Structural Rehabilitation

renovation and restoration of existing structures

Divine Design: Renovating and Preserving Historic Houses of Worship

Part 2: Walls

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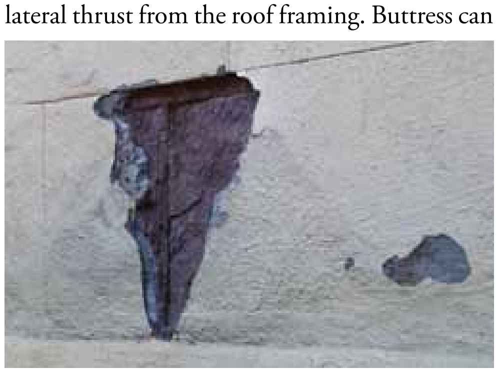
This series of articles discusses some of the commonly encountered structural issues with renovation projects focusing on historic buildings of this type, and provides guidance on ways to address them. Part two of this series focuses on wall systems. Part one, published in the December 2014 issue of STRUCTURE magazine, reviewed common issues with foundations. Part three, to be published in an upcoming issue of STRUCTURE, will focus on historic roof systems.

Unreinforced Masonry Walls

The exterior walls of historic houses of worship are typically unreinforced masonry that support the roof and at least some portion of the floor loads. Stone masonry, brick masonry, or a brick or stone back-up wall with stone cladding are the most common exterior wall systems seen in houses of worship in the northeastern U.S., although some smaller structures have wood-framed exterior walls.

Typical Masonry Wall Systems

Although load-bearing, unreinforced masonry (URM) is a very common construction type for exterior walls in buildings built prior to the 1920s, historic houses of worship often feature their own unique variants that can amplify the effects of the expected in-service deterioration, lack of ductility, or weakness in flexure or tension typical for URM elements. The large, open spatial areas within these buildings often create significant distances between levels of lateral support for the walls; unbraced heights of wall can be 30 feet or more. To counteract the slenderness effects of these large un-braced heights, walls are either built very thick (3 to 4 feet or more), or are reinforced with exterior buttresses to provide increased lateral support. The buttresses are typically located between window openings, and are also usually positioned to align with the main roof-framing members (where they bear on top of the wall) to help resist the outward lateral thrust from the roof framing. Buttress can



Spalling of brownstone behind painted cement stucco.

Spalling of cast stone masonry.

vary in size from relatively small, 3- to 4-foot protrusions, to extremely large, such as the flying buttresses seen in many gothic cathedrals.

The exterior masonry walls also typically feature large window and door openings. The openings can be 20 feet or more in height, and 6 feet or more in width. They will typically feature half-round or gothic arches at their tops and are usually lined with wooden door or window frames. These large openings can significantly affect the ability of exterior walls to act as shear walls to resist in-plane loads from wind and seismic effects, and must be carefully considered when undertaking major renovations or alterations.

Deterioration

As with any masonry wall, deterioration of the masonry and mortar will occur over time due to exposure to weather and potentially ineffective in-place water-management systems. Repeated wetting and drying of the mortar and masonry, as well as freeze/thaw effects, will cause deterioration of the mortar, spalling of masonry, and formation of cracks or other distress. Exposure-related deterioration or erosion of mortar is typically addressed through periodic repointing of the mortar joints. However, if left unattended, the mortar joints can erode to the point that the support for the masonry units becomes compromised, movement ensues, and additional distress results in the formation of cracks and bulges. If the deterioration is pervasive, significant strengthening or rebuilding of the wall may be the only option. Timely, planned maintenance and repair cycles are key to longevity of these wall systems.

Although stone masonry is typically more resilient than clay-fired masonry, some stones are still susceptible to spalling and other deterioration. Susceptibility of sandstones to spalling depends on how the stone is cut and installed. Thinner sections of sandstone are often cut along the bedding planes, which is the weakest part of the stone and easiest to cut. The stones are then placed on the building with the bedding plane oriented vertically. Given the relatively porous nature of sandstone, freeze/thaw effects related to the absorbed moisture can often lead to substantial exfoliation of the vertical face (as the

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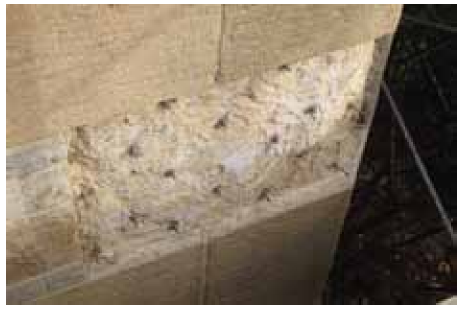
bedding planes delaminate), leading to section loss and more spalling. In some sedimentary stones such as brownstone, clay particles encapsulated within the stone will react with the absorbed water, which then can lead to exfoliation as the now wetted clay creates a weak point within the stone.

In an effort to preserve exterior walls on aging houses of worship, stucco coatings are often applied over the masonry. The stucco is typically cement based, and is often painted. Older paints are not vapor permeable and will actually create a barrier that traps moisture within the masonry, which accelerates the deterioration processes within the mortar and stonework. Ironically, while the application of stucco and paint was meant to be a preservative treatment, it often amplifies water-management problems. Also, while such situations can "fester" for a while without manifesting themselves, up close examinations and probing can reveal areas where the coating is delaminated from the masonry, and where moisture is trapped within the system. Loose, delaminated stucco or parging layers are a falling hazard, and should be removed promptly. Periodic inspections and reviews are paramount.



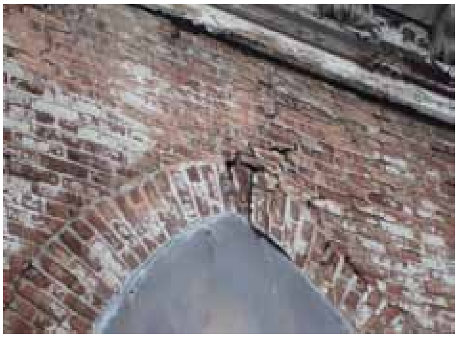
Preparation of repair area for cast stone with shear pins.

When spalling is present, it can be repaired through application of repair mortars to build out the full cross section of the stone. Mortars can be pigmented to match the existing color of the stone and aggregates can be added to match the texture. All loose material needs to be removed from the existing stone to ensure that the mortar patch achieves a good bond, and deeper repairs (typically greater than 1-inch) may require additional mechanical attachment (shear pins, wire mesh, etc.). Failure to properly prepare the stone surface prior to applying the patch material will result in premature failure of the patch and is one of the main causes of failure.

Arched Openings

Of particular concern when it comes to the condition of masonry and mortar joints are arched openings at doors and windows. Deterioration of the mortar within masonry arches can cause the masonry units within the arches to shift, or even fall out of the arch. Loss of masonry and mortar can alter the load path within the arch system, cause the arch to sag and spread, and render the arching action ineffective (arches are meant to resist predominantly compressive forces). This can result in transfer of the building loads into the window or door frames. Therefore, care must be taken when replacing existing frames to make sure that no masonry loads are being carried by the frame prior to removal.

Distress at arches is commonly manifested by cracks running through the peak of the arch. This can often be remedied by stitching the masonry with mechanical anchors. Helical ties, embedded epoxy bars, or grouted bars can be used to provide mechanical attachment to the arch sections, and cracks can be filled with mortar or epoxy to reestablish the load path through the arch. If substantial movement has occurred (masonry is severely



Distressed masonry above gothic arch.

displaced), the arch is likely beyond repair and will need to be rebuilt. This will typically require a carefully planned and implemented phasing of shoring, rebuilding, and load transfer (e.g. needle beams to temporarily support the masonry above the arch to allow for rebuilding).

New Openings in Masonry

Renovations of historic houses of worship often include proposed new openings in the masonry walls. These openings are typically meant to accommodate new means of egress associated with relocated stairs, or possibly a new elevator. Because the exterior masonry walls are also typically the main lateral-load resisting system (shear walls), creating new openings in these walls needs to be carefully considered. Even without introduction of new openings, masonry walls of this type usually do not meet, nor were they ever designed to meet the lateral load resistance requirements of modern-day building codes.

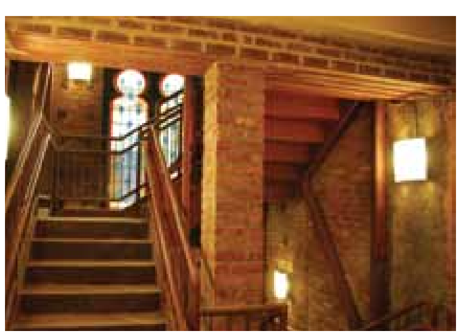
To complicate matters further, the lateral load path is often not very well defined in these types of structures. In general, lateral loads are typically expected to be transmitted from exterior walls through the floor and roof framing (diaphragms) to the perpendicular walls, which then act as shear walls to resist these forces and transfer them to the foundations. However, any of the elements along this load path may or may not be built with strength and stiffness sufficient for transfer of the design-level forces. Openings within the masonry can only make things worse.

Therefore, when considering new openings in masonry walls, the effect on the overall strength and stiffness of the building needs to be carefully considered. While the building codes typically do not require historic structures, when renovated, to be retrofitted to meet the current load requirements, engineering judgment should be employed to arrive at a solution that at a minimum does not result in weakening of the global lateral-load resisting systems in place. Openings should be sized to minimize the change in the walls' strength and stiffness, or additional framing should be added to make up for the loss. For instance, a braced frame or a reinforced concrete or CMU liner (shear) wall can be added within a stair tower to account for new openings. Consideration of strength and stiffness compatibility and distribution are also important: load paths should be examined, weak links addressed, and alternatives considered.

New openings within masonry walls also need to be able to support masonry and other framing above the opening. This is commonly accomplished by installing steel lintels to span over the opening and support the masonry above. Steel lintels can be relatively easily installed in thin masonry walls (3 to 4 wythe brick walls, and about 12-inch thick stone masonry); however, thicker walls will typically require temporary shoring (e.g. needle beams) to allow local removal of masonry and lintel installation. Once the lintel is installed snug to the masonry above, shoring can be removed, and masonry below the lintels can be removed to create the opening. The need for new openings should be carefully considered, as the effort and expense for creating even a single opening in thick masonry walls can be significant.

Floor Framing Support at Masonry Walls

Moisture absorbed by masonry walls can lead to deterioration of the wood framing that bears on the masonry. The orientation of the framing and masonry-pocket configuration typically results in wood end-grain exposure towards the wall exterior. Because of the nature of the wood cell structure, the end-grain of the wood will more readily absorb moisture through capillary action. If the waterproofing system is compromised or overwhelmed, and moisture gets to the wood-member ends, decay (a.k.a. rot) will invariably ensue. The decay process, which turns an ordinarily very ductile wood material into a brittle mass, can significantly compromise the strength of the wood structure and, if allowed to persist, can result in sudden or even catastrophic failures. This can be especially critical in non-redundant systems (often featured in historic house of worship structures), where the majority of floor or roof loading is carried by a relatively small number of members (e.g. roof trusses), and whose failure can affect the integrity of the entire structure. Proactive preventive work (e.g. inspections, maintenance) is therefore critical.



New lintel at stair opening and new braced frame within stairwell.

Partial-length strengthening of floor joists and new ledger at masonry wall.

Depending on the extent of the deterioration, reinforcement as well as partial or full replacement of the wood or timber elements may be required to maintain adequate support for the floor framing. Depending on the size and type of the compromised elements, different remedial or strengthening solutions may be available; typically they include some form of supplemental steel or timber framing and temporary shoring. Regardless of the provided remedial design, future exposure, as well as displacement compatibility, connections, and load sharing between the remaining (healthy) members and the new supplemental structure, need to be carefully considered.

For redundant, light-framing systems like wood-joist floors, and if determined that the deterioration mechanism is no longer active (but the extent of decay requires action), simple sistering or full replacement may be an adequate solution. A new ledger can then be attached to the masonry wall to provide additional bearing for the reinforced elements.

Conclusion

Unreinforced masonry has been successfully used in building applications throughout the world for centuries. Understanding the characteristics, expected performance, and limitations of these systems allows engineers and architects today to design successful renovation or remedial projects, and to avoid pitfalls that can seriously affect the building's service life. It is hoped that the above discussion, which features a number of potential structural issues and possible remedies often seen in practice, helps practitioners in future work on these challenging and exciting buildings.▪