Practice Points NUMBER 15

Architectural Terra Cotta

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Terra cotta has been used as a building material for thousands of years. Literally translated, terra cotta means "baked earth," a mixture of clay and water that is fired to the point of sintering. Today the term architectural terra cotta may be used to refer to terra cotta that is unglazed and buff or red in color; to slip-glazed material coated with thin clay slurry for a matte finish; or glazed terra cotta coated on the outer surface with a semivitreous or vitreous glaze created by adding fluxes and coloring agents to the clay slurry, which fused into a layer of glass during firing.[1]

The use of terra cotta flourished in the United States in the late nineteenth and early twentieth centuries as a less-expensive alternative to carved stone for embellishing brick buildings. Its use as a cladding material generally coincided with the development of the skeleton-frame structural system and the skyscraper in the 1880s. The popularity of terra cotta during this time as a cladding component was logical given the concurrent development of the skyscraper. In the 1880s the New York City stonecutters' union initially limited the introduction of terra cotta to the United States. In Chicago terra cotta had gained favor as a fireproof material following the 1871 fire.[2]

Terra-cotta units were lighter than stone and were considered more durable than some commonly-used building stones. Like cast iron, terra cotta is created using reusable molds and dies, leading to a significant financial savings compared to hand-carved stone. The plastic properties of the clay also provided the opportunity for new forms and finishes with glazes that offered a wider variety of colors and textures than building stone. By the 1920s, rather than imitating stone, architects were using elaborate shapes and surface finishes for terra cotta, creating spectacular designs that included polychromatic and metallic-luster glazes.

The terra-cotta industry all but disappeared between the Depression and World War II. The decline continued after the war with the rise of Modernism. Prior to the Depression, there were almost 30 terra-cotta manufacturers in the United States. However, following World War II and the revival of the construction industry, the terra-cotta industry essentially disappeared until the late 1970s. The National Historic Preservation Act of 1966 fostered an appreciation for historic buildings, and eventually historic skyscrapers with masonry facades were being restored. These efforts resulted in a new demand for architectural terra cotta and jump-started a limited revival of the industry.

The basic fabrication process for architectural terra cotta has remained the same for the past 150 years. Clay is shaped into the required form, dried,

Fig. 1.
Hand-packing clay into a plaster mold at Gladding McBean factory in Lincoln, California, 2014. All photographs by Edward Gerns..

then glazed and fired (Fig. 1). Today there are only a handful of terra-cotta manufacturers in the United States and Western Europe, and each employs at least one of five methods of terra-cotta fabrication, including hand pressed, extruded, slip cast, ram pressed, and hand sculpting. Each method has advantages and limitations.

Hand pressing, the traditional approach, consists of creating models and then plaster molds from the models. Clay is then pressed into the molds, and intermediate walls or stiffeners, known as webs, are incorporated to strengthen the unit and limit deforma-

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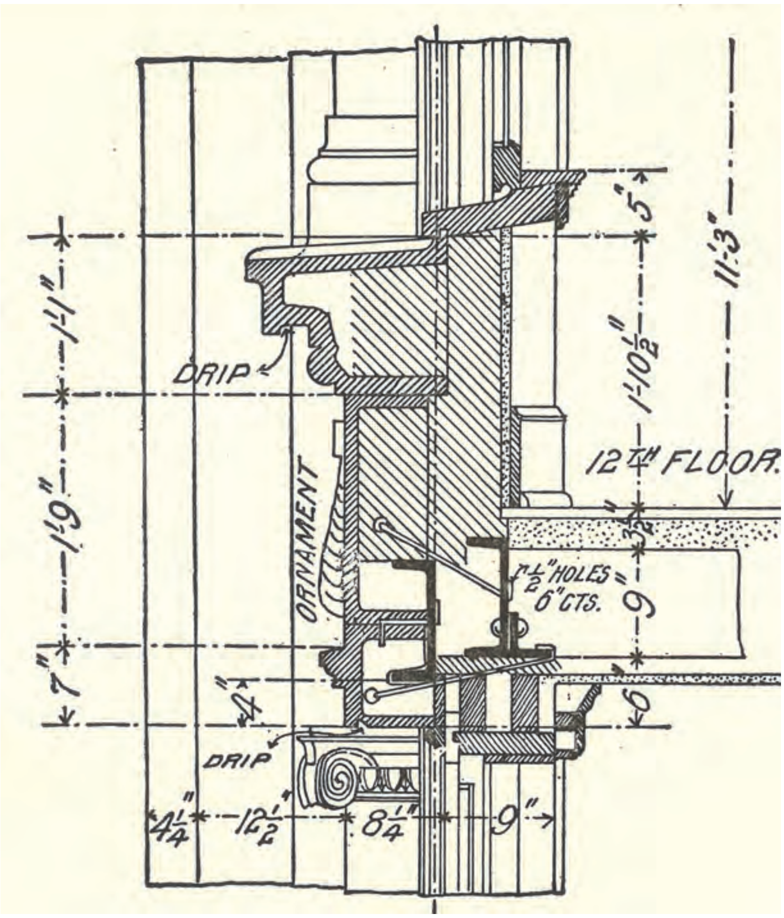

Fig. 2.
Fort Dearborn Building (demolished), Chicago, Illinois, original spandrel section from Joseph Kendall Freitag, Architectural Engineering*, 1901 edition, p. 170.*

tion during drying. Web geometry can vary slightly for some units, depending on the individual pressing the units. Typically webs are between 1 to 1¼ inches thick, and the area between the webs is referred to as a "cell." After a drying period, the molds are stripped away, and the pieces are glazed and fired.

Slip casting is a similar process, but a chemical (known as a deflocculant) is added to the clay mix to allow the clay to flow into an interlocking closed mold that simultaneously results in webs and walls created by the geometry of the mold. Extruded pieces are created by mechanically pressing clay through a steel die, creating the walls and webs with open ends. Ram pressing, typically used for flatter, more two-dimensional pieces such as roofing tiles, consists of mechanically pressing clay between interlocking steel plates. The least common method is sculpting, which is used to create one-of-a-kind large units.

Of these techniques, extruded and ram-pressed units are the most economical when numerous repetitive units are necessary, provided the geometry of the unit is conducive to the fabrication process. Hand-pressed and slip-cast units are typically more ornamental or necessary for transition and termination units that are often exposed on more than one surface.

Each fabrication method requires a special formulation of clays and grog. Grog, or refractory clay, is analogous to aggregate in concrete, as it is used to control shrinkage deformation and cracking. Surface texture is typically applied to the surface of the green clay and varies from a smooth to a bark-like texture. In some instances the texture can be achieved by a thicker glaze or combination of glazes being sprayed on the surface of the units prior to firing.

Glaze formulations changed as the use of terra cotta evolved between the 1880s and 1920s. Early glazes were typically clay slips intended to imitate stone. Later, vitrified glazes were used for both aesthetic and practical reasons. These glazes were extoled as "self-cleaning" and became architectural expressions in and of themselves, providing vibrant colors readily embraced by architects during the Art Deco period of the 1920s. These colors were made possible by the incorporation of heavy metals into the glazes. Similar colors are still available today, but the formulations have changed, as heavy metals can no longer be used for environmental reasons.

Wall Assemblies and Installation

Installation methods for architectural terra cotta evolved along with innovations in the construction industry. Terra cotta was first used as a decorative masonry component integrated into load-bearing walls (Fig. 2). As construction methods changed and terra cotta was used more as a cladding material, the installation detailing for terra cotta would change as well. The early practice of filling units with brick and mortar shifted to rely heavily on ferrous fasteners or attachments to secure the terra-cotta cladding to the larger steel-frame superstructure.

Typical terra-cotta cladding systems consist of an outer wythe of terra cotta and either a two- or three-wythe brick backup system or a terra-cotta (clay tile or speed tile) block backup system of similar thickness. Terra-cotta cladding units were typically installed concurrently to bond the cladding with the backup masonry by means of the mechanical key of the brick and mortar fill in the cells. In addition, various types of mild-steel bent bars were installed during construction to anchor the terra cotta to the backup and provide stability to the system until the mortar had cured. In some instances concrete or grout may have been used on a limited basis, most commonly when the main structure system was concrete. However, the intent was generally not for the terra cotta to provide lateral support for the unit but for it to function during the construction process, essentially clamping the

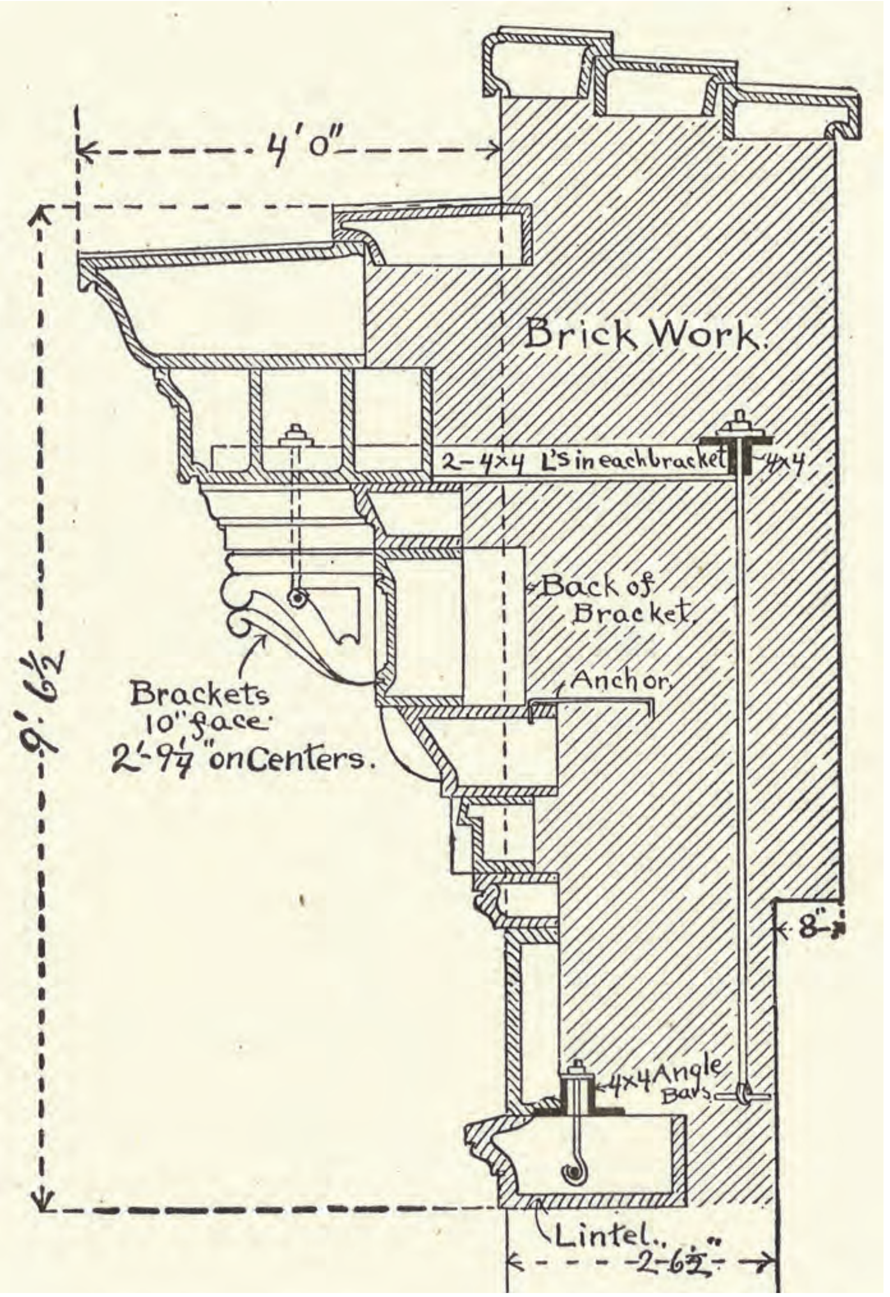

Fig. 3.
Equitable Life Insurance Building (demolished), Denver, Colorado, cornice section from Frank Eugene Kidder, Building Construction and Superintendent, *1905, p. 255.*

wythes together until the mortar cured. Horizontal framing members, such as steel shelf angles, supported the weight of the terra-cotta cladding at each floor level, with the units bearing directly on the support angles and subsequent units stacked on the pieces below. Historically, units were generally referred to as balanced units when they were installed within the plane of the wall, such as ashlar units. Unbalanced units referred to units that projected from the wall, such as watertables; they required additional anchorage support during installation.

In some cases individual units or entire courses of terra cotta were hung from horizontal supporting members. These hung pieces, such as window lintels, were supported by horizontal bars inserted into preformed holes in the side webs and supported by hooked bars. The hangers, known as J-bolts, were suspended from shelf angles, hooked over the top flange of an embedded structural member, or hooked through a hole in the web of a member. Complex terra-cotta assem-

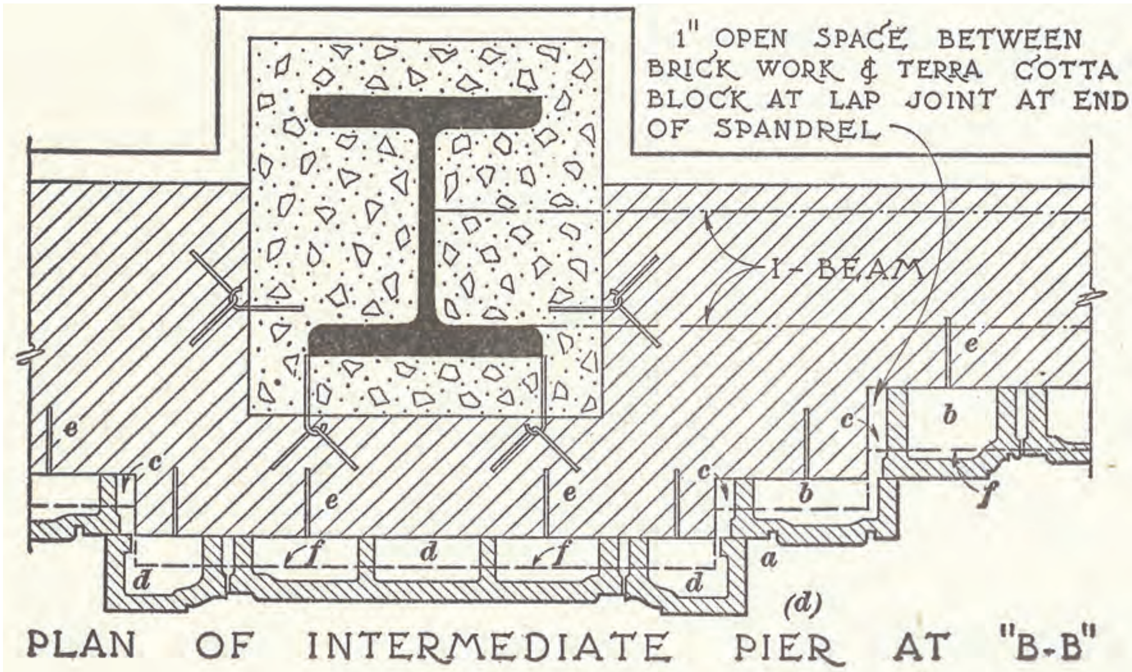

Fig. 4.
Carbide and Carbon Building, Chicago, spandrel and pier area. Note layering of cladding at pier. Pier plan detail from Architectural Terra Cotta, International Correspondence Schools, 1938.

blages, such as cornices, often combined unbalanced, and hung pieces, which required an extensive steel framework to provide structural integrity, including gravity support, lateral support, and overturning resistance for the individual terra-cotta units (Fig. 3).

One design issue that is still debated is the filling of terra-cotta units to improve performance and durability. In the 1920s the National Terra Cotta Society (NTCS) stated that "Exposed free-standing construction, subject to the absorption of water through mortar joints and liable to injury from subsequent freezing, or the expansion of improper filling material, should generally be left unfilled."[3]

The practice of filling units with concrete was also discouraged by the NTCS because the increased rigidity of filled construction would induce extra and unanticipated stresses on the terra-cotta claddings and the added weight would also require more a more robust structural system, thereby adding unnecessary costs.

Detailing Modifications

Many of the modifications to the design and anchorage detailing that occurred in the early twentieth century were based on in-service performance of terra-cotta cladding. As distress began to manifest, the industry recognized the need to change. One characteristic of clay-based masonry units is that they are at their smallest dimensions when leaving the kiln after the firing process, due to the virtual absence of moisture in the units. As the units are exposed to a normal in-service environment, they absorb atmospheric moisture and expand in volume. Once the unit's moisture content reaches equilibrium with the environment, the volume stabilizes, with only minor increases over time and some cyclical changes in volume due to seasonal fluctuations. This irreversible expansion due to initial and progressive moisture absorption, as well the cyclical volume changes due to seasonal effects, can impart significant stresses on cladding systems. Thus it became necessary to incorporate provisions for movement of the cladding.

Another condition characteristic of some masonry-clad structures is the impact of the irreversible shrinkage and creep of the supporting structural frame over time. This type of change conflicts with most masonry wall materials that remain constant or increase in volume over time. The amount of shrinkage of the frame is proportional to the height. When load is applied to a structure and sustained, it will initially deflect and continue to deform over time. This long-term change in volume is referred to as "creep" and typically results in a continual vertical shortening of the structural frame and becomes greater as the load increases. Both shrinkage and creep will have the most impact on a structure shortly after loading but can continue to have a modest effect throughout the life of the structure.

Today, the conditions described above would be addressed in masonry-cladding systems by incorporating expansion joints. Horizontal expansion joints were rarely incorporated into historic terra-cotta cladding systems, suggesting that the exterior walls, while supported at each floor, were still being considered as mass or bearing walls in many respects by the designers. While the outer wythe was often partially supported at each floor, the backup wall system was usually set directly on the floor slab. The position and configuration of shelf angles that supported the cladding often extended less than half the depth of the exterior cladding wythe. The remaining portion of the unit that was not bearing on the steel was typically intended to be filled with brick and mortar.

Similarly, discontinuous support of a rigid system like terra cotta can result in distress, typically in vertical cracking. Often, steel support for the terra cotta was continuous except at corners, small returns, and transitions. Thus, when the system was installed with all mortared joints, portions of units were supported at shelf angles at each floor, but the portion not on the shelf angle support might be stacked over several floors or even the entire height of the building.

Vertical expansion joints were also very rarely explicitly incorporated into building facades. Horizontal movements were often accommodated by the detailing of the wall cladding created by layered planes of materials sliding parallel to each other without transferring load to the adjacent plane (Fig. 4). This practice was common below roof areas but less common at roof elements such as parapets, cornices, and watertables. As a result, many of these elements frequently exhibited movement and shifting consistent with unaccommodated expansion and contraction, particularly at corners.

As terra-cotta cladding systems age, the passivity of the mortar decreases, and discontinuities in the enclosure develop that result in increased water infiltration and corrosion of the underlying steel. The accumulation of corrosive scale on the ferrous-metal rolled shapes used to support the exterior cladding material further exacerbates the conditions listed above.

Generally, the corrosion process of metal components within a masonry wall system can be divided into three phases. The first phase includes the initial 30 years of service life of the building and represents the period of time when the underlying steel is protected by the alkalinity of the environment and various applied coatings. During the second phase, while the protective systems deteriorate, the steel begins to corrode as it becomes exposed to water and oxygen. This results in the third phase, in which significant distress can manifest as the cladding system attempts to accommodate the accumulated corrosion scale, which occupies four to ten times the volume of the uncorroded steel (Fig. 5). As a result, an understanding of incorporating non-corrodible metals or protecting ferrous metals was recognized.

Fig. 5.
Roanoke Building, Chicago, 1915 and 1925, corroded beam flange at 37th floor, 2005.

Water-management provisions were integral on a limited basis to this process as well. They included the understanding that water would get into the cladding and that it had to escape through mortar joints between units and weeps within overhanging and projecting units. Flashings began to be introduced on a very limited basis beginning in the late 1920s, most commonly below copings at parapets. Drainage cavities, the more developed flashing systems, and non-corrodible metals would have been the natural progression of the cladding system detailing had the Depression not occurred.

Repair Approaches

Repairs should address the cause of distress rather than just treating the manifestation of the cause, requiring implementation of a prioritized, phased approach or incremental or remedial repairs intended to protect public safety or to slow the progression of distress. Treating the underlying causes is typically very expensive, however. Evaluating the cause of distress is beyond the scope of this document. Regardless of the extent of the repair program, regular inspection and maintenance are necessary.

Fig. 6.
New York Life Building, Chicago, 1889, terra-cotta lintel reinstallation, 2013.

In-situ repairs. If the cause of the cracking is determined to be the result of unaccommodated movement or frame shrinkage, in-situ repairs of the cracks should be undertaken to limit moisture infiltration into the cladding system. These repairs can consist of routing and installing sealant into the crack. Depending on the anchorage, supplemental through-face anchors could be added once the cracks have been repaired. Selection of sealant or mortar for the repair should depend on whether the cracks are determined to be cyclically moving or static.

If the cracking is determined to be the result of the corrosion of underlying steel, in-situ repairs are generally not recommended as a long-term repair. While treating the crack will limit moisture infiltration, the underlying steel will continue to corrode, possibly resulting in further cracks, displacements, or spalling. In addition, units that are hung, such as window lintels, soffits, and brackets, often cannot be pinned effectively since these units may not have consistent and reliable backup, and the corrosion has likely caused-distress to the support components of the terra cotta. Recommendations to address these conditions are presented below.

Repointing mortar joints between terra-cotta units is critical to minimizing water infiltration into the cladding and subsequent distress. It is important to understand that the mortar joints are typically the means by which the wall system discharges water and dries out. As such, sealant or sealers should not be applied to the mortar joints, because they will trap moisture in the cladding, resulting in accelerated deterioration. The one exception is treatment of upward or skyward-facing joints between units. To limit water infiltration through these joints, sealant or a lead T-cap should be installed, understanding that water that does enter the units can escape through the vertical joints and bed joints below.

Other repairs that can be implemented for aesthetic reasons include coating of shallow spalls. Numerous proprietary coating systems are available for terra cotta. Preparation of the exposed clay body is important to reduce the potential for premature failure of the coating. The specific properties of the coating vary between breathable and impervious. While patching is often considered, patches should not be considered a permanent repair, particularly in temperate climates.

Finally, cleaning of the terra cotta is often incorporated into repair programs. Cleaning can have a dramatic impact on the appearance of the building. Care should be taken to select an appropriate cleaning system that does not damage the terra-cotta glaze.

Cleaning trials should be undertaken to determine the most-effective and least-damaging cleaning method. The selection process should take into account the type of soiling and the glaze characteristics. For polychrome-glazed terra cotta, testing may be required for each color type. Similarly, if a facade is comprised of many different types of masonry, cleaning trials may be needed for each type to address each soiling condition. There is not a one size fits all cleaning method, and there are many potential systems that can be used.

Remove, repair, reinstall. To address the cause of the distress in terra-cotta cladding, it is often necessary to remove existing material to repair substrate conditions (Fig. 6). Distress in terra cotta is often misunderstood and assumed to be a function of terra cotta not being a durable material. In reality, this is rarely the case. Removing distressed units to expose substrate conditions is certainly more invasive than the in-situ repairs described above, but removal is frequently necessary to treat corroded steel, to reinstall displaced units, or to repair cracked units that should not or cannot be effectively pinned in situ. When units are removed to repair cracks, incorporating mechanical anchorage, specifically pins or other means, along the cracked surface will provide additional strength to the repair.

Corrosion of the components supporting the cladding is a common cause of distress. Replacing bent bar ties with stainless-steel components is preferable to reusing existing bars, regardless of their condition. Similarly, replacing J-hooks and bars with stainless-steel components is preferred if the units are distressed. This approach often requires removing units above those supported by the J-hooks so as to access the supporting steel. At a minimum these components should be cleaned and coated with a corrosion-inhibiting system. Finally, the primary support components should be evaluated to determine whether the existing components can be retained or reinforced, or whether replacement is required. Conventional structural analysis can be misleading as these components were typically installed relying on standard industry details. A common geometry detail is the horizontal leg of the shelf angle that extends only to the midpoint of the terra cotta. Complete replacement of isolated elements, such as shelf angles, may be more economical than cleaning and painting the steel; a longer horizontal leg can be used to add bearing support area for the units. Adding support at locations of discontinuous support should also be addressed as appropriate with angle repairs or replacement. Replacing shelf angles typically requires cutting off existing rivets and replacing the rivets with bolts. Addressing discontinuous support conditions may require the installation of additional components to anchor the new steel support within the same plane. Incorporation of flashings is sometimes considered, but the effectiveness of the flashing as a water-management system in a mass wall is debatable.

Replacement. Most restoration projects require replacement of some terra-cotta units if the units are not salvageable (Fig. 7). Terra cotta is certainly the preferred material for replacement. Because the lead time for fabrication, generally between six to eight months, can impact construction sequencing, consideration of lead times is necessary to establish realistic schedules. The fabrication of replacement units should begin as soon as possible in the restoration process. Caution should be exercised when modifying any industry-accepted specifications in an attempt to improve the performance of the units or to address specific issues on a project because of the risks involved. Modification of standards and fabrication methods could result in fabrication delays, increased costs, and high rates of material loss during the fabrication process.

Alternative materials such as glass-fiber-reinforced concrete (GFRC), panelized GFRC, panelized fiber-reinforced polymers (FRP), stone, and precast concrete can be considered, but they require an understanding of the limitations of matching existing material, weathering characteristics, material compatibility, preferential deterioration, and fire-code requirements, as well as the additional weight of solid units such as stone and precast concrete.[4] In addition, panelized systems, such as GFRC and FRP, are typically designed as non-bearing systems and often require supplemental or alternative structural framing. In addition, they may not be as durable as the surrounding architectural terra cotta. Generally, it is preferable to limit substitute materials to replacement of continuous design elements and not single units within the field of the facade, as the material characteristics are not compatible and could result in unintended deterioration of the terra cotta.

Other considerations. Other factors sometimes need to be considered, depending on the project. For example, providing for horizontal expansion or addressing stacking effects due to a lack of horizontal expansion joints may be necessary. In the case of horizontal expansion, installing vertical expansion joints is sometimes justified, but beyond the visual impact, the effectiveness of joints should be also evaluated. Similarly, vertical expansion, frame shrinkage, and cladding stacking can be accommodated by cutting new joints below support locations; in this case it is important to completely free the “stack” of masonry to dissipate the accumulated stresses. However, this process typically results in cracking of additional units;

in other cases, the stacking effect may be have little effect, depending on the stress redistribution. The behavior and extent of cracking varies dramatically from building to building and even within the same building, making it difficult to match. In addition, while these wall systems were generally designed to function as mass walls, incorporation of weep provisions and drips into replacement units and assemblies is necessary to limit distress resulting from moisture entering and getting trapped within the system. Reconstruction of entire assemblies, such as cornices, parapets, and watertables, may justify the introduction of a drainage plane or alternative support methods and panelization.

Finally, the issue of how the cells of both the new and replacement units are treated is an important factor to consider. Traditionally, units were filled with bricks and mortar and constructed integrally with the backup wall. Almost without exception, filling replacement units with grout or mortar is not now recommended. In some instances partially filling units may be necessary, but in general the units should not be filled to prevent water from becoming trapped within the units.

Conclusion

Developing a repair program for a terra-cotta-clad building requires an understanding of the original construction type, as well as the extent and cause of the distress. Economic considerations often dictate prioritized repairs and consideration of alternate materials. Regardless of the approach, the primary goal should be to maintain as much of the existing terra cotta as possible and to incorporate new terra cotta. When needed, taking shortcuts often results in further deterioration and higher repair costs when considering life-cycle costs.

Any repair program must be accompanied by a regular maintenance program. The maintenance requirements will vary depending on the scope of restoration. Maintenance should include regular inspections and repointing, sealant replacement, unit pinning, crack repair, and unit replacement. Minimal intervention may result in more frequent and likely more invasive maintenance in the future.

Current standards and guides for the manufacture, installation, and repair of terra cotta have existed for decades. Designers, manufacturers, and installers are now collaborating to update these documents and create one to guide designers and installers who may not be as familiar with the fabrication and installation of new terra cotta or the repair of existing terra cotta. With proper understanding of the material, deterioration mechanisms and repair approaches, terra-cotta facade restoration projects can be performed successfully, enabling continued appreciation of this unique material.

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Notes

1. Michael Stratton, "Nature of Terra Cotta and Faience," *Architectural Ceramics: Their History, Manufacture and Conservation*, ed. Jeanne Marie Teutonico (London: English Heritage, 1996), 50-52.

2. Susan Tunick, *Terra-Cotta Skyline: New York's Architectural Ornament* (New York: Princeton Architectural Press, 1997), 7.

3. *Terra Cotta: Standard Construction*, rev. ed., National Terra Cotta Society, 1927, various plates.

4. Tiller de Teel Patterson, "The Preservation of Historic Glazed Architectural Terra-Cotta, Preservation Brief No. 7," U.S. Department of the Interior, National Park Service, Preservation Assistance Division, Technical Preservation Services, 1979, 7-8.