



HYDRATED LIME AS AN INGREDIENT IN HISTORIC RESTORATION REPAIR MATERIALS*

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Abstract

The use of Type S hydrated dolomitic lime in the formulation of repair materials for historic structures has a long and successful performance history. This is true both for lime used as the sole binder and when used in combination with portland cement, alternative pozzolans, and/or synthetic binders.

This paper reviews more than 20 years of performance history of repairs to historic buildings and monuments using specialty materials that incorporate Type S hydrated dolomitic lime. Applications discussed and illustrated include:

- Custom composite repair mortars for stone, masonry, and historic concrete
- Micro-injection grouts for masonry crack repair
- Void-filling grouts for seismic repairs and masonry stabilization
- Cement/lime stucco and stucco repair mortars
- Historic repointing mortars

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Case studies are used to illustrate applications. Discussions of common errors in laboratory testing of lime mortars are also included.

1 Introduction

The design of customized restoration mortars requires careful consideration of a wide variety of performance, appearance and compatibility issues. Restoration mortars must generally be able to develop high bond strength to the substrates being restored. They must avoid distressing historic substrates as they expand and contract through seasonal temperature changes and undergo freeze-thaw and wet-dry cycling. They must transmit moisture and moisture vapor at rates similar to their substrates. They must be sufficiently workable to allow trades-people to achieve the desired finishes in an efficient and cost-effective manner. Finally, they must perform for the maximum possible length of time, in order to avoid the disruptions and collateral damage invariably associated with repeated interventions.

Hydrated Type S lime, conforming to the requirements of ASTM C 207 Standard Specification for Hydrated Lime for Masonry Purposes, is an invaluable ingredient in historic restoration mortars since it contributes to the attainment of these performance and compatibility objectives. It is a key component in a wide variety of historic repair products, including masonry repointing and rebuilding mortars, cement plasters, renders, coatings, grouts and composite repair systems. It may be the sole binder used in these systems, or it may be used in combination with other binders, such as portland cement or natural cement, to achieve a particular balance of performance properties and working characteristics. It may be a major component in these systems, or may be used as a low-level additive to modify the other binders. It may be used in relatively simple systems, consisting only of lime and aggregates with or without portland cement, or may be incorporated into more complex systems, in which any number of other natural and/or synthetic admixtures are included.

This paper is intended as an overview of one firm's experience with the use of Type S hydrated lime as an ingredient in thousands of custom formulations of restoration mortars, spanning over the course of the past 25 years.

2 Historic Mortars: Replicate or Simulate?

When formulating mortars for use in historic repairs or repointing, one of the preliminary decisions to be made is whether the new materials should be exactly the same as the original materials, or should simply *appear* the same as the original materials. In masonry mortar and stucco formulations, there may be an option to produce materials that are almost exactly the same in composition as the original, historic materials. If the same aggregates can be located, and binders of the same quality, color and composition are available, the replication approach provides a potential means of producing repairs that are indistinguishable from the original materials. While this approach should constitute the preferred, default option when available, there are also cases where replication is not the best alternative.

When mortar analyses were performed on a series of 90-year-old historic mortars during restoration of the Key West, Florida U. S. Customs House (shown in Figure 1), two major deficiencies were discovered. First, red iron oxide pigments had been used at a level of more than 20% by weight of the portland cement content. Modern standard ASTM C 979, Standard Specification for Pigments for Integrally Colored Concrete, limits the use of iron oxide pigments

to 10% of cement weight, as the ultra-fine pigment particles would otherwise be expected to negatively impact water demand, shrinkage and strength². The second deficiency discovered was in regard to sand particle size distribution, a consideration that is too often overlooked in historic mortar replication. In particular, the calcareous sand used in the original mortar was narrowly graded and much finer than standard sands conforming to ASTM C144 Standard Specification for Aggregate for Masonry Mortar. This, too, would be expected to increase water demand and shrinkage, and reduce durability of the mortar.



Figure 1. Custom lime-cement repointing mortars for the Key West Customs House simulated, but did not replicate the original mortar, in which poor practices were evident.

When such deficiencies are discovered, preservation philosophy and performance-based standardized practices come into direct conflict. Faithful reproduction of the historic mortar, exactly as it was originally formulated, was an option for which the architectural conservator initially argued, observing that the original mortar had endured 90 years of severe Key West exposure. From an engineering-performance point of view, however, the appropriate choice would have been a Type N mortar conforming to ASTM C 270 Standard Specification for Mortar for Unit Masonry, given the wind-driven rain exposures and the moderate hardness of the original vitrified brick, terra cotta and sandstone. Any other approach to mortar selection would amount to ignoring the engineering knowledge gained over the past century and would intentionally produce a mortar with poor durability. The historic mortar was in exceptionally poor condition for mortar of only 90 years' age, and it had been deteriorating for some time before the repointing work was undertaken. Although repointing of lime-cement mortar will typically be required by the time a building reaches 90 years of age, the expected mode of failure, as frequently observed on other buildings of this age, would not include substantial disintegration of the mortar, as was observed in this case. The expected failures would typically include cracking

² ASTM C 979 does not specifically address masonry mortars or repair mortars, for which similar standards are absent. Because performance issues are generally the same, commercial producers have tended to apply the same ASTM C 979 standard to pigmented cementitious materials other than concrete. While this is generally appropriate, one shortcoming of ASTM C 979 in regard to its application to masonry mortars is the absence of any consideration of the effects of lime as a co-binder. To address this issue, some masonry mortar formulators add the lime content to the cement content when setting pigment dosage limits, using 10% of the total binder as the upper limit.

due to embrittlement, often manifested as a delamination at the masonry interface, and surface erosion.

At the U. S. Customs House, a decision was made to produce a mortar meeting the property requirements of ASTM C 270, Type N, properly limit the pigments to 10% by weight of the cementitious binder, and utilize a blend of sands meeting the requirements of ASTM C 144. Sand fineness was controlled to produce the finest particle size distribution allowable under the ASTM C 144 standard, in order to approach the composition of the original mortar as closely as possible while complying with the modern standard.

Compressive strength was an issue that engendered multiple rounds of test mix preparation, laboratory evaluation, and discussion. The ASTM C 270 property specification requirements for Type N mortar include a minimum compressive strength requirement of 750 psi at 28 days, but do not include a limit on maximum compressive strength. In this sense, ASTM C 270 is an inadequate standard for historic repointing mortars. Restricting the strength of repointing mortars is given high priority in the National Park Service guidelines for repointing of historic buildings, which state that mortars for repointing *“must be...as soft or softer (measured in compressive strength) than the historic mortar”* (Preservation Briefs 2). The complication in applying these principles, in this case, stemmed from the poor condition of the original mortar and from the lack of reliable methods for measuring compressive strength of existing hardened mortar. Existing mortar strength could only be inferred from the original mix proportions, which included equal proportions of cement and lime.

The Proportion Specification Requirements in Table 1 of ASTM C 270 are usually intended to be a separate alternative to the Property Specification Requirements in Table 2. Although the standard states that “the proportion *or* property specifications shall govern as specified” (emphasis added by author), it is not unreasonable for restoration architects to specify supplemental requirements, as was done in this case. Because mortars prepared in accordance with the proportion requirements will often far exceed the minimum 750 psi compressive strength listed in the property requirements of Table 2, a supplemental requirement that maximum strength shall not exceed 1,200 psi was added to the project specifications. The objective was to further assure that the repointing mortar was not substantially harder than the original mortar’s design strength.

The final mortar formulation decisions for this project reflected a best effort to balance the various competing criteria. Lime content, in effect, became the controlling factor in achieving the specific mortar strength objectives for the project. By assigning proportions of lime to cement of 1:1.25, which coincided with the maximum lime content permissible under the ASTM C 270 Table 1 Proportion Specification Requirements for Type N mortar, the new mortar would presumably be as soft or softer than the design strength of the original 1:1 cement-lime mortar, while providing a mortar suitable to the wind-driven rain exposures at the site. Conformance with the supplemental requirements, which limited maximum strength, was confirmed through laboratory testing.

The restoration mortars finally produced for this project satisfied both the historic repointing and performance guidelines, while visually matching the original, historic mortars. Although approaching the original material in composition as closely as possible, the repair mortars were formulated for function first, as a well-engineered simulation was deemed preferable to replication of a mistake.

For composite repair mortars used in patching of natural stone, replication is not an issue. A patch, after all, is not natural stone, however closely it is made to match stone in appearance and/or strength. Repair mortars for stone have historically utilized a wide variety of binders, including various forms of lime, various blended cements, various combinations of pozzolans, and a wide variety of proprietary systems. Accordingly, performance has been highly variable.

3 Composite Repair Compounds: Standards Absent

The lack of consensus-based standards for performance of stone repair systems has engendered a remarkable level of partisanship for these products in the United States, at times to the detriment of actual performance. In the absence of industry-wide standards, each manufacturer has been left to formulate toward the balance of properties they deem to be most appropriate and/or most marketable. In the engineering approach to this problem, potentially critical performance properties were considered and prioritized, and potential ingredients were evaluated on the basis of their ability to contribute to the achievement of these objectives.

For the repairs at the Palladium Building in New Haven, Connecticut, seen in Figure 2, the performance properties given the highest priority were high tensile bond strength, low-modulus of elasticity, and low drying shrinkage. High adhesive bond strength was considered the primary performance property, as it is a prerequisite to all of the other properties. Low-modulus of elasticity was considered critical to durability, as the face-bedded Portland, Connecticut brownstone substrate was in poor condition, low in cohesion, and likely to be distressed if more rigid repair mortars were applied. Low shrinkage was deemed important in order to eliminate stress to the substrate during cure and to provide of crack-free surfaces for maximum protection of the water-sensitive sandstone.

Moisture vapor transmission, closely-matching color, and good workability were secondary properties that were considered. Formulation of the repair system for this application was further complicated by the necessity of providing a mortar that could be formed and poured for large and deep repairs, but hand-applied in a non-sag consistency for other, smaller repair areas.

Portland cement was selected as the primary binder for this application due to its ability to achieve fast set and reliable target strengths with a minimum of attention to curing. It could also readily be colored to match the stone by using a combination of brown-colored aggregates and stable, commercially-available concrete colorants. Portland cement remains the most widely-used binder in stone repair mortars in the United States today.

Portland cement alone was deemed inadequate for meeting all of the performance priorities, however. In particular, sand-cement mortars tend to produce relatively rigid, high strength patches, while sandstone meeting ASTM C 616 Standard Specification for Sandstone Building Stone may exhibit compressive strength as low as 2,000 psi (13.8 MPa). Strength for the repair mortar was targeted to be under 3,000 psi (20.7 MPa) in order to avoid creating repairs that were substantially harder than the host stone. Since facade repairs are generally non-structural, compressive strength of repair mortar is not as critical as in load-bearing concrete applications. Modulus of elasticity, which affects the capacity of the repair mortar to deform and relieve stress, is a more significant component of mechanical compatibility than compressive strength (ICRI #03733).



Figure 2. The 1855 Landmark Palladium Building, New Haven, Connecticut (left) shown in 2004, 22 years after application of some 16,000 lbs. of custom latex-modified lime-cement repair mortar. Cast-in-place quoins (right) retain sharp detail, exhibit no evident deterioration and are not readily distinguishable from the original stone.

In repair applications, simple portland cement-sand mortars also have significant workability limitations. Although forming and pouring is relatively easy to execute, workability of hand-applied patches for vertical and overhead repair surfaces is less than ideal. Sand-cement mortars do not develop sufficient tack or cohesion to be useful in hand-applied patching. Low levels of two modifiers were added to the mortar formulation to improve performance and workability: hydrated Type S lime and an ethyl acrylate-methyl methacrylate latex copolymer.

For both modifiers, the level of modifier use was on the order of 3% on a dry basis. This equaled a polymer-cement ratio of 0.15 for the latex modifier. Both modifiers reduced the modulus of elasticity and provided superior stress-relief and distress-avoidance to the soft brownstone substrate. The effect of polymer and lime addition on modulus is shown in Figure 3.

The effect of polymer addition on general physical properties is shown in Table 1. All specimens used to develop Table 1 data were simple 3:1 sand-cement mortar samples, adjusted to the same working consistency by varying the level of water addition. As the table indicates, water reduction of 20% or more is achieved without changing workability by incorporating polymer at 10% of cement weight or higher. All unmodified mortars (0 polymer-cement ratio) were properly wet-cured for 28 days. All modified mortars were air cured, which is the proper regimen for latex-modified mortars. The data indicates that equivalent tensile and compressive strengths are achieved between the dry-cured latex-modified mortars and the wet-cured unmodified mortars. Therefore, the latex-modified mortars reliably achieve their design strength without the need for wet-curing. The latex-modified mortars also achieved high adhesive bond strength that could not be duplicated by unmodified mortar (Lavelle 1986). The higher flexural strengths reported for the latex-modified mortars are related to reduction in modulus of elasticity, since the latex-modified mortars efficiently deform to relieve applied stress.

Modulus vs. Polymer-Cement Ratio

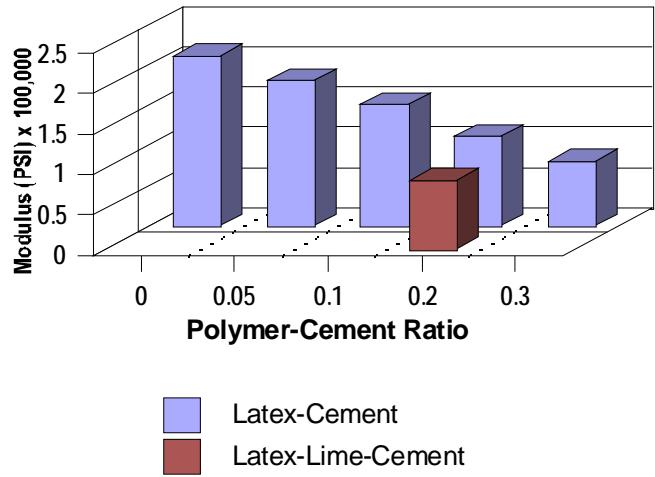


Figure 3. Effect of Polymer Concentration and Lime Addition on Modulus of Elasticity (Lavelle, p. 14)

For the shear bond adhesion tests, (A) indicates adhesive failure at interface. (C) indicates cohesive failure in substrate. When the mode of failure is cohesive, adhesion of the repair mortar is greater than the tensile strength of the substrate.

The tendency of lime to increase drying shrinkage was more than overcome by the tendency of the latex admixture to reduce shrinkage through significant reduction in water demand. Shrinkage of the mortar was sufficiently low that even relatively fluid mixtures, prepared for pouring in-place repairs up to 6 inches (15 cm) in thickness and up to 2 feet or more in height and width (60 cm), did not cause development of any visible shrinkage cracks. ICRI Guideline #03733 defines “Low Shrinkage” as less than 0.05% and more than 0.01%, while defining “Moderate Shrinkage” as more than 0.05% and less than 0.10%. The addition of latex to the lime-cement mortar, in this case, reduced the shrinkage from “moderate” to “low”. Low-shrinkage materials are preferred due to their reduced tendency to crack. Cracks of width exceeding 0.008” (0.2 mm) will leak when exposed to intermittent moisture, and the transmission of this moisture to the repair interface can be expected to diminish patch durability. Comparative shrinkage data for a cement-lime mortar and a latex-modified cement-lime mortar are shown in Figure 4.

Moisture vapor permeability was controlled through adjustment of sand proportions and particle size distribution. This approach allowed creation of sufficient air voids within the cured mortar to permit free transmission of moisture vapor. Comparative water vapor transmission data for a sandstone specimen, two commercial latex-modified cement-lime repair mortars, and one unmodified commercial repair mortar are listed in Figure 5. The study utilized specimens of 6 mm thickness that were tested using ASTM E 96 Standard Test Methods for Water Vapor Transmission of Materials (water method). All specimens displayed rates of water vapor transmission close to the rate of the sandstone specimen. Latex-modified mortar #4 displayed the highest rate of moisture vapor transmission. It differed from latex-modified mortar #1 only in its air void volume.

Table 1. Physical Strength Properties of Portland Cement Mortars (Lavelle 1986)

Ratio of Acrylic Polymer Solids to Cement Weight	No Polymer (0)	0.10	0.15	0.20
Water-Cement Ratio to Achieve Equivalent Workability	0.48	0.40	0.37	0.35
Tensile Strength, PSI	535	530	615	855
Compressive Strength, PSI	5795	5450	5715	5690
Flexural Strength, PSI	1070	1355	1585	1835
Shear Bond Adhesion, PSI	185 (A)	>500 (C)	>650 (C)	>550 (C)

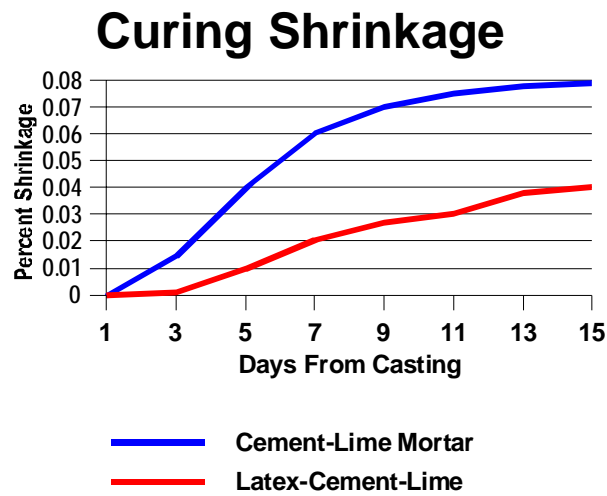


Figure 4. Curing Shrinkage of Latex-Modified and Unmodified Cement-Lime Mortars (Edison, 1998)

Water Vapor Transmission, ASTM E96

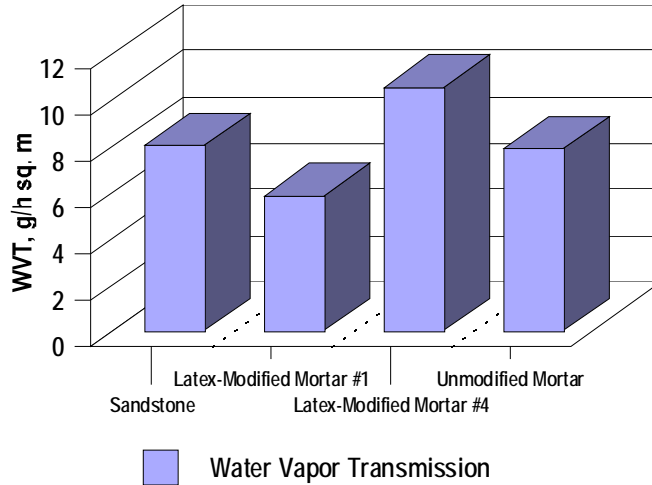


Figure 5. Water Vapor Transmission in Sandstone and Commercial Repair Mortars (Edison, 1997 & 2001)

The same specimens were tested for liquid water transmission rates using RILEM Method 11.4 Water Absorption Under Low Pressure (Pipe Method). While the importance of moisture vapor transmission is generally recognized, the desired function of the repair mortar in response to liquid water exposure is much less often discussed.

“There is no industry standard that directly addresses or specifies desirable or undesirable levels of (liquid) water permeability for repair materials. The objective, however, should be to achieve a kind of balance, allowing internal moisture to pass through the patch material, while maintaining reasonable water-shedding characteristics for repaired building surfaces. Generally, we would like the permeability of a repair material to be relatively close to that of the sound building stone.” (Meyer 2000)

As seen in Figure 6, the results of this testing indicated that the rate of liquid water transmission of the latex-modified Mortar #1 was closest to the sandstone’s rate. Latex-modified Mortar #4’s water transmission was an order of magnitude higher than the sandstone. Transmission through the unmodified mortar was three orders of magnitude faster, with water leaking all the way through the specimen within 5 minutes. The moisture vapor and liquid water transmission test results were combined to lead to the conclusion that latex-modified Mortar #1 most closely resembled the original stone with regard to these characteristics. This was the formulation used in the restoration of the Palladium Building.

Some 16,000 lbs (7270 kg) of repair mortar were placed in 1982. Twenty-one years later, when the building was pressure-washed following its sale in 2003, virtually all of the 1982 mortar was found to have remained in excellent condition (Figure 2). At ground level, minor repairs were required in a limited area that had been affected by winter snowplowing operations, and several small areas of previously unrepaired and subsequently exfoliated brownstone surfaces were also addressed.

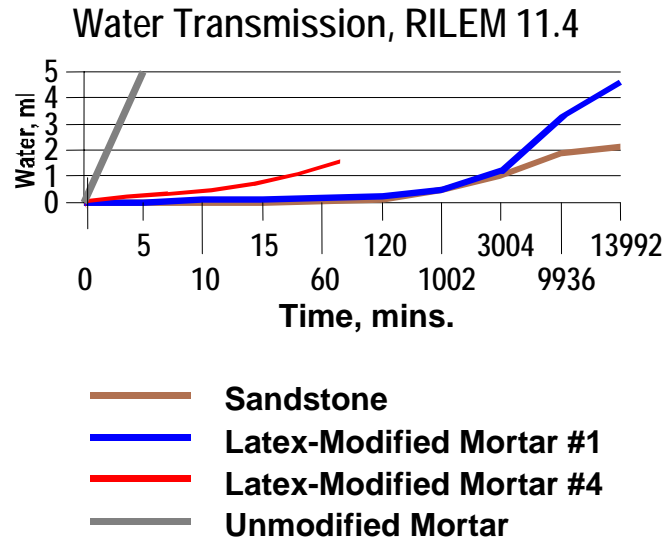


Figure 6. Liquid Water Transmission in Sandstone and Commercial Repair Mortars (Columbia University)

In a manner similar to the repointing mortar formulations used at the Key West Customs House, the restoration mortar produced for the Palladium project satisfied all engineering and performance requirements while visually matching the original, historic material. Although lime was a minor component in this system, its contributions to overall performance and workability are significant. This approach to stone repair mortar formulation has been finessed and updated over the course of the past 23 years, but the core design has been maintained and has performed successfully on thousands of projects throughout the United States and Canada.

In the absence of consensus-based industry standards for composite repair mortars, some conservators tend to specify stone repair mortars strictly according to their particular composition, rather than on the basis of performance. In some cases, acrylic latex modifiers have been excluded; in others, portland cement has been excluded; and in yet others, the use of lime putty is specified to the exclusion of hydrated Type S lime or other suitable alternatives.

From an engineering viewpoint, there is rarely only one acceptable way to achieve a particular balance of performance properties. ASTM standards for various masonry materials often specifically permit the use of materials that do not comply with the standard specifications, if they have proven satisfactory in performance and durability. From a preservation perspective, replication of original materials for masonry mortars and plasters are often valid decisions, particularly when the original materials were properly selected and prepared, and have performed well. But in composite repair, replication is not an option, and there is no philosophical justification for restricting repair materials to any one particular 18th or 19th century technology.

4 Grouts for Cracks and Voids: Engineering Applications

Injection of cracks in concrete structures has generally been performed using epoxy resin systems. However, there are a number of concerns with this approach when treating historic masonry.

Epoxy systems are irreversible treatments. Once an epoxy resin has reacted with its curing agent to form a higher molecular-weight solid polymer, there are no practical means for removing these materials without destroying the substrates to which they have been applied. This concern may extend beyond the crack void surface itself into the sound adjacent masonry.

Epoxy resin injection systems are generally low viscosity, 100% solids formulations designed for maximum penetration into small cracks. Since these systems contain no fillers or other macroscopic particles, they are very efficient in penetrating very small voids and pores. When used in porous masonry, this capacity to penetrate may lead to migration of the uncured adhesive from the crack void, where the resin has intentionally been placed, to the masonry pore structure, where the presence of adhesive is undesirable. Epoxy resin systems tend to visibly darken porous masonry, creating a deep “wet” appearance. As a result, the zone alongside injected cracks, darkened by epoxy migration, can become irreversibly unsightly.

A great deal of discussion has also been aimed at the mechanical incompatibility of epoxy resin systems, particularly with softer masonry. As shown in Table 2, epoxy systems have a much higher linear coefficient of thermal expansion than masonry substrates. While this is unlikely to be problematic where small volumes are used in filling fine cracks, distress to masonry substrates may occur if larger voids were to become filled with epoxy. Typically, epoxy systems are also much harder and higher in modulus than most masonry substrates, and any stress developed between the epoxy and the masonry will invariably damage the masonry.

Table 2. Linear Coefficient of Thermal Expansion for Various Materials (BIA 1991)

MATERIAL	Linear Coefficient of Thermal Expansion, in/in/°F x 10⁻⁶	Linear Coefficient of Thermal Expansion, m/m/°C x 10⁻⁶
Clay Masonry	2.5 – 3.6	1.4 – 2.0
Concrete	4.5 – 6.0	2.5 – 3.4
Granite	4.7	2.6
Limestone	4.4	2.4
Marble	7.3	4.1
Stainless Steel	9.9	5.6
Structural Steel	6.5	3.7
Epoxy*	18 - 20	10.1 – 11.3

* http://www.engineeringtoolbox.com/14_95.html

Moisture vapor permeability has also been an issue with regard to epoxy resin use in masonry crack injection. Cured epoxy films are essentially impermeable to moisture vapor, and if films are oriented parallel to the surface of the masonry, moisture entrapment can occur. This creates the potential for eventual delamination along the adhesive interface, particularly in freeze-thaw exposures. This is unlikely to occur, however, when injecting typical stress cracks that are perpendicular to the surface.

Lime-cement grouts overcome most of the objections inherent in the use of epoxy systems by utilizing lower strength materials that are based on fine particulates that cannot as readily migrate into small pores. They do not tend to darken treated surfaces, do not undergo greater expansion and contraction than masonry substrates with temperature change, and do not

significantly impede the transmission of moisture and moisture vapor. Although injected grout treatments are not readily reversible, they are more readily separated from stone substrates than the interpenetrated and interlocked epoxy alternative treatments. Performance data for a latex-modified lime-cement grout is listed in Table 3.

Table 3. Typical Performance Properties of a Latex-Modified Lime-Cement Grout (Edison)

PROPERTY	RESULT
Compressive Strength, PSI (MPa), ASTM C579	1300 – 1800 (9.0 – 12.4)
Tensile Strength, PSI (MPa), ASTM C307	300 – 400 (2.1 – 2.8)
Flow, ASTM C230-Modified (No Vibration)	116 mm
Direct Tensile Bond Strength, PSI (MPa)	>125 (0.9)
Drying Shrinkage, ASTM C1148	0.10%
Moisture Vapor Transmission, g/h sq. m, 6 mm specimen thickness, ASTM E96	5.1 – 10.5
Linear Coefficient of Thermal Expansion	4.7 in/in/ ^o F x 10 ⁻⁶

Pressure-grouting of masonry cracks and voids with lime-cement grouts has become a relatively common approach to addressing structural cracking problems in unreinforced masonry. From 1987 to 1991, the Hazardous Buildings Committee of the Structural Engineer’s Association of Southern California worked to develop a protocol for cementitious grout injection to stabilize masonry cracks resulting from seismic events. This led to adoption of the protocol as part of the City of Los Angeles Building Code. Requirements are detailed in document RGA #1-91 (currently reissued as P/BC 2002-056) by the City of Los Angeles Department of Building Safety, entitled “Crack Repair of Unreinforced Masonry Walls With Grout Injection” (<http://www.ladbs/faq/info%20bulletins/building%20code/IB-P-BC%202002-056%20Crack%20Repair%20of%20URM.pdf>).

The methods detailed in the protocol are described in the document as “economical, structurally effective and aesthetically satisfactory”. By filling the cracks and the surrounding voids inside the wall, the wall strength is restored without disturbing the adjacent mortar. According to the SEAOC, more than 7,000 buildings have been stabilized using the methods and materials prescribed.

The materials specified for use in grouting include fine sand, portland cement, hydrated Type S lime, and Class F fly ash. While this type of grout is effective for filling cracks from approximately ¼” up to approximately ¾” in width, finer cracks and larger voids are not addressed.

In 2002, the State of California Direct Construction Unit evaluated two prepackaged polymer-modified grouts designed for use in a broader range of crack widths. The grouts were tested for a variety of characteristics, including flow and adhesion, in accordance with the methodology used by the SEAOC in developing the materials specified in the L.A. Building Code. Although the grouts included lime, portland cement and sand, the formulations took different approaches to particle size distribution and incorporated a number of flow-enhancing, set-controlling and adhesion-promoting admixtures. The coarser of the mixes was found suitable for filling cracks and voids ranging from ¼” width to several inches in diameter, while the finer grout was found suitable for cracks down to approximately 1/16” width. Both grouts exhibited compressive

strength and modulus of elasticity comparable to a Type N masonry mortar, as required by the project's engineers.

The same dual grout approach was used to stabilize historic masonry retaining walls in the City of Savannah, Georgia. Large cracks, caused by horizontal displacements, were injected with the coarser grout, while finer cracks were injected with the finer grout. In both applications, a positive displacement grout pump was used to deliver the grout to sections of small diameter steel pipe set into the wall at injection points prepared along the length of the cracks. Refer to Figure 7. Pipe nipples were set in a lime-cement masonry mortar, matched to the existing historic mortar. Grout was pumped into each port until it emerged from the adjacent port. According to field observations, no difficulties were encountered in achieving grout flow to adjacent ports and, in some cases, grout emerged from ports up to 6 feet (2 m) from the injection point. Based on these observations, the grouts were determined to have effectively achieved the objectives of the project: filling a wide range of cracks and voids, achieving efficient flow, and providing positive aesthetics, as shown in Figure 8.

As the lime revolution in restoration takes hold in the United States, some conservators have required injection grouts based almost entirely on lime, rather than on the types of lime-cement formulations specified in the Los Angeles Building Code. The repair of cracked joints on the dome of the North Carolina State Capitol, using a pozzolan-modified lime, was one such instance.

Work on the octagonal dome, shown in Figure 9, was undertaken to restore watertight integrity, which had been compromised by cracked masonry mortar joints between the dome's stone blocks. Old mortar joints were raked out to a depth of 1" and ¼" diameter holes were then drilled to a depth of 6" to 8", spaced at 2' on center along the length of each of the raked and cleaned joints.

Sections of plastic tubing, ¼" in outer diameter and 18" in length, were inserted into each hole and stabilized with custom matched prepackaged lime mortar. All joints were then repointed with custom lime mortar to within ¼" of the original joint surface. Water was injected into each tube in preparation for grouting. Bulk caulking guns, reduced to a ¼" tip size, were used to inject the lime grout into the plastic tubes. Each port was injected until one of the following occurred:

1. Grout emerged from the adjacent port
2. No further grout flow could be achieved
3. Grout emerged on the interior surface (Figure 9, Right)
4. Four to five quarts of grout were injected into any single port



Figure 7. Injection of polymer-modified lime-cement grouts on historic masonry retaining walls on Factors Walk in Savannah, GA, was performed using two different grout formulations.



Figure 8. Cracks in Historic masonry retaining walls on Factors Walk, Savannah, GA, before and after injection with a combination of fine and coarser polymer-modified grouts.

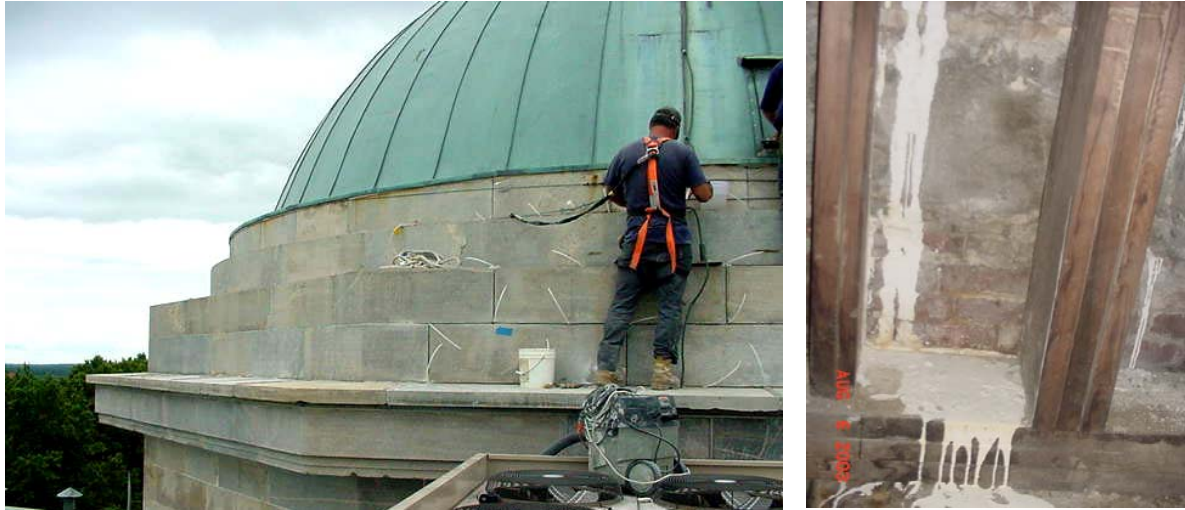


Figure 9. Workers prepare injection tubing for installation of lime-based grout at the North Carolina State Capitol (left). In some areas (right) the lime grout flowed all the way through the masonry to the interior surface .

As injection was completed at each port, the tubing was folded over and secured with an elastic band to prevent back flow. Location and quantity of grout injected for each port was recorded. Once the grout set, all tubing was removed and the holes were repointed. A final ¼” lift of custom-matched, prepackaged lime mortar was then placed in all joints to complete the repointing.

The pozzolan-modified lime grout was designed to provide somewhat lower compressive strength than the cement-lime grout applied in Savannah (900 – 1,000 psi vs. 1,300 – 1,800 psi). The higher lime content would also be expected to reduce modulus of elasticity, thereby minimizing transmission of stresses from stone to stone.

5 Conclusions

The diverse applications of Type S hydrated lime in historic restoration mortars and grouts have been illustrated. Properly formulated mortars combining lime, aggregates and any number of potential additional binders, modifiers, colorants and additives, restoration mortars and grouts can be customized to meet the performance and aesthetic requirements of a wide range of historic restoration applications. Lime can be used as the primary binder to provide low-strength, low-modulus mortars; or used in combination with other binders, such as portland cement to reduce modulus and increase water retention; or used as a low-level additive to improve adhesion and workability. Type S lime is one of the most useful tools available to formulators of mortars and grouts for use in historic restoration.

Acknowledgements

Table 1, Reference material and data courtesy of Rohm & Haas Co.
Figure 7, Photo courtesy Alpha Construction
Figure 8, Photos courtesy Alpha Construction
Figure 9, Photos courtesy Carolina Restoration and Waterproofing

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