REHABILITATION OF HISTORIC MASONRY BUILDINGS USING CONTEMPORARY MATERIALS AND DETAILS

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Many obstacles must be overcome to maintain and ensure continued use of historic buildings. Water absorption and leakage through the exterior building envelope, resulting in interior and exterior damage, are frequent obstacles. For historic masonry buildings, water leakage is a common occurrence, as well as degraded materials, falling hazards, and compromised structural integrity.

In these situations, the need for building envelope repair is obvious, but the materials and details used to repair and protect historic masonry buildings from future deterioration can be a major source of disagreement in the preservation community. Changing the fundamental construction of an historic masonry wall system is typically discouraged, even if it improves long-term performance and has little effect on building aesthetics. This article discusses how to rehabilitate a historic masonry building, perform the necessary repairs, and maintain the historic aesthetic while using contemporary materials and details.

PERFORMANCE OF HISTORIC MASONRY BUILDINGS

Before buildings were constructed with structural steel and reinforced concrete frames clad with a veneer, the walls (typically masonry) and the building's self-weight were relied on to support the live and dead loads from each floor level. Wall thickness was proportional to building height, with taller buildings requiring thicker walls to support the gravity loads. Wall thicknesses varied from 8 in. (203 mm) to several feet (meters). Although not designed specifically for lateral loads, load-bearing masonry walls resist wind pressure and suction by interlocking multiple masonry wythes to create a composite section. These load-bearing walls also function as the building envelope. Because masonry is porous, masonry walls act as reservoirs, collecting water within their mass during rain events and releasing it as vapor during dry weather. In today's terminology, this is known as "barrier wall" construction.

In the United States, many historically significant masonry building envelopes are either solid load-bearing or transitional masonry. The transitional masonry combines a mass masonry wall with a structural steel frame for gravity support, but it behaves similarly to the solid load-bearing masonry wall regarding lateral loads and envelope performance. This type of construction subjects the masonry envelope to a variety of deterioration mechanisms. Continuous wetting and drying of historic masonry walls can result in erosion of the mortar. If the masonry remains saturated and is exposed to freezing temperatures, freezing-and-thawing damage can occur. Multiple cycles of freezing and thawing exacerbate the deterioration of the mortar, causing cracking in the masonry that eventually may compromise the structural integrity of the masonry. The subsequent damage results in a decreased capacity to limit water infiltration to the interior, creates potential falling hazards (as pieces of masonry and mortar fall from the building), and eventually affects structural capacity.

Case-study investigations of masonry buildings in cold climates reveal that certain barrier wall masonry building components are more susceptible to deterioration than others. Towers, chimneys, parapets, and spires exhibit more severe moisture- and freezing-and-thawing-related damage than other components of a building. Several common factors contribute to the accelerated deterioration of these components. Because most of these elements extend above roof lines, they are commonly subjected to two-sided wetting, which significantly increases the potential amount of water that can be absorbed by, and cause damage within, these wall elements. Skyward-facing mortar joints at top-of-wall copings also allow increased water infiltration and damage, especially if proper flashing is not present. In historic construction, many towers, chimneys, and other projecting elements are separated from the rest of the building environment and therefore remain unheated, increasing the depth and severity of freezing-and-thawing damage. If deterioration occurs, the lack of reinforcing and mechanical attachment of these components results in the potential for falling debris to occur, particularly given their elevated location on many buildings.

Historic masonry building envelopes need routine maintenance and inspection to identify and repair damage related to ongoing water infiltration. Once damage occurs beyond normal maintenance repairs, the question becomes how to repair the damaged areas.

STRATEGIES FOR REPAIR OF HISTORIC MASONRY BUILDINGS

The Secretary of the Interior's Standards for the Treatment of Historic Properties (Standards) are the generally accepted guidelines and standards for treatment of historic buildings in the United States. As discussed in the Introduction of this document, "The Standards are neither technical nor prescriptive, but are intended to promote responsible preservation practices that help protect our Nation's irreplaceable cultural resources." The Standards contain four approaches to sustain historic properties: preservation, restoration, rehabilitation, and reconstruction, generally defined as follows:

- Preservation "places a high premium on the retention of all historic fabric through conservation, maintenance and repair."
- Restoration "focuses on the retention of materials from the most significant time in a property's history, while permitting the removal of materials from other periods."
- Rehabilitation "emphasizes the retention and repair of historic materials, but more latitude is provided for replacement because it is assumed the property is more deteriorated prior to work."
- Reconstruction "establishes limited opportunities to re-create a non-surviving site, landscape, building, structure, or object in all new materials."

Most building envelope preservation work in existing structures is prompted by visible deterioration or interior leakage that typical maintenance or preservation measures cannot remedy. Determining the appropriate materials and details for repairing the deterioration can be difficult; and, in most cases, the decision comes down to two considerations: performance improvement and sensitivity to historic details (Fig. 1).

In an effort to be true to the historic character and architectural significance of a building, many preservationists will approach building envelope repairs with the same philosophy as they use to approach the rest of a historic building: replace existing materials and details in kind to avoid any deviation from the original design intent. However, buildings restored with historic materials and details likely will age and weather similar to the original construction, making the observed deterioration likely to reoccur more quickly in the future. Thus, building performance is not significantly improved.

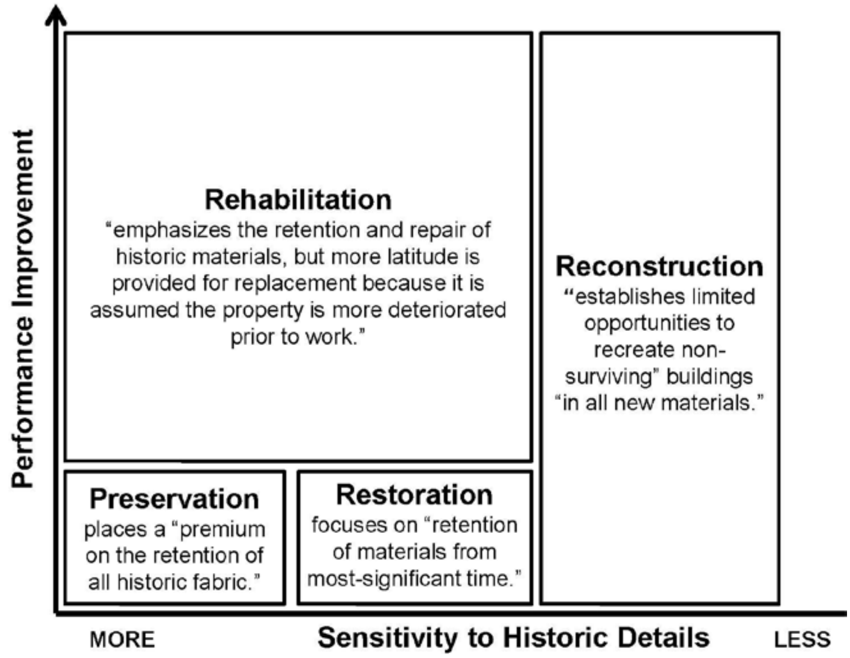


Fig. 1: Performance versus historic sensitivity for preservation standards

It is possible to rehabilitate the architectural fabric of an existing building envelope, while staying true to its historic aesthetic, without completely restoring historic materials and details. Contemporary materials and details, when applied properly, can enhance the performance of the building without affecting the overall aesthetic. Using contemporary materials may allow for new wall-system details that solve the underlying limitations of the original design, thus significantly reducing or eliminating future deterioration. Rehabilitated buildings can not only maintain the original aesthetic but also provide more durable results.

ADVANTAGES OF CONTEMPORARY MATERIALS AND DETAILS

Contemporary concrete materials provide flexibility and strength that their historic load-bearing or transitional masonry counterparts cannot easily match. Materials such as precast concrete and concrete masonry units facilitate more efficient rehabilitation work because they are premanufactured and easily assembled on site. Cast-in-place concrete, shotcrete, and grout can provide effective structural solutions where the original building geometry is complex or must remain in place. Contemporary materials often provide greater strength with less mass than the original masonry. Reduction in the overall mass of the structure may eliminate cracking resulting from gravity-load overstress. The reduction in structural size also provides the opportunity for reconstructing the wall system to better manage water and reduce long-term

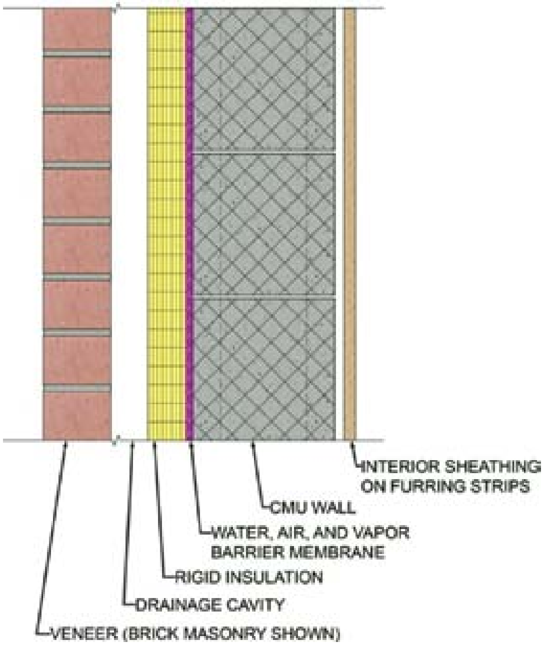


Fig. 2: Typical masonry cavity wall construction

deterioration and damage by including a drainable cavity space (Fig. 2).

In modern times, cost and scheduling implications of load-bearing masonry construction have moved the industry away from barrier wall construction. Instead, modern standards typically involve installation of veneer walls with waterproof, drainable, and flashed cavities. Cavity wall systems typically include exterior cladding (such as brick or stone masonry), an open cavity space, and a waterproofing membrane (which may also function as an air and vapor barrier) outboard of the new backup wall. These wall systems are much cheaper, lighter, and faster to construct than their bulky and labor-intensive predecessors. Cavity wall systems also provide more durable, reliable water management. The cavity space prevents the masonry from storing excess amounts of moisture during rain events and promotes drying from both the outboard surface and the cavity side of the wall cladding, all of which serve to limit freezing-and-thawing damage. The inclusion of a dedicated waterproofing membrane also prevents infiltrating water from contacting and damaging moisture-sensitive interior finishes. Historic masonry building envelope repairs that use contemporary cavity wall construction techniques can produce a more long-term durable repair while maintaining the historic exterior aesthetic because the visible exterior cladding can be replaced in kind.

CASE STUDIES

The following case studies illustrate how various contemporary cement-based structural materials have been used to rehabilitate a variety of historic masonry structures and improve the overall performance of the wall systems. Precast concrete, concrete masonry units, and shotcrete were used in the projects discussed in the following to address ongoing performance issues without affecting the architectural intent of the historic construction.

CONTEMPORARY MATERIALS: REHABILITATION OF BELL TOWERS

New precast concrete backup walls were installed at The Chapel at Bowdoin College in Brunswick, ME. The Chapel, which was dedicated in 1854, was designed by Richard Upjohn in the German Romanesque style using locally quarried granite bearing walls. The building is characterized by twin slender square towers that face the campus quadrangle. Small loophole punched openings with leaded-glass windows appear at what would be floor levels, and larger arched openings with louvers are located at the belfry level. Above the belfries, the towers taper into stone-clad spires with sloped cornices.

A consultant was hired to conduct an investigation of the towers that revealed out-of-plane bulges in the exterior wythe of the granite masonry below the loophole and arched openings. They also found vertical cracks at the tower corners and above the loophole openings. Heavy efflorescence staining, deteriorated interior masonry, and rotted wood floor framing were also apparent. Exploratory openings showed that constituents of the mortar collar joint between the exterior wythe and rubble core had washed out and now consisted mainly of sand. The rubble core and interior masonry wythes were typically in sound condition. It was determined that the observed bulges were caused by the undercut shape of the exterior stones, which created a rotation point for the self-weight of the stones and freezing water within the collar joint to jack the exterior wythe out of plane. Two-dimensional finite element analysis of the towers indicated that the combination of the lateral thrust imposed by the sloped cornice stones, the gravity load of the wall itself, and initial crack propagation resulted in the observed cracking.

Because the rubble core was essentially in good condition below the belfry level, they determined that it could remain in place while the exterior wythe was rebuilt. Although the existing rubble core mortar was a natural hydraulic lime mortar, testing revealed that portland cement mortar provided a good bond to the existing exterior granite when the hydraulic lime mortar did not. For this reason, portland cement mortar and grout for the exterior wall reconstruction were specified. Deterioration above the belfry level, from exposure and unresolved thrust loads, was significant enough to require rebuilding of the entire wall section. They also designed a precast-concrete backup structure

Fig. 3: Precast concrete for bell tower backup wall

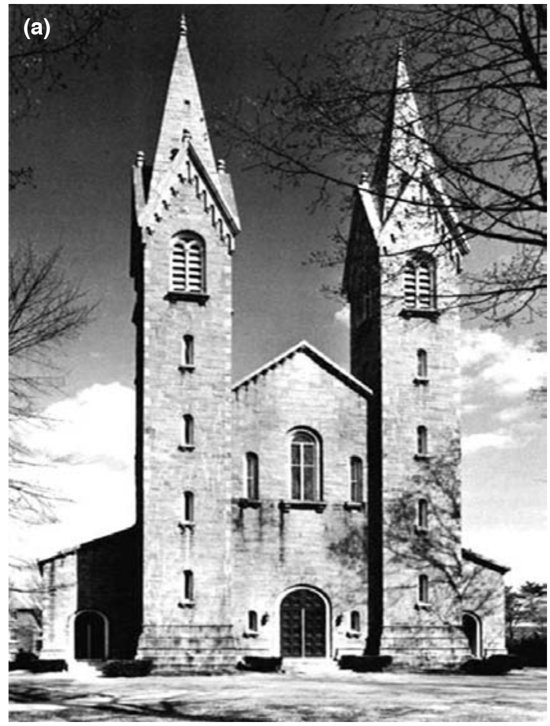
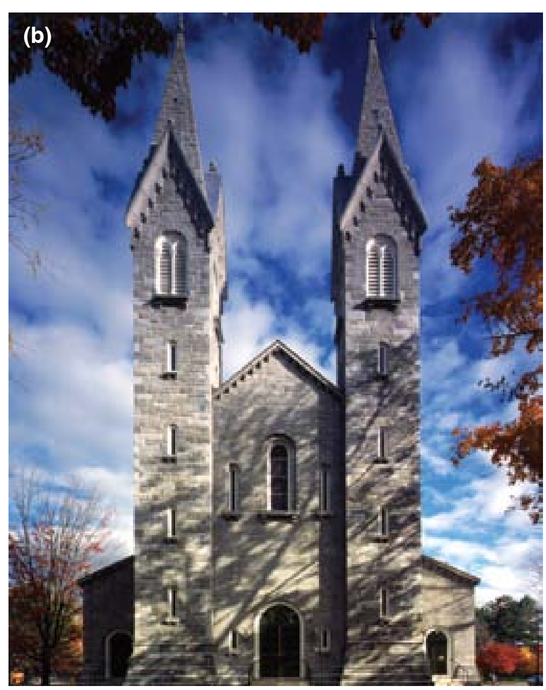


Fig. 4: Images of rehabilitated bell towers:
(a) before; and (b) after



to replace the original deteriorated backup wall address seismic issues, provide supplemental support of the sloping cornice, reduce horizontal thrust at the top of the wall, and provide solid attachment and support for the exterior granite (Fig. 3). In this case, the collar joint between the granite and precast concrete was grouted solid with portland-cement-based grout to reduce water penetration. The college and contractor found the original granite quarry located a few miles from the school and sourced all new granite from that quarry.

The final reconstruction maintained the original building aesthetic despite the introduction of contemporary materials and details (Fig. 4).

CONTEMPORARY MATERIALS: REHABILITATION OF MASONRY WALLS

Although removing and reconstructing historic masonry walls with new concrete masonry or precast-concrete backup structures can provide a durable and economic solution to ongoing issues with historic masonry buildings, there are some cases where this strategy is impractical. In cases where portions of the existing masonry wall system are in good condition and can be salvaged, reconstruction is uneconomical.

One such case of historic masonry rehabilitation without rebuilding the entire wall system also occurred at Bowdoin College. When completing an interior gut renovation of one of the historic dormitories known as "The Bricks," the contractor found significant brick masonry backup deterioration at the upper floor of the building. The exterior wall had recently been restored, and schedule requirements meant reconstruction of the wall was not an option, eliminating new precast-concrete or concrete masonry unit backup walls and cavity wall construction. To provide structural stability for the wall and keep the renovation on track, a new shotcrete backup wall was designed that is mechanically fastened to the recently restored brick masonry veneer to provide composite action (Fig. 5). The new shotcrete wall was reinforced and kept to a minimum thickness to prevent significant impact to the interior renovation. The consultant designed the shotcrete wall to function as a fully independent backup wall system capable of resisting all loads on the wall system. This novel approach to the reinforcement of an existing wall system allowed the college to open the renovated dormitory on time without any change in exterior historic appearance.

Fig. 5: Shotcrete backup wall fastened to the restored brick masonry veneer

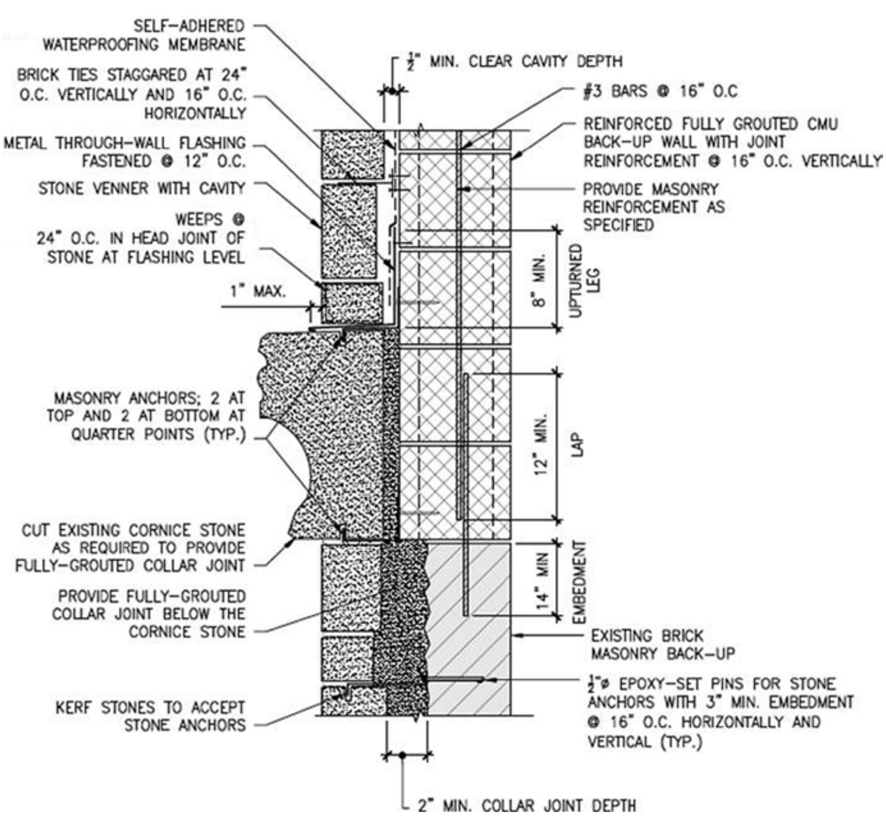


Fig. 6: Cross section of rehabilitated tower wall (Note: 1 in. = 25.4 mm)

CONTEMPORARY MATERIALS AND DETAILS: REHABILITATION OF AN ICONIC TOWER

The main quadrangle of Emma Willard School (EWS) in Upstate New York has several historic masonry buildings dating from the 1910s, 1920s, and 1930s, many designed by M.F. Cummings and Sons in the collegiate Gothic style. A masonry condition assessment showed significant deterioration of masonry elements above the uppermost building cornices, primarily the crenellated parapets. The parapets are solid limestone masonry and are exposed to water infiltration on both the inboard and outboard sides. In addition, parapet coping stones are incompletely flashed. These factors caused the parapets to absorb significant amounts of moisture and remain continuously saturated. Because the parapets extend above the roof level, they are entirely unheated, which allowed the saturated parapets to undergo extensive freezing-and-thawing deterioration throughout their entire thickness, resulting in the formation of cracks and bulging and loose stones that posed falling hazards.

After completing immediate stabilization work, EWS elected to rehabilitate the deteriorated upper portions of their iconic 110 ft (33.5 m) tall Sage Hall Tower, which can be seen for miles from the school. Although the building is historically significant, it is not listed on the historic register, allowing the school maximum flexibility with the wall repairs. The school had one requirement for the restoration team to follow: "the final aesthetic of the tower could not be changed."

Because the existing crenellated parapets had to be removed and the tower walls reconstructed from the upper-level window heads to the top of the tower, the consultant decided early in the process to reconstruct the parapet's structural walls using reinforced concrete masonry units in place of the historic brick and limestone load-bearing walls. In addition to providing cost- and time-saving benefits and efficiently matching the existing variable wall thickness, the use of a concrete masonry unit backup

Fig. 7: Images of rehabilitated tower: (a) before; and (b) after

wall allowed for the parapets and upper tower walls to be reconstructed as a cavity wall system.

By creating a cavity wall, the water that bypasses the exterior stone veneer is captured, managed, and directed out of the wall at a flashing placed at the base of the cavity wall section. To protect the new reinforced concrete masonry backup wall from water, it was covered with a waterproofing membrane that is integrated with the flashing at the base of the wall section (Fig. 6). Standing-seam copper panels cover the backside of the crenellated parapets and prevent two-sided water absorption. The entire adjacent flat-seam copper roof is wrapped in waterproofing to further prevent water from entering the backup wall or wood-framed roof system. The use of reinforced concrete masonry structure and cavity wall construction increases the service life of the rehabilitated masonry parapets, and the building aesthetic has not changed (Fig. 7).

REHABILITATION STRATEGIES SUCCESSFUL

The case studies show how existing masonry exterior envelope rehabilitation can be completed using contemporary cement-based materials and details without affecting the aesthetics of the buildings. By employing a rehabilitation strategy instead of preservation strategies that rely on period materials and details, the repairs can eliminate the original cause of deterioration and create a more durable building envelope.

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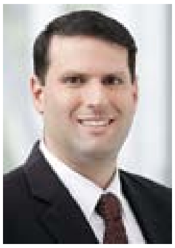

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