. The supposition is that less damage to the masonry units would occur using hand tools. In reality, damage to joints is typically caused by workers with a low level of skill and experience. If the craftworker can demonstrate safe and effective use of power tools without damage to the stone or widening the joint, then such devices can be utilized in the removal of mortar joints When properly used by skilled craftworkers, angle grinders with a diamond impregnated blade, routers with diamond or carbide bits, worm-drive saws fitted with a diamond blade (preferably water-cooled) and with the blade-guard removed for better visibility (sanctioned by OSHA directive number STD 1-12.026) or orbital action brick and mortar saws, or combination thereof, are all effective tools used in removing mortar from joints. In all cases, the blades should be thinner or the router-bits diameter smaller, or both, than the width of the mortar joint being removed. In situations where water cannot be used to control the dust, OSHA approved vacuum systems should be incorporated. The use of a small pneumatic hammer and chisel with a blade that is thinner than the thickness of the mortar joints has proven to be an efficient method of mortar removal. Again, the craftworker may be asked to demonstrate proper skill in using such a method prior to doing the actual work.

11.1.1.3 *Sealant Removal*—Sealant is most often removed by cutting through the sealant bead along both sides with a razor knife and then pulling the sealant from the joint. Remaining sealant on the sides of the joints is typically removed with solvents or additional scraping. Before using solvents, tests should be performed to determine their effectiveness and potential for staining the stone or damaging materials that are to remain. Solvents remaining on the stone may interfere with the bond of the new sealant. Roughing the joint with sandpaper or lightly and carefully grinding the joint substrate with a diamond tool, after removing the old sealant, helps to ensure a clean surface for adhesion of the new sealant.

11.2 *Repointing with Mortar:*

11.2.1 *Reprinting Mortar Composition*—When repointing, the original mortar should be analyzed in accordance with Test Method C1324 to identify constituent materials and their relative proportions and air content Repointing mortars should not be harder, denser, or less absorbent than the stone and original mortar (both setting mortar and pointing mortar), or stone deterioration could result. When performing historic restoration, it is also important to match mortar color and texture. Both the binder and the aggregate affect mortar physical properties and appearance.

11.2.1.1 Binders may include a wide range of hydraulic and non-hydraulic materials. For all mortars, both the type of binder and the fineness of the particles should be identified.

11.2.1.2 For contemporary construction, identification of the original cement type may be adequate to define a compatible binder for repointing mortar. Masonry cements and mortar cements often incorporate materials other than lime to provide workability, including crushed limestone, air entraining admixtures and other additives. Lime should not be used in combination with these cements.

11.2.1.3 Modern portland cements are ground finer than historic cements, and if used in the same proportions as in the original historic mortar, could result in a mortar harder than the original. Natural cement fineness may be specified to match historic materials. Specification C10 has more information regarding natural cement and Specification C150 has information on portland cement. Also see Specification C91 for masonry cement information.

11.2.1.4 Non-hydraulic building lime is a mixture of quicklime (lime with limited impurities) and water to form hydrated lime. It is called hydrated simply because it is mixed with water. Hydrated lime is a dry powder. The addition of more water to hydrated lime makes lime putty. Lime mortars are based on non-hydraulic lime in lieu of cement. Lime mortar hardens slowly by means of carbonation of the calcium and magnesium hydroxides in the lime binder and therefore requires exposure to air. Modern hydrated lime is not hydraulic. Hydraulic means that it can harden under water. Hydraulic lime is a common term for lime with clay or silica impurities, or both, that allows some hardening without exposure to air. Hydraulic limes and pozzolan-lime binders rely to varying degrees on both carbonation and hydration to harden. Since the inception of portland cement, lime mortars have seen very limited use in new construction. Lime mortar mixes are primarily used for restoration. Also see Specification C5 for quicklime, Specification C141 for hydraulic hydrated lime, Specification C207 for lime, and Specification C1489 for lime putty.

11.2.1.5 When repointing masonry in which the original mortar is a combination of lime and hydraulic cement, the repointing mortar should not contain less lime than the original mortar. In these systems, lime reduces modulus of elasticity, allowing mortar to deform and relieve stress, and may also increase moisture vapor permeability.

11.2.1.6 The sand that comprises the aggregate in the original mortar should be identified by mineralogical makeup and particle size. If possible, sand from the same source as that used in the original mortar should be obtained, because sand can contribute up to 80 % of a mortar's color and texture. This is particularly true in historic masonry, where the surface paste has been lost due to weathering and the sand particles are exposed to view. Natural impurities found in some sands, such as natural metallic oxides or clays stained with such oxides, can act as pigments in historic mortar.

11.2.2 *Mixing Repointing Mortar*—For contemporary mortars based on portland or blended cements and lime, masonry cement or mortar cement, comply with Specification C270, Appendix X3 and the following procedures. Mix the mortar thoroughly to obtain uniformity of both visual and physical characteristics. Dry ingredients should be mixed before adding water. The mixture, especially if it contains an appreciable amount of portland cement, should be prehydrated to help minimize drying shrinkage. To prehydrate mortar, sufficient water is added to the dry mix to make a damp, stiff mortar; just damp enough to be squeezed into a ball with the hand. The mortar is then left to prehydrate for about one hour, after which more water is added to provide the desired consistency for placement.

11.2.3 *Preparing Joints for Repointing*—After removing mortar, all loose particles should be removed from the joint using a stiff-fiber brush, pressurized water, or compressed air. Stone and existing mortar should be wet, but no excess water should be present. Thoroughly wetting the masonry will provide a reservoir of moisture for the pointing mortar to assist in keeping joints from drying out too quickly.

11.2.4 *Placing Portland Cement Pointing Mortar*—Where existing mortar has been removed (or has fallen out) to a depth greater than that required, the joint should be partially filled first, compacting mortar in several layers and bringing it out to the level of the remainder of the joints. Once this is done, the entire joint may be filled by applying mortar in ¼ to ⅜ in. (6- to 10-mm) layers. Another layer may be applied as soon as the previous layer has lost most of its free water and is thumbprint hard. Several layers of about the same thickness are needed to fill the joint. These individual layers are called "lifts". Recommended methods for compacting the mortar are small hawk and tuck-pointer, pointing tool, or a slicker. Methods not recommended are grout bags, auger-actuated pumps or modified caulking guns.

11.2.4.1 *Placing Non-Portland Cement Pointing Mortar*—Other mortars, including natural cement mortars do not need to be placed in lifts. Always consult the manufacturer of the mortar for placing recommendations.

11.2.5 *Curing Pointing Mortar*—Pointing mortar should be kept continuously damp and above 40°F (4°C) for 72 h. This is especially critical in the case of higher lime-content mortars. If this is not done, the mortar becomes very soft and powdery. Non hydraulic limes cure by reacting with carbon dioxide from the air, and water aids in this process by transporting carbon dioxide (in solution) into the joint. Once the surface of the joint starts to harden, carbon dioxide cannot get into the joint as easily. Differing conditions during the initial curing of mortar joints have a pronounced effect on the color of the finished joints. In general, if joints are allowed to dry out during the first 72 h, the joints will be lighter in color. Pointing mortars that utilize cement in combination with lime and those that utilize natural cement, masonry cement or mortar cement need not be kept damp as long, but should not be permitted to dry out before the mortar has had the opportunity to hydrate the cement. Repointing mortar utilizing portland cement is particularly susceptible to drying out in hot windy conditions from rapid evaporation because it is applied in a thin layer.

11.3 *Replacing Joint Sealant:*

11.3.1 *Sealant Selection*—Elasticity and compressibility of the sealant and backing must be adequate for the expected movement within the joints. The amount of movement in the joints due to temperature changes can be calculated by knowing the spacing of the joints, the coefficient of thermal expansion of the stone, and the temperature range that the stone will experience. The sealant installation temperature should be considered when predicting thermal movement requirements. Joint movement due to settlement and due to frame deflection under live loads must be added to the movement due to temperature changes to determine the total joint movement. Total joint movement is then compared to nominal joint size to determine the percentage of movement that the sealant must be able to experience without failure. Sealant selected for joints in horizontal surfaces that must withstand foot or vehicle traffic must be recommended for such use.

11.3.2 Sealants should be tested to ensure that they will not be harmful to the stone or that compounds in them will not be absorbed and stain the surrounding stone. Sealants should also be tested for compatibility with other materials that they will contact. Adhesion tests should also be performed with proposed sealants and the substrate being sealed to confirm appropriate adhesion.

11.3.3 *Joint Preparation*—Sides of joints must be cleaned of oils, loose materials, and other substances that might interfere with sealant adhesion. Sides of joints should be primed according to sealant manufacturer recommendations. Backs of joints must have bond breaker applied, either in the form of a backer rod for deep joints or a bond-breaker tape for shallow joints. A foam backer rod is recommended to control the joint depth and profile, so that the sealant will stretch rather than tear loose from the joint sides. Verify with the sealant manufacturer whether the backer rod should be open cell or closed cell. For joints in horizontal surfaces that must withstand foot or vehicle traffic, backing material must be sufficiently rigid to support the sealant. The backer rod should be installed after the joints have been primed.

11.3.4 *Sealant Application*—The sealant should be installed into the joint without voids and tooled to ensure complete adherence to joint sides and proper joint shape, usually slightly concave. Joint masking and sealant smears should be removed immediately after tooling joints, while the sealant is still wet. Refer to Practice C1521 to determine correct installation of sealant.

12. Cleaning

12.1 For cleaning exterior stone, refer to Guide C1515.

13. Replacing Stone with Other Materials

13.1 When a particular historic stone variety is no longer available and no suitable replacement can be found, or when the particular historic stone variety does not possess suitable durability, use of a substitute material may be necessary. The use of a fine textured precast concrete to replace brownstone is an example. Another example would be the use of other natural stones possessing similar physical properties, performance characteristics and aesthetic qualities (color, grain size, etc.) as the original material. This sort of replacement should be considered a last resort to be used only when other conservation methods are not suitable.

14. Keywords

14.1 anchor replacement; consolidation; dimension stone restoration; dutchman repair; historic restoration; repointing stone; stone cleaning; stone consolidation; stone patching; stone replacement; stone restoration

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