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Journal

Historic Stone Masonry Restoration

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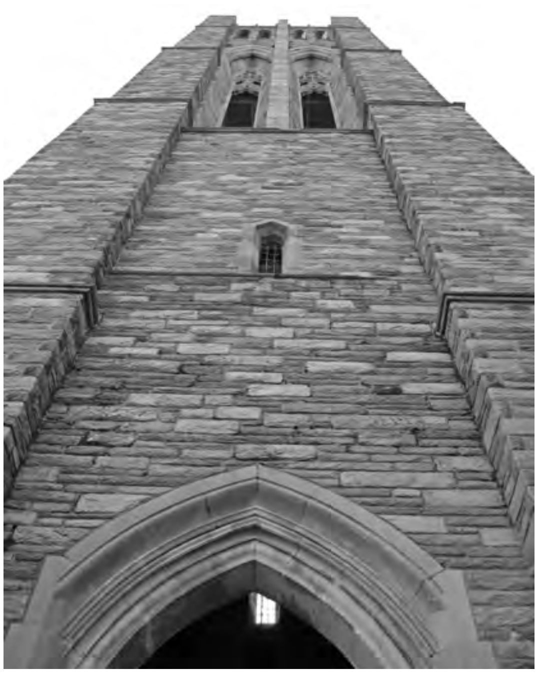
Delicately carved ornament, distinctive tooling and bonding patterns, and rich surface textures, along with soaring arches, towers, and buttresses, inspire awe and give historic stone masonry a sense of the sublime. Yet it is those details we most admire that are often the most vulnerable, succumbing not only to the effects of time and weather, but to the consequences of insensitive repairs, from inappropriate coatings to careless repointing.



To ensure the legacy of historic stone structures endures, it is important to apply appropriate conservation strategies.

As the number of new buildings constructed of solid stone masonry has diminished over the past century, so too has the number of skilled artisans available to restore these structures as they age. With few craftspeople proficient in the treatment of traditional stone structures, building owners may unwittingly employ inexperienced tradesmen, whose repair efforts may cause more damage than they resolve. Too often, that damage is irreversible. As such, discussions about the restoration of historic stone must address not only the treatment of age-related wear and decay, but also the best ways to arrest and, to whatever degree possible, undo the damage caused by poorly conceived repairs.

To best treat a historic stone structure, consider ongoing concerns, such as leaks and deterioration, in the context of past repair work, as well as properties and features of the stone itself. Through stone condition evaluation, laboratory testing and analysis, and historical records review, the design professional can determine the deterioration mechanisms at work and prepare an appropriate restoration program. With thoughtful design and proficient execution, restoration can preserve architecturally and culturally significant details, while reestablishing the resiliency that has enabled the historic stone to last through the years.

Evaluating Masonry Construction

Before developing a stone treatment, it is necessary to develop an understanding of the history and condition of the existing building. The design professional should consider the original design intent, particularly in terms of how the stone type, surface dressing, bond pattern, pointing, and other attributes contribute to the function and appearance of the exterior envelope. Stone is generally chosen based upon both its structural properties and its aesthetic qualities, so the initial investigation should identify those

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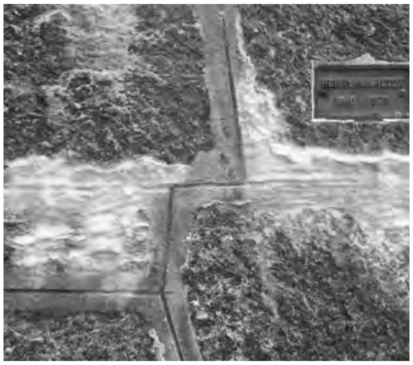


Efflorescence.

Iron subflorescence.

Exfoliation.

properties of the stone that are integral to the design and performance the building.

In the field, the investigation begins with a visual survey, at times involving a stone-by-stone evaluation of existing conditions. To identify concealed deterioration conditions and locate points of water infiltration, wall openings may be performed as part of the assessment. Laboratory analysis of stone and mortar samples may yield additional useful data, particularly where the resiliency of the stone is called into question due to age, observed deterioration, or, more often, due to the ill effects of inappropriate prior repairs. The investigation should incorporate an inventory of previous treatments and repairs, as well as a recommended program for restoration.

Characteristics of Stone Masonry

Thermal and moisture management in a traditional stone masonry building is quite different from that in modern construction, which uses impervious materials, vapor barriers, and cavity space to prevent the migration of moisture across the building envelope. In contrast to the thin exterior envelope of a contemporary veneer assembly, load-bearing historic stone masonry is characterized by massive, thick walls, which absorb moisture at the outer surface and release it gradually, before it reaches the building interior. Repair programs that fail to consider the distinction between traditional stone construction and modern cavity walls can adversely impact the moisture balance in the assembly, resulting in poor indoor air quality, leaks, and damage to the stone.

When selecting stone, whether for reconstruction or for isolated replacement, the architect or engineer should consider performance features and known properties, as well as texture and color. Strength, coefficient of expansion, weathering characteristics, durability, porosity, appearance, and workability are all key considerations. Sound knowledge of the harmful effects of salt contamination, erosion, chemical attack, frost action, and vegetative growth is also important to predicting the resiliency of stone to environmental factors.

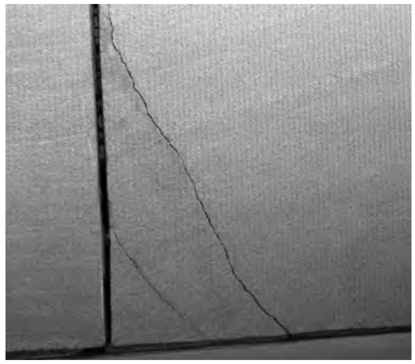
For vulnerable areas, subject to severe exposure, atmospheric pollution, and repeated wetting, the choice of stone is especially important. Steps, curbs, pavers, and base courses near grade and adjacent to hardscapes are all prone to degrade at a greater rate than are smooth, vertically-oriented surfaces. Strong and resilient stone, such as granite and quartz, is generally better suited to these high-traffic, sensitive areas. The softer the stone, the more it will react to impact damage and be subject to erosion.

Just as the stone's inherent properties affect the performance of the wall assembly, so too does the style of construction influence the longevity of the stone. Traditional stone detailing often served to direct water away from potentially vulnerable areas and to prevent concentrated streams that cause staining and freeze-thaw damage.

Drip edges on the undersides of window lintels and sills prevent water from passing along the length of the protruding element back into the wall assembly. Throats, which may be present as gargoyles or other troughs, also channel rainwater away from the building, as do stoolings, a sloped portion of the sill built into the surrounding wall to shed water. The slope, or weathering, of the sill is usually set at an angle pitched to direct water away from the wall. At roof lines, coping stones, which are large, sloped cap stones, are set atop parapet walls to serve a similar function. Unfortunately, today's climate of acid rain, airborne pollutants, and soluble chemicals tends to accelerate damage to stone masonry despite these traditional deterrents to moisture-induced deterioration.

The size and tooling profile of mortar joints has a direct impact on the ability of the masonry wall to shed moisture. Some joint profiles can effectively double the surface area of the joint and, consequently, increase the absorption capability of the wall

Delamination.



Cracking.

Sugaring.

assembly. In cases where an inappropriate tooling profile or deteriorated mortar allows water to pool in the joint, the mortar and adjacent stone can become severely deteriorated.

Forms of Deterioration in Natural Stone

Depending upon the type of stone, the climate, exposure, orientation, building use, provision for moisture management, and type of construction, the causes and manifestations of stone deterioration can be diverse.

As moisture within the wall evaporates from the exterior face, it leaves behind waterborne salts, which remain on the stone surface. This characteristic white stain, or ***efflorescence***, is often a result of rising damp, which occurs when groundwater is drawn up into the base of the wall. Efflorescence may also be caused by moisture introduced into the wall assembly through improperly installed or missing flashings at the top of a parapet.

Where efflorescence is observed, ***subflorescence*** also may be present. As trapped moisture migrates through stone, it may leave behind a potentially harmful accumulation of crystallized salts along veins or internal cracks, which can damage the stone's internal structure. In some cases, these salts may accelerate corrosion of naturally occurring ferrous compounds in the stone, leading to characteristic rust-colored stains.

Where a portion of the stone surface has broken away, the problem could be delamination, exfoliation, or spalling, depending upon the type of stone and the nature of the break. Often caused by freeze-thaw cycling, ***spalling*** is the result of trapped moisture and salts that expand beneath the surface of the stone, forcing off a piece of the outer face. As stone is exposed to age and wear, the surface layer may separate from the body along a vein, through processes resulting from salt crystallization. Spalling can also result from poor repointing techniques and from using too hard a repointing mortar.

Delamination takes place when the outer surface of the stone splits into thin layers, which then peel off the face. Sedimentary stones are naturally prone to delamination, which occurs along the bedding planes when the rock is set perpendicular to the direction in which it was originally formed.

Like delamination, ***exfoliation*** is a type of surface disintegration in which the stone sloughs off in very fine layers. Although the two terms are often used interchangeably, delamination tends to refer to fracture along natural bedding planes, whereas exfoliation is usually due to thermal stress, impeded moisture movement, or other environmental factors.

Where a crack in the masonry unit leads to a clean break, the fracture is referred to as ***detachment***. Detachment may be due to failure of an original construction joint, or it may be the result of a weakened plane within the stone.

Tracing the source of ***cracking*** in historic stone masonry can be difficult, as it can originate in a wide variety of sources, ranging from structural settlement to a repointing mortar that is incompatible with the stone. If cracks are narrow and short or confined to within a single stone unit, the issue may be relatively minor; cracks that are wider and longer or those that extend over large areas may be indicative of systemic problems.

If, with light rubbing, the surface of the stone falls away in small granules, similar in texture to granulated sugar, the stone may be succumbing to surface disintegration, or ***sugaring***. Cohesive minerals in the stone dissolve, and the remaining deposits are easily brushed from the surface. Carbonate stones, especially fine-grained marble, are particularly susceptible to this type of granular separation.

As the building ages, the natural disintegration and erosion of stone due to wind and rain leads to ***weathering***, which results in worn and rounded surfaces. Exposure to acid rain tends to drastically increase the rate of weathering and produce a noticeable softening or loss of detail.

Selecting a Preservation Treatment

Once the design professional has catalogued the location and extent of deterioration, along with the probable causes – whether normal wear, excessive contaminants, flaws in the original design or construction, inappropriate previous repairs, or other such conditions – he or she can identify and test methods for restoration to address the deficiencies.

Cleaning

While it may sound simple enough, cleaning of historic stone is a delicate process. As a general rule, use the gentlest method possible to remove staining, to avoid damage to the stone color or carved detail. Cleaning can reveal the natural color of the stone, while exposing damage that may require repair.

Water washing may be the most versatile and gentle technique for removing dirt and stains from historic stone masonry. Methods include prolonged spraying with fine mist, low-pressure washes, and water used in combination with chemical agents. Take note, however, that even simple water washing should be carried out with caution. Permanent discoloration may result should dissolved minerals or impurities leach out of the stone, or if absorbed water corrodes metal elements. Soft water should not be used on calcium carbonate stone, such as limestone, as its acidity can cause dissolution of the stone surface.

Any wet cleaning method should be carried out only when there is no danger of frost or freezing. If the wall remains saturated during cold temperatures, absorbed water may freeze and expand inside the stone, causing cracks and spalls.

Chemical cleaning agents, including organic surfactants, should be selected based on the type of stain, the presence of biological growth, atmospheric pollutants, and, most importantly, the stone substrate. Alkaline cleaners, which are used on limestone and marble, should not come in contact with polished granite or windows, as the high pH may cause etching. Acidic cleaners, formulated for granite, slate, sandstone, and other non-calcareous stone, must be removed from masonry by a water rinse to neutralize the acid following application. It is crucial to protect facade elements, such as light fixtures and ornaments, that may be damaged during the cleaning process.

Abrasive cleaning may be used, in lieu of or in addition to chemical cleaning, to remove soil, stains, and coatings by abrading the surface of the stone through impact. Sandblasting, grit, and/or pressure washing are all common forms of abrasive cleaning, as is the use of power sanders, wire brushes, and other hand tools. Due to the high potential for damage, abrasive cleaning should only be used for historic masonry in special circumstances, and then only under direction of an experienced architect or engineer.

Stone Repair/Restoration

Repointing is used to repair deteriorated mortar joints. The existing mortar is removed by hand to a depth of two times the joint width, or until sound mortar is reached (whichever is greater), and new mortar is set in

Stone Consolidation: Benefits and Risks

Consolidants may be applied to stone when its composition is no longer stable, as occurs with crumbling or sugaring. A consolidant is a chemical, typically composed of polymers, that is applied to the stone surface in cycles over a specified length of time. The end result is a substrate whose microstructural stability is restored. Consolidants require reapplication over time, so there is scheduled maintenance involved in this repair.

Consolidants alter the physical character and color of the stone. The liquid polymers applied to the surface are drawn into the stone via capillary action, and subsequently solidify within the stone matrix. The application area is transformed permanently into a combination of stone and polymer. As such, the use of a consolidant to stabilize historic stone must be carefully considered, because the result is a new substrate.

The extent to which a consolidant will darken the stone can vary from slightly to markedly along a facade composed of the same stone exhibiting the same levels of deterioration. Performing a mockup of the application will produce the variety of results that can be expected though the course of the project. A mockup is always recommended to determine the appropriateness of consolidation, because it is an irreversible repair. ■

place and tooled to match the original profile.

For the majority of older buildings, a historically accurate mortar mix should contain only sand, lime, and water. White Portland cement may be substituted for a portion of the lime to improve workability and plasticity. A high-lime-content mortar is softer than the stone and prevents damage to the stone masonry by acting as the sacrificial element in the wall assembly.

To achieve a mortar mix that approximates the character of the original, it may be necessary to add pigment, crushed shells, or colored sand. Testing and analysis of the original mortar may facilitate accurate identification of mortar components.

Mechanical stitching stabilizes and arrests wide cracks that extend deep into or through a stone unit. The stitch pins are usually stainless steel, to resist corrosion and to accommodate the tensile forces that caused the stone to crack. To execute the repair, the face of the crack is routed in a "V" shape, and the ends of the stitch pins are embedded in the stone surface. Then, the pin holes and the crack surface are patched.

Patching with cementitious material may be used to treat small areas of deteriorated or spalled stone. If carried out by a skilled worker, patch repair may blend into the facade more than a stone replacement or Dutchman repair, and it is usually less expensive. Patch materials vary according to the type of stone masonry being repaired, but they should be weaker than the stone substrate. If the patching compound is too hard, it may accelerate deterioration of the surrounding stone.

To match the color and texture of the patching material to the existing stone, colored sand is often used, along with ground stone. Pressing stone dust

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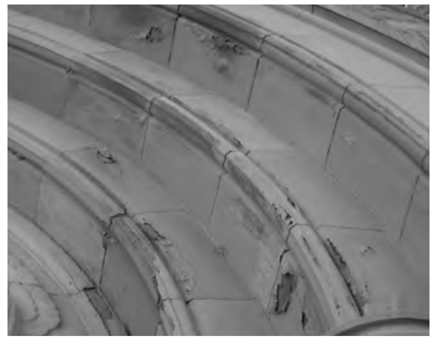
Inappropriate Repairs

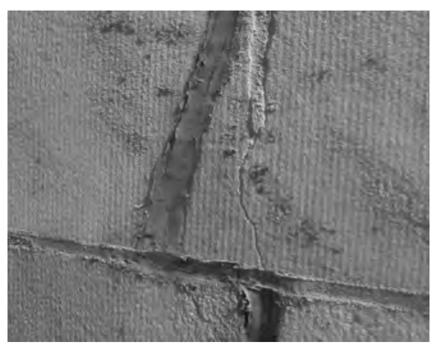
As holds the principle of bioethics, so should the approach to treating historic stone: "First, do no harm." If the degree of deterioration does little to detract from the architectural character of the building or to call into question its structural stability or performance, no repair may be needed.

Too often, application of a "protective" waterproof coating, aimed at preventing hypothetical moisture-related deterioration, has the unintended effect of sealing moisture inside the masonry surface and leading, in many cases, to real and irreversible damage. Stone masonry buildings of traditional construction were designed to "breathe;" to be permeable to air and moisture, allowing water to leave the wall assembly through the natural process of evaporation. Introducing impervious coatings and vapor barriers disrupts the balance of moisture across the building envelope, which can result in dire consequences for the stone, at both a macro- and micro-structural level.



Blistering waterproof coating.

Deteriorated face-pointed mortar.



Incorrect use of sealant.

As a shortcut to address deteriorated mortar joints, a thin layer of mortar is sometimes added without first removing the existing mortar to the appropriate depth. While quicker and cheaper than full repointing, face-pointing is inadvisable, as it does not provide suitable stability and tends to crumble out of the joint.

Introduction of pointing mortars of incorrect composition may restrain the natural expansion and contraction of stone masonry subjected to moisture absorption and drastic temperature swing cycles, leading to cracking and spalling. Faulty patching mortars and ill-conceived pinning methods may have similar detrimental consequences. Even stone cleaning, which sounds innocuous enough, is fraught with hazards, as using abrasive or chemically incompatible cleaning methods can abrade or otherwise damage the stone surface. ■

(continued from page 5)

and chips into the surface of a newly formed patch may aid in blending the repair area with the surrounding masonry. To achieve an accurate match, artificial colorants may be used, although these may fade or change slightly in appearance over time.

Equally important as color matching to the success of the repair is preparation of the patch area. Identifying appropriate locations for support pins, where necessary, and keeping those pins clean and free of adhesive or epoxy is crucial to the durability of the patch, particularly for large areas. Patching material should be applied past the stone surface, to facilitate finish carving once the patch has set.

Dutchman repair replaces the missing portion of a chipped or broken stone unit with a newly carved piece of stone. Typically, the repair piece is natural stone, chosen to match the hue and texture of the existing masonry, and it is wedged in place, secured with adhesive, or set with pins; larger pieces may be set in mortar. To maintain the appearance of a continuous stone unit, the joint between the repair piece and the existing stone should be as narrow as possible.

Stone replacement must be considered where repair and patching techniques are impractical or ineffective, or where stone units are missing or so severely broken or deteriorated as to be unrepairable. Use of natural stone carved to match the existing masonry is generally preferable to replacement with non-matching or synthetic material. However, accurate replacement may be contingent upon locating a suitable quarry and a satisfactory color match.

Mockup test of stripping agents to remove prior inappropriate coating.

Dampproof course installation addresses rising damp by incorporating a water-resistant material into the wall just above grade. Many historic masonry buildings include some type of dampproof material, such as tile, slate, bituminous felt, or metal, to prevent the rise of ground moisture into the wall, but such a layer may also be added as a remedial measure.

Dampproofing may be used for walls that are regularly coursed and stable, but which are experiencing moisture migration originating at the portion of the wall that is below grade.

Water-repellent coatings, unlike *waterproof* coatings, are breathable, allowing water vapor to escape outward through the pores in the stone, while preventing liquid water from penetrating into the wall. Typically, these coatings are colorless; however, they may impart an undesirable sheen to the stone and may darken its color. Water-repellent coatings should never be applied to a damp or wet building, particularly one that might have subflorescence under the surface. If applied to a wet wall, the coating prevents moisture within the wall from drying out, increasing the risk of damage to the stone.

One case where a water-repellent coating may be appropriate is on a facade that has undergone previous—and often detrimental—waterproof coating application. As the waterproof coating may have permanently altered the properties of the stone, it may be impossible to return to a stable, uncoated state. Application of a breathable coating may protect the porous surface of the existing stone from further damage. Considerations include altered appearance, which may be evaluated through mockup testing, and the maintenance demand of periodic re-application.

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Set In Stone

Sedimentary stone is formed through the deposition of clay and sediment layers over the course of thousands of years. Sedimentary stone, such as schist, slate, and sandstone, is most durable if it is bed set, that is, oriented in construction, the same direction as it was formed in nature. When sedimentary stone is permanently positioned on its side, perpendicular to its natural orientation, those layers that were once horizontal are prone to shearing and delamination on the stone face.

The lifespan of face-set stone is significantly shorter than that of its bed-set counterparts. There are design conditions and decorative shapes that may be impossible to carve for a bed set installation. In these situations, consider an alternative type of stone; otherwise, anticipate stone replacement well before the standard life expectancy for the material.

representative projects

Historic Stone Masonry

Before selecting a treatment for historic stone, Hoffmann Architects considers the ways in which the original construction responds to air and moisture, and how time, weather, and alterations to the natural stone have affected its properties. Since each stone building is unique, our architects and engineers test and evaluate restoration strategies to see that proposed treatments perform as intended.

Hoffmann Architects has designed stone masonry solutions for historic commercial, institutional, and government structures, including:

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Clothier Hall
Swarthmore, Pennsylvania
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Lehigh University
Packer Memorial Church
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Quartzite and Sandstone Master Plan and Restoration

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Bureau of Engraving and Printing
Washington, District of Columbia
Limestone Facade Restoration

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Limestone and Granite Facade Consultation

American University
McKinley Building
Washington, District of Columbia
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Washington, District of Columbia
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Caring for Natural Stone

Since stone is not homogeneous, and time, weather, and stress affect each structure in different ways, mockup tests should be used to evaluate the performance of proposed repairs prior to full implementation. Product manufacturers, stone quarries, and masons are useful resources; they can provide test and performance data, along with experiential advice, on the restoration strategies and stone samples under consideration. Ultimately, though, each building is unique, and even carefully formulated approaches require *in situ* evaluation.

Together, the owner, design professional, and restoration contractor should use the results of mockup testing to establish baseline expectations for the program of repairs. Historic stone derives its character from its age, and it is neither achievable nor desirable for it to emerge from a conservation effort looking like new. Realistic goals for the aesthetics and expected longevity of repairs should take into account the natural qualities of the historic stone that give the building its personality. ■

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