The Empire State Building

Façade Evaluation and Repair of an Engineering Landmark

By Robert J. Nacheman, P.E.

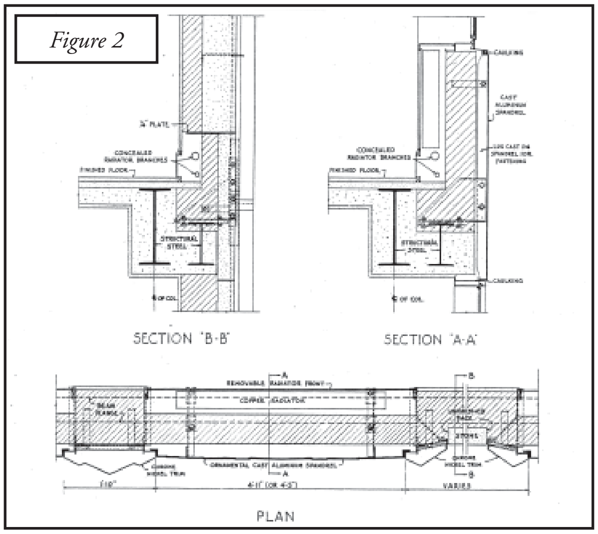
The Empire State Building was completed in 1931, after only sixteen months of construction. At 1250 feet to the top of the dirigible mooring mast, the Empire State Building was the world's tallest building for over 40 years, until the construction of the World Trade Center towers. Around 1950, a 200-foot tall broadcast antenna tower was added to the top of the building. A New York City and National Historic Landmark, the Empire State Building has also been cited by the ASCE as a National Civil Engineering Landmark. (*Figure 1*)

One of the many innovative characteristics of the building is the curtain wall design for the façade. This wall system evolved from the traditional rigid masonry façades that predated it, and pioneered the concepts of flexible curtain walls that are now commonly incorporated into high-rise buildings. This article examines some of the challenges faced by the designers of the building's exterior façade walls and by the Thornton-Tomasetti Group in designing its repair after 60 years of service. That period without major restoration represents a very respectable service life for the exterior wall system of a high-rise building.

Original Façade Wall Design

The building's façades consist of a series of vertical bands of brick back-up masonry faced with limestone, alternating with vertical bands of steel framed windows with cast aluminum spandrel panels. Continuous vertical stainless steel mullions are anchored to the steel spandrel beams. The mullions are located between pairs of windows and at the edges of the limestone clad column piers (*Figure 4*). The brick back-up masonry fully embeds the building's steel columns and backs up the intermediate stainless steel mullions. A single wythe of brick masonry in-fill backs up the cast aluminum spandrel panels (Figures 2 and 3). The narrow vertical bands of limestone clad brick masonry with stainless steel mullion trim, separated by the continuous strip of cast aluminum spandrels and steel window frames, are flexible enough to deform during horizontal sway of the building under wind load. Hence the limestone cladding has not cracked as a result of wind induced movement.

Figure 2



Drawing courtesy of ***Architectural Forum Magazine****, June 1930*

Figure 1

The structural steel frame incorporates two spandrel beams at each floor level; an inboard beam to support the concrete floor and live loads, and an outboard beam to support the exterior wall masonry. Each story of the masonry "piers" typically has four courses of limestone cladding in front of the common brick backup masonry. Typically, three out of the four limestone courses at each story are four-inch-thick stones backed up by eight inches of brick masonry. The back-up brick masonry behind those stones is supported on the outer spandrel beams. One stone course at each story is eight inches thick with only one wythe of brick masonry back-up. This "key" stone is supported on one of the wythes of brick back-up masonry below it, which in turn is supported by the outer steel spandrel beam The brick back-up masonry is anchored to the structural steel columns with bent ⅜-inch diameter steel rod anchors, and the limestone is anchored to the brick masonry with flat section bent iron bars that are hooked into the brick masonry and into cut out slots or "kerfs" in the top, bottom and side edges of the limestone units.

Façade Investigation Program

The Thornton-Tomasetti Group was retained in 1987 to evaluate the condition of the exterior walls, roofs and windows of the building and make repair recommendations. The built-up roofs at the setback levels and their deteriorated perimeter base and counter flashings were allowing the passage of a lot of water into the façade walls. As a result of water penetration through the many setback roofs, parapet masonry joints, wall masonry joints, and windows, deterioration had occurred. Scaffold-accessed investigation was performed throughout the building's façade walls. It was found that the mortar joints between the limestone units were in severely deteriorated condition and that this too was allowing moisture to infiltrate the walls,

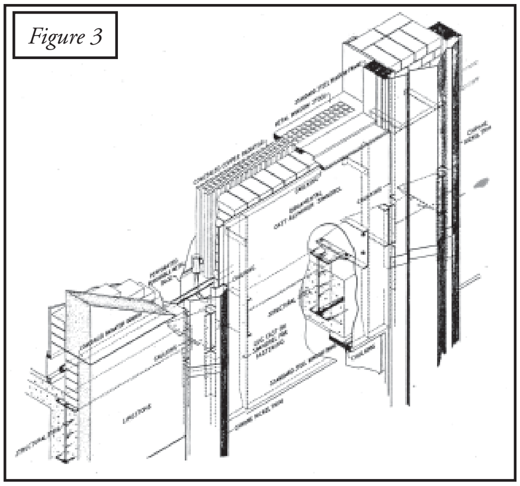


Figure 3

Drawing courtesy of ***Architectural Forum Magazine****, June 1930*

causing corrosion of the iron strap anchors attaching the limestone to the brick back up wall. At these locations, as the iron anchors corroded, the corrosion product expanded, causing a shard of the limestone to pop out, and severely diminishing the limestone anchorage capacity. The parapet walls were severely deteriorated as a result of water infiltration, which caused corrosion of the steel spandrel beams, and also freeze-thaw damage to the masonry. At the building corners, the stone was cracked and many years ago, steel straps had been bolted on to the surface of the limestone in an attempt to confine the limestone cladding in place. (*Figure 6*)


Figure 4

Like many solid masonry clad buildings of this time period, there were no surface-visible "soft" joints in the façade masonry to handle the initial column shortening, temperature and moisture expansion, and wind movement. Archival research and later invasive investigation did identify that a compressible filler consisting of corrugated lead, lined top and bottom with sheet lead, was installed in the bed joint at the eight-inch-thick key stone. It appears that this compressible layer did serve very well to accommodate permanent shortening of the steel structure during erection, because, as we later found, these lead strips were compressed solid in the stone joints. At some point, these joints had apparently been re-cut and pointed, and thus apparently they provide minimal ability to accommodate additional strain. Yet in our investigations of the masonry facade, no significant damage related to compressive stress was evident.

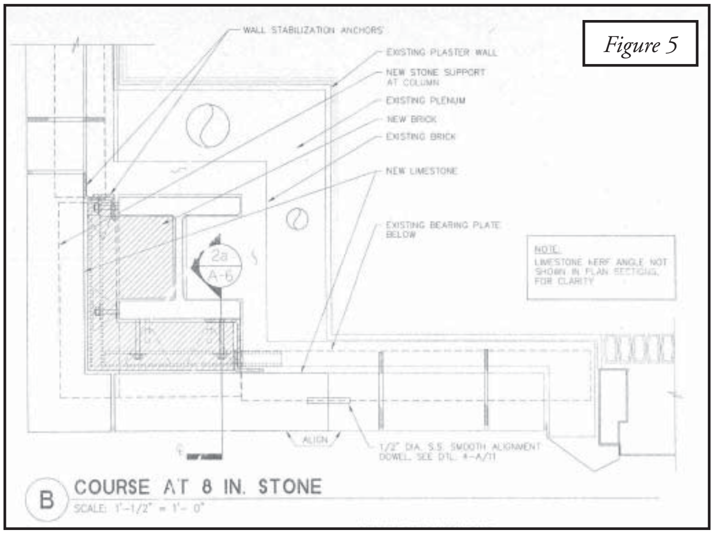


Figure 5

Like other buildings of its era, the Empire State Building walls work because they are thick, solid, composite masonry. Gravity loads are relieved at each floor into the building structure so gravity load stress does not accumulate in the masonry. It can be rationalized and empirically confirmed that the thermal expansion and contraction of the masonry is minimized because the heat sink effect of the massive masonry and embedded steel. Stress resulting from the initial expansion of the brick masonry also unloaded one floor at a time into the floor spandrel beams.


Figure 6

Wind movement is minimized by the very stiff structural steel frame, which weighs in at a hefty 60 pounds per square foot of floor area, with columns spaced at approximately 20 feet on center, compared to about half that weight per square foot and 30-to-45-foot column spacing in modern high-rise buildings. Movement of the structural steel frame of the Empire state Building is thus relatively low, in comparison to modern high-rise buildings with optimized (therefore lighter and more flexible) structural steel frames.

Façade Repair Program

In 1989, a program of façade repair was specified by the Thornton-Tomasetti Group and work was begun by A. Best Contracting. This work included cutting all of the existing limestone joints to a depth of about ¾ inch. Closed cell polyethylene foam backer rod and Sika® polyurethane sealant were then installed in the limestone masonry joints. The unorthodox installation of sealant at the front of the limestone joints provides further protection against the infiltration of water through the many joints between the limestone panels. Although these sealed joints also prohibit expiration of moisture out of the masonry and this practice is therefore usually not desirable, moisture evaporation from the wall is more than adequately provided for by the large area of vapor permeable limestone. The joints between the limestone units will be kept weather tight by the low elastic modulus polyurethane sealant.

The wall surface was sounded to detect latent spalls at the corroded iron anchors. A new anchor was installed to replace the function of each corroded iron anchor that was removed. Some of the new anchors were Dur-o-wall® stainless steel threaded rods with mechanical brass expanders at each end that engaged the brick back-up masonry and the limestone. In other locations, epoxy adhesive was used to anchor threaded stainless steel rods for the same purpose. The shards in the limestone and the corroded iron anchors were saw cut and removed. The exposed stone was grooved and ¼-inch diameter stainless steel wire anchors were embedded in the limestone (*Figure 8*). The voids in the limestone were filled with specially formulated Jahn® repair mortar that matched the thermal expansion and moisture absorption rate of the surrounding limestone. At parapet locations where the spandrel beams had been severely damaged by corrosion, the displaced limestone and brick back-up masonry was removed, the structural steel was repaired and epoxy coated, and the masonry was replaced. At cracks in the large limestone units at the building corners, the initial plan was to use epoxy set stainless steel pins to stitch the stones together and to the brick masonry back-up wall, and this work commenced.

In 1989, an investigation of the 6400 window frames and adjacent interior walls was performed. The original anchorages of the existing windows to the brick masonry were found to be in good condition. However, the steel window frames and the double hung sash frames were severely corroded and the weather stripping was in poor condition.

Figure 7

It is interesting to note that the Chrysler Building (featured in the December 2005 issue of STRUCTURE magazine), which was built at approximately the same time, has similar steel-framed windows. However, these were originally galvanized, while the windows at the Empire State Building were originally painted. After 60 years of service, the Chrysler Building's windows were in much better condition than those in the Empire State Building. Repair of the original windows was studied but it was found to be impractical. The 12 existing coats of paint over the corroded steel would have had to be removed and the steel prepared and treated with two or three coats of new paint. This would have involved removal of the sash for surface preparation and painting, requiring temporary closure, interior restoration and tenant disruption. Work on the steel window frames in place would have been tedious and costly, especially with lead paint removal safety issues. Corrosion of inaccessible surfaces of the frame and sash would undoubtedly have continued, with no guarantee of the durability of the repaired windows, even after spending millions of dollars for repair work. Since the original sash did not tilt or rotate, window washing had to be done from the outside, typically by personnel tied back to buttons on the window frames. This method is currently not acceptable by OSHA and certainly the corrosion of the frames made this procedure even less safe than in the past.

Figure 8

Replacement windows were specified as Series 9000 windows manufactured by TRACO®. These replacement windows have several important features. The windows were designed to pan over the existing Campbell® steel windows. The existing window paint coatings were tested to determine the original color of the windows. The original red color was matched on the replacement windows. The new double hung tilt windows have aluminum frames and sash with very narrow profiles to keep the total width of the metal minimized and the "sight lines" maximized. The sash is glazed with insulated glass units. The new frames are thermally broken, accomplished by connecting the front and back extrusions with a continuous cast-in-place section of polyurethane, which has a much lower thermal conductance rate than aluminum. The condition of the steel sub-frame and anchors into the brick masonry were in good condition, and so they were re-used. The new windows were screwed to the Campbell steel sub-frames with self-drilling/tapping stainless steel screws. The joints at the outside perimeter of the windows were sealed with Sika® polyurethane sealant, to the stainless steel mullions at the jambs and to the cast aluminum spandrel panels at the sills and heads.

There are 19 separate roof areas on the building, totaling 33,380 square feet in area. The roofs were originally built-up, multiple ply coal tar roofs with quarry tile walking surfaces in mortar setting beds. Over the years most of the roofs had been covered with additional layers of built-up roofing, with stone ballast above that. By 1989, many of the roofs were leaking both into the interior spaces and into the façade walls. A roof replacement program was executed. The roofs were stripped down to the concrete slabs. New counterflashing pockets were created at the inside face the parapet walls. Polyisocyanurate foam insulation board was installed and covered with an adhered single-ply EPDM membrane. The membrane was then covered with a protection board and concrete pavers in a terra cotta color similar to the original quarry tiles. The replacement roof for the high traffic observation deck was specified and executed by others using Kemper® liquid applied polyester roof membrane, also topped with protection board and concrete pavers.

continued next page

Figure 9

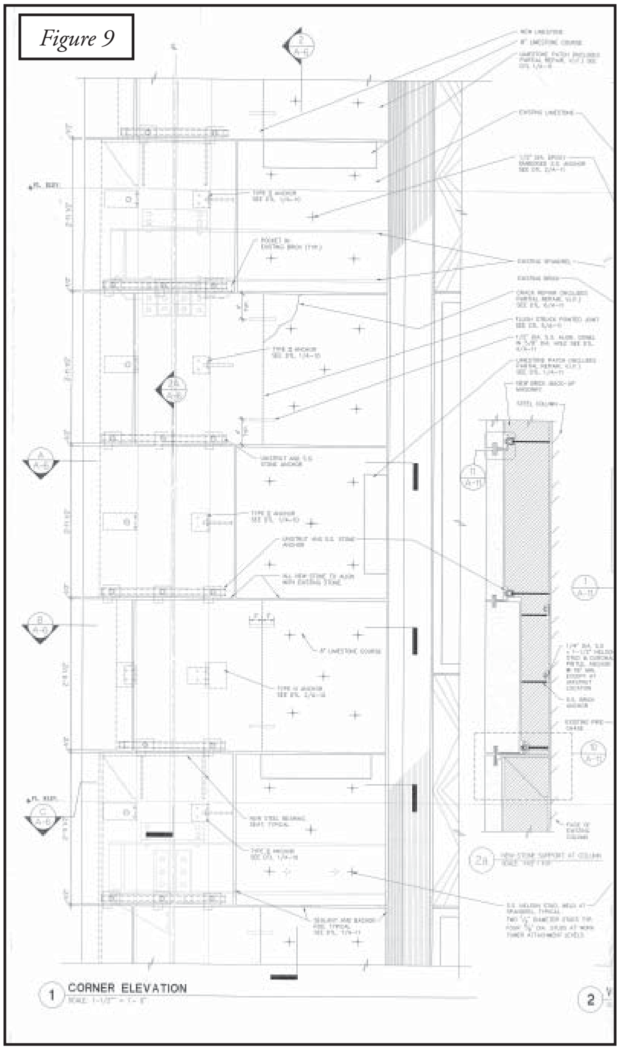


Figure 10

Major Repair Of The Corners

During the course of the repair of the field of the façade, roofs and windows, it had become very clear that the cracks at the corners of the building were indicative of a problem that could not be fully addressed by surficial repairs of the limestone masonry.

The mostly vertical cracks in the limestone facing and brick masonry back-up at the building corners were probed to confirm that the cracks were directly correlated to conditions of outward expansion resulting from corrosion of the structural steel (*Figure 7*). However, the amount of section loss at the structural steel framing sections was for the most part structurally insignificant. A detailed survey and invasive probes provided correlation between the degree of limestone cracking at the eight corners of the tower and the severity of corrosion of the structural steel building columns within the corner piers.

Several alternatives for restoration of the façade at the building corners were studied, including replacement in kind, replacement with pre-cast concrete, and replacement with glass fiber reinforced concrete panels. After a process of value engineering, the final scheme included localized replacement in-kind. The repair scheme was influenced by the extent of the repairs, the logistics of working up to 85 stories high on the exterior of an occupied building in mid-Manhattan, the need to improve on the original anchorage and support of the stone, to repair and to protect the vulnerable structural steel, and of course to preserve the original appearance and integrity of this historic landmark building.

A significant cost saving was realized by not replacing the entire corner piers. Once it was confirmed that only the masonry directly in front of the columns was damaged, it became feasible to replace only that masonry. Because of this, approximately three feet of masonry pier width at each side of the corner had to be removed, and approximately three feet between the window jamb and the removal line could be pinned in place and restored. The remaining limestone panels were re-anchored to the brick back-up masonry with ½-inch diameter threaded stainless steel rods set in epoxy (*Figures 5 and 9*).

The next step of the corner rebuilding work was the removal of the limestone and brick masonry back-up wall at the corners. A. Best Contracting had made extensive use of suspended scaffolds for most of the general façade repair work. Most of this work involved cutting, sealant, anchor pins, and mortar installation, and the relatively light duty suspended scaffolds were well suited to this work. However, for the masonry replacement and steel modifications at the building corners, they used a relatively new approach for executing the work. Steel support dunnage was installed at the 25th and 30th floor roof setbacks, and a trussed tower was installed on one side of each of the eight corners up to the 72nd floor setback roof, at three corners at a time. The trussed towers were laterally anchored to the building with epoxy-adhered threaded studs through the façade masonry into the concrete behind the building's outer steel spandrel beams. The scaffold tower was a variation of the more typical rack-and-pinion construction hoist, but instead of a cab, it had two independently operating L-shaped platforms on each tower that wrapped the corner work area with a 7,000-pound-capacity enclosed work platform. This equipment facilitated installation of the limestone units, which weighed up to 1,500 pounds each, and access by labor to the work areas.

The first step of the corner rebuilding work was the removal of the limestone and brick masonry back-up wall at the corners. Fortunately, investigation had shown that the corrosion damage to the structural steel was limited to the outboard surface of the columns and spandrel beam ends, with diminishing deterioration at about six inches back into the brick masonry/steel interface.

At the corners with limestone masonry cracks, the severely corroded structural steel columns were stripped of masonry and all exposed steel was power-tool-cleaned to meet the requirements of SSPC- SP11, which requires removal of all loose corrosion products to a sound, bare surface. Two coats of epoxy paint were then applied to the steel to protect the steel from corrosion. Care was taken to avoid removing the full thickness of the brick masonry abutting the steel columns so that the occupied tenant space remained enclosed at all times (*Figure 10*). Custom fabricated stainless steel Z-clips were connected to the columns with Nelson® threaded stainless steel studs, to positively engage the now discontinuous façade wall after demolition of the corner masonry. It was efficient to do all of the demolition in one phase, so it was necessary to leave the corners excavated for a few months time over the winter. Installing temporary tarps would have caused more damage to the limestone at anchorage points and would have been difficult to maintain in this very windy exposure. It was decided that all

Figure 11

Figure 12

voids and spaces between the bricks and between the masonry and the steel would be filled with mortar and that the demolition surface would be coated with a vapor-permeable, Portland cement, sand, and acrylic product manufactured by Sonneborn, called Sonoblok®. This coating successfully sealed the disrupted masonry until the steel and the masonry was replaced months later.

The limestone support configuration in the corner masonry replacement area was modified by welding on structural steel supports directly under the eight-inch-thick stone course. (*Figure 11*) The limestone at the rebuilt corners is now directly supported by the structural steel, rather than by the brick masonry as in the original construction. It is interesting to note that like many of the buildings of this vintage, there is no flashing over the structural steel beams, nor is there any weep system to allow drainage of water out of the wall assembly. Rather than change this concept in a localized zone, it was decided that the two coats of Tnemec® epoxy coating would adequately protect the prepared structural steel surfaces, and that the concept of filling every void in the wall with mortar would be maintained in the replaced masonry, making drainage and flashing less important than it would be in a cavity wall system.

Figure 13

In the replacement phase, thousands of two-inch-long, ¼-inch-diameter stainless steel threaded Nelson anchor studs were welded to the columns and triangular wire masonry ties were then connected to the threaded studs. Half-inch-diameter threaded stainless steel Nelson studs were welded to the steel columns to anchor stainless steel Unistrut®tracks placed horizontally in alignment with the horizontal joints in the limestone, to be installed later (*Figure 12*). The severe-weathering-rated bricks were set in ASTM Type N mortar to fully encase the structural steel, and to bring the brick back-up masonry to within one inch of the back of the new limestone panels. Temporary foam inserts were placed above and below the Unistrut tracks to allow for additional vertical adjustment to align the Unistrut tracks with the horizontal bed joints in the limestone facing to follow. When the replacement limestone was installed, custom-made ¼-inch-thick stainless steel split tail anchors, with vertical slots to allow adjustment, were bolted to the Unistrut tracks and the split tail anchors were engaged into slots cut into the edges of the new limestone units. (*Figure 13*) The new stainless steel anchors will not cause the same type of corrosion failure that deteriorated the original plain iron strap anchors and caused cracking and spalling of the original stone. The foam was later removed and the voids above and below the tracks were filled solid with mortar.

The limestone used for replacement at the corners was quarried from the same quarry as the original stone in Bedford, Indiana. Construction of a full-size mock-up of a story-high corner section and a rack of multiple full-size stones were constructed at the quarry. A range of colors and textures was agreed upon, and the accepted stones were then cut in half. One half was used at the fabrication shop for stone and finish quality control and the other half stones were used at the building for appearance verification. The limestone material was also subjected to extensive laboratory tests for compressive and tensile strength and for water absorption. Fabricated stones, including many L-shaped corner stones, were shipped by truck to New York City. The stones were brought down to the building cellar and inspected again. The stones were then transported upstairs by freight elevator to a convenient location, and passed out through a window opening onto the work platform, which carried them within inches of their installation location.

Figure 14

After the brick masonry cured for about a week, the limestone was installed. All of the collar joints, which are the vertical spaces between the masonry wythes, were filled solid with mortar. The mortar was sampled and compression tested at seven and 28 days. All limestone head and bed joints were filled with ASTM type "N" mortar to within ¾ inch of the front face. Closed cell polyethylene foam backer rod and urethane sealant were then installed at the front of the limestone masonry joints (*Figure 14*).

A lesson that was reinforced on this project is that when engineers work on vintage buildings, it is challenging to understand the intent of the original designers and to be sensitive about how modern design and detailing practices are combined with very different older design practices.

The Empire State Building façade is now ready to face the next 60 years of its service, with of course, regular maintenance.▪

Robert J. Nacheman, P.E. is a Principal, Thornton-Tomasetti Group Inc., LZA Technology Division in Newark, New Jersey. Mr. Nacheman can be reached at ***RNacheman@TheTTGroup.com***