Case Study 4: **TERRA COTTA REPLACEMENT WITH GLASS FIBER REINFORCED CONCRETE**

Project: **RANDELL HALL, DREXEL UNIVERSITY**

Location: **PHILADELPHIA, PA**

Randell Hall, Drexel University

EXECUTIVE SUMMARY:

As part of a 6-building, rapid initial make-safe program in the early 2000’s, Drexel University investigated whether to repair or replace the terra cotta cornices on 4 of the original buildings and some of the oldest buildings on campus.

The cornice on Randell Hall was found to be in very poor condition, and probes exposed severely corroded mild steel back-to-back angles which aligned with the cracks in the tops of the cornice. Since the support steel frame was severely deteriorated and the terra cotta courses that were surrounding and supported by the steel framing were damaged, the project team agreed that the upper three courses of terra cotta cornices and supporting framework on Randell Hall needed to be replaced.

In order to meet the project’s short timeframe and budget, new terra cotta was removed from the list of possibilities for replacement of the original terra cotta cornice and cast decorative Glass Fiber Reinforced Concrete was used instead.

The project demonstrated through careful design, engineering, fabrication, and installation that decorative glass fiber reinforced concrete can be considered as an alternative to in-kind replacement of terra cotta. In addition, GFRC can provide successful long-term performance in locations with relatively aggressive weather.

BACKGROUND:

The original academic buildings for Drexel University included the Main Building, designed by the Wilson Brothers and Co. Architects and constructed in 1891; Randell Hall, also designed by the Wilson Brothers and built in 1901; and Curtis Hall completed in 1928 and designed by Simon and Simon Architects. These three abutting structures remain the center of the campus at Chestnut and 32nd Streets in Philadelphia, PA. (See Figure 1.) Curtis Hall façade are primarily limestone. Main Building and Randell Hall consist of a range of ochre colored brick and coordinated decorative terra cotta elements. Decorative architectural elements on these buildings include projecting terra cotta cornices. The terra cotta has a mottled low gloss glaze, similar to a clay coat or slip-glaze brick.

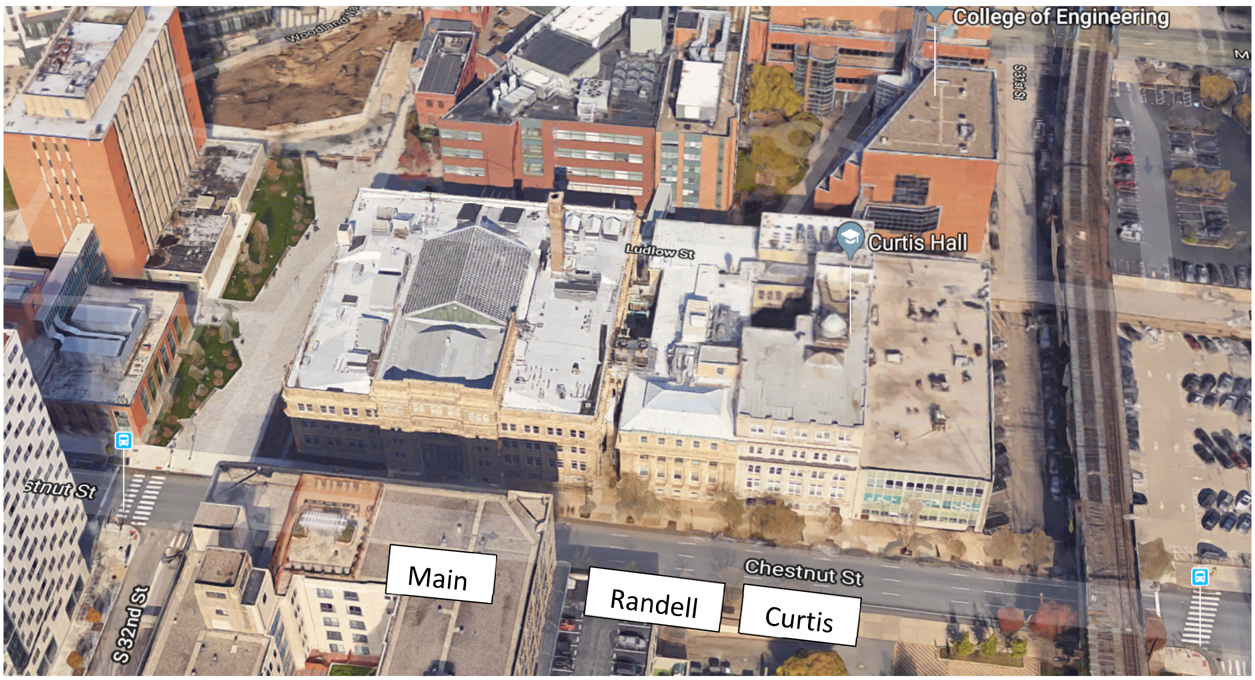

Figure 1. Site View

As part of a 6-building, rapid initial make-safe program in the early 2000’s, Drexel University needed to repair or replace the terra cotta cornices on 4 of the original buildings and some of the oldest buildings on campus. The Main Building cornice was repaired in place. Curtis Hall cornice is a gutter, pitched toward the building with drains to the interior. This was in good condition and did not require repairs. The Randell Hall cornice was replaced with custom molded and colored decorative glass fiber reinforced concrete (GFRC).

The project investigation began in January 2001 and construction was completed in 2005. The buildings were investigated and repaired in series to reduce campus impact and manage budgetary cash flow.

This study focuses on the Randell Hall cornice replacement and its performance after 11 years.

PROJECT – INVESTIGATION:

The inspections began with visual observations from grade and adjacent roofs using binoculars and telephoto cameras. In many areas the cornices appeared to be in relatively good condition. However, the horizontally projecting cornices skyward facing surfaces did not have cap flashings and there were indications of water infiltration and retainage within the original terra cotta cornices including vegetation growth and shell cracking at vertical ribs. (See Figure 2 and Figure 3.) Previous repair efforts were also observed. These were primarily cracks sealed with sealant. No reinforcing or pinning was observed. (See Figure 4.)

Figure 2. Vegetation growth from mortar joint

Figure 3. Cracks at shell/rib

Figure 4. Previous sealant application at cornice cracks

Based on their terra cotta experience, the engineering team recommended a series of probes, initially opening damaged units in order to observe the underlying construction and determine the structural support condition. The terra cotta cornice in the Main Building, ca 1891, was determined to be solidly back-filled with masonry, was effectively corbelled out from the wall, and did not have any supporting steel framing. While this may not be the recommended installation method by contemporary standards, it was fairly common during its era of construction. The assembly appeared to accommodate the range of expansion between the brick and terra cotta and the compression placed on the terra cotta without significant amounts of damage and the terra cotta was in relatively good condition. There were only a few units with relatively minor cracks. The project team agreed, within the parameters of the project scope, that repairing these cracks by embedding stainless steel cramps or “staples” set in epoxy across the cracks and sealing the cramp edges and cracks with urethane sealant would be appropriate and cost effective.

The cornice on Randell Hall was in very poor condition. The probes exposed severely corroded mild steel back-to-back angles (See Figure 5, Figure 6, Figure 7, and Figure 8.) which align with the cracks in the tops of the cornice. The outer edge of these units were not secure and created a potential fall hazard. The angles provide support for the ‘J’-hooks which suspend modillions below the upper cornice units. A few of these modillions were missing and the ‘J’-hooks were corroded. The terra cotta egg and art / dentil course and others below appeared to be in good condition.

Figure 5. Severely corroded back-to-back steel angles. Arrows point to ‘J’-hook modillion hanger.

Figure 6. Severely corroded back-to-back steel angles aligning with cracks in terra cotta cornice. Outer portion of the cornice is a potential fall hazard.

Figure 7. Missing modillion with corroded ‘J’-hook hanger rod on the right. The left modillion is severely deteriorated.

Figure 8. Severely corroded outrigger beam. Top flange is gone.

The general construction of these cornices was similar to typical details illustrated in Architectural Terra Cotta Standard Construction, National Terra Cotta Society, originally published 1914. (See Figure 9.)

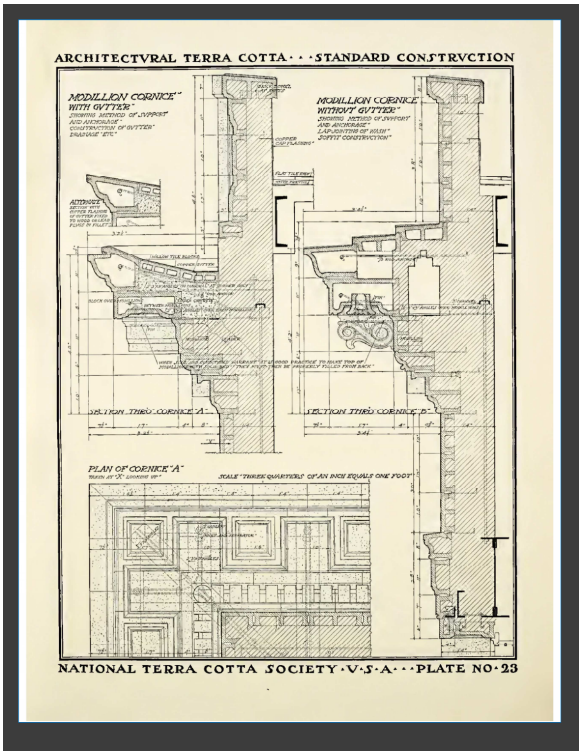

Figure 9. Curtis Hall cornice is similar to the detail on the left. Randell Hall is similar to the detail on the right.

Since the support steel frame was severely deteriorated and the terra cotta courses that were surrounding and supported by the steel framing were damaged, the project team agreed that the upper 3 courses of terra cotta cornices and supporting framework on Randell Hall needed to be replaced. The lower courses are corbelled out from the brick wall, were substantially back-filled with brick and in good condition. No work was needed there.

At this point in the project, the team discussed various options for replacing the finish masonry including new terra cotta, glass fiber reinforced concrete (GFRC), precast concrete and glass fiber reinforced polymer (GFRP or fiberglass). Removing the terra cotta and filling in with brick was not considered due to the architecture and significance of this buildings on campus.

In order to meet the project's short timeframe and budget, terra cotta was removed from the list of possibilities. GFRP has a substantially greater coefficient of expansion than terra cotta or GFRC and significant expansion allowances must be made. Also, the gel coat color is quite thin, and the University wanted a longer performing dependable material. The project team also felt that the gel coat finish of GFRP could result in an overly pristine finish not matching the terra cotta. Precast concrete masonry units are solid and weigh more than terra cotta. This would require substantial supporting framework and greater analysis of the building superstructure.

GFRC weighs about the same as terra cotta and its finish color extends through the entire shell thickness. The material has very low shrinkage during fabrication so molds can be taken directly from the original units. This saves substantial amounts of time and cost. GFRP also has a matt finish and can be tinted with slight variations in the ochre color, not a coating or topically applied. This would allow the GFRP to very closely match the original terra cotta. The project team felt that GFRC could be fabricated fairly rapidly and could replicate the mottled coloration of the original terra cotta so we recommended replacing the severely damaged terra cotta and steel framing with custom molded GFRC with stainless steel framing and armatures.

REPAIRS:

Since the general contractor was on board, the project team was able to concurrently develop final construction documents, engineers analyzed the loads of the new cornice and designed a new frame that closely mimicked the original. Also prepared were architectural drawings, details and specifications for the new cornice, repairs to the adjacent masonry that was to remain, waterproofing, etc. Since the general contractor was already part of the team, they began to develop cost estimates for performing the work, contracted with a GFRC fabricator and began removing the deteriorated cornice elements and salvaging units for replication molds. As mentioned previously, one of the distinct advantages of GFRC over terra cotta is the relatively low shrinkage of the newly fabricated units. Terra cotta generally requires fabricating new models slightly larger than the final piece in order to accommodate the clay shrinkage during drying and firing. GFRC allows molds to be taken directly from the existing masonry units.

Then samples of each different piece were removed from the building. Color matching and mold fabrication undertaken. Color samples were delivered to the site for project team review, comment and approval. (See Figure 10 and Figure 11.) Rubber molds were taken directly from the terra cotta. (See Figure 12 and Figure 13). Initial samples prepared for size and finish. (See Figure 14.)

Figure 10. Some locations the steel had not corroded severely and the terra cotta was in good condition. These were used for models

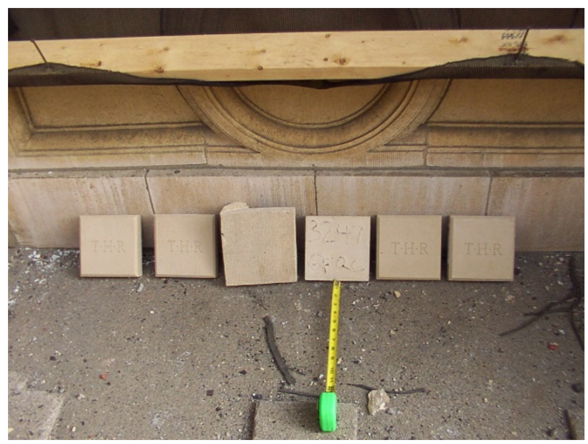

Figure 11. Color samples leaning against terra

Figure 12. GFRC Molds

Figure 13. GFRC Molds

Figure 14. Early replacement sample showing alignment with original terra cotta.

The project engineers designed the new structural stainless steel support frame and building façade connections. The GFRC fabricator undertook the engineering and design of the units including internal reinforcing, recommended adjustments to the support frame, attachments to the new support structure and integrating the GFRC with the existing masonry. They also proposed combining some units into larger composite units in order to reduce cost and improve the efficiency of the design.

Throughout this portion of the design phase, all efforts were focused on getting the lowest course units into fabrication as soon as possible so that the reconstruction could begin as soon as possible. Once the GFRC fabrication and curing process was underway, the project schedule could be firmly established.

GFRC is applied by hand spraying, similar to shotcrete. First a modified sand and cement “face” mix is sprayed onto the forms. The base coat is then consolidated by back brushing. This thin layer is critical as it will become the visible surface of the unit. However, the application is blind, and you cannot see the finish until the unit is removed from the mold. The reinforcing back-up coats are applied immediately following the base coat. This layer is thicker and includes chopped glass fibers which will provide structural reinforcing to the unit. Each layer of the back-up reinforcing coat is consolidated by back-rolling. Stainless steel embdments and structural attachments are added during this phase and incorporated with additional layers (wads) of the same glass fiber reinforced mix. (See Figure 15, Figure 16, Figure 17, Figure 18, Figure 19 and Figure 20.)

Figure 15. Hand spray fabrication of GFRC

Figure 16. Note visible glass fibers in the mix

Figure 17. Back rolling fiber consolidation

Figure 18. Back rolling fiber consolidation

Figure 19. Stainless steel subframe on back of a cornice unit.

Figure 20. Close up of stainless steel subframe.

The units were cured in a humidity controlled room for a minimum of 7 days. Once the fabrication was underway, it progressed much faster than the on-site construction. The number and variety of units made the project complex and sometimes crowded the fabricator’s shop. (See Figure 21 and Figure 22.) Each unit is unique and must accommodate specific conditions on site. Units are numbered with a corresponding identification in the shop drawings. (See Figure 23 and Figure 24.)

Figure 21. Curing and storage of the GFRC. Note the variety of shades indicating relative rate of drying

Figure 22. Curing of the GFRC

Figure 23. Top course with shoulder to integrate with existing terra cotta window surround.

Figure 24. Side view of top course with stainless steel support frame.

During the GFRC shop fabrication, selective removals and wall preparation was underway. As can be seen in Figure 25, Figure 26, Figure 27 and Figure 28, the steel frame was in worse condition than initially thought. As removals began, many structural steel units failed under their own weight.

Figure 25. Severe corrosion of cornice support steel. Also note back up masonry included terra cotta in compression.

Figure 26. Failed outrigger beams and terra cotta units at base of pier in compression.

Figure 27. Outriggers failed under their own weight.

Figure 28. Severe corrosion at joint with embedded façade beam and outrigger

As soon as the old deteriorated terra cotta and steel were removed, the new structural steel framing was installed, this included opening holes into the back up for cantilever beam supports and repairs to deteriorated masonry, setting base plates, etc. This work also had to be coordinated with installing the lower courses of GFRC below the primary support frame. (See Figure 29 and Figure 30.)

Figure 29. Cantilever base plates installed

Figure 30. Back-to-back angle outriggers and 'J'-hooks to support suspended modillions below.

The stainless steel frame and GFRP installation was well planned and the project went smoothly. (See Figure 31, Figure 32, Figure 33, Figure 34, Figure 35, Figure 36, Figure 37, Figure 38, Figure 39 and Figure 40.)

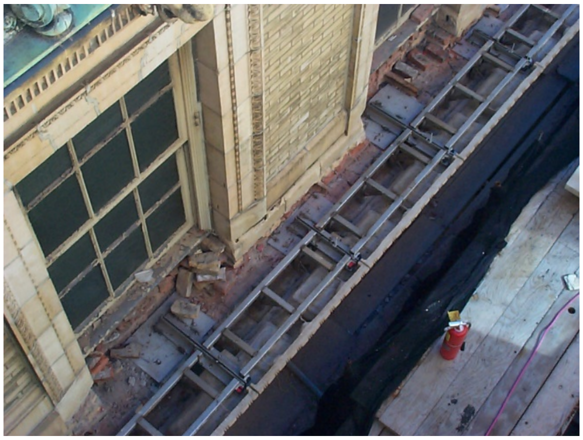

Figure 31. New stainless steel support frame in place

Figure 32. Field welding

Figure 33. Lower course units. Note these were originally 5 separate units.

Figure 34. Corner framing partially complete

Figure 35. Cantilevers embedded, lower units installed and back up masonry repaired.

Figure 36. Capstone installation

Figure 37. Note upper face extends into the wall.

Figure 38. Back up masonry repaired and parged

Figure 39. New GFRC modillion course and original terra cotta egg and art / dentil course

Figure 40. New GFRC modillion course and original terra cotta egg and art / dentil course

COMPLETION AND CONDTIONS AFTER 11 YEARS:

It should be noted that the University value engineered the project and eliminated lead coated copper cap flashing that the engineers had intended to include. In lieu of the sheet metal flashing, urethane sealant and backer rod were installed in the skyward facing joints and mortar provided everywhere else. The rest of the skyward faces of the cornice are exposed to the weather. Upon binocular inspection, it was observed that several of these joints had washed out. However, it should be noted that after 11 years, no discernable deterioration or damage was observed, and the GFRC retains the original colors and clean crisp lines of the original units. (See Figure 41, Figure 42, Figure 43, Figure 44, Figure 45, Figure 46, Figure 47 and Figure 48.)

This project shows that through careful design, engineering, fabrication, and installation that decorative glass fiber reinforced concrete can be considered as an alternative to in-kind replacement of terra cotta. In addition, GFRC can provide successful long-term performance in relatively aggressive Philadelphia weather.

Figure 41. Randell Building south facade in 2016, 11 years after completion


Figure 42. Southwest corner


Figure 43. Up-close detail

Figure 44. 11-year old GFRC cornice and modillions integrated into historic terra cotta.

Figure 45. GFRC modillion course on top of original terra cotta dentils

Figure 46. Close up of GFRC

Figure 47. Southeast corner

Figure 48. Close up. Note, modillion course and cornice above is 16-year old GFRC, all other masonry is historic terra cotta.