16 Keynote: GRC for the Restoration of Historic Buildings

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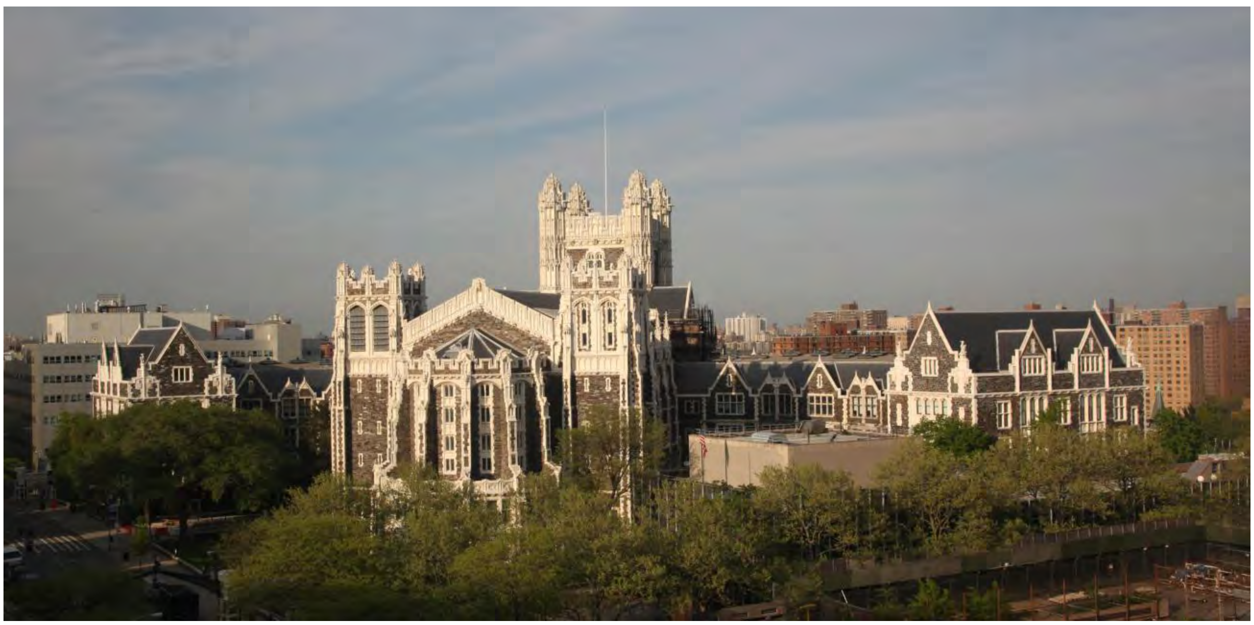
BACKGROUND

Figure 01



In 1986, The Stein Partnership, Architects (now Elemental Architecture, LLC) was commissioned to investigate strategies for reconstructing the envelope of Shepard Hall, the 36,000 m^2 gothic revival structure that was the original main building of the City College of New York. Completed in 1907, the envelope of Shepard Hall included more than 72,000 individual pieces of architectural terra cotta which were incorporated into the exterior structural masonry walls.

The terra cotta was used interchangeably with the primary stone, a local schist – a relatively soft metamorphic stone having pronounced laminar properties and high iron content.

Figure 02

The terra cotta units ranged from flat panels and simple extruded moldings…

Figure 03

… to highly complex sculptures in the round, the largest being over 2 m tall.

Figure 04

One of the rooms in Shepard Hall…

Figure 05

…the Great Hall has a floor area of 1,275 m^2 with ceilings 18 m high.

At the beginning of the project, the Great Hall was closed because fragments of terra cotta from the interior of the window tracery – each window being more than more than 12 m tall – had fallen to the floor and were considered to be significant threats to public safety.

Figure 06

In terms of the number of replica pieces that would be required, the first phase by itself was more than three times larger than any similar project undertaken anywhere in the United States and possibly the world. Further, this first phase represented less than 20 percent of the entire reconstruction.

Figure 07

To complicate the matter, whereas most previous terra cotta replacement projects had been carried out for private clients using small, incrementally negotiated contracts, the work at Shepard Hall was for a public client and would be competitively bid as large, lump-sum all-inclusive contracts. This necessitated a very precise documentation of all work in order to avoid expensive change orders after the award of contract.

Although at first glance, the building appeared to need only a general refurbishment and cleaning, in fact, conditions were far worse.

Figure 08

Prior to the start of the project, more than one third of the original terra cotta had failed, and been removed and replaced with brick and stucco.

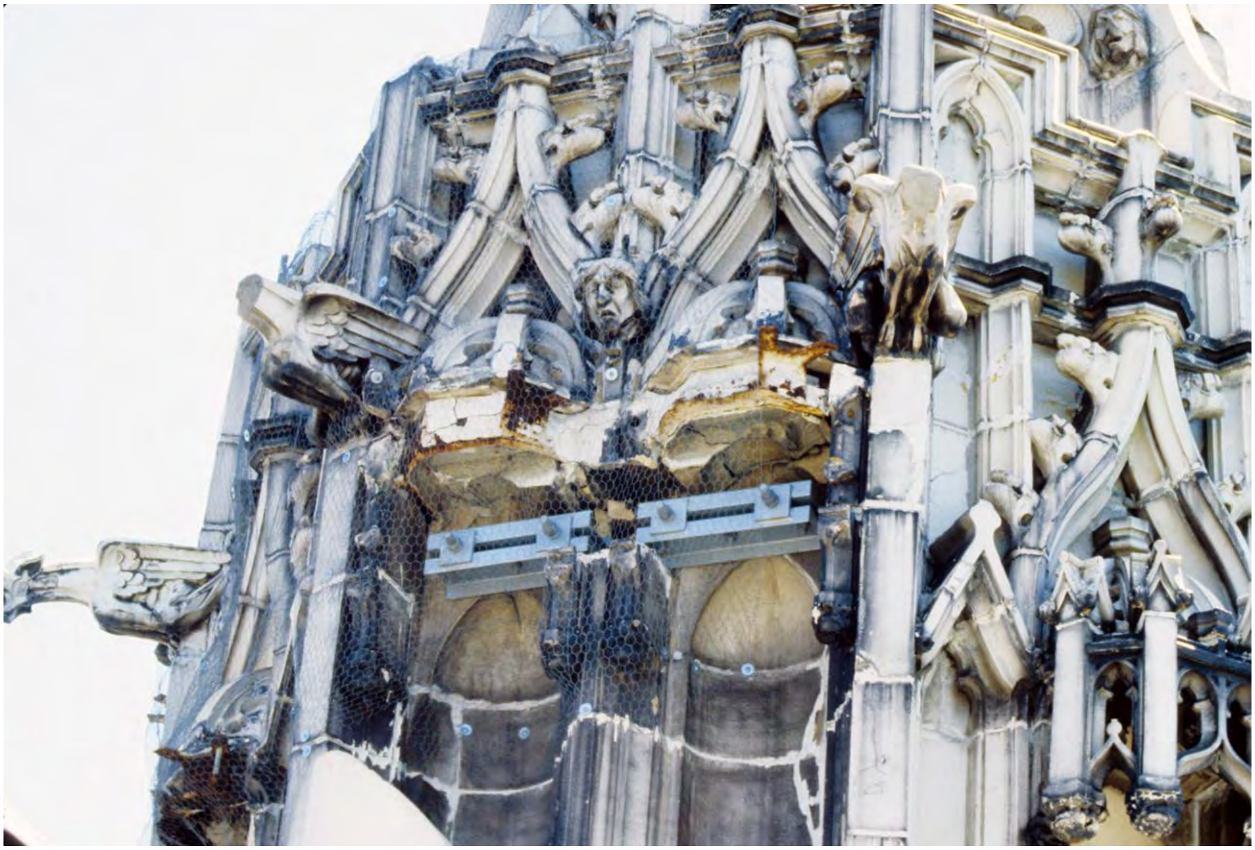
Figure 09

By 1986, a number of these repairs were, in themselves, already failing.

Figure 10

Of even greater concern was the fact that many of the steel members embedded in the masonry were exhibiting signs of failure and probes indicated that some of the steel had completely rusted away. Shown here are one set of the temporary tension rods placed through tops of the Main Tower turrets to prevent their collapsing outwards. Even these interim repairs added to the damage to the terra cotta ornamentation.

Figure 11



The building was quite literally falling down. If Shepard Hall was to survive at all, let alone continuing as an integral part of the City College Campus, a comprehensive reconstruction plan would be required.

The causes of the structural failures were manifold. Although there were some problems associated with manufacturing defects and improper installation of the terra cotta, a great many of the failures were due to the fact that the building was designed without expansion joints or other means to accommodate thermal movement, and, as noted above, the terra cotta was installed integrally with the stone.

Figure 12

As the building moved, the terra cotta was crushed allowing water to attack the steel. Steel rusted and expanded increasing the openings and increasing the amount of water reaching the steel. In the winter, water freezing in the cracks exerted tremendous prying action causing sudden failures.

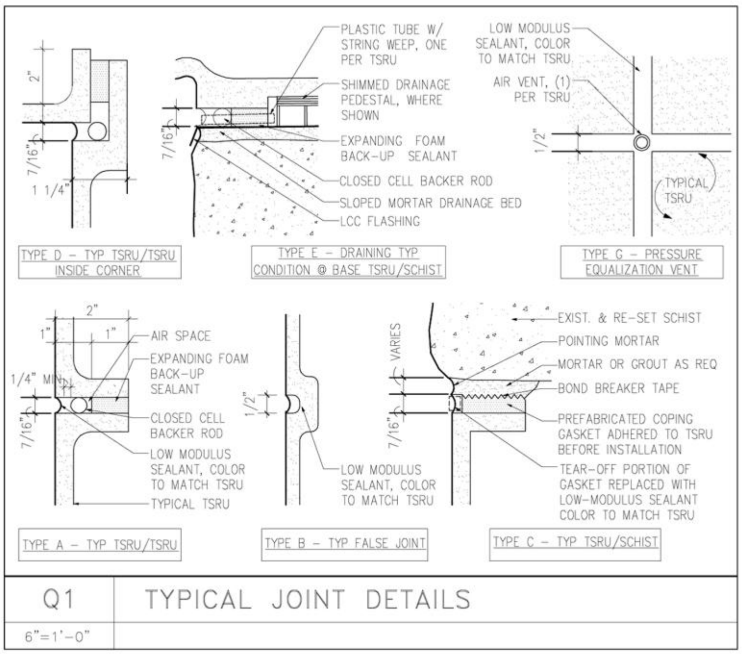
Figure 13

In some cases pieces of terra cotta weighing over 10 kg fell from heights of more than 30 m. Amazingly, no one was hurt, however areas of the lower roofs showed the effects of having been hit by falling debris, as can be seen in Figure 13.

The reconstruction had to precisely replicate the detail and recreate the sense of solidity of the terra cotta, yet at the same time, had to incorporate a system to address building movement in order to avoid the crushing action that had essentially destroyed the original construction.

The solution was to remove all of the terra cotta and replace it with either brick or stone, to a plane approximately 10 cm behind the eventual finished face. GRC replicas of the terra cotta forms were then individually attached to the new masonry using a system of galvanized steel channels and clips allowing adjustment in three planes.

Figure 14



All of the joints between the GRC units utilize a soft, three-part system of an expanding foam tape, a closed cell backer rod and polyurethane sealant. (Joint Types “A” and “D”) The joints between the GRC units and the stone masonry vary substantially due to the irregular rustic stonework. The variations are accommodated with traditional mortar joints but, between the mortar and the GRC, there is 8 mm thick foam tape with a tear-off strip at the face which allows application of sealant to the gap. (Joint Type “C”) As such, every joint whether between GRC units or between GRC and stone can accommodate approximately 2.5 mm of movement.

Figure 15

Since each field of GRC has multiple joints, the system utilized for the reconstruction of the decorative areas of the building is more than capable of absorbing all of the building movement. The extent of these de facto expansion joints, that is the areas having multiple soft joints between cladding units, can be seen in Figure 15.

To date, nine construction contracts have been awarded with eight having been completed and one several months from final signoff. In terms of GRC, the smallest project involved approximately 500 units, and the largest involved approximately 14,000 units. To date, a total of approximately 66,000 units have been fabricated and installed and the final phase of reconstruction will involve about 6,000 additional units.

MATERIAL SELECTION

The 1986 Feasibility Study identified a number of criteria for the replacement cladding at Shepard Hall. Three of the most important led to a pre-selection of a thin shell, glassfiber reinforced cementitious replicas. These were:

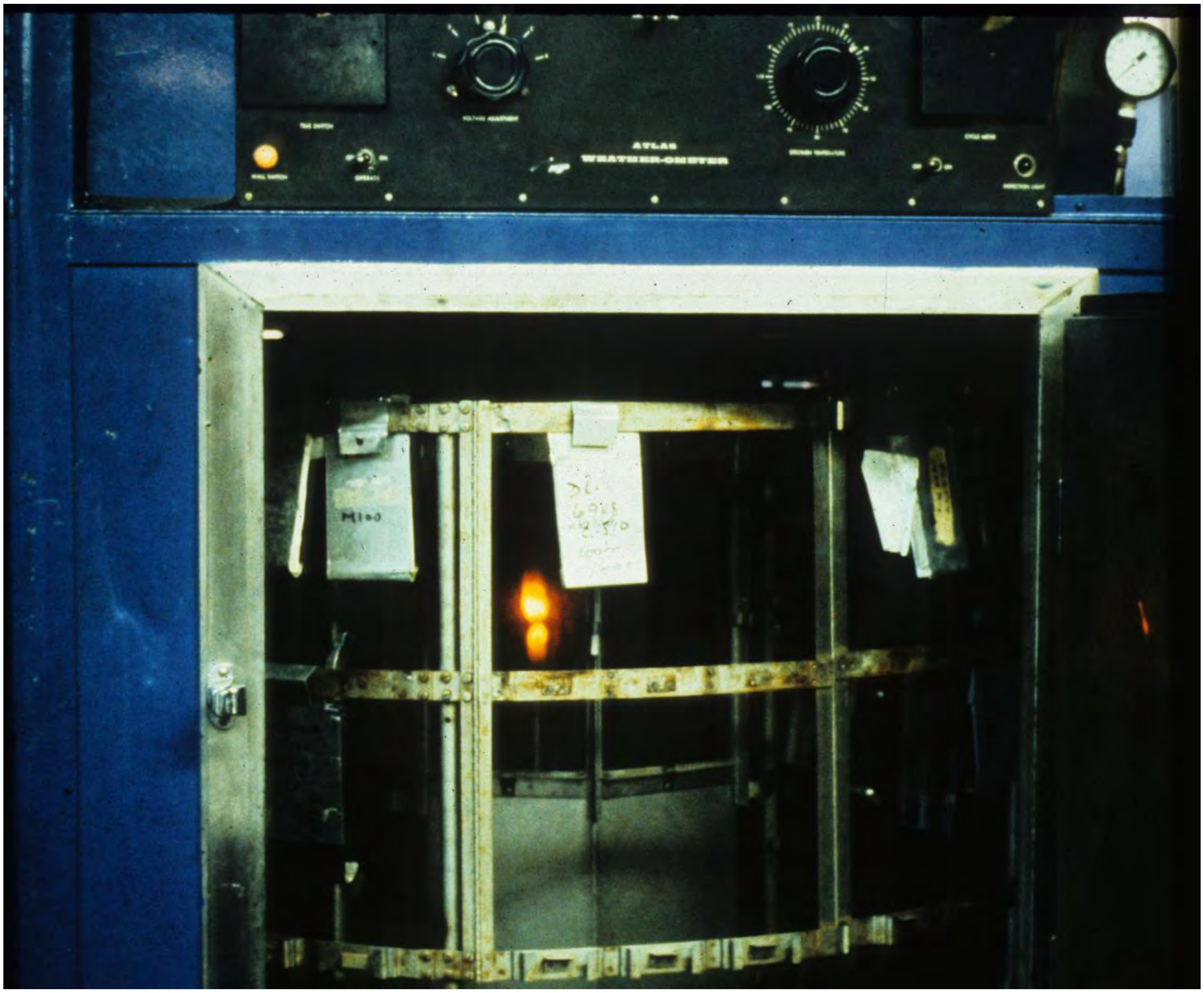
- The material was to be compatible with an attachment system in which each replacement unit would be independently supported. This was necessary in order to realize the design for accommodating building expansion and to permit the high degree of field adjustment necessary when installing the fields of replica units into the surrounding masonry of rough stone. The individual attachment of the pieces also permits the structural reconstruction to proceed in advance of the decorative cladding, and facilitates future replacements should these ever become necessary.

- The material had to be suitable for producing relatively thin units. In this way, by replacing most of the volume of the terra cotta with structurally sound masonry leaving a narrow recess at the outside face, the replica units could be installed with an adjustable steel attachment system such that the original finish profile would be faithfully replicated. The zone behind the replicas would fully flashed and waterproofed, essentially creating a Gothic revival rain screen. Once the GRC system had been selected, the unit dimensions were established at a nominal material thickness of 16 mm with a 50 mm edge return for stiffening and to accept the three-part joint sealant system.

- The material, which had to replicate a smooth white surface, was to be essentially monolithic so that any long-term surface erosion would not compromise color.

Because of the small sizes of the individually supported units, the environmental stability of the architectural surfaces was at least as much of a concern as were structural properties.

Figure 16



The Feasibility Study included several series of accelerated aging tests emphasizing the environmental stability of the surface and color properties of various glassfiber reinforced materials.

Figure 17

In the initial tests run in 1986, a proprietary system using a calcium alumina silica cement and E-glass showed clear architectural advantages. The first phase was carried out using this system. Now in place for more than twenty years, the product has performed well; however, it was difficult to manufacture and supplies were somewhat unpredictable.

As the first construction phase was being completed in 1990, the client commissioned a new series of tests in order to determine whether a more readily available and easy to manufacture alternative could be found that would have comparable durability. Thirteen different GRC formulations were tested. One system incorporating metakaolin and small amounts of polymer tested significantly better than the rest of the samples. The finished surface was given an application of a breathable “neat” silane sealer to minimize dirt accumulation and to reduce the temporary color change when the material becomes wet. Other than this, there is no applied surface treatment.

Figure 18

Originally, it was anticipated that the remaining 80 percent of the envelope reconstruction would be completed in four phases, each approximately the same size as the first reconstruction project. The original schedule called for the construction to be complete in 1999. Construction documents for all four phases were essentially complete by 1995. However, funding for this work was sporadic and as early as 1992, the originally-planned four phases were being sub-divided into smaller contracts. The current projected schedule has the final pieces of GRC installed in 2013. While the delay has proved in many ways frustrating, it has allowed the performance of the GRC to be monitored over an extended time period.

Figure 19

The GRC system described above was exclusively used for the next eight phases of construction and is specified for the ninth and final phase. The earliest installations of this material were in 1993. The most recent were in mid-2011. Not including the first phase material, the GRC units have been produced by four different suppliers, fabricated at seven different production plants, and installed by three different contractors. There are areas of the building in which immediately adjacent GRC units have been installed more than fifteen years apart from one another.

Figure 20

For example, the GRC at the left of this composite image was installed in 1995; the one in the middle in 1999; and the one at the right in 2005. Each was produced by a different fabricator.

The applications of GRC at Shepard Hall are atypical in several aspects. Because of the complexity of the shapes and the requirements for patterns (models) to replicate the sculpted originals, the cost of the raw material is a relatively small part of the total finished GRC cost; and an even smaller part of the overall project cost. As such, some of the economies in material use that are sought in most GRC installations have been intentionally ignored at Shepard Hall.

Also, because the areas of new GRC must be integrated into irregular stone masonry, the ability to easily make fine adjustments in the field is more important than the cost savings that result from large-scale pre-assembly. Despite this, the dimensional stability inherent in the GRC production process, particularly as compared with fired clay products, has allowed the use of digital three-dimensional modeling to preview the fit and alignment among the GRC units and between the GRC assemblies and the surrounding stone.

Figure 21

R E C O N S T R U C T I O N

VIRTUAL BUILDING

CAD and photogrammetry play an important role in designing and managing a complex project in which deteriorated terra cotta and iron fasteners are replaced with GFRC and stainless steel.

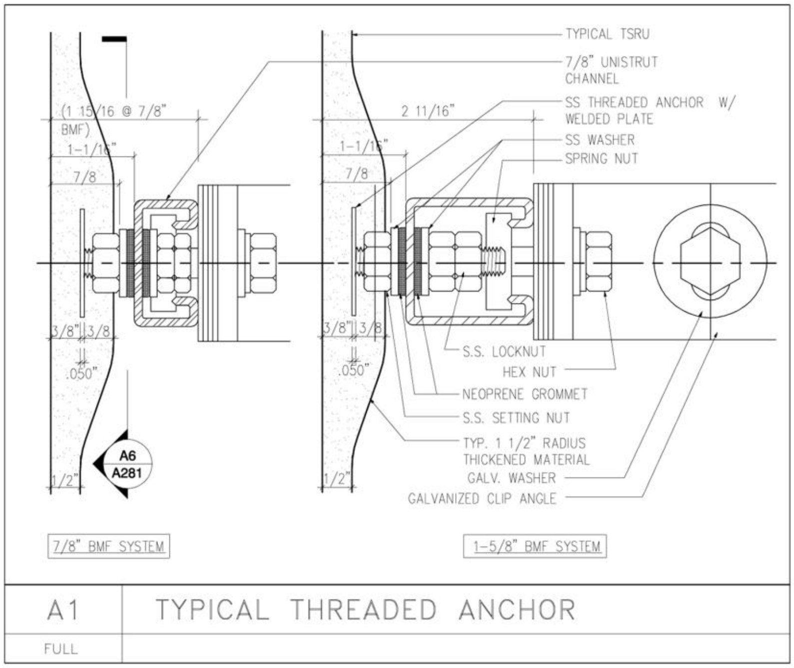
Few restoration projects better demonstrate the advantages of using CAD in restoration work than the highly complex project underway at Shepard Hall, the main building on the campus of New York's City College. In 1986, when The Stein Partnership, a New York City-based architectural firm, undertook the first phase of the restoration project, computer technology was not sufficiently developed to make effective use of CAD, and so the architects developed drawings by hand. However, when Phase II of the project began in 1991, significant advances in both equipment and software allowed the architects to adopt a computerized process for documentation and development of contract documents. An integrated CAD and database program, developed in-house, has enabled the architects to track every aspect of the work, from contract documents to shop drawings to the manufacture, scheduling, and delivery of each component. This exact control of the project has helped keep the installation of the sixty thousand GFRC units, which are being used to replace the deteriorated original terra cotta, on schedule and within budget.

HISTORY

Completed in 1907, Shepard Hall was designed by George B. Post in the gothic revival style. The building was conceived as a composite structure of load-bearing stone, glazed terra cotta, and steel. Because the structure was designed during a period when the building industry was moving from the traditional technology of load-bearing masonry walls to the new and untested technology of steel framing, the original architects failed to allow for movement within the building or the differences in behavior of the various materials. In addition, they seriously overestimated the load-bearing capacity of the terra cotta. By the mid 1930s major failures in the building envelope were evident. And by 1986, when The Stein Partnership began work, some sections of the building were in immi-

Here too, because of the size of the undertaking, the documentation methodology developed specifically for the work at Shepard Hall has become a prototype for numerous subsequent projects. As an aside, these same properties of GRC and digital modeling coupled with CNC pattern production are ideally suited to non-orthogonal contemporary sculptural architecture.

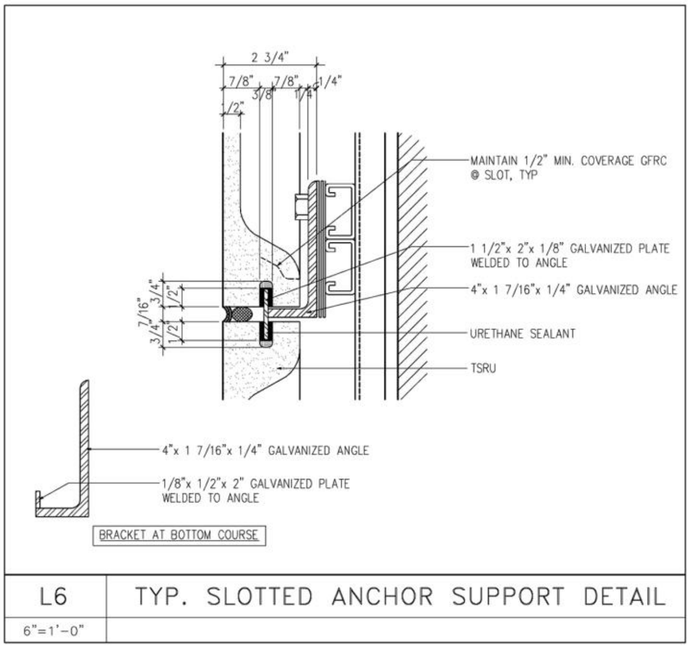
Figure 22



Attachment has been achieved in two basic ways. The first is the use of embedded stainless steel plates with threaded studs set into the backs of the panels.

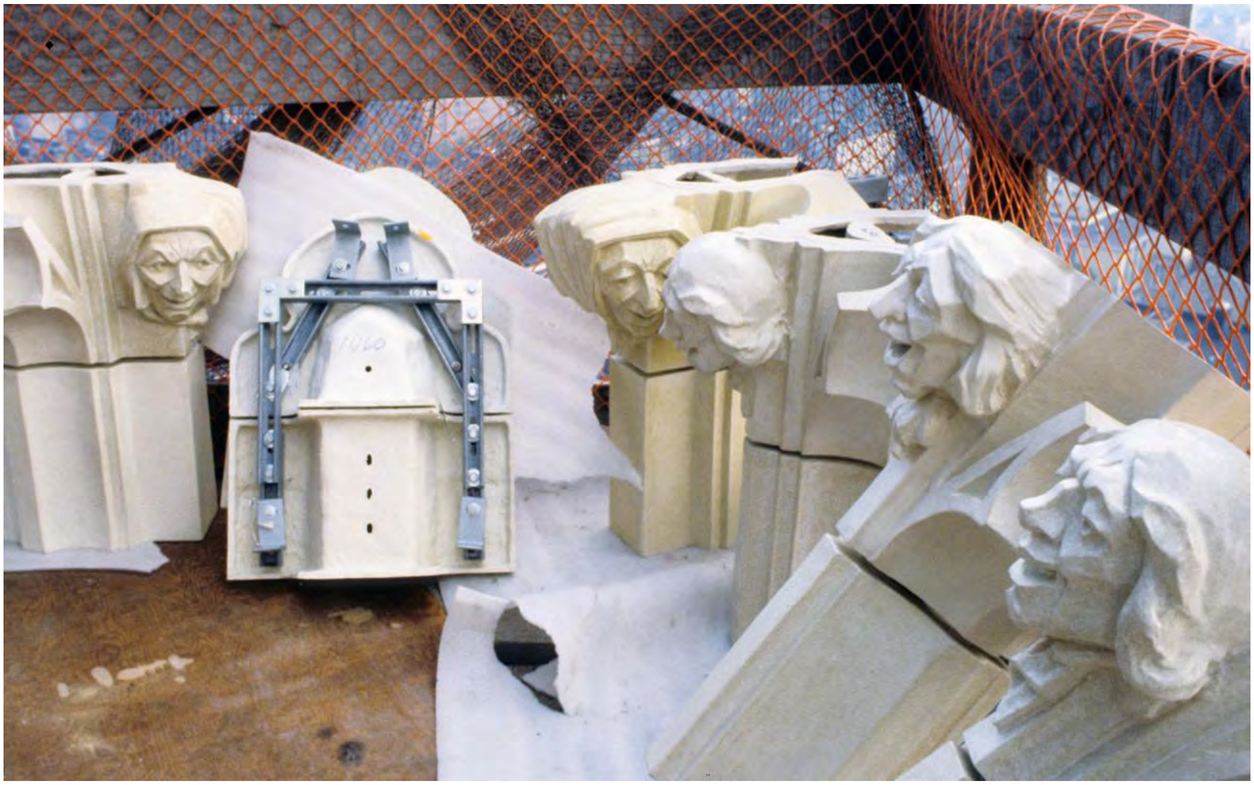
The second is forming slotted sockets in the edge returns of each panel and supporting the panels with "L" or "T" clips.

Figure 23



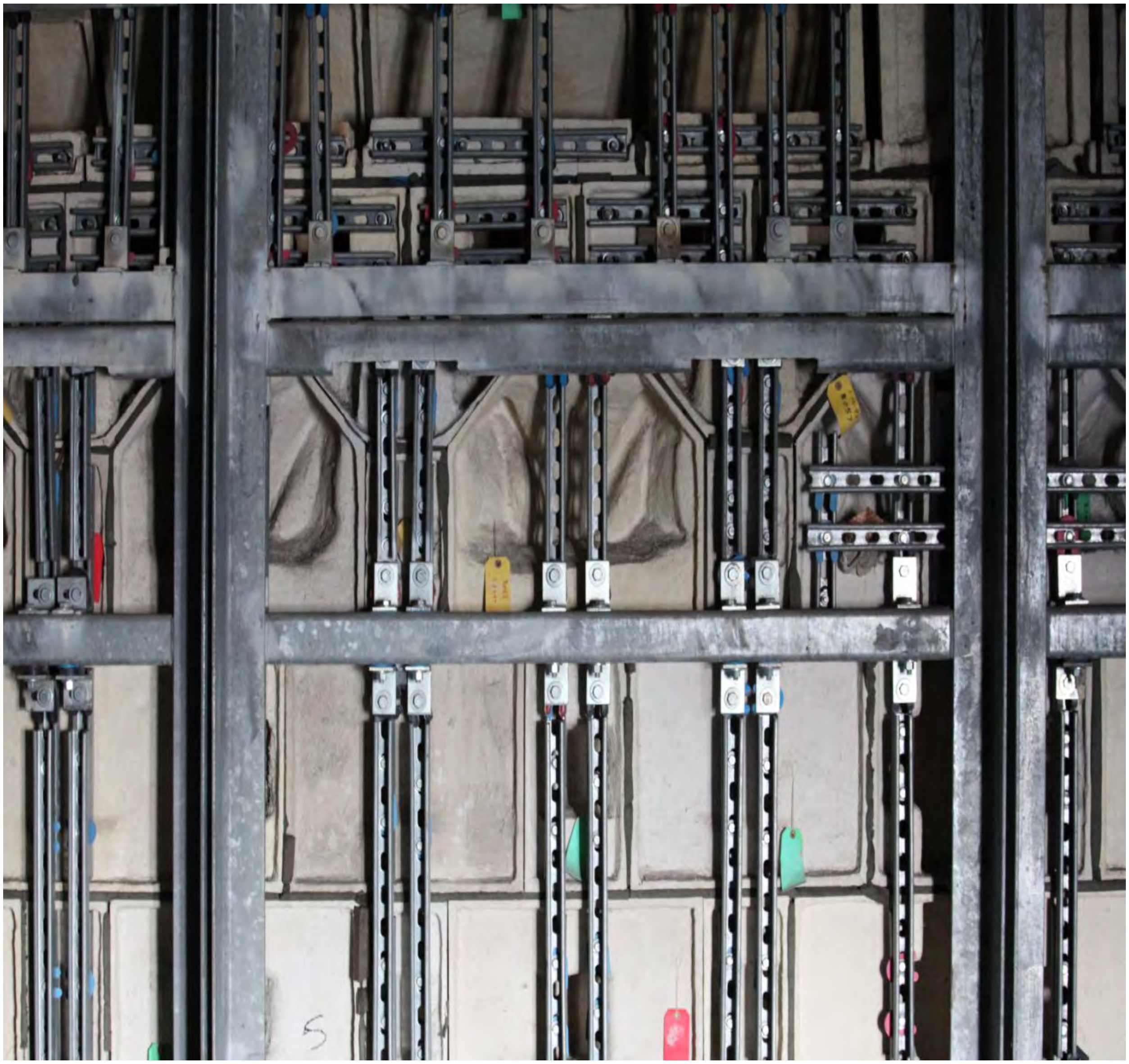
For either mounting system, the individual panels "float" on resilient bushings that occur at each attachment point, thus insuring that there are no undue stresses introduced between attachment points or from panel to panel. In considering this method for addressing thermal movement, it must be remembered that the individual GRC units at Shepard Hall are almost always less than 90 cm in any direction.

Figure 24



One typical application of the embedded anchors allows pre-assembly of groups of units prior to their final placement on the building. This facilitates installation where the arrangement and shapes of the parts make individual attachment difficult. Each sub-assembly is pre-assembled, test fit in place, adjusted as necessary and then installed.

Figure 25



The embedded fasteners are also used where the backs of the GRC units are accessible, allowing the nuts for the threaded studs to be installed and tightened as the units are set into their final position.

Figure 26

Note the contrast between what is clearly a thin screen assembly as is evident in the interior view and the appearance of solid masonry when seen from the exterior.

The slots and “L” or “T” clips are generally used where installation is from the outside face and there is no rear access.

Figure 27

The only disadvantages of the slot and clip system are that the installation of the GRC units must proceed sequentially, and that the connection of the final unit generally requires an access panel. For both attachment systems, full adjustment in three axes is provided by a combination of channels with sliding bolts, slotted holes and shims.

Both attachment systems depend on the creation of a relatively precise plane from which to work.

Figure 28

Where the GRC is being incorporated into an existing masonry surface, this plane is achieved using unit masonry which generally is filling the bulk of the void left by the removal of the original terra cotta.

Figure 29

In areas where entire portions of the building must be completely replaced, the new structure which is typically either cast-in-place reinforced concrete…

Figure 30

…as in the case if the upper 12 m of the Bell Tower, the area pictured in Figures 25 and 26,

Figure 31

or in precast/post-tensioned concrete as for the upper 20 m of the Main Tower.

Figure 32

These new structural elements establish the precise reference plane that permits the design, dimensioning and fabrication of the GRC to be carried out as though this were a new building rather than a complex insertion into an irregular historic landmark.

OBSERVATIONS

First and foremost, the GRC-based system developed for the reconstruction of the Shepard Hall envelope and associated structural repairs has worked extremely well.

Figure 33

In addition to the performance of the material itself, the development and application of a rigorous system that integrates material production issues, construction and installation procedures, and documentation has delivered a project which although taking much longer than originally intended due to budget constraints, and having had far more fragmented contracting arrangements than anticipated, has maintained remarkable consistency. All of the advance preparation has allowed construction contracts for smaller work scopes that had been originally planned to be issued on relatively short notice; in turn, accommodating the somewhat unpredictable nature of project funding in the City University construction program.

Figure 34

A further benefit is that as the GRC technology has developed and become more common, the resulting cost savings have funded a number of secondary projects including the total renovation of the Great Hall.

Figure 35

The construction system, as well as the overall approach to designing, bidding and contracting, would not have been possible without the availability of a high quality, well controlled and predictable GRC material. This has not only supported the technological basis of the solution, it has produced a finished result that has been enthusiastically received by the clients. It has also validated the use of GRC for complex historic reconstruction, a practice that is becoming increasingly widespread in the US.

Figure 36

The system has also depended on the availability of crafts personnel who are able to meet the stringent criteria for the patterns and molds required for historic preservation. This skill, coupled with the ability of GRC to present extremely fine detail, has generated literally thousands of unique, highly nuanced sculptural replicas for the Shepard Hall reconstruction. Perhaps not surprisingly, over the two decades of GRC use at Shepard Hall, application of GRC for the reconstruction of deteriorated historic buildings has transitioned from a novelty to common practice.

At the beginning of the work at Shepard Hall, the specialty GRC producers had to dramatically expand their capacities to meet the demands of this one building. Now, the Shepard projects wait their turn among other reconstruction programs. This, in turn, has resulted in reduced costs for finished product, making the system not only technologically advantageous but also very highly cost-competitive with materials such as cast stone.

Figure 37

The success of approaches taken for attachment has led to their becoming prototypical for other similar GRC work. As noted above, these methods are not particularly suitable for the cladding of large, repetitive surfaces but do accommodate the unique characteristics found in many historic reconstruction projects. In particular, the option for in situ adjustment of individual pieces allows fitting of complex forms into irregularly configured settings.

Figure 38

Also as noted above, the extended timeframe for the work has provided real-time bases for evaluating the stability of the visual properties of the GRC castings by providing side-by-side installations of units that have been installed fifteen years apart from one another. The most important finding has been that to most observers, there is no readily discernable break between the work of any of the phases.

Figure 39

Here, the GRC in the background to the left was installed in 1995 while that in the foreground to the right was installed in 2005.

That said, the oldest of the GRC units, those installed in late 1993 show slight etching of the surface; however, the fact that the units were produced without any surface film makes the mild surface deterioration virtually invisible. The final phase of reconstruction will include a complete wash-down of all of the GRC and a reapplication of the “neat” silane sealer. This will bring the twenty-year-old GRC onto the same surface aging and cleaning cycle as the newest GRC.

An important benefit to the tightly controlled GRC specification has been the ability to obtain compatible product from a number of different suppliers. This is particularly important for publicly bid and contracted work in which the material may be provided by anyone who can demonstrate compliance with experience qualifications. For example, at Shepard Hall, the fabricator for one of the medium sized projects (approximately 6,500 units) was a company specifically formed for the contract but one which employed a number of key personnel from previous phases. Another fabricator began his involvement with the Shepard Hall project by producing units for a small phase (approximately 500 units) but has continued by providing GRC for three medium sized phases. Throughout the building facade, the GRC fabrications from the various producers are almost indistinguishable from one another.

Figure 40

Despite the large size and atypicality of the Shepard Hall project, none of the phases has experienced any significant delay due to failure of GRC production to keep up with the rest of the construction operations. All of the producers have been certified by the Precast Concrete Institute for Group G (GRC) products resulting in similar quality control procedures being observed for all productions.

CONCLUSION

More than twenty years into the largest reconstruction of a terra cotta building envelope using alternate material, the decision to use GRC is proving to have been a highly appropriate choice. In addition to its technical success, it has allowed material supply from a diverse range of producers and has resulted in a visual unity despite the fragmented construction sequence and the passage of time.

IMAGE LIST