

# BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

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## STRUCTURAL CHALLENGES OF BRICK MASONRY RECLADDING PROJECTS

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## ABSTRACT

Many commercial and multistory residential buildings constructed since 1960 are clad with brick masonry veneer, typically installed over steel stud or concrete masonry backup walls. After several decades in service, many of these buildings require significant façade rehabilitation work or even wholesale façade replacement to address water leaks, to improve poor thermal performance, or simply to upgrade their appearance. This work can alter the structural performance of exterior walls in unexpected ways. We will review common brick masonry wall assemblies and available strategies to resist gravity and lateral loads. The presentation also describes typical waterproofing and restoration needs. We will draw on case studies to dissect and understand the structural performance of typical brick masonry wall assemblies, as well as strategies to upgrade their structural capacity.

## SPEAKERS

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# STRUCTURAL CHALLENGES OF BRICK MASONRY RECLADDING PROJECTS

## INTRODUCTION

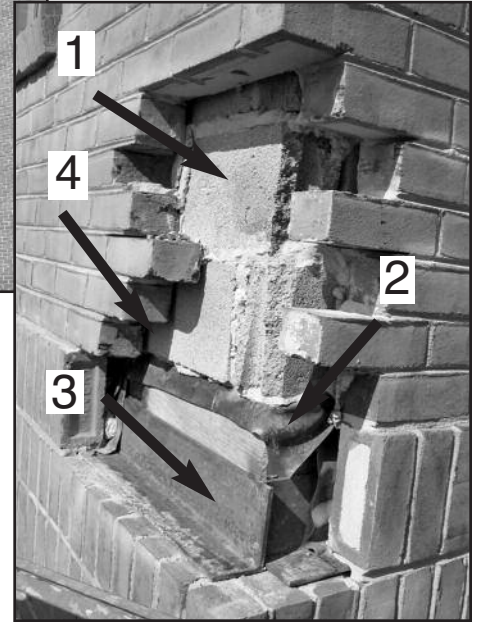
Many commercial and multi-story residential buildings constructed over the past 50 years are clad with brick masonry, typically installed over concrete masonry backup or cold-formed, steel-stud walls. After several decades in service, many of these buildings require significant façade rehabilitation work or even wholesale façade replacement to address water leaks, moisture-related deterioration, poor thermal performance, or simply to upgrade their appearance. Necessary brick masonry and waterproofing rehabilitation work can alter the structural performance of the exterior walls in unexpected ways. Examples include multi-story brick masonry walls that must be partially dismantled to install waterproofing repairs and wall assemblies where long-term masonry movement has caused unintended redistributions of load paths and changed the wall's response to lateral loads from its original condition.

This paper reviews three common brick-clad wall assemblies and the concepts they utilize to resist their self-weight and out-of-plane (lateral) loads. It describes typical waterproofing and masonry restoration needs and how commonly performed waterproofing repairs can influence the structural performance of some brick masonry wall assemblies. This paper draws on the authors' experience in the rehabilitation of exterior envelopes and the review approaches undertaken to evaluate the structural performance of brick masonry wall assemblies, as well as strategies to upgrade their structural capacity.

This paper was written by structural engineers, but it is not intended as a rigorous review of all structural-engineering issues associated with brick-cladding rehabilitation. Rather, the paper describes in qualitative terms some important structural concepts related to exterior wall rehabilitation work in order to make these concepts accessible to other design professionals



*Photo 1 - Multistory brick-masonry-clad building with punched windows.*



*Photo 2 - Wall Assembly 1 is composed of (from interior to exterior): 1) concrete masonry backup, (not shown) truss reinforcement, 2) PVC flashing, 3) steel shelf angle, and 4) brick masonry cladding. Note lack of waterproofing membrane over the concrete masonry backup.*

without structural engineering backgrounds, as well as to alert them to common pitfalls affecting exterior wall rehabilitation design.

## COMMON WALL ASSEMBLIES

Most brick masonry wall assemblies utilize a drainage wall system to resist water penetration. The drainage wall typically includes the following components:

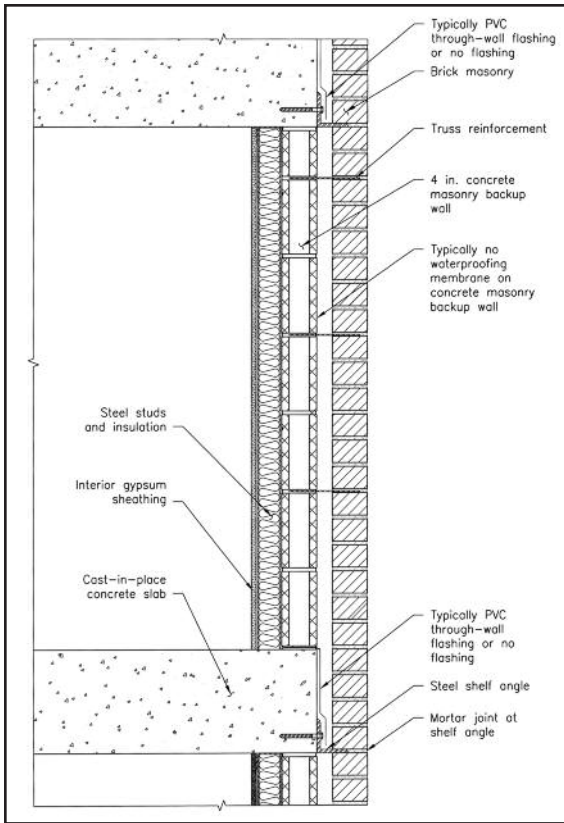
- Exterior brick cladding to provide aesthetic appeal and to shed water.
- Airspace behind the brick to allow water that penetrates the brick to drain.
- Waterproofing membrane applied to the backup wall to protect the backup-wall material and the interior space from leakage.
- Through-wall flashing to collect water at the bottom of the cavity and direct it to the exterior.
- Backup-wall construction.

The wall assemblies contained in this paper are part of the exterior cladding system of the building. The wall assemblies do not participate as part of the load-bearing frame to resist overall structural gravity loads, and they do not contribute to the overall lateral-load resistance and stability of the building.

## Brick Masonry with Concrete Masonry Backup

In Wall Assembly 1, the concrete masonry backup usually bears on a con-

crete floor slab and spans floor to floor. Windows are usually set in "punched" (discontinuous) openings that interrupt the continuity of the backup wall (*Photo 1*). The concrete masonry backup frequently is not covered with waterproofing. The backup sometimes incorporates vertical steel reinforcement grouted in the cells of concrete masonry, but more typically we have seen unreinforced backup walls. The exterior brick masonry is typically tied to the backup with continuous horizontal steel wire truss reinforcement set into masonry bed joints. In wall assemblies with punched openings, the weight of the brick masonry is typically supported on continuous steel shelf angles attached to the edge of the con-



**Sketch 1 - Wall Assembly 1: wall section.**

crete floor slab (Photo 2). Brick masonry above window openings is supported by steel lintels. This arrangement is shown in Sketch 1.

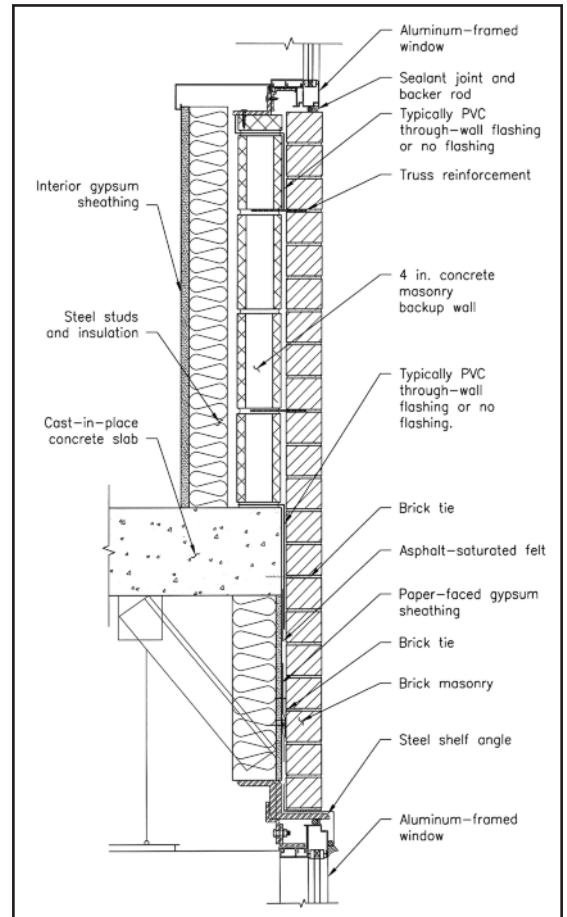
A common construction from the 1950s to the 1970s for Wall Assembly 1 consists of a 4-in-thick unreinforced concrete masonry backup and a 4-in-thick brick masonry cladding tied together with horizontal truss reinforcement. Original designers of this wall assembly relied upon empirical rules to establish the required thicknesses of the

concrete masonry backup and the exterior brick masonry. The empirical rules consider that both the brick masonry and concrete masonry backup participate to resist out-of-plane loads. Further discussion of empirical design is contained in Section 4.1.

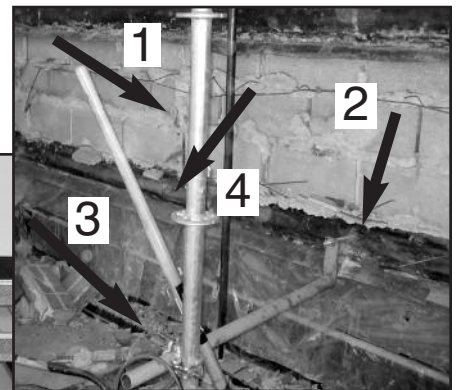
In many buildings, windows are installed in continuous strips or ribbons (Photos 3 and 4), rather than in punched openings. In wall assemblies with ribbon windows (Wall Assembly 2) the weight of the concrete masonry backup is supported on the floor slab, and the weight of the brick masonry is supported on shelf angles that are suspended from hanger assemblies attached to the floor slab and positioned above the head of the

window below. This arrangement is shown in Sketch 2. Original designers of this wall assembly either relied upon empirical rules to establish the required thicknesses of the concrete masonry backup or utilized a rational design methodology using engineering analysis to determine the required thickness and the need for reinforcement of the backup. The former method considers that both the

brick and concrete masonry participate to resist out-of-plane loads. The latter method considers only the concrete masonry resists out-of-plane loads. Section 4.1 will address the engineered analysis.



**Sketch 2 - Wall Assembly 2: wall section.**



**Photo 4 - Wall Assembly 2 is composed of (from interior to exterior): 1) concrete masonry backup, 2) truss reinforcement, 3) steel shelf angle, 4) PVC through-wall flashing, and (not shown) brick masonry cladding.**

**Photo 3 - Multistory brick masonry-clad building with ribbon windows.**

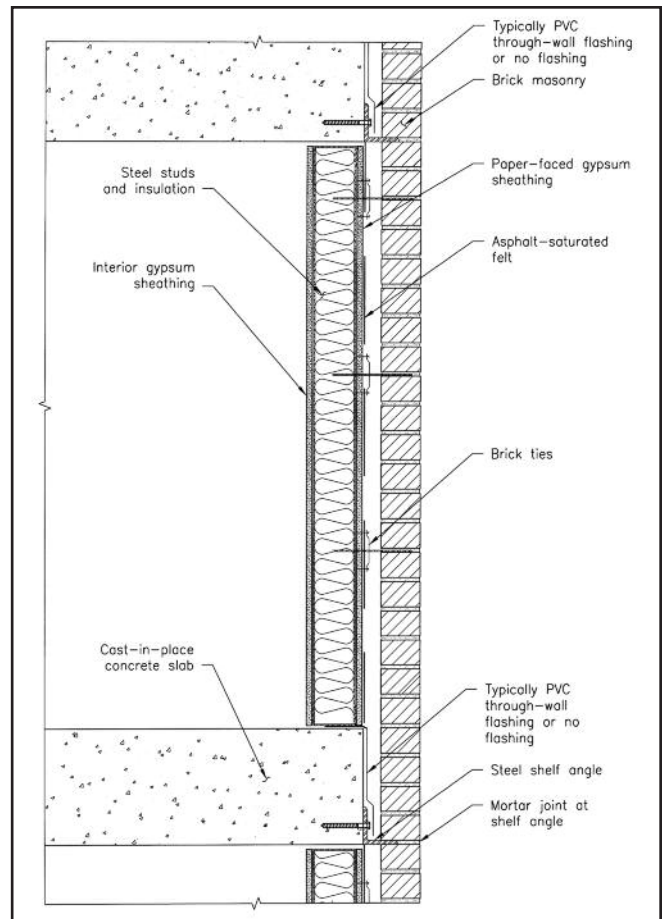
## Brick Masonry with Steel Stud Backup

In Wall Assembly 3, the backup consists of cold-formed steel studs that span floor to floor. Windows are set in either punched openings or continuous ribbons. In most buildings we have seen, the steel studs are covered with gypsum sheathing and asphalt-saturated felt waterproofing. Similar to the wall assemblies with concrete masonry backup, the exterior brick masonry is supported on steel shelf angles attached either directly to the floor slab edge (punched windows) or suspended from hangers attached to the floor slab (ribbon windows). The brick masonry is tied to the steel stud backup with individual adjustable steel wire ties. This assembly is shown in *Sketch 3*. Unlike the concrete masonry backup configurations discussed above, designers of Wall Assembly 3 use an engineered analysis to select the steel studs for strength and deflection limitations. In the analysis, the brick masonry does not participate in the load-resisting capacity of the wall assembly.

## Mechanisms that Affect Structural Behavior

The wall systems and load paths described above represent idealized as-designed conditions and frequently are not representative of the actual building construction encountered in rehabilitation design work. In addition to material deterioration, which is discussed in the next section, original construction techniques and gradual changes to the main building structure and the exterior wall materials during the building's service life can affect these load paths over time and change the structural behavior of the wall system. Most of these mechanisms are caused by the unintended distribution of gravity loads into the brick masonry, backup walls, or other façade components. The following are a few examples:

- **Original construction sequence and detailing.** Good construction practice requires the provision of soft joints below shelf angles to accommodate the immediate downward deflection of the shelf angles under gravity load when the brick is placed as well as the long-term or seasonal movements of the building frame and the façade elements below the shelf angle. In some instances, shelf angles were originally installed tight against the brick masonry below them. During construction, the downward movement of the shelf angle was resisted by the brick in the floor below, and a portion of the self-weight of the brick masonry above is supported by the brick masonry below rather than the slab edge. Similarly, we have seen instances where shelf angles were installed tightly on top of window heads, causing a portion of the brick masonry weight to be supported by the window frame (*Photo 5*).
- **Effect of structural frame movements.** Like nearly all engineering materials used in building construction, structural-steel and cast-in-place-concrete building frames undergo short-term and long-term structural frame movements. Many different mechanisms contribute to the movement, and some movements are cyclic while others are unidirectional and cause permanent deformation. Important examples are the shortening of concrete frames or concrete masonry bearing walls as a result of creep and shrinkage, and the elastic deformation of steel, concrete, and concrete masonry under gravity loads. Frame shortening can be accommodated by providing horizontal soft joints and sliding connections between cladding and structure. In instances in which these devices were not originally provided or detailed to accommodate sufficient movement, structural frame movements can cause load distribution from the building frame into the cladding.
- **Effect of cladding movements.** Cladding movements can compound with structural frame movements to produce large relative



*Sketch 3 - Wall Assembly 3: wall section.*



*Photo 5 - Window sagging (arrow) as result of the downward deflection of the shelf angle.*

movements between cladding and building frame. For example, in addition to cyclical daily and seasonal thermal movements, brick and other clay-based building materials undergo irreversible expansion often referred to as “brick growth.” Most brick growth takes place soon after brick production, and the rate of brick growth diminishes with age. Similar to structural frame movements, cladding movements must be accommodated with vertical and horizontal control joints and with sliding connection details. Unintended load distribution into the cladding will result if these are not provided (Photo 8).

## REHABILITATION NEEDS

After decades in service, most buildings clad with brick masonry require exterior envelope rehabilitation work. The analysis of the specific repair needs of these buildings is beyond the scope of this paper, but the following problems and repair approaches are common for older multistory buildings:

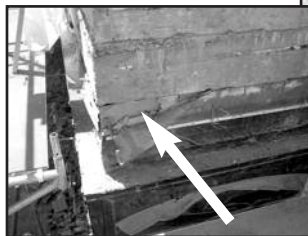
- **Water leakage.** Water penetration and resulting deterioration of exterior wall components (see the next item) are the most prevalent performance problems of brick-clad walls. Typical causes of water leakage include the following:
  - **Missing or defective flashing.** Brick-clad systems frequently incorporate unreinforced sheet membranes (e.g., PVC) as through-wall flashing (Photos 2 and 4). These materials cannot be reliably sealed watertight at membrane joints, cannot be exposed to form a drip, and are susceptible to mechanical damage. Appropriate rehabilitation options include copper and stainless steel flashing.
  - **Missing or defective backup waterproofing.** Many concrete masonry backup walls lack waterproofing membranes because the wire truss reinforcement interferes with the sheet membranes that were typically utilized for wall waterproofing until the advent of contemporary fluid-applied weather barriers. Reliable rehabilitation work includes installation of an effective

weather barrier on the backup wall, which requires removal of the brick cladding.

- **Deterioration of exterior wall components.** Exterior wall components in leakage areas or in the portion of the wall outboard of the waterproofing deteriorate over time with exposure to moisture and require replacement. Typical items include corroded steel stud backup or gypsum sheathing (Photo 6), corroded truss reinforcement or adjustable brick ties (Photo 7), corroded shelf angles, deteriorated weather barrier membranes, and deteriorated brick masonry (Photo 8). Repairs are almost always performed from the exterior and require removal of the brick cladding to allow access to concealed components.
- **Brick masonry damage caused by restrained movement.** Restrained frame and cladding movements discussed in the previous section can damage the brick masonry. Typical damage includes spalled brick below shelf angles (Photo 9). Repairs generally entail reconstruction of the affected masonry and installation of masonry expansion joints to accommodate differential movement.
- **Poor thermal performance (walls and windows).** Buildings constructed prior to the 1970s generally do not have exterior wall insulation. Fenestration, if original, frequently incorporates single glazing. Very few buildings of any vintage have effective air barriers. These conditions result in poor energy efficiency, and during major building rehabilitations, it is desirable and frequently mandated by building codes to upgrade the thermal performance of the walls and windows. Typical required work includes window replacement and installation of air barrier membranes and insulation in the exterior wall assembly.

## MASONRY DESIGN METHODOLOGIES AND BUILDING CODES

The design professional undertaking the exterior envelope rehabilitation project will benefit from an understanding of the historical approach and associated structural behavior likely contemplated by the original designer for the wall assembly. As always, a condition appraisal is necessary to understand the as-built construction and the existing conditions of the wall assembly. Overarching the rehabilitation project will



**Photo 6 – Damaged exterior gypsum sheathing (arrow) on a building with a steel stud-framed backup wall.**

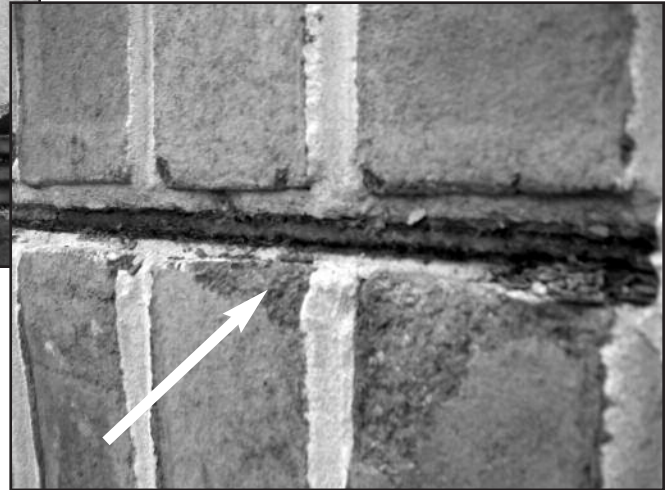


**Photo 7 – Corroded adjustable brick tie over plastic sheathing. Note brick tie is attached through plastic sheathing and exterior sheathing to steel stud.**



**Photo 8 – Corroded steel reinforcement (arrow) and truss reinforcement in a concrete masonry backup wall. Also note incompletely filled head joints, exposed reinforcement, and lack of waterproofing membrane on backup.**

**Photo 9 – Spalled brick masonry below a corroded shelf angle (arrow). Note lack of soft joint below the shelf angle.**



be the requirements of the applicable building code. The following sections provide some background information on masonry design methodologies and building codes.

### Wall Assembly Design Methodologies

There are numerous historical industry documents related to the design methodology of masonry. These historical documents contain both engineered design methodology and empirical design methodology. Allowable stress design is an engineered design method where calculated stresses in the wall components are compared to allowable stresses. The empirical design method is an alternate method to an engineered analysis where the exterior masonry walls are sized and proportioned according to established minimum thicknesses based on laterally unsupported heights. Wall Assemblies 1 and 2 as described above, constructed from the 1950s to the 1970s, often were based on empirical methods in which the nominal thickness of the wall assembly was the sum of the unreinforced concrete masonry backup and the exterior brick masonry.

In the context of the rehabilitation project being contemplated, the design professional must also be familiar with current masonry design methodologies. The *Building Code Requirements for Masonry Structures* by the American Concrete Institute (ACI 530-05/ASCE 5-05/TMS 402-05), the referenced specialty masonry code by International Building Code 2006, contains provisions for three methods of the design of masonry: allowable stress design, ultimate stress design, and the empirical design method. Ultimate strength design is

an engineered design method in which structural demands like load factors are calculated for the wall components and compared to design strengths, such as a strength reduction factor. The other two methods follow the same general principles as their historical roots, but they certainly have evolved with time. The design professional must understand how current methods deviate from historical methods, especially in the context of reviewing building code requirements.

### Building Codes

The structural requirements of the building code on an exterior envelope rehabilitation project of an existing building are dependent on the adopted codes at that locality, whether it be at the township, city, county, or state level. As such, the design professional must carefully review the applicable building code provisions on a project-by-project basis.

We offer the following general thoughts as background:

- National model building codes (such as International Building Code 2006 [IBC]) contain Chapter 34, Existing Structures, which addresses the requirements (whether prescriptive or performance based) when dealing with modifications to existing buildings. In addition, Chapter 21, Masonry, addresses the applicable masonry design provisions.
- A supplement to the IBC, which must specifically be adopted by the

governing agency, is the International Existing Building Code 2006 (IEBC). The IEBC replaces Chapter 34 of the IBC and provides expanded direction on dealing with existing buildings. There are several additional classifications and requirements for the proposed work beyond those in the national model code.

- Certain states adopt their own statewide building codes, which may either incorporate portions of a national model code addressing existing buildings such as Chapter 34 of the IBC, or be entirely unique to that particular state.
- Certain states adopt their own supplemental statewide codes for the rehabilitation of existing buildings, which may either incorporate portions of a national supplement like the IEBC or be entirely unique to each particular state.

### REPAIR APPROACHES THAT DIMINISH STRUCTURAL PERFORMANCE

Effective repair approaches to brick masonry-clad exterior walls must resolve the exterior envelope performance problems and preserve at least the current structural performance level of the wall assembly.



**Photo 10 – Installation of steel reinforcement into cavities cut into the concrete masonry backup wall as part of remedial work.**

Depending on the scope of the building repairs, applicable building codes may mandate structural strengthening work. Section 4 outlines some of the applicable building codes. A detailed discussion of the development and execution of a rehabilitation program is beyond the scope of this paper. However, we provide some insight into two repair approaches and their impact on structural performance.

The notion that the exterior cladding does not participate with the building frame in resisting main building loads is a fundamental principle of all cladding design, and it must pervade all aspects of the cladding design and construction. The unintended redistribution of structural loads into the brick cladding discussed in Section 2.3 above is consequential not only because the resulting loads and restrained movement can damage the façade components and their attachment to the structure but also because they impart a compression load into the exterior wall, increasing the lateral-load resistance of the wall assembly. Although this effect was not intended by the original design, it nonetheless lends some lateral-load capacity to the cladding assembly, which, if released as a result of the remedial work, will change the behavior and performance of the wall assembly.

Two examples of remedial approaches that eliminate this beneficial structural resistance are the introduction of horizontal soft joints beneath relieving angles where



**Photo 11 – Installation of grout around steel reinforcement in concrete masonry backup wall.**


the original construction had a mortar joint, and the leg-and-leg removal of brick cladding to install shelf angle flashing or even window removal.

Remedial waterproofing work to concrete masonry backup walls frequently requires the installation of waterproofing membranes over the backup. Retaining the existing horizontal wire truss reinforcement is generally impractical because it is difficult and costly to protect during the brick removal, is compromised by corrosion, and interferes with the installation of reliable sheet membrane details. As a result, the truss reinforcement is typically cut off at the face of the backup wall. When the truss reinforcement is cut, the wall assembly no longer behaves as intended by the provisions of empirical design.

Experience with buildings of the vintage described earlier shows that the unreinforced concrete masonry backup wall alone will not satisfy either the provisions of empirical design or an engineered analysis. The design professional must evaluate options to restore the behavior de-

stroyed by the removal of the horizontal wire to remain within the provisions of empirical design or strengthen the concrete masonry backup using an engineered analysis. Options for strengthening include the installation of steel reinforcing bars grouted into cavities cut into the concrete masonry backup (Photos 10 and 11) and installation of supplemental steel framing on the interior side of the backup wall (Photo 12).

## SUMMARY

Waterproofing repairs to exterior walls that entail removal of brick masonry or windows require a thorough understanding of the structural behavior of the individual wall components and their role in the overall ability of the wall to resist out-of-plane loads. Original construction details and long-term movement of building components can cause distribution of structural loads into the brick cladding in ways that were not anticipated by the original design. Commonly performed waterproofing repairs can disrupt these load paths and diminish the structural performance of the wall assembly. A structural engineering evaluation is required to assess the performance characteristics of the original and the modified assembly and, if necessary, to develop structural strengthening strategies. As always, the remedial work must also be evaluated in the context of the applicable building code. 



**Photo 12 – Installation of supplementary steel framing at the interior side of a concrete masonry backup wall.**