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Damage Assessment and Repair for Older Brick Buildings

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Abstract**—**The experience of engineers and architects practicing today is typically limited to current building code requirements and modern construction methods and materials. However, many cities have a mix of new and old buildings with many buildings constructed over one hundred years ago when building codes and construction methods were much different. When a brick building sustains damage, a structural engineer is often hired to determine the cause of damage as well as determine the necessary repairs. Forensic studies of dozens of brick buildings shows an appreciation of historical building methods and materials is needed to correctly identify the cause of damage and design an appropriate repair. Damage on an older, brick building can be mistakenly attributed to storms or seismic events when the real source of the damage is deficient original construction. Assessing and remediating damaged brickwork on older brick buildings requires an understanding of the original construction, an understanding of older repair methods, and, an understanding of current building code requirements.

Keywords**—**Brick, damage, deterioration, facade.

I. Short History of Brick Construction Methods

BRICK is one of the oldest and most enduring man-made building materials. Sun-dried mud brick, or adobe, appeared about 10,000 years ago, and the earliest kiln-fired or clay-baked brick dates to 3,500 BC. Brick makers first appeared in North America in the early 1600's when English brick makers came to Virginia. Old brick structures still prevail in many colonial cities like Philadelphia and Boston. Brick defines America's industrial age buildings and remains linked to notions of the American factory, school and single-family house. During this period, brick was manufactured with incredible variety. Today, brick use is far more limited and not typically used as a structural element, but rather as a decorative veneer [1].

In current typical building practice, brick veneer is laterally tied to the underlying structure. According to both the International Building Code and the Brick Industry Association's Technical Notes 44B "Wall Ties for Brick Masonry", masonry veneer must be laterally tied every 18 inches vertically and every 32 inches horizontally [2], [3]. In most modern brick buildings, brick is used as a veneer like vinyl siding or stucco and is not part of a building's structural support.

Even though brick is now used mainly as a veneer, many older buildings remain with structural brick walls as an independent structural element. In older cities, like Philadelphia, entire blocks consist of buildings with structural brick walls 2-3 stories high with little or no lateral restraint other than that provided by the brick itself.

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II. Assessing Damage on Older Brick Buildings

Structural engineers are often hired to assess brick building damage. A damage assessment requested by an insurance company, real estate agent or buyer may come with little background information on the subject building. When there is limited knowledge of the building and building history, the structural engineer must evaluate the brick construction method as part of the assessment.

Fig. 1 Brick wall damage

When a brick wall suddenly collapses, the immediate cause is unknown. The collapse could be attributed to the weather or vibrations from nearby construction. A structural engineer called on to investigate many such collapses will learn to include an evaluation of the original construction as part of the forensic study.

Construction methods have evolved over time. Building codes and construction practices one hundred years ago were much less restrictive and many brick buildings constructed during these times lacked construction details that are required today. Many older buildings used brick as a load bearing element. Without interior framing, load bearing brick walls were self supporting. Construction methods have improved over time and now require additional lateral restraint for tall, thin masonry structures. Unfortunately, many older brick buildings were not built with sufficient lateral restraint even though these buildings continue to be occupied today. Brick walls built in this manner would be considered structurally deficient according to current building code requirements and

construction practices.

Deficient original construction methods on older brick facades can result in brick facades that bulge out of alignment. When such deteriorated, weakened brickwork suddenly fails, the failure can be mistaken for seismic, storm or construction related damage.

Many years of ongoing deterioration on buildings that used older construction methods is often made apparent during structural renovations in older neighborhoods. In other cases, a sudden brick facade failure is mistaken for storm damage. A comprehensive brick damage investigation should determine whether the brick is a freestanding structure and separate out damage caused by normal deterioration, construction activity or an isolated event such as wind or seismic activity.

Once long thin columns of masonry begin to bulge, they become unstable. The weight of the overlying brick continues to bear down on the column of brick. Once the brick bulges outwards, the weight of the overlying brick imparts an eccentric load on the bulged brick wall. The eccentric load creates a bending force and tensile loads in the outer wythe. Masonry is weak in tension and the resulting eccentric load creates conditions where the long thin column of brick can suddenly collapse. When a brick façade suddenly collapses, the collapse may be incorrectly attributed to weather, seismic activity or nearby construction. Storms and seismic activity can often be ruled out by researching weather and seismic records for the days leading up to a collapse. If weather records show winds were benign and geological records show a lack of seismic activity, storms and seismic activity can be ruled out as the cause.

Where multiple homes have similarly constructed, structural brick front walls, bulged brick can extend over several homes. Without a visual frame of reference, bulged brick on multiple front walls can go unnoticed for years. When discovered, bulging brick can be mistaken for sudden damage.

New construction can expose ongoing deterioration and bulging brickwork. Where bulging brickwork extends across multiple buildings, renovating the front façade of one of the buildings can expose the extent of movement on neighboring structures. A new, plumb front facade on a renovated building makes the extent of movement on a neighboring building's bulged front brick façade suddenly apparent. The sudden discovery of bulging brick may be incorrectly blamed on renovation efforts on the neighboring building.

Fig. 2 New plumb wall next to old bulged brick

Structural brick walls often bulge around door and window openings. As brickwork bulges, gaps open up around windows and doors. These gaps are typically not uniform and taper down following the bulging brick. Over the years, patch repairs to the building will often include filling gaps in between the door and window openings and the bulging brick with mortar or caulk. Evidence of such previous repairs often remain even on collapsed brickwork and can be used to help determine whether a brick façade was bulging when it collapsed.

Fig. 3 Bulge at window opening

Dozens of forensic studies of brick building damage show a full structural assessment must include an evaluation of the original construction method. Cities have many older buildings which contain features that do not conform to current building codes and construction practices. Brick work is one building element where building codes and construction practices have incorporated features to prevent sudden failures. When investigating brick building damage, the structural engineer must be aware of the construction methods used on older brick buildings.

III. Repair Methods on Older Brick Construction

For years, brick has been used to construct load bearing, structural walls in many buildings. These walls are typically tall, slender structures made solely of brick, no steel reinforcement and little, if any, lateral support. Many old brick buildings often have iron stars decorating their front facades. To the casual observer these stars can be mistaken for decorative embellishments. In reality, the stars are used to repair bulging brick. On older brick buildings' front facades, structural brick walls often consist of two wythes of brick built two and three stories high. These tall slender walls are prone to bulging out of alignment over time. When structural brick was a common building element, bulging brick front walls were a common occurrence. Bulging brick walls were routinely addressed by the use of steel plates and tension rods. The steel plates hold the brick in place and the tension rods run back and attach to structural elements within the building. A building's front wall faces the street and to give better visual appearance steel plates used to repair bulging brick

front walls were sometimes made into decorative shapes.

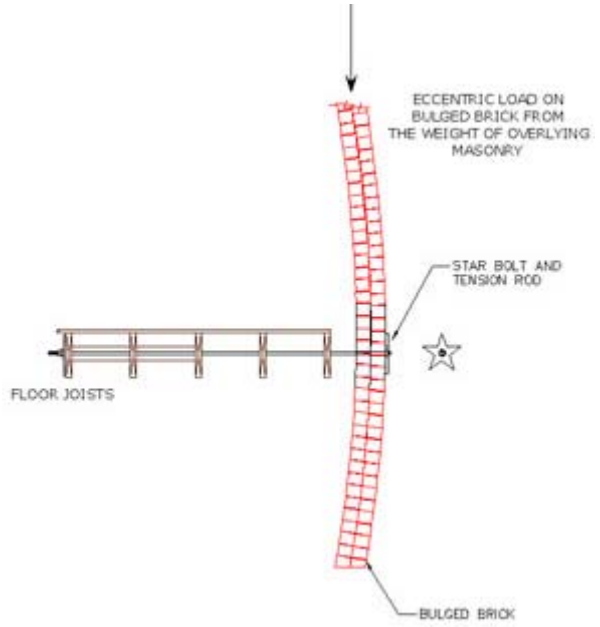

Fig. 4 Star bolt repair

As brick construction methods evolved, brick was no longer a structural element but a veneer with closely spaced lateral restraint provided at by an underlying structure. Typically, modern construction methods laterally tie brick by the use of wire or corrugated sheet metal ties embedded in the brick mortar joints. These metal ties laterally tie the brick to an underlying structure every couple feet. Current construction practice discourages using tall, slender free standing masonry wall [5]. As a result, today, a typical contractor is often unaware of the historical use of structural brick and the methods used to repair older bulging structural brick walls.

Modern construction methods eliminated many structural problems with brick façade construction. However, as modern construction methods developed, repair methods used to compensate for deficiencies in previous, centuries old construction methods have been lost. For example, star bolts and decorative ironwork on the front facades of many older buildings is actually structural reinforcement needed to pull bulging brickwork back into alignment. As construction methods improved, such corrective measures were no longer needed and the expertise to implement these repairs was no longer widely known and used.

In densely populated cities, homes often extend right up to their property lines. Typically, such row homes share a common wall with the neighboring building. Buildings constructed in this manner typically have floor joists that span from one shared, party wall to the other shared party wall on the opposite side of the property. In such construction, the front wall carries very little load other than its own weight. In many densely populated areas of older cities, older buildings constructed from structural brick can often have a free standing brick facade several stories high. In areas where many homes were constructed at the same time and using the same construction methods, free standing brick walls can extend for an entire block.

Brick and brick mortar joints deteriorate over time. Without periodic maintenance, brickwork weakens. The Brick Industry Association Technical Note 46 “Maintenance of Brick Masonry” indicates that brick mortar joints have a useful design life of about 25 years. [4] On older brick buildings constructed with structural brick walls, over time, as a result of normal deterioration and a lack of lateral connectivity between the brick and the rest of the building, brick walls can bulge out of plumb.

When trying to determine the cause of damage to a brick building, the presence of star bolts or other restraining repairs indicate that the original construction may be contributing to the damage.

IV. Incorporating Modern Structural Elements in Repairs

Modern building codes typically allow existing buildings to remain in service, even when building code requirements become more stringent. However, major renovations or repairs are viewed as an opportunity to bring a building into compliance with the current code. Substantial repairs or renovations must not only rebuild the impacted area of the building, but, more extensive efforts are required to bring structural elements into compliance with current building code requirements. When an older brick building suffers from substantial structural damage or undergoes significant renovations, the repair or renovation must often include adding lateral restraint and structural features capable of withstanding wind and seismic load requirements [6].

Modern construction techniques and current building codes require lateral restraint for brick walls. There are several methods commonly used to add lateral restraint to older, free standing structural brick walls. This restraint is normally provided by metal ties between the brick and supporting structure [7]. In new brick construction, metal ties are embedded in the brick mortar joints. On existing construction, the brick's mortar joints are already set. However, metal ties can still be used to provide lateral restraint for the existing masonry. Masonry screws can be used to attach metal ties to the existing masonry with the anchors designed to provide the necessary lateral restraint. Another method used to add lateral restraint to existing brick walls is to install metal studs behind the existing brick. The metal studs can be sistered with sections of steel stud fitted to match any curvature in the brick wall. The existing brickwork can then be attached to the metal studs with masonry anchors. The new studs are attached to the ceiling and floor with sufficient anchors to resist the required seismic and wind loads.

Window and door openings are often modified as part of repair efforts on older brick buildings. Window and door openings in older buildings tend to be smaller than those in modern structures. Building repairs and renovations often include enlarging windows and door openings. Such challenges can be overcome by incorporating structural steel in the repair or renovation.

Masonry, including brick, works best in compression. Masonry and brick have very little tensile load carrying capacity. As an example, steel rebar is commonly added to concrete to compensate for its lack of tensile strength. Bigger window and door openings result in longer spans and more significant tensile loads in the overlying brick wall. A squeeze beam made up from a pair of steel angles or channels placed on each side of the brick wall and through bolted makes an effective method to create larger window and door openings in existing structural brick walls. The steel framing carries the tensile loads from the overlying structure and the brick helps carry the resulting compressive loads.

A squeeze beam used to span over larger window and door openings also helps minimize the need for temporary shoring and simplifies construction. The existing brick can be saw-cut to accept the angles or channels. The angles or channels can then be installed and through bolted together. The bolts should be spaced close enough together, and torqued sufficiently to hold the masonry together. Once the squeeze beam is in place, the door or window opening can be widened.

V. Economic Considerations

Efforts to repair damage to an old, existing brick wall should include a cost analysis of the repair versus demolishing and rebuilding the wall from scratch with modern materials. When encountering a bulged brick wall, there are at least two approaches. Reinforcing the wall in its current state is normally the most economical approach; however, some walls are so severely deteriorated and out of alignment to pose an immediate collapse hazard. In these cases, the wall can be realigned or removed and rebuilt.

One method used to realign a severely bulged brick wall installs heavy structural framing on the inside and outside faces of the wall. The framing is temporarily shored in place and through bolts installed to attach the exterior framing to the interior framing. Pressure is applied to the framing by torquing individual bolts, a little at a time, so as to push the bulged brick into alignment while holding the rest of the wall steady. The design and construction cost associated with such temporary structural framing can be significant.

Not only is realigning a severely bulged brick wall expensive, there are risks associated with working with old brickwork. Oftentimes, the strength of the brick is unknown and there are deteriorated and cracked bricks in the wall. The force needed to align the bulged brick can cause additional damage. Old brick walls have been subjected to years of exposure to the elements and the repair is reusing brick and mortar that have already expended a significant portion of their intended design lives. Oftentimes, the expense of the realignment framing is equal to or more expensive than the temporary shoring needed to hold the building in place and remove and replace the deficient brick wall. The realigned wall will need further work to repair any masonry damaged during the realignment and lateral restraints are also typically required to make sure the wall remains plumb. The realigned brick wall will likely blend in better with the surrounding buildings; however, the realignment repair will likely result in a wall that will need more maintenance than a wall rebuilt with modern materials and construction techniques.

VI. Conclusion

An historical understanding of construction methods is needed to provide a comprehensive structural damage assessment on older brick buildings. Over the years, brick has gone from being used as a load bearing element to a cosmetic veneer. As brick construction methods evolved, brick repair methods have also changed. A careful forensic investigation of a damaged older brick building should include looking for previous repairs. On older buildings where the brick was used as a structural element, the presence of steel plates and tension rods show a brick wall was previously bulging and subsequently repaired. Bulging brick walls extending to neighboring buildings and patch repairs around window and door openings can all help determine whether a brick wall was already bulging and structurally compromised prior to a collapse. Weather and geological records can also be used to help evaluate brick wall damage. Careful review of the brick façade construction combined with analysis of weather and seismic conditions in the period prior to when damage was first discovered can be used to determine whether brick façade damage is the result of deficient original construction and a lack of maintenance over time, construction damage or the result of an isolated storm or seismic related event.

Repairs to damaged brick walls must take current building code requirements, the effective remaining life of the brickwork and the cost to accomplish the repair into consideration. Brick walls built many years ago often were built without adequate lateral restraint. Significant structural repairs must typically include bringing deficient original construction into conformance with current building code requirements and often includes adding lateral restraints. There are many ways to repair structural damage in an old building. Any structural repair should include evaluating the most economical approach. Oftentimes, severely bulged or deteriorated brick walls are most economically repaired by removing the deficient wall and replacing it with a new wall built from contemporary materials and using modern construction techniques.

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