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REVISITING STONE REPAIRS: ESTABLISHING EVALUATION PROTOCOLS AND REVIEWING PERFORMANCE

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Abstract

Traditional methods for repairing stone have been supplemented over the last three decades with new materials and techniques conforming to conservation standards developed for historic buildings and monuments. Treatments for surface loss and disaggregation have evolved, as have new materials for crack and loss repairs, but the durability of modern treatments is not widely known beyond individual or institutional experience. This paper will set forth evaluation criteria and protocols that were used to revisit and evaluate treatments performed over the last 30 years in the New York City metropolitan area. Adoption and modification by other investigators would be welcome.

1. Introduction

General methods for repairing exterior stone that have been used for thousands of years still serve as the basic toolkit for conservators and crafts persons. Repairs to cracks and losses have been the standard treatments, supplemented in recent centuries by remedies for surface loss and disaggregation. The last thirty years have seen the use of some different materials and techniques, but their performance in the field has been mostly anecdotal; repair projects are rarely revisited with the express purpose of ranking how the treatment performed over time. To the best of our knowledge there is no durability measure for different repairs on the same material, or in different climates or exposures. This paper is an effort to begin the process of collecting data for evaluation of the effectiveness and durability of exterior stone repairs by revisiting treatments performed over the last 30 years in the New York City metropolitan area.

The average longevity of surface repairs made with cement or lime based materials has been established by observation – inspections of masonry facades often reveal failed repairs for which installation dates are known. Over the last few decades, however, prepackaged proprietary materials have been installed extensively in favor of traditional site-mixed repair materials. Polymeric adhesives have found widespread use. Stainless steel pins are used to stabilize broken or displaced stones, enabled by hand-held percussion drills. Alkoxysilanes have been adapted for the consolidation of disaggregating stone where lime based or organic materials had traditionally been used. But the adoption of new technologies is not universal and traditional materials and techniques are still being employed.

To evaluate the durability of the recently developed materials and techniques as well as the traditional repairs, a number of exterior stone projects completed between 1979 and 2006 were reviewed, and the repairs were evaluated for efficacy, durability, and appearance. A protocol and criteria for evaluation have been developed to establish the performance of the repairs. The repaired stones are marbles (mostly dolomitic), limestones, granite, and sandstones (primarily brown sandstone).

2. Developing evaluation criteria

The effectiveness of a repair over time should be measured against the original treatment objective, which varies with the type of damage being repaired and its location on a structure. Considered in this study are surface losses, cracks, and surface disaggregation. In addition to having a physical function, many repairs also function aesthetically by contributing to the re-establishment of the appearance intended by the original architects or builders.

As considered in this study, loss repairs are generally intended to meet the following objectives, recognizing that single repairs may have more than one physical objective. Typical treatments are listed after the objectives:

- Prevent water from collecting on building surfaces: dutchman repair, patching repair, retooling surface
- Re-establish load path continuity at large losses: unit replacement, dutchman repair
- Reduce surface area subject to weathering forces: dutchman repair, patching repair, retooling surface (small shallow losses)
- The repair itself must not become a hazard: dutchman repair, patching repair
- Re-establish original design intent: unit replacement, dutchman repair, patching repair

Crack repairs generally address related issues, with objectives for different types of treatments, as follows:

- Prevent detaching stone segment from falling: anchoring, pinning
- Prevent water penetration into the crack: surface patching, grout or epoxy injection
- Re-establish load path: grout injection
- Accommodate inherent movement: sealant or gasket installation

Surface disaggregation can be treated to the following ends, with treatments listed:

- Arrest disintegration and re-establish strength and mineral cohesion: consolidation with alkoxysilanes
- Reduce surface area subject to weathering forces: surface retooling (large shallow areas)[i]

With identification of the repair objectives, factors for establishing the failure of the repairs can be established. In the absence of failure factors, the repairs are considered successful in the following cases.

Loss repairs:

- Should not be loose or de-bonded lest they become a potential falling hazard
- Should remain cohesive to retain load path continuity, and to prevent pieces from becoming a potential falling hazard

- Should not have separations (cracks) at interface with surrounding stone
- Should not have weathered differently from mother stone
- Should not have shifted color

Crack repairs:

- At repair to prevent falling, such as pinning, the piece should not have moved
- Avenues for water entry into crack should not be present
- Where load path was re-established, movement of stone at or adjacent to repair should not have occurred after repair
- Inherent movement was accommodated
- Should not have weathered differently from mother stone

Surface disaggregation:

- Surface should be cohesive, with no loose stone grains or crystals
- Surface irregularities that could collect water should be at a minimum

2.1 Inspection protocols

This study examined the in-service performance of stone repairs on multiple buildings. The projects were not under construction so scaffolding was not generally available.[ii] Accordingly low cost methods were relied upon to gather the data. Repairs were evaluated in most instances from the ground level or roofs. When repairs could be accessed, they were tapped with a mallet while a hand was held on the repair to detect any vibration that might indicate adhesion problems; the sounding technique was used on dutchman repairs, patches, and crack repairs. Repairs were also examined visually to detect edge separations and surface cracks. The presence or absence of loose stone grains on surface repairs was detected by manually rubbing the surfaces without force.

Where access to repairs was not possible, visual evaluation methods were developed. Loose stone grains and vibrations could not be detected. Repairs were examined with binoculars. Digital photographs, taken with telephoto lenses, were manipulated by increasing the contrast to enhance any visible edge separation of patches and crack repairs.

Color photographs taken at the time of installation were used to determine whether mortar repairs had retained their original color. The color of the mortar repair in the original photograph was compared to the surrounding stone. The 2012 photograph of the repair was then examined and the two photographs were compared to detect any change in the visual difference between the mortar and stone. The manipulated photographs (with increased contrast) could not be used to make the color evaluations.

3. Repair Evaluations

Eighteen buildings or structures were visited for this study. The stone repairs in most of the reviewed projects were designed by the authors. At all but one of the projects[iii], implementation of the repairs was overseen or monitored by the authors, who also took project photographs documenting the repairs. Those photographs, as well as the original project drawings, specifications and product submittals were consulted for this study. When drawings were available, they were taken to the building to locate repairs. The full information listed above was not available in all cases. In the case of the three projects from the early 1980s only the authors' recollection was available to identify the type and location of repairs. The following is a summary of our observations in 2012 of various repairs carried out at the buildings that were visited for this study. Completion dates for the projects ranged from 1979 to 2006.

At Brooklyn Borough Hall, one of the 18 reviewed buildings, repairs made to the Tuckahoe marble (dolomitic) in 1989 were monitored by R. Pepi. In 2001 D. Koga examined the stone again and designed repairs that were completed in 2006. The 2001 survey identified some repairs from 1989 that had failed, as well as conditions that had either not existed in 1989 or had not been addressed at the time. The building was revisited for this study in 2012.

For this study, repairs were reviewed in the following stone types (with number of projects in parentheses):

- Granite (5)
- Brown sandstone (4)
- Ohio sandstone (1)
- Limestone (5)
- Tuckahoe marble (6)
- Serpentenite (2)

The repairs examined were:

- Dutchman repairs, with and without metal anchors
- Cast stone veneer full face dutchman repairs
- Mortar patches and surface crack repairs: site mixed portland cement and lime mortars, with and without acrylic admixtures; proprietary mortar mixes, with and without acrylic admixtures; site mixed epoxy mortars; pigmented polymeric adhesives
- Pinning repairs to cracked stones
- Injection crack repairs: epoxy; grout
- Surface retooling
- Chemical consolidation

Dutchman repairs ranging in size from roughly 100 sq. cm to 1,000 sq. cm were examined in granite, brown sandstone, Ohio sandstone, Indiana and Alabama limestones and Tuckahoe marble. Most were set with acrylic modified mortar; a few were set with unmodified portland cement mortar. With one exception, the repairs employed stainless steel anchors fabricated from wire or rods set in epoxy or polyester adhesive. Some of the dutchman repairs performed in 1989 at Brooklyn Borough Hall were installed without metal anchors or ties, were found to be loose when examined in 2001, and were pinned in 2005. All dutchman repairs examined for this study were sound. There was no evidence, either visual or tactile that any of them had become detached or even partially separated. Edge separation of hydraulic lime perimeter mortar joints was observed at two dutchman repairs in Tuckahoe marble at the Washington Square Arch, although the repairs were otherwise sound. Some perimeter mortar joints on the 1989 dutchman repairs at Brooklyn Borough Hall were discolored but sound.

Cast stone face veneers were employed in two rock-faced brown sandstone projects (1983 and 1999) revisited during this study. In both cases molds for the veneers were taken from the existing stone. The veneers were anchored with threaded stainless steel rods set in modified polyester adhesive. None of the examined repairs exhibited any signs of failure or apparent change in color.

The authors routinely encounter previously executed patch and crack repairs of mortar. Chemical analysis of the repairs is not always practical, nor required, therefore composition of the mortars is usually uncertain. Sound and failed repairs of both types are usually found on the same building. The failure of individual repairs of a given type is dependent on the microclimate and individual craftsmanship of the item as well as the inherent properties and suitability of the technique and materials. Sound repairs are often left untreated on the same buildings where failed patches are replaced. At Brooklyn Borough Hall, one older patch, left in 2001 as sound, is now starting to separate at its edges.[iv]

The present study reviewed patch repairs on limestone, sandstone and Tuckahoe marble executed with polymer modified mortars, either site mixed or manufactured, or proprietary mortars with no polymer additives (as claimed by the manufacturer). Dozens of repairs with proprietary patching mortars (Jahn repair mortars and Edison Custom System 45) were observed or inspected and failure was observed in only one case in a repair installed in 1995 at the New Victory Theater. A crack had propagated through the repair (in brown sandstone) and adjoining stones; sounding indicated that the mortar had partially separated from the underlying stone, although no edge separation was observed. The crack could have occurred after reconstruction of an adjacent staircase redistributed the loads in the wall.

Because the crystalline mineral makeup of granite differs so markedly from the surface appearance of mortar, aggregate from matching granite (crushed and sieved) was set into the surface of its repair material in all of the projects reviewed. In two projects the mortar contained acrylic additives and the repairs remained sound, although one repair was significantly darker than the surrounding stone. A construction era photograph of the repair was not available for comparison. In another project, 365 Fifth Avenue, completed in 1993, epoxy was the matrix for the granite particles. Some of the repairs appeared darker than the surrounding stone and in others the visible portions of the epoxy matrix appeared to have yellowed. One repair on an arris at pedestrian level was missing altogether; remnants of the epoxy were visible in the cavity. In the same project, detached granite fragments were reset with epoxy mortar, which was also used to fill the shallow adjacent losses. Flecks of white discoloration were visible, as well as partial yellowing of the matrix.

In two projects completed *c.* 1983 near Gramercy Park, composite patches in brown sandstone were shop or site mixed and incorporated acrylic additives (Acryl 60) in the scratch coat and the colored finish coat. Aggregate was selected to match the color of the stone. The surface paste of the patches has weathered somewhat, exposing the aggregate. Edge separation is apparent on one of approximately one dozen patches reviewed in the two projects.

In a pilot project from *c.* 1982 a deteriorated flute on a Tuckahoe marble column was reconstructed with a site mixed portland cement/lime mortar with crushed Tuckahoe marble as the aggregate. An acrylic admixture (Acryl 60) was added to the mortar. The repair is on the back of the column in a portico and is semi-protected but shows no edge separations. A few small fissures are evident across the repair but the mortar seems otherwise sound.

Patching repairs performed with pigmented polymer adhesives (manufactured by Akemi), primarily used to patch interior marble, were observed on serpentenite on two buildings. Polyester adhesive was installed on the Swiss Center in 1998. Of the approximately two dozen repairs reviewed, two exhibited minor edge losses. Pigmented epoxy adhesive was installed at the door enframements of the other building (11 Madison Avenue) in 2002. Approximately twenty repairs were reviewed, and three failures were observed, all adjacent to doorways. There was some edge loss in two repairs. One repair had cracked through its center and had partially detached. The original patches were pigmented to correspond to the surrounding stone, which varied significantly and the patches blend with the stone with varying success. Construction era photographs were not available so color shifts in the patches could not be determined.

Mortar repairs in cracks yielded varying results. The most successful repairs were routed out a minimum of 3 mm wide and filled with site mixed acrylic modified mortar (Acryl 60 admixture). Edge separations were observed in repairs made with all other types of mortars, but not on every building. Scaffolding was available for inspection of crack repairs of unmodified pointing mortar in Tuckahoe marble, installed *c.* 1979 on St. Patrick's Cathedral; neither the authors nor their colleagues were involved with the original work. The majority of the repairs exhibited edge separation and cracks across their width. This finding supports the widespread belief that conventional mortar repairs have a service life of approximately 30 years. Cracks repaired with proprietary patching mortars fared much better, although none of them had been in service as long. The failure rate was much lower and was roughly correlated with crack width and location relative to vertical mortar joints. Mortar in cracks narrower than 2 mm was sometimes missing. Those types of narrow cracks were generally filled with a grout or epoxy, and the mortar was a topping or cosmetic cap that did not contribute to the function of the crack repair. Where epoxy was the crack filler, it was raked out of the top portion of the crack and residue likely remained on the walls of the crack and prevented the mortar from adhering to the stone.

In two instances mortar in a crack spanning between two vertical mortar joints had separated from the stone on one edge, as had the mortar in the joints above and below. At the Washington Square Arch, completed in 2004, the mortar was a hydraulic lime pointing mortar;[v] in the other building a polymer free proprietary mortar was installed. It is probable that no mortar would have remained intact in those circumstances. Accommodation of inherent movement is an objective of crack repairs, but it is not always possible to know if movement that caused a crack will recur. In the cited cases that objective was not met. In other locations on the Washington Square Arch, narrow crack repairs[vi] were treated as sacrificial, with the expectation that an annual or biennial conservation program would replenish the treatments. The cracks were filled with dispersed hydrated lime putty and topped with hydraulic lime mortar, which was used to point the joints. When observed this year, mortar was missing from many of the cracks.

In the west wall of Grand Central Terminal, a limestone building, some wall sections exhibited multiple vertical crack systems, including continuous step cracks in mortar joints. At least one of the vertical crack systems in each wall section was treated with elastomeric sealant in the vertical joints and lead caulking in horizontal joints to accommodate movements. The remainder of the cracks were filled with patching mortar and the repairs are intact. The project was completed in 2005.

Pinning repairs of cracked stone units were observed on marble, limestone and sandstone. Approximately one quarter of the repairs could be touched and sounded, and no movement was detected. The other repairs were examined visually with signs of movement apparent in only one repair out of approximately three dozen. In that instance, a marble lintel, cracked vertically through its approximate center, was stabilized with stainless steel anchors installed across the crack into the stone above. The crack was filled with proprietary patching mortar, which has partially separated. Because the repair objective was to stabilize the stone, and water cannot dwell in the crack, the crack filler is performing an aesthetic function and should not be considered a failure. Nine other repairs of the same type were observed on the building with no visible separation at the cracked patch.

At the project completed in 1993 at 365 Fifth Avenue, proprietary grout (Jahn injection mortar) was injected into cracks in limestone and filled them to the surface. No distress was observed in the repairs and the color of the grout was close to that of the limestone. In the limestone at 281 Park Avenue South, some cracks were injected with epoxy adhesive. Where the crack was approximately 1 mm wide or less, the epoxy was allowed to fill the crack to the surface. Where cracks, or portions of cracks, were wider, the adhesive was raked out and proprietary patching mortar was installed at the crack surface. Failures in the topping treatment were described above, but the overall treatment should be judged a functional success because the respective pieces haven't moved, and water cannot penetrate the crack.

Shallow spalls and losses were retooled, at locations not visible to pedestrians, on Grand Central Terminal. No surface erosion was visible, although the repairs could not be touched. Some of the retooling repairs were adjacent to mortar patching and dutchman repairs, reflecting the careful selection of appropriate repairs. Retooling of rock-faced surfaces was observed on Lambert Castle, a brown sandstone project completed in 1999. The surfaces were relatively intact, with some flaking at the edges of the stone lamina. In one area, the surfaces of three stones, untreated during the repair campaign, are beginning to delaminate. On the same building, alkoxysilane (Conservare H) was applied to the stones of a chimney that is out of service. No loose stone grains could be felt on the surface of the stones; other signs of surface deterioration, such as flaking or delamination, were not observed. Stone was consolidated with alkoxysilane on four other projects visited for this study, but access was not available to touch the stone. This is a repair that requires tactile inspection.

4. Conclusions

This study represents a very small sample of projects that are meant to serve as the beginning of a data collection effort. Despite the limited number of examples, general trends could be identified. It is no surprise that dutchman repairs were the most successful, with no observed failure and only one documented occurrence of a previous failure, made *c.* 1989. Stone remains more durable than any repair material, by far. Metal anchors and setting materials with more adhesive capacity seem to have extended the service life of dutchman repairs. Cast stone veneers are also effective and long lasting repair materials.

Patching repairs have been advanced by polymer additives to mortars and by prepackaged proprietary materials. There is a definite trend away from mixing materials on site if they can be batched in controlled conditions and sent to the site in sacks. Quality control is enhanced with factory mixed materials, a fact that has even affected pointing mortars. More and more, contractors and designers are asking for prepackaged mortars. Patching mortar is part of that trend, and has performed well in the study projects.

This study underscored the importance of selecting appropriate repairs for the specific conditions being treated. In several projects, the full gamut of loss repair treatments were brought to bear, depending on the size, depth of loss, and location. The overall success of mortar patching repairs was likely enhanced by their relatively small size, which reduces the surface area subject to failure.

The study also brought out the importance of selecting the appropriate treatment for cracks. The forces that caused the crack should be identified, if at all possible, and the repair selected to address the cause – or the symptom if the cause has been remedied in some other way. If the cause cannot be identified, it is often prudent to assume that it is still present and plan the repair accordingly. Accommodating movement is often overlooked in crack repair design, and repair failures result. There were more failures of crack repairs encountered in this study than any other repair type, though the amount of failure was small. The failures partially resulted because some causes of cracks never go away and partially because the objective of the repair was not properly identified. In the case of Grand Central Terminal, the overall crack treatment was successful because continued movement of the façade was recognized and multiple crack repair treatments were employed to accommodate the movement.

It is hoped that this first attempt at studying the in-service performance of stone repairs will spur similar efforts that will contribute to a better understanding of contemporary stone repair materials and techniques, including effects of different exposures and climates.

PROJECT	Rest. Completed	View from	Stone Types	Crack Repairs	Patch repairs	Dutchman repairs	Consoli-dation	Pinning	Retooling Surface	Comments
1 Madison Avenue	2002	Ground and binoculars	Limestone		Jahn M 70	Set with mortar A[1]				No visible defects
			Tuckahoe marble	Jahn M 120	Jahn M 120	Natural stone and cast stone, set with mortar A				Sound
11 West 54th Street	c. 1982	Ground	Tuckahoe marble		Mortar B[2] and ground marble aggregate					Column flute - sound with cross fissures
			Granite		Mortar B, set with granite chips					Sound
11 Madison Avenue	2002	Ground	Serpentinite		Akemi epoxy					1 cracked repair, 2 repairs with separation, approx. 20 repairs sound
			Limestone		Jahn M 70					Sound
15 Gramercy Park South	*c.* 1983	Ground	Brown sandstone		Mortar C[3]					1 repair with edge separation; approx. 6 sound
34 Gramercy Park East	*c.* 1983	Ground	Brown sandstone		Mortar C	Cast stone veneers				No defects
281 Park Avenue	2002	Ground	Limestone	Sikadur Injection Gel	Edison Custom	Set with mortar A				Sound - some surface patching missing in
			Granite			Set with mortar A			Surface not tooled flat	Sound - no disaggregation
365 Fifth Avenue	1992	Ground	Limestone	Jahn M 40 or Jahn M 50	Jahn M 70	?	Conservare OH Stone Strengthene	Y		Sound - consolidation not accessed
			Granite		Epoxy mortar, set with granite chips					Sound, except for one repair missing
Baruch College Site	1993	Ground	Granite	Mortar B		Set with epoxy				Sound
Brooklyn Borough Hall	1989	Ground	Tuckahoe marble		PC/lime mortar - predated 1989 work					1 patch, assesed as sound in 2001, now separating
			Tuckahoe marble			Portland cement/lime mortar				Loose in 2001; pinned in 2006; appears sound
Brooklyn Borough Hall	2006	Ground	Tuckahoe marble	Edison Custom System 45	Edison Custom System 45	Set with mortar A		SS threaded rods. Hilti HIT HY-20		Sound
			Tuckahoe marble	Edison Custom System 45				Cintec anchors 5/8" SS rod		Partial edge separation in surface patch - 9 sound
Carnegie Hall	1994	Ground	Granite		Mortar B, set with granite chips	Set with mortar B				Sound
City Center Theater	1999	Gound, binoculars, roof	Ohio sandstone	Jahn M70	Jahn M70	Set with mortar A	Conservare OH Stone Strengthene r			No visible defects - consolidation not accessed
Grand Central Terminal West Wall	2005	Ground	Limestone	Jahn M 70	Jahn M 70	Set with mortar A			Small, shallow spalls	Sound
			Limestone	Dow Corning 756 sealant						Stepped exp jt. Portions missing at upper wall
			Granite			Set with mortar A				Sound
Lambert Castle	1999	Ground and roof	Brown sandstone	Sikadur Injection Gel, capped with Jahn M 70	Jahn M 70	Natural stone and cast stone veneers, set with mortar				Sound - some surface patching missing in cracks
			Brown sandstone				Conservare H Stone Strengthene		Remove delaminations and flakies	No disaggregation
New Victory Theater	1994	Ground and grand stair	Brown sandstone		Jahn M 70	cast stone	Conservare OH Stone Strengthene			Sound - consolidation not accessed; 1 cracked repair
St. Patrick's Cathedral	*c.* 1979	Scaffolding	Tuckahoe marble	Portland cement/lime mortar						Majority cracked and edge separated - designed by others
Swiss Center	1998	Ground	Serpentinite		Akemi polyester					3 repairs with partial edge failures where patch overlapped stone; approx. 50 sound patches
Washington Square Arch	2004	Ground	Tuckahoe marble	Dispersed hydrated lime putty capped with NHL-2 lime mortar		Set in ? Perimeter joints NHL-2	Conservare OH Stone Strengthene r			Designed by others- edge separation in repairs, consolidation not accessed

[1]Mortar A: Thinset mortar with Laticrete 4237

[2]Mortar B: Portland cement/lime mortar with Acryl 60 admixture

[3]Mortar C: Site mixed portland cement/lime mortar with aggregate selected for color, Acryl 60 admixture in slurry and finish coat

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[i] Most often used on sandstone that has exhibited partial delamination

[ii] The one exception is St. Patrick's Cathedral, where scaffolding is available

[iii] Building Conservation Associates inspected St. Patrick's Cathedral in 2012, where work was last performed *c.* 1979. Representatives from the contractor who performed the work discussed the repairs with the authors.

[iv] The patch predated the 1989 work. No mortar patches were performed in the 1989 project.

[v] Project not designed by the authors.

[vi] The width criteria for this repair is not known