TERRA COTTA INSTALLATION: THE EVOLUTION AND DEVELOPMENT OF ANCHORAGE SYSTEMS

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ABSTRACT

Traditional construction in the first half of the 19th century relied on solid masonry walls as both the building's structural system and the exterior enclosure. The industrial revolution of the late 19th century dramatically changed building construction of large scale commercial buildings. The economical manufacturing of steel shapes was a major contributing factor in the development of the skeleton frame structural system in which the exterior wall could be treated as the "skin" of the building and no longer an integral part of the main structural system.

Terra cotta has been used for thousands of years in the construction of buildings. With the development of the skeleton frame system, in combination with the dramatic increase in urban density and the desire for greater speed and economy in construction, terra cotta quickly gained acceptance as an economical alternative to stone as an exterior cladding material. Unlike traditional solid walls which were keyed together, terra cotta cladding systems required supplemental anchors, which included a variety of bent bars and rods, were installed to anchor the terra cotta to the backup masonry or structural steel to provide stability during construction as well as lateral and/or vertical support for the units.

The first part of this paper will review early development of the terra cotta anchorage systems. The second portion will present three case studies of alternative anchor systems used in early terra cotta skyscraper restoration projects. The alternate approaches were developed to reduce repair costs by minimizing the removal of undistressed integral units to address the underlying causes of distress.

KEYWORDS: terra cotta, lateral anchors, metal

INTRODUCTION

Prior to the 1870s, the exterior walls of buildings functioned as both the building's structural system and the enclosure for the interior space. The height of load-bearing buildings was dependent on the thickness of the exterior walls and the load capacity of the underlying soil. Early masonry walls were solid walls of multiple wythes. Typically the walls were constructed with face brick, decorative terra cotta or stone on the exterior surface and common brick for the remaining backup wythes. The wythes of these walls were often tied together by uniformly distributed headers, which are individual units turned perpendicular to the plane of the wall and span between adjacent wythes.

The Industrial Revolution of the late 19th century led to the introduction of steel as a building material. With the ability to economically manufacture steel shapes, the skeleton frame building system soon developed. Steel frame buildings became common practice in the construction industry because of their economy, scale and speed of construction that could be achieved when compared to traditional load-bearing masonry buildings. Skeleton construction allowed exterior walls to be designed "primarily for the purpose of excluding [sic] the elements, and to provide opportunity for architectural treatment." [1].

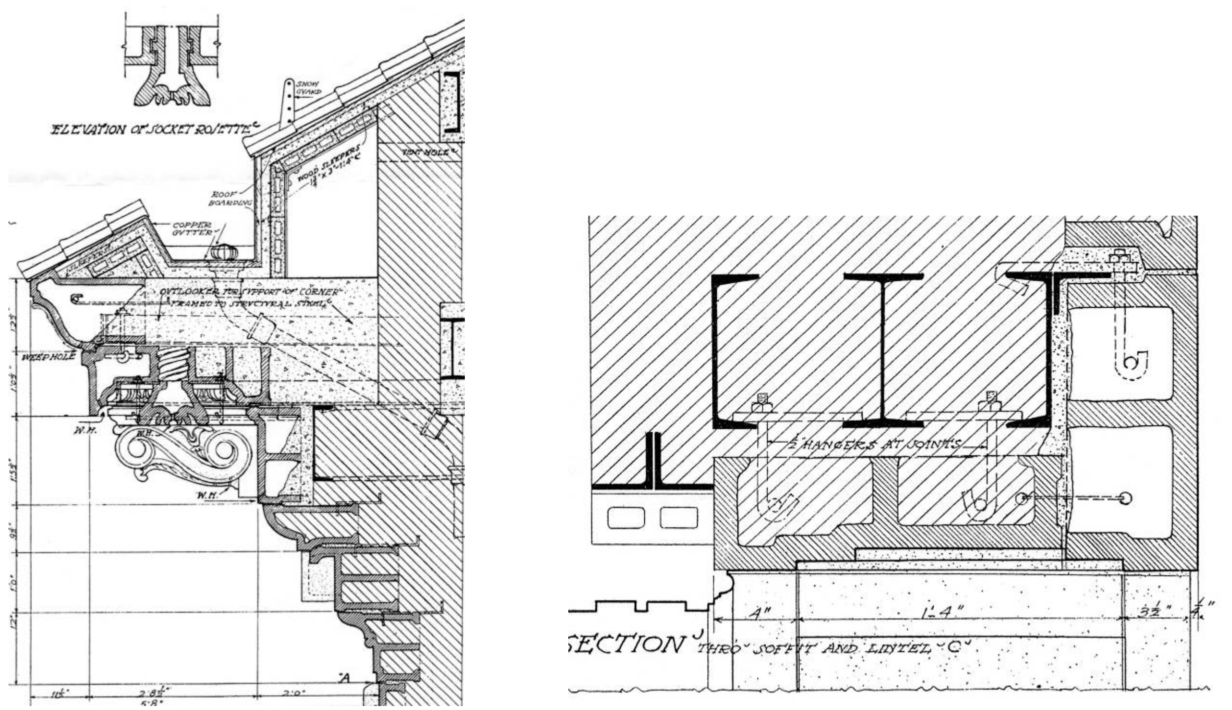

Figure 1 - Representative sections details from National Terra Cotta Society, Standard Construction Details, 1927 edition

Also during this time, terra cotta was gaining popularity as an economic alternative to stone, and was regarded as "artificial stone". Several repetitive ornamental units could be cast from one mold, thus offering economical and decorative flexibility. Terra cotta also had the advantage of being a lighter substitute for stone. Terra cotta units were first used on buildings for roofing, flooring, and sculptures, and later, terra cotta began to be used for other cladding elements such as window spandrels, sills, jambs, heads; water tables and cornices (see Figure 1).

This new cladding systems necessitated the development of a system to attach the terra cotta units to the building's structural frame and to provide lateral stability and vertical support of each unit during construction. The exterior wall was constructed after the frame was in place and generally consisted of the decorative exterior wythe and a backup wall system intended to provide fire protection for the steel frame. Thus, the exterior wall was assembled around the frame and the terra cotta units were installed as the wall was constructed and packed solid with bricks and mortar from behind as they were installed. To increase the efficiency and speed of the installation, supplemental anchorage was added to secure the unit until the wall was completed. This anchorage typically consisted of bent steel or iron bars which were installed into the top of the unit or through a preformed hole in the web of the unit. Generally, projecting units had only the portion of the units within the wall surface filled with brick and mortar to keep the center of gravity of the unit as close to the face of the wall as possible and transfer loads through the units. Metal hooks, bars, and rods were used to resist the over turning moment from gravity loads, but were also critical to allow construction of the wall to proceed prior to the mortar curing.

TERRA COTTA

For manufacturing purposes, terra cotta units were usually about 45.7 cm (18 in) long, but generally no longer than 61.0 cm (24 in), 15.2 to 30.5 cm (6 to 12 in) deep; the height was determined by the character of the piece. Units are comprised of an outer shell, and are braced with intermittent webs to prevent warping of the unit during firing and add strength to the units. Spacing of the webs was generally intended to create cells, or the area between webs, to be no greater than 6 inches (2). Bricks and mortar were used to fill the cells in the terra cotta units from behind to create a solid wall. Pieces were generally referred to as *balanced* if they were installed within the plane of the wall, and *unbalanced* if they projected from the wall and required additional anchorage support during installation.

When compared to stone, the relative "lighter" weight of terra cotta units allowed architects to more readily introduce cornices and other projecting building elements. Supplemental steel framing was added to the structural building frame for support. Hung units such as window heads were supported by horizontal bars which were inserted through holes in the webs and supported by J-hooks. The J-hooks are anchored to structural steel elements such as shelf angles or spandrel beams. The structural elements could be located directly above the hung units or embedded within the brick masonry or behind additional terra cotta units within the system.

MAINTENANCE AND REPAIR OF EARLY CURTAIN WALL SYSTEMS

As the early twentieth century buildings continue to age, the need to economically and effectively maintain and repair these buildings continues to increase. As embedded steel members and anchors are exposed to moisture, the resulting corrosion and expansion caused by the corrosion scale build-up damages the adjacent building materials. While original construction allowed easy access to the top of units as the wall system was constructed, replicating a similar system for replacing units would require removal of significant material which may not be necessary.

A conventional and certainly, rational approach to address terra cotta repairs is to replicate the existing original anchorage system in kind but replace the original carbon steel components with new corrosion resistant materials such as stainless steel. While this approach is consistent with repair and preservation criteria, it can add considerable cost to the project as well because of the need to remove 'sound' material to address the causes of the distress.

Several factors contribute to a traditional approach not always being the most cost effective. As previously discussed, in tradition construction methods, the terra cotta units were typically constructed integrally with the wall by keying the units into the wall with bricks set into the cells in the back of the units. Therefore, removal of existing units is difficult since the system was effectively stitched together, and if great care is not used to remove undamaged units, the loss of additional units can occur. If extreme care is not used, damage caused by unnecessary removal of units will potentially add unnecessary costs and delays to the project.

The following case studies provide a range of approaches which have been used by the authors in an attempt to minimize costs associated with removing and replacing or reinstalling terra cotta units.

CASE STUDY 1

Between 2001 through 2003, WJE performed terra cotta repairs to a 38-story terra cotta clad building that was constructed in 1929 in Chicago, Illinois. Years of differed maintenance and economic constraints required a repair approach that addressed the most significant distressed areas, maintained the integrity of the facade, but by no means resulted in a facade that could not be regularly and vigorously maintained.

The majority of the early skyscrapers made no accommodation for the accumulation of compressive stresses within the cladding system. In this particular building, the combination of initial moisture expansion, thermal cycles and frame shrinkage resulted in significant compressive stresses within the cladding system. These stresses resulted in cracking and localized displacements of the terra cotta. The accumulated corrosive scale on the underlying steel at pier areas was found to be minimal and determined not to have significantly contributed to the distress within the terra cotta, but portions of the support steel had significant loss of cross sectional area. Therefore, it was deemed necessary to address the accumulated stress by cutting relief joints in combination with replacing significantly distressed and displaced units and in-situ pinning of cracked pieces within the piers and some spandrel areas, as described below.

Since the underlying steel support and lateral anchorage were found to be in serviceable condition at most locations, it was WJE's opinion that if the stresses in the cladding system were relieved by a combination of shelf angle replacements and stress relief cuts, that the cracked units could be pinned. Therefore, terra cotta units which exhibited minor cracking and were not displaced were pinned in-situ using stainless steel helical anchors. Limited inspection openings determined that these units were generally cracked as a result of the corrosion of the lateral anchors in combination with accumulation of compression with the cladding system.

The helical anchors were selected due to the ease of installation, cost, and lack of weather restrictions for installation. Helical anchors are analogous to self tapping screws and are intended to withstand lateral loads only. The number of pins installed in the distressed unit depended on the size and the number of individual cracked pieces within the unit. The hole in the face of the terra cotta resulting from the installation was filled with a sealant. While the installation of the pins has limited visual impact, it preserves the original building fabric and limits the amount of original terra cotta that has to be removed; it does not address all of the underlying causes of the cracking since the original lateral anchor remains in place. Further, the anchor is installed 'blind' and relies on the contractor to install the anchor into sound substrate to be effective.

Often the extent of deterioration of the supporting steel components and the resulting terra cotta distress necessitates reconstructing portions of the facade. At several shelf angle locations, the corrosion of the embedded steel necessitated the replacement of the supporting steel and repair or replacement of the damaged terra cotta units. The expense of fabricating new terra pieces, particularly unique pieces, as well as a general philosophy of maintaining existing fabric as much as possible, resulted in the development of various techniques of repairing and reinstalling existing terra cotta. The use of epoxy and various pinning techniques were successfully employed for pieces that were installed in a bearing condition. Relying on the epoxy bond, even when supplemented with pins, is generally not advisable for hung pieces because of the lack of redundancy in the system. Due to the significant cost of reconstruction, all accessible existing lateral anchorage was replaced with new stainless steel components and all readily accessible portions of the supporting steel were treated, replaced or reinforced as necessary (see Figure 2).

In some instances, the existing terra cotta was deteriorated so severely that it could not be effectively, safely or economically repaired and reinstalled. For pieces that were relatively simple and repetitive, such as ashlar units and some lintel units, extruded pieces were used as a more economical alternative to traditional hand-packed pieces. Terra cotta replacement for this project was limited as much as possible since more than 25 percent of the units on the building were cracked. Repairs at areas of significant deterioration required removal and reinstallation or replacement of terra cotta units and repair of steel supporting members. These repairs required the removal of many terra cotta units above and below the steel member. The repair approach in these areas was consistent with the conventional method of replacing terra cotta and deteriorated embedded steel elements discussed earlier. The configuration and size of the terra cotta units made development of an alternate support system less practical.

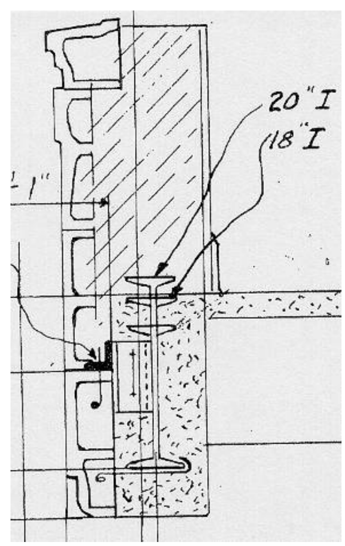

Figure 2 - Installation of new hung terra cotta units (left), original detail of spandrel section

A previous replacement scheme for hung lintel units had been employed prior to WJE's involvement which was an effective economical approach to replacing distressed units, but it did not address the underlying cause of the distress. It is speculated that the previous repairs attempted to limit the removal of terra cotta units above the support shelf angle by cutting out small pieces at the bottom of the terra cotta units above the shelf angle to access the J-hooks, see Figure 3. Once the new anchor was installed to support the designated unit, a terra cotta dutchman (a partial replacement of the unit) was installed in the openings. While economical, this approach did not address the underlying support steel.

Figure 3 - Previous lintel repairs by others which do not address the supporting steel

CASE STUDY 2

In 2002, WJE was retained to design repairs for the exterior facade of a 17-story building that was constructed in 1894. The original terra cotta cornice at the top of the building was removed in the 1950s, and the first phase of the 2002 restoration was the installation of a GFRC replica cornice.

WJE's inspection revealed that the majority of the terra cotta deterioration existed at the 16th floor level immediately below the location where the cornice previously existed. Prior to the installation of the GFRC cornice, the replacement wall behind the cornice was removed and a fully grouted reinforced concrete block masonry wall was installed. The new block wall was installed for structural reasons, but also provided an excellent substrate to install the new terra cotta units below the GFRC cornice. An alternative installation scheme for the new terra cotta units was developed since the terra cotta courses below the cornice were going to be installed following the completion of the new wall rather than concurrently.

Three courses of terra cotta had to be removed, damaged units replaced and original pieces reinstalled at the head of the 16th floor windows including a course of hung lintel units and a course of flat ashlar units. A system was developed that employed proprietary Unistrut members in various configurations. Sections of Unistrut were bolted to the existing steel members or to the new back-up wall. Anchorage for the hung terra cotta window heads consisted of stainless steel bent plates that were bolted to the web of the existing steel floor beam. On top of the horizontal leg of the angles, a continuous stainless steel Unistrut was installed to support the terra cotta units. Horizontal threaded support rods were installed through the full width of the terra cotta window head units as shown in Figure 4. The horizontal support rod was secured in each unit with nuts and washers on the outside face of the outside webs of the units to prevent the rods from moving or slipping out during installation. Once the horizontal support rod was installed, the unit was captured by the J-hooks (with threaded upper portions) which were suspended from the Unistrut above. The J-hooks extended through a hole in the underside of the Unistrut, through a hole in a stainless steel plate placed on top of the Unistrut, and was suspended from the Unistrut by a bearing nut and washer on top of the plate. Once the unit was in place, vertical adjustments were made by turning the nut above the Unistrut. Lateral support of the hung units was accomplished by hooking bent threaded rods in the hole on the top of the terra cotta unit and back to the existing steel beam. To accomplish a tight fit a "U" shaped bent threaded rod was installed in the top hole of the terra cotta unit and a separate thread rod was hooked to an I-bolt which was anchored into the steel beam. To adjust the two threaded rods, a turnbuckle was used to secure the units in place.

The flat ashlar coursing above the windows was installed by anchoring into the new backup wall at the 17th floor. Hooked rods were installed at the locations of the head joints between the two adjacent units and were epoxied into the backup wall. A pull pin was installed into the side web of two adjacent ashlar units and through the hooked rod (see Figure 6A).

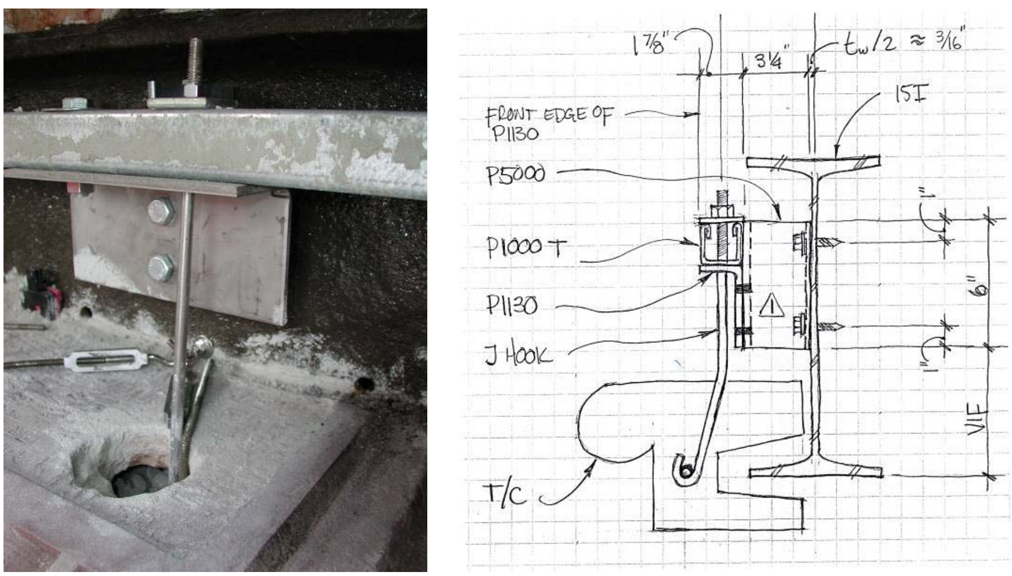

Figure 4 - Hung lintel installation system

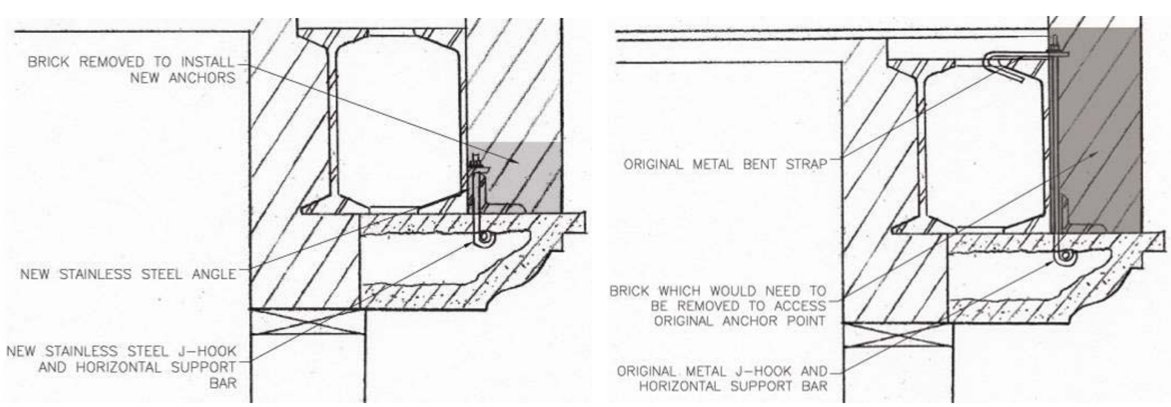

Figure 5 - Comparison of extent of brick removal for alternative assembly

Another terra cotta anchorage configuration had to be developed for typical window lintel replacements. The typical bays were constructed with face brick and decorative terra cotta units around window perimeters; sill, jamb and head units. The structural system at each floor level consists of (from the interior to the exterior) an I-beam, channel (toes facing towards the interior), and an angle attached to the channel with the horizontal leg level with the bottom of the channel. The angle was riveted to the channel with a spacer between the angle and the channel to allow hanger bars to pass through the assembly. The window heads were hung from J-hooks which were connected to a bent steel strap that was hooked over the top of the channel around the flange. The J-hooks originally extended through the gap between the channel and angle, to the horizontal bar which supported the terra cotta units. When these head units were removed, installation of new anchors in the original configuration would have required removal of nine courses of the brick in the spandrel area to access the top of the steel channel. An alternative system was employed, which required removing only two courses of brick to access the top of the angle, see Figure 5 (left). A stainless steel angle, sized to fit into the gap between the angle and the channel was installed such that the vertical leg extended into the gap and the horizontal leg rested directly on the top toe of the existing angle, see Figure 5 (left) and Figure 6b. The new threaded stainless steel J-hooks were installed through the horizontal portion of the stainless steel angle and adjusted with a stainless steel nut and washer.

Figure 6 - Terra cotta installation anchorage, a) ashlar units and b) hung lintel

CASE STUDY 3

For the past five years, WJE has been performing inspections of the exterior facade and implementation of repair programs for a building that was constructed with a variety of masonry materials including terra cotta, marble, granite, limestone, and brick. The building complex is comprised of eight interconnecting building sections that were built in seven phases between 1892 and 1914 in Chicago, Illinois. Six of the building sections are thirteen-stories in height and the other two sections are nine-stories tall.

In 2004, WJE implemented a repair program to address the most significant distressed conditions, as well as additional routine maintenance repairs in an effort to prolong the service life of the facade. The repairs included in-situ stabilization of cracked terra cotta units and the removal and replacement of designated distressed terra cotta units. In-situ repairs were performed on cracked terra cotta units which were found to only need supplemental lateral anchorage. Stainless steel helical anchors were installed in the same fashion as described in *Case Study 1*.

In some instances, the existing terra cotta was deteriorated so severely that it could not be effectively, safely or economically repaired and reinstalled or stabilized. Terra cotta soffit panels located at the head of the 12th floor were cracked and had been previously stabilized, but continued deterioration necessitated the need to replace these units. Due to their condition and location, salvaging, repairing and replacing the terra cotta soffit units were not reasonable options. Since the soffits were simple identical rectangular units, new pieces were fabricated using an extrusion technique rather than the more traditional hand-packed technique. By extruding these units, the cost of replacing approximately 40 units was much more economical and production and delivery times were substantially reduced.

The cracks in the soffit units were caused by corrosion of the supporting J-hooks and the horizontal support rods that typically extended through the full width of the units. The structural framing members were found to be in serviceable condition with only minor surface corrosion. During the removal of the distressed soffit panels, it was revealed that the 12th floor soffit units were supported with different anchorage systems at the two different building sections. Soffits in one area could be reinstalled effectively re-established the original anchorage design with the exception of incorporating stainless steel anchorage rather than carbon steel. The existing holes in the horizontal flange of the built-up I-beam could be reused to install the new stainless steel J-hooks following painting of the original steel.

The soffit units at the other area were originally hung from J-hooks, which were supported from the top flange of a structural I-beam. The support system at this section of the building consisted of a built-up I-beam, located at approximately at mid-span of the soffit unit, and a pair of back-to-back angles towards the exterior face of the building. A fascia unit was supported by the larger of the two back-to-back angles. The soffit units were hung from J-hooks connected to a steel strap that was hooked around the top of the built-up I beam. The J-hook extended vertically through the space between the built-up I-beam and the angles and captured a horizontal rod within the soffit unit. Although the fascia units were either being replaced or removed and reinstalled wherever a soffit was so designated, the top of the I-beam was not being exposed to gain access to replicate the original support configuration. In order to expose the top flange of the I-beam, a decorative water table above the fascia units would have had to be dismantled, which was not feasible or practical. Therefore, an alternate approach for supporting the new soffit units was required.

The new support system for the soffit units relied on the existing built-up I-beam and angles (Figure 7). A stainless steel plate was inserted to span between the bottom flange of the built-up I-beam and the adjacent angle. The new stainless steel J-hooks were hung from the plates by a bearing nut and washer and hooked under the horizontal support rods in the terra cotta units. The units were adjusted vertically by turning the nut on top of the plate. Although replicating the original system may have been easier for installation of the new terra cotta units, the cost of selective demolition of the masonry above to access the top of the I-beam necessitated modification of the anchor scheme. The new anchor design did not result in significant alternations of the load path within the cladding system.

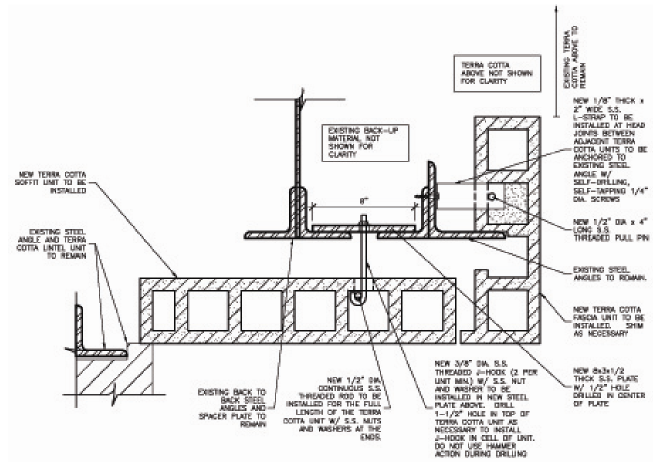

Figure 7 - Typical cracked terra cotta soffit units (left), new hung soffit detail (right)

SUMMARY

As the twenty-first century continues to move forward, there will be an increased need for repair and maintenance of early terra cotta buildings to protect our architectural and cultural heritage. As terra cotta cladding supports and anchors continue to age, corrosion and subsequent damage necessitate the need to develop economical yet effective repair techniques. The historical significance of these early structures and the need to maintain safe building facades relies on the professional to develop minimally invasive yet economical repair details and approaches. Professionals must seek to develop alternative methods to repair and support terra cotta that are constructible, effective, safe and economical.

REFERENCES

1. Voss, Walter C., and Varney, Edward A., Architectural Construction. Volume Two, Book Two, Steel Construction. New York, United States. 1927.
2. Kidder, F. E., C.E., Ph D., Building Construction and Superintendence. Part 1, Seventh Edition, Masons' Work. New York, United States. 1905.