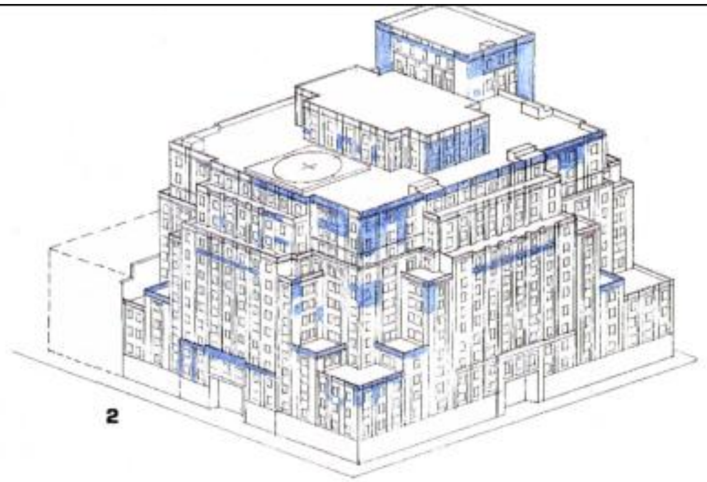
Repairing Limestone Cladding

Corroding anchors and spalling limestone at the main Philadelphia store of Strawbridge and Clothier promoted a simple and cost effective repair program.

1 Overall view of Strawbridge and Clothier, Market Street East. 2 Overall axonometric view locating areas needing repair. 3 Detail of working drawings identifying spalls, patches, and spalling patches.



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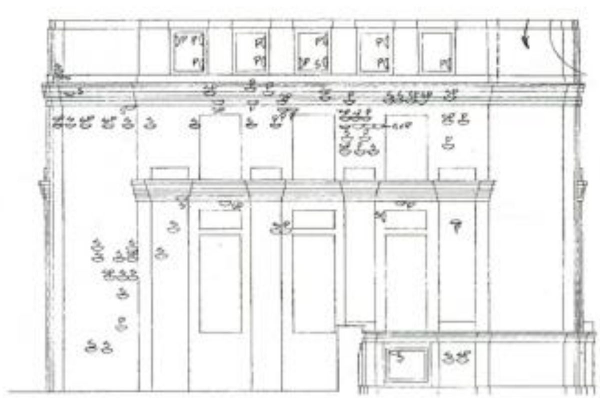

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One of the most frequently encountered masonry deterioration problems is spalling, a loss of surface material that does not affect structural integrity. Typically caused by a variety of processes, including freeze/thaw cycling and the expansion of corroding iron or steel fasteners (called oxide-jacking), spalling is disfiguring and potentially dangerous to building occupants and pedestrians.

Strawbridge and Clothier, a Philadelphia-based department-store, occupies a 13-story limestone-clad building in the center city. When the limestone began to spall, the company recognized the danger to its customers and employees, and twice in the last 15 years engaged a contractor to repair the spalled areas with a cementitious patch. Each repair campaign ultimately failed when patched areas themselves began spalling.

In early 1991, Strawbridge and Clothier contracted with John Milner Associates (JMA) to perform an investigation of the deteriorating facades of the 1929 building. In their report, JMA noted that when the local architectural firm of Simon & Simon had designed the structure they specified that the limestone cladding be secured to the masonry backup wall with galvanized cramps, or strap anchors, a detail that met building standards of the early twentieth-century. After extensive research and testing, JMA concluded that the spalling was caused primarily by the corrosion of those cramps, and recommended the removal of all anchors and the replacement of spalled areas with stone dutchmen to eliminate the threat to life safety.

Documentation and Testing

During the initial work John Milner Associates and the Structural Engineering firm, Keast and Hood, collaborated on a thorough survey of building maintenance files and a physical survey and condition assessment of the structure.

Archival Research

The original architectural and structural drawings, found in the building's maintenance files, provided valuable insight into the building's steel frame and masonry construction. Construction texts of the period were consulted to confirm that the anchoring system they had identified from the construction documents was, in fact, a typical solution.

Inspection

Once the original construction was understood, the team of architects and engineers conducted an extensive survey of the exterior envelope. Using binoculars, they examined each cramp location either from the street or the roofs of adjacent buildings for evidence of spalling or patching. Elevation drawings, reworked from the original prints, became the baseline for recording the condition of each stone as either spalling, patched, or patched and spalling. Because of the steep, and often awkward viewing angle, and the unpredictable lighting conditions outdoors the surveyors' were often unable to detect smaller spalls. Still, they identified over one-thousand spalls, and spalling patches, and predicted that as many as twenty percent more spalls would be detected as work progressed.

Photodocumentation

In addition to writing field notes, members of the team photographed typical examples of the deteriorated limestone cladding. The photographs become part of the record of work performed on the building and provide proof of contract completion.

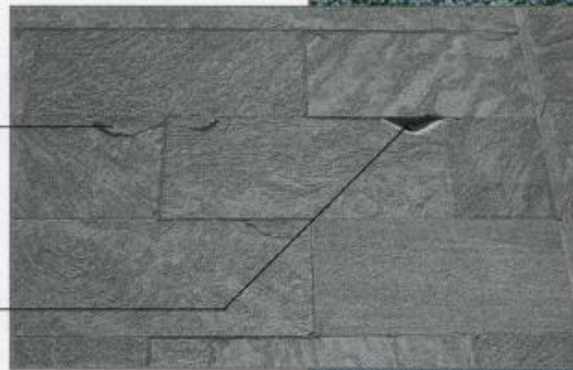
Probes

By observing the structure behind spalls the investigating team confirmed its suspicions, based on extensive experience and knowledge of old structures and historic building technology, that the deteriorating anchors held the limestone skin to a masonry backup wall. In fact, the team had performed destructive probes on other limestone-clad early twentieth-century buildings in Philadelphia and believed that this system was comparable and that further testing would be unwarranted.

Suspected Cause

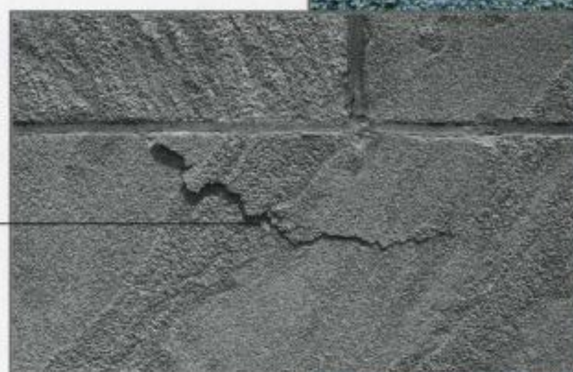
Once the extent of deterioration had been defined, the team began an analysis of the failures. They found that the primary cause of deterioration at Strawbridge and Clothier was the presence of moisture in the wall cavity. Free water had entered the limestone blocks through deteriorated or absent pointing in bedding joints, and moisture, in the form of vapor and air-borne droplets had penetrated the interior skin of the building. The accumulation of moisture coupled with air infiltration and the loss of the protective cadmium coating on the steel led to the corrosion of the anchors.

Although much of the spalled limestone was visible through binoculars from the street or adjacent rooftops, the steep viewing angle and unpredictable lighting conditions meant that as many as 10 to 20 percent of the problem areas are missed through this survey method.

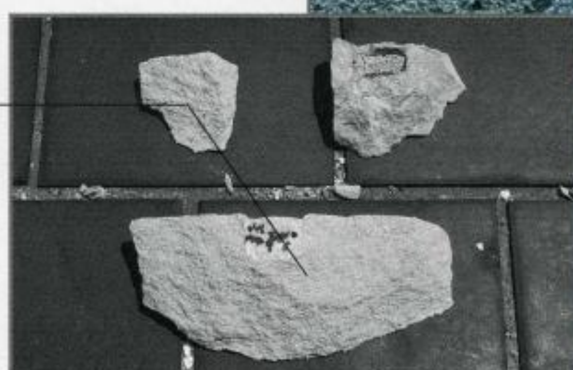


The spalled areas tended to be at the upper corners of the limestone blocks, where the original ferrous anchors were located. Highest priority was given to repairing those spalled areas directly above pedestrian areas or where falling stone could rebound onto pedestrian areas. About 1000 spalls were identified, of which 247 were considered priorities and patched during the first phase of the work.

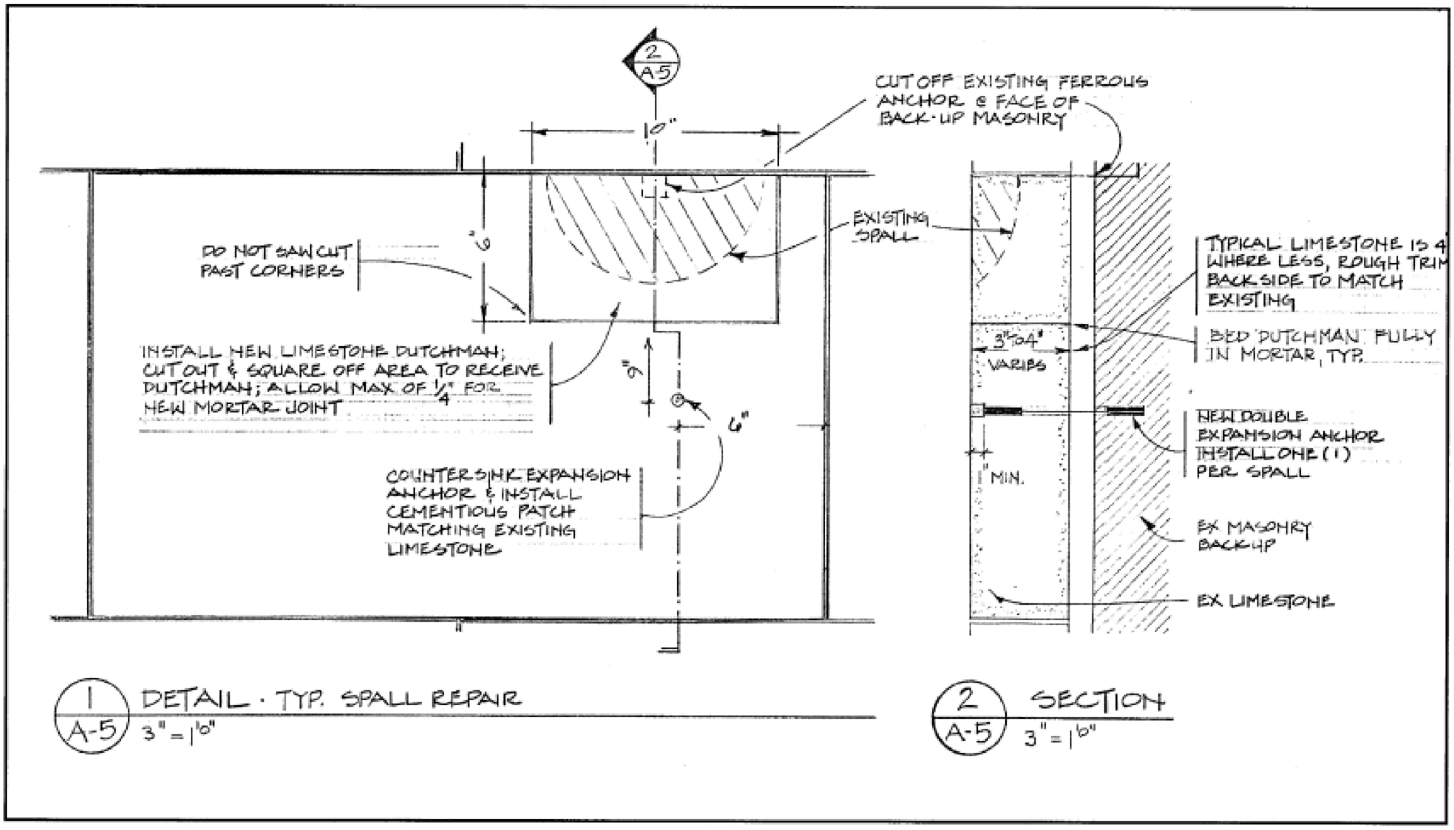
The spalling begins as a U-shaped crack caused by the internal pressure of rusting anchors, exposed to water through leaks in the stone joints, condensation on the inner face of the wall, and gaps in the roofing, flashing, and coping above. Once the crack occurs the exposure of the ferrous anchors to water accelerates the process until a piece of the stone pops off.



The spalled sections varied from small chips to large pieces 8" in diameter and over an inch deep. Each piece of limestone (or cement patch from previous repair efforts on the building) weighed between one and two pounds. Most of the chips were falling from the upper floors of the building, 10 to 13 stories above grade.



Once a section of stone had spalled off, the anchor was exposed to further corrosion, leading to additional cracking of the limestone. Repairs were necessary, not only to protect pedestrians from falling stone chips, but to stem the continued deterioration of the limestone wall.



Specifications for preparation and repair of spalled limestone blocks.

Changes in Practice

In the sixty-three years since this building was constructed, the Indiana Limestone industry has revised its standards of practice to eliminate coated anchors from its list of acceptable fasteners. JMA could not locate a specific reference to the change in recommended practice. However, the probable impetus for the change was recognition of the relationship between corrosion of iron and steel and alkalinity in concrete.

Corrosion of Iron and Steel

Iron and steel reinforcement in concrete is passively protected from corrosion by the alkaline qualities of the cement paste (typically, pH equal to or greater than 10). The pH level falls as carbon dioxide in the air reacts with calcium hydroxide in the concrete to form calcium carbonate. When the level falls below the threshold of a pH equal to 10, corrosion of ferrous materials may commence. JMA confirmed this hypothesis when they collected rainwater from the face of a limestone wall and found its pH to range from 8.0 to 8.2.

Cathodic Protection

The steel anchors originally had been coated with a sacrificial layer of cadmium. However, the life of that coating is limited. In the presence of an electrolyte, such as water, the cadmium and steel create a galvanic cell (essentially a mini-battery) in which a minute current flows from the cadmium to the steel. The flow of electrons prevents the steel from corroding, but accelerates the deterioration of the cadmium. At some point, the supply of cadmium is exhausted and the steel begins to corrode.

Spalling

Corroding steel may expand to 8 times its original dimension and in the processes induce huge stresses in the material in which it it embedded. In this case, the corroding steel anchors in many of the limestone blocks exerted forces that exceeded the ultimate strength limits of the stone and chips spalled from the surface. This is not always true, in some cases the internal stress is rising, but is not large enough to induce failure. Such incipient spalls are difficult to detect. However, JMA believes that a device that can measure changes in pressure and strain within the stone can be developed to detect potential spalls before they occur. The details of this device have not been fully developed.

Therefore to avoid costly delays in project execution, JMA ordered 20 per cent more dutchmen and anchors than they had identified.

Scheduling

The team developed a work schedule that prioritized repair of the most severely deteriorated material that also posed the greatest pedestrian hazard. Work that was "imperative"- indicating that it should be executed within a calendar year and represented a threat to life safety or structural integrity- was divided into "high", "moderate", and "low" pedestrian hazard zones. Other work, termed "required", represented major repairs or significant deterioration that should be completed in 1 to 3 years, or "desirable" work that could be left for 3 to 5 years. The first phase of the project, involving about 300 of the most severe spalls, was successfully bid by Joseph Dugan & Sons, contractors.

Evaluating Alternatives: Technology

Anchors

In testing conducted on other projects with similar cladding problems the team found that an anchor using two brass expansion shells and a stainless steel rod outperformed other devices in securing the stones. Because the anchors had to resist only a minimal outward thrust of the cladding, the substantial thrust capacity of a nut and washer combination was deemed unnecessary. Further, when a typical combination single expansion shell and nut/washer anchor is properly tightened it induces a potentially detrimental bending stress in the cladding. The double expansion anchors, in contrast, rely on friction between a hole in the cladding and the outer expansion shell, which bears on a fixed thrust plate, to resist thrust loading. The lateral loading caused by the expansion of the brass shield are within the strength limits of the stone.

Quality Control

Quality assurance is built into the installation of the double expansion anchors. The force with which an expanded brass shield grips the limestone is directly related to the force applied to expand the shield. This force is measured directly on the torque

An Indiana Oolitic limestone (ASTM C568, Category II) was quarried to match the color of the existing stone. The stone was lightly sand blasted to closely imitate the weathered texture of the existing material.

To avoid the 6 week delay in ordering additional dutchmen, the architect and contractor decided to order 70 extra stones (in addition to the 247 identified in the initial survey), of which 64 were used.

To reduce cost and to allow for fabrication in the factory rather than in the field, the architects standardized the size of each dutchman (6" high, 10" wide, 4" deep), which was large enough to accommodate the largest spalled area.

The corroded ferrous anchor at each spall point was cut off at the face of the back-up masonry and a new stainless steel double expansion anchors was installed 3" below each dutchman, countersunk 1", and covered with a cementitious patch to match the limestone's color.

Once the spalled sections were identified and located, the contractor scribed around the damaged area using a template and a sharp chisel, and cut out the damaged material using a combination of 4" and 7" diameter saws, drills, and hammer and chisel so that each hole was the same size as the standardized dutchman.

The finished dutchman in place is nearly invisible from the street, although its slightly smoother texture clearly identifies it as a patch from close up. The cost of the dutchman repair about equalled that of cement patches, but the dutchman will last 50 to 60 years, while a cement patch will last only 10 to 20 years.

The new stainless steel anchors were located 9" from the nearest horizontal joint and 6" from the nearest vertical joint. The cementitious patch over the new anchor is nearly invisible.

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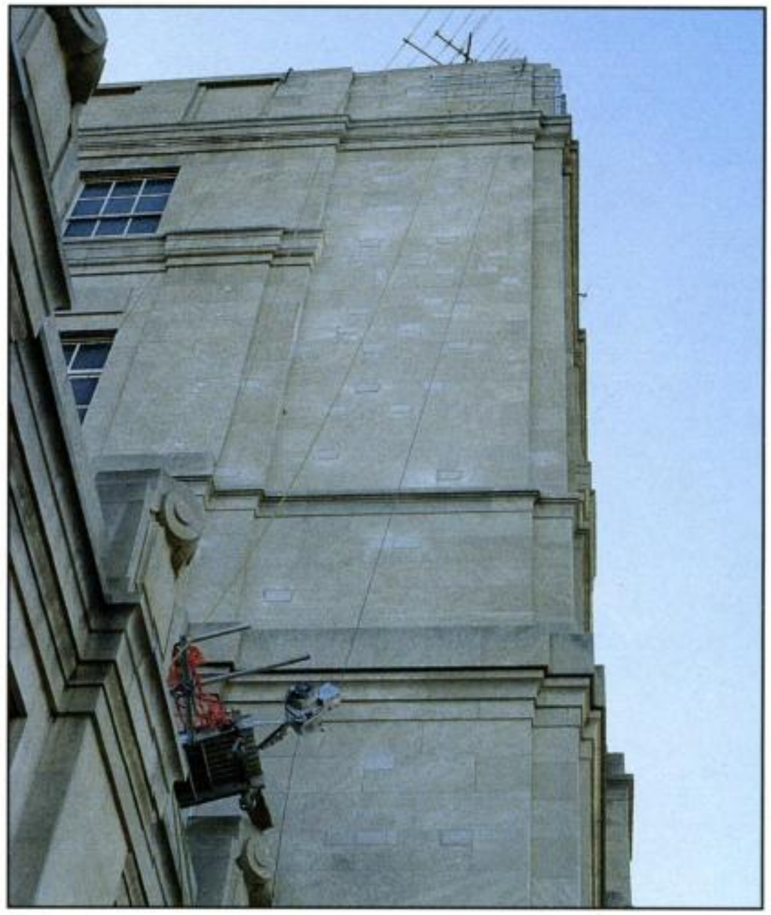

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wrench used to install the anchor. Anchors that do not resist the minimal load are removed, and replaced by a new anchor in another location.

Limestone repairs

Two choices also were considered for masonry repairs: cementitious patches, and traditional dutchmen- new limestone blocks inserted into the existing stone cladding. Cementitious repairs are relatively inexpensive, readily installed by a semi-skilled mechanic, and can be formulated to exactly match the color of the existing stone, but have a typical life of only 10 to 20 years. A cementitious patch also will look significantly different two to five years after installation. Conversely, dutchmen are expensive, require patience and experience to install, and are available in a limited range of colors and textures, but have an average life of 50 to 60 years and will age like the material in which it is fitted. By locating a source of stone similar in color and texture to the original and by standardizing the size of the dutchmen, JMA managed to make the dutchmen competitive with the cementitious repair.

Evaluating Alternatives: Aesthetics

The limestone dutchmen were competitive for repair of the broad flat expanses of stonework. However, carved grilles on the upper facade provided a more difficult challenge. The cost to accurately replicate severely degraded carving would have put the project over budget. Yet, because most of the carved facade elements were difficult to see from the street JMA decided that these elements could be replaced with stones of similar shape, form, and shadow lines and remain virtually indistinguishable from the original work. Importantly, the replacement stones were oversized to allow missing detail to be recarved at a later date, if desired.

Conclusion

The spalling of the limestone cladding at Strawbridge and Clothier was successfully repaired by standardizing the size of dutchmen and the repair process. This systemization made a durable, but more complex solution competitive with the short-term patching more commonly used. Further, by maintaining the weather tightness of the walls and monitoring the limestone cladding for developing spalls, Strawbridge and Clothier will minimize the need for extensive repairs in the future.

Finally, despite the common occurrence of stone spalling as a result of corroding anchors in buildings of this period, the solution employed in this project was developed in direct response to the conditions that were discovered by John Milner Associates. Every building has unique problems that must be analyzed and addressed individually.

4 Preparation of the spalls prior to the installation of the limestone dutchmen. 5 The completed first phase of work, which involved installing approximately 300 dutchmen into standard-sized holes.

Building Materials

Anchors: Dur-O-Wal, Arlington Heights, IL, Series 500500 Double Expansion Repair Anchor for Facade Stabilization.

Dutchmen: Indiana Oolitic Limestone, ASTM C568, Category II.

Project Team: Architect John Milner Associates West Chester, PA; F. Neale Quenzel, Dir., Building Mat'ls. Conservation Dep't.; Frederick Walters, Proj. Manager; Alfonso Narvaez, Arch. Conservator

Client: Strawbridge and Clothier; Tim Sheahan, Operations

Contractor: Joseph Dugan and Sons Erdenheim, PA; George Folkman

Engineer: Keast and Hood, Inc.; Philadelphia, PA; Carl Baumert, Engineer

Costs: Unit costs per dutchman, including stone, installation, demolition and double expansion anchor: excluding scaffolding & site access $125.00.

Photos: Alfonso Narvaez