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FACADE STABILIZATION: A PROLOGUE TO MASONRY RESTORATION

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ABSTRACT

Prior to a comprehensive building facade restoration, stabilization of significantly distressed masonry is often necessary to provide public safety and prevent further damage to building facades. Since the development of the skeleton structural frame system, veneer wall systems have provided a barrier from exterior elements and defined aesthetics of the building envelope. Masonry facades are traditional laterally tied to back-up materials or structural members with ferrous metal wall ties, bent bars and rods. Gravity loads are typically resolved with horizontal steel members that transfer load back to the building's structural system or adjacent masonry jambs.

Corrosion of underlying metal components, along with environmental and material related movement within masonry walls can cause distress to masonry cladding systems and create unsupported, unstable elements and potentially hazardous conditions. Options to address these conditions include pinning, strapping, netting, enclosure, and in some instances removal of a unit(s) and securing the remaining wall areas with support members and a weather tight enclosure. However, to determine an appropriate stabilization method, an understanding of the wall construction and backup material is critical. The longevity of supplemental anchorage as well as aesthetic appearance of the building facades after such implementation should also be considered.

This paper will discuss various distressed conditions which have been encountered by the authors in masonry facades and the mechanisms of deterioration contributing to the distress. The second part will review supplemental stabilization approaches, concerns, and related issues which should be considered and understood before deciding on the implementation of such stabilization as well as sensitivity which is often necessary to achieve public safety while not impeding future repair and restoration efforts.

KEYWORDS: stabilization, supplemental anchorage

INTRODUCTION

As buildings throughout the United States and abroad continue to age, maintaining safe exterior facades for occupants and the general public continues to be an ever growing issue for municipalities and building owners. Several cities in the United States have adopted building facade ordinances which require regular inspection and maintenance of the exterior walls. The purpose of these inspections is to have a licensed architect or engineer assess the condition of the exterior walls and identify deficiencies which threaten public safety (Figure 1) as well as assist in developing a long term maintenance plan. As such, it is the responsibility of the professional to identify and understand the cause of the distressed observed and provide recommendations for interventions which may include short term repairs, stabilization or permanent repairs.

Figure 1: Examples of inappropriate maintenances resulting in public safety conditions.

Frequently, due to time and economic constraints, the professional may recommend in-situ repairs of distressed materials rather than removing and rebuilding entire areas. In severe cases, temporary stabilization may need to be installed to remediate conditions deemed as public safety issues. This is often done in combination with installing a sidewalk protection canopy or completely restricting access below. In both instances, it is important that the professional understand the building construction to design the proper repair or stabilization method which both protects the public while remaining sensitive to preservation issues-- specifically preserving historic building fabric.

The Secretary of Interior's Standards states: *Deteriorated architectural features shall be repaired rather than replaced, wherever possible* [1]. Further, if an interpretation program involves the introduction of new materials … *these alterations should be reversible and removable without leaving permanent traces* [2]. All repair approaches should be designed to be removed or replaced in the future when implementing better techniques and materials is possible if and when they become available [3].

With many older buildings, different professionals are often retained to perform inspections of a building throughout its lifetime, especially for buildings in private ownership. Each professional involved with a building is responsible for repair decisions and must feel certain that the conditions of the building do not threaten safety of the occupants or public. To ensure this level of comfort, each new responsible professional must understand the theoretical approach taken, the technical detailing, and the scope and scale of previous repairs. Effort to gain this knowledge may lead to inspection openings and corresponding destruction of historic fabric.

The professional has a pallet of numerous materials and stabilization techniques available. For example, masonry units can be pinned in place; or restrain in place with plywood enclosures or netting. In some extreme conditions, removal of the distress units, shoring the remaining surrounding wall area, and installing a weather tight enclosure may be necessary. Often, creating inspection openings is necessary to identify the as-built conditions. It is necessary to evaluate the type and condition of the substrate to which the repairs will be anchored. Improper anchorage choice or installation, based on the substrate material, can cause the repairs or stabilization techniques to be ineffective.

DETERIORATION AND DISTRESS

Types of masonry distress include cracking, spalling, displacement, and/or bowing in the exterior wall materials. These types of distresses can be caused by environmental factors in combination with material properties. Clay masonry materials such as brick and terra cotta initially expand from moisture absorption and, over the life the material, thermal cycling will occur resulting in expansion and shrinkage proportional to temperature changes. The initial and cyclical expansion will cause both horizontal and vertical movement within the wall. At corners, expansion can cause walls to displace at corners, especially at the parapets which are exposed on three sides rather than one or two sides which are typical in other wall areas. Masonry movement can also be restrained in the field of the wall by the lateral or gravity supports between the exterior walls and backup structure. The rigid supports generally do not accommodate expansion. Restrained expansive forces within a wall can cause bowing or budging between supports, at masonry openings, or other building elements and components. In some instances, no distress will be readily visible however high internal forces could result in unintended load paths within the cladding system and undetected concealed distress.

The weight of masonry veneer walls are typically transferred back to the building’s structural system with corrodible steel members, such as shelf angles, plates, channels or beams. Exposed to moisture, these members corrode, creating corrosion scale which will occupy up to ten times the original material thickness. The expansive forces from restrained accumulation of corrosion scale can also cause movements within the wall, producing cracking or budging. Corrodible metal ties are also used in masonry walls to laterally anchor the exterior walls to the backup structure. Thin metal straps are typically used as brick ties while bent bars, rods, or straps are used to anchor larger masonry units such as terra cotta, stone, and limestone to the backup material. Corrosion of these lateral anchors occurs within the masonry walls and may or may not be visible on the exposed surfaces of the masonry. Visual distresses may include cracking and spalling. Corrosion can also occur at isolated locations along the length of the anchor. This type of corrosion typically occurs at the interface between materials resulting in a loss of cross sectional area. A corroded anchor may cause distress or reduce the capacity of the anchor to the point that it does not provide adequate lateral support for the unit. Detecting the loss of lateral support during a closeup inspection can sometime be achieved by sounding the masonry units and feeling the units for vibrations or movement. However, a visual inspection of the embedded anchors is the only method to definitively determine the condition of the anchor and support of the unit.

CASE STUDY 1

In 2006, WJE was retained to perform an exterior facade inspection of an eleven-story building that was constructed in two phases during 1900 and 1903 in Chicago, Illinois. The building had a structural steel frame and the exterior wall system consisting of terra cotta cladding with a two-wythe brick backup wall. The inspections were being performed to comply with regular facade evaluations which are required by the City of Chicago. The purpose of these code mandated facade evaluations is to determine that buildings are being maintained in “sound condition and good repair” for the necessity of the “health, safety, welfare and general well-being of the general public” [4].

The facade inspection was performed from suspended scaffolding to allow close-up access to the building facade elements. The facade was inspected for visual deficiencies such as cracks, spalls, displacement, or bowing. Terra cotta units were also individually evaluated by lightly tapping each unit with an acrylic hammer in an attempt to identify hidden deficiencies such as cracks within the body of the unit behind the exterior face, loose units, or spalls.

The building facade had been previous inspected by others; however, documentation of the type and extent of repairs was not available. The majority of the building was clad with terra cotta ashlar units, except at corners and window perimeters where decorative units were installed. The building also had decorative water tables at various levels. Previous in-situ pinning had been performed. Stainless steel threaded rods had been installed through the face of the terra cotta units presumably in an attempt to anchor the exterior material to backup material. Our inspection revealed that holes were predrilled through the units before a stainless steel screen and rods were installed. Epoxy was then installed into the anchor screens prior to the installation of the threaded rod. Once the threaded rod was installed, the epoxy was suppose to extrude through the screen to provide a bond to the backup material and key the anchor in place.

During our inspections, ashlar units on the columns were found to vibrate and shift when tapped with a sounding hammer. Tapping the units caused the surrounding mortar joints to crack and spall. This condition occurred at previously repaired locations and at locations which exhibited no visible exterior distress.

Based on these observations, a masonry contractor, who was assisting with the inspection, was directed to grind out the adjacent mortar joints of an ashlar unit at the column in an attempt to remove the unit in its entirety and create an inspection opening. Immediately after the joints were cut, the face shell of the unit fell out into the contractors’ arms. Observations of the inspection opening revealed that the accumulation of stresses within the exterior veneer had caused vertical cracks to develop through the body of the unit behind the exterior face; shearing the unit. The face shell of the cracked units was no longer connected or structurally anchored back to the facade. The face shell was being retained in the wall only by the surrounding deteriorating mortar. The remaining portion of the cracked unit was removed to observe the as-built construction and condition of the original metal anchors. At this location, the anchors were found to be in serviceable conditions.

The cells of the ashlar units were found to be unfilled. The ashlars were anchored back to the structural steel columns or adjacent terra cotta units with bent square bars through holes in the top surface of the unit. Typically, the original steel lateral anchors were in serviceable condition with only minor surface corrosion. The building structure was comprised of built-up I-shaped steel columns and on this facade the web was parallel to the exterior wall. The space between the steel column and back face of the terra cotta was void at the top and intermittently filled with brick and mortar from mid-height to the floor level (Figure 2).

Figure 2: Representative examples of the conditions found in Case Study 1: a) Previous repair anchor remaining after removal of terra cotta unit; b) Shear cracks through terra cotta unit behind exterior face (note: angle on right side of photograph was installed as a temporary support).

Since the large void areas existed behind the terra cotta, the previous repair attempts were ineffective. The threaded rod stabilization anchors were not installed into sound backup material. Instead, the anchors were installed through the face of the terra cotta units and hung freely in the void area. At some locations, there was evidence that the contractor who had installed the anchor had encountered steel while drilling the pilot hole for the anchor as indicated by the scratches in the column directly behind the repair anchor locations.

To determine the extent of this condition, the masonry contractor removed an ashlar unit at another location around the corner on a return wall. A number of ashlar and decorative corner units had been previously repaired at this location. As described above, once the mortar joints were cut the face shell was easily removed. The threaded rod, which had been installed through the face of the removed unit, remained in place. The threaded rod had been installed at an approximate 30 deg downward angle and was embedded only 19 mm (0.75 in) into loose masonry infill brick. Also, as previously observed, the cavity behind the exterior veneer had numerous voids as well as areas of loose brick infill at the floor lines.

The other end of the threaded rod had been installed such that the end of the rod was recessed back from the exterior face of the units approximately 12.7 mm (0.5 in). The thickness of the

face shell of the terra cotta units ranged between 1 inch and 31.75 mm (1.25 in). The back of the face shell was spalled from drilling the anchor hole into the terra cotta unit. The depth of the spall was approximately 12.7 mm (0.5 in). Thus, the threaded rod likely engaged less than 6.35 mm (0.25 in) of the face shell. The previous repair therefore did not adequately engage the face shell of the ashlar unit or provide adequate embedment of the anchor into the substrate.
The previous thread rod installation into adjacent corner units and ashlar unit on the other side of the corner could also be observed from this inspection opening. As observed during the first inspection opening, anchors installed through the units at or near the corner above the floor line had been installed back to the structural steel column and did not engage any masonry backup.

Based on these observations, the masonry contractor was directed to install plywood over units which were identified to be loose or vibrate when sounded. The plywood was lapped over adjacent ashlar units and secured with stainless steel threaded rods with epoxy, washers, and nuts into the cells of the adjacent units. This approach was used to prevent loose face shells from dislodging and falling by restraining the delaminated portion with the plywood enclosure. At the completion of our inspection, we advised the owner that a repair plan should be developed and implemented the following year. The repairs would include the removal and installation of new terra cotta ashlar units at all of the plywood locations.

Though not an ideal choice, anchoring through the adjacent sound terra cotta units rather than into the mortar joints was based on the deterioration of the mortar as well as the ashlar terra cotta units being reasonably economical to replace, if necessary. Also, relatively minor damage of the units would occur by installing the anchors into the units. By anchoring to secure units, a consistent and reliable load path was achieved to address the observed distress.

CASE STUDY 2

In 2007, WJE was retained to perform an exterior facade inspection of a 13-story building constructed in the 1920s. The concrete frame building was clad with terra cotta and brick masonry. The majority of the building cladding was brick with terra cotta sills and coping units, except for the main building facade which had terra cotta units installed around the perimeter of punched and bay windows. The entire first story of the main facade was clad with terra cotta with continuous terra cotta water tables at the second, fourth and twelfth floor levels. Terra cotta banding and decorative units exist at the roof parapet walls. The purpose of this inspection was to evaluate of the condition of the building facades to comply with the facade ordinance for the City of Chicago. The previous building facade report had stated that the building facade was in “excellent” conditions. The report stated that when the building was developed into condominiums in the mid 1990s the developer had performed exterior repairs which consisted of “tuck pointing portions of all wall” and repair of terra cotta units consisted of “re-cementing where required”.

During our initial suspended scaffolding inspection, a visual survey of the parapet wall revealed diagonal cracking and a significant bulge at the center of the parapet wall between the coping and banding course. The parapet was also found to be significantly out of plumb with the facade area below. To assess concealed conditions and determine the appropriate remedial approach, bricks were removed at the parapet wall by the masonry contractor assisting with the inspection. The as-built construction consisted of hollow clay tile block infill between the concrete building frame. A 25.4 mm (1 in) wide collar joint was found between exterior face brick and the backup wall. Steel dovetail brick ties were observed in vertical dovetail slots cast into the concrete columns. Limited brick headers were originally installed between the exterior wythe and the backup every 6 to 8 courses.

A limited survey of the collar joint at the inspection opening revealed that no brick ties existed between the field of the face brick and the backup wall. The majority of the brick headers were actually false headers, with true headers being installed randomly throughout the parapet wall. The true headers visible at the inspection opening were cracked at the collar joint interface and the outer wythe was displaced outward as much as 38 mm (1.5 in). A loose laid steel angle had originally been installed on top of the terra cotta banding course and was significantly corroded. Loss of section and corrosion scale accumulation of the angle had caused the parapet wall to be displaced upward, resulting in the observed cracking and displacement of the brickwork (Figure 3).

Figure 3: Representative examples of conditions found in Case Study 2:
a) Cracked headers and displaced parapet wall; b) Significantly corroded angle.

Based on our observations of the existing construction and the severity of the exterior wythe displacement, we recommended that the parapet wall cladding be removed from the terra cotta band up to and including the coping units. The backup walls remained and a wood-framed wall was installed in front of and anchored back to the concrete structure. Plywood sheathing was installed on the exterior of the framing and the joints and perimeter sealed to provide a water tight enclosure. Due to economic constraints, we recommended that the owners develop and implement a repair program for the building facade which would be performed in a phased approach over a number of years. The repair program will include reconstruction of the parapet walls removed during the inspection as well as repair and/or replacement of other areas of deterioration on the facade.

CASE STUDY 3

In 2005, WJE was retained to perform an exterior facade inspection of a seven story building constructed in the 1920s. The concrete frame building was primarily clad with face brick with limestone sill and coping units. The main building facade of the building was entirely clad with limestone. Limestone cladding from the main facade also extended around the building corners onto the return walls. Similar to the previous case studies discussed above, the purpose of this inspection was to evaluate the condition of the building facades to comply with the facade ordinance for the City of Chicago. The building had been previously cited by the City for visual facade distress observed by city inspectors.

From suspended scaffolding, WJE performed an inspection of the return wall at the west end of the main facade. Diagonal cracking and displacement of the brickwork and displacement and spalling of the limestone units were observed in the brick parapet wall at the corner of the building. Limestone spalling was occurring at the locations of metal strap anchors embedded into the top of the units. Bricks were removed from the parapet wall, adjacent to the limestone corners panels, to observe as-built construction and concealed conditions. These openings revealed that the backup wall consisted of common brick infill between the concrete structural frame. The exterior masonry facade was separate from the backup wall by a 25.4 mm (1 in) collar joint which was generally found to be open.

At the inspection opening, it appeared that the limestone units were originally laterally restrained by metal dovetail strap anchors set into vertical dovetail slots cast into the face of the concrete column. However, at numerous locations, corresponding to the displace limestone panels, the limestone dovetail strap anchors were no longer engaged in the slots in the columns. The anchors had either been pulled out of the slot by the horizontal movement and associated forces within the wall, or they had not originally been installed into the slots. Thus, the limestone units at the top of the parapet wall were not adequately anchored to the backup (Figure 4). The brick portion of the wall was originally anchored to the masonry backup wall with smooth or corrugated metal brick ties. However, the ties were found to be randomly installed and several were severely corroded or had pulled out of the bed joint of either the backup or exterior wall from the forces resulting from the wall displacement.

Figure 4: Representative examples of conditions found in Case Study 3:
a) Displaced brick and limestone; b) Bent original dovetail anchor (left arrow) and new epoxy threaded rod stabilization anchors (right arrows).

In order to secure the limestone in place, the contractor was directed to install stainless steel threaded rods through the face of the units set into an epoxy filled hole in the concrete column. A washer and nut were installed on the end of the rod and installed snug to the face of the limestone to prevent further outward movement of the units. The brickwork was stabilized by installing a stainless steel retaining system consisting of a grid of stainless steel straps installed over stainless steel mesh. The straps and mesh are held in place with stainless steel threaded rods set in epoxy into the backup brickwork. The mesh and straps were installed snug to the face of the limestone with washers and nuts on the ends of the rods. The owner is currently in the process of developing and implementing a repair program which includes removing and rebuilding the displaced masonry walls.

Similar to Cast Study 1, it was not an ideal choice to anchor through the ashlar limestone units. However, the spalling of the units due to embedded steel damaged many of the units beyond practical for salvage. By anchoring the units with stainless steel fasteners, the time frame for replacing the units could be significantly deferred. This approach also provided a consistent and reliable load path to address the observed distress.

GENERAL APPROACHES

Often discrete elements, which are significantly deteriorated, can be stabilized by wrapping nylon netting or other fabric or membrane materials around the elements to address immediate public safety issues. The advantage of this approach is that they are lightweight and relatively easy to install, but the susceptibility to UV deterioration limits their service life (Figure 5). These systems are often installed when the units comprising a particular component are deteriorated beyond being reasonable to salvage. These systems must be designed based on the load which could be imposed from a component becoming dislodged as well as the size of fragments resulting from a failure.

Figure 5: Representative examples of netting systems.

In some instances the most effective method of addressing severe deterioration is removing the significantly damaged area in its entirety. This approach is most appropriate when the substrate is significantly compromised while the individual cladding units are mostly intact. These conditions typically occur when the metal anchorage and support are not embedded into the units or when the distress is limited to unrestrained thermal and moisture expansion. Removing units in their entirety retains historic fabric but leaves the building envelope susceptible to water infiltration. Therefore, it is critical that an effective weather protection system be installed.

CONCLUSION

As masonry buildings continue to age, there will be an increased need for repair and maintenance of their facades. Distress from natural movement within the walls or corrosion of embedded steel members will need to be stabilized, repaired or removed to provide public safety. The professional is not only responsible for inspecting and identifying unsafe conditions but must also understand their cause(s) and how to mitigate them. It is important that the professional verify the existing as-built conditions to be able to select the appropriate materials and stabilization and/or repair techniques. Once the professional verifies the building construction and the proper intervention, the information must be effectively conveyed to the contractor to assure proper execution and maintain public safety. The professional should establish open communication with the contractor. The contractor should not only be aware of the locations to install the repairs but should also be informed of the intent of the repairs. Communication with the contractor is very important during the installation of the interventions. If the contractor encounters conditions different than the professional anticipated, the contractor should understand the importance of contacting the professional to notify them of the conditions and request direction for how to proceed. Open communication between both the contractor and the professional will help to ensure that the work is performed as intended and the unsafe conditions effectively addressed while also being sensitive to the historic fabric of the building.

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