Evaluations, Repairs, and Retrofits of the Historic Sherman Building in Washington, DC Following the 2011 Mineral, VA Earthquake.

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Abstract
As a result of the Mineral, Virginia earthquake on August 23, 2011, a number of historic masonry structures throughout the Baltimore-Washington, DC area sustained varying degrees of damage. Following the earthquake, Keast & Hood had numerous opportunities to provide structure engineering services as part of the post-disaster response, assessment, and recovery of historically sensitive structures. This paper provides a case-study of a successful earthquake recovery and reinforcement project at the Sherman Building in Washington, D.C.

Introduction
The Sherman Building is located at the Armed Forces Retirement Home (AFRH) in Washington, D.C., a 272-acre federal campus used as a retirement community for U.S. military veterans. The Sherman Building was constructed in three phases between 1852 and 1891. Since opening in 1857, this impressive structure served as a dormitory, dining hall, library, billiard hall, post office, barber shop, and canteen. Today, the building is the centerpiece of the U.S. Soldiers' and Airmen's Home National Historic Landmark.

Designed by Lt. Col. Barton Alexander and built by Gilbert Cameron from 1852-1857, the Sherman Building was originally a two-story masonry structure with a modest tower. Between 1868 and 1871, Architect of the Capitol Edward Clark designed a third floor addition with a Second Empire style mansard roof and added a tower clock. The building's final phase of construction occurred from 1887-1891. Architect William M. Poindexter and Co. replaced the mansard roof with distinctive ornamental parapets and turrets in the Richardsonian Romanesque style. This phase included construction of the north wing and extension of the clock tower to its current height of 130 feet. It is interesting to note additional renovation and supplement construction phases likely occurred between initial construction and the building that exists today. However, as is the case with many historic structures, the building's saga is mostly unknown. What is known is pieced together through a scatter of historic drawings, paintings, and photographs.

On 23 August 2011, a 5.8-magnitude earthquake hit Mineral, Va., causing damage throughout the Mid-Atlantic region. The Sherman Building was significantly affected, with hazardous conditions created by fallen stones and structural distress. In terms of severity of structural distress as a direct result of the earthquake, the Sherman Building was the most significantly affected historic building in the Baltimore-Washington area. After 160 years of continuous use, the Sherman Building was vacated for the first time in its history.

Recovery

A two-year earthquake recovery project restored the Sherman Building's iconic structure. The recovery project serves as a model for how a dedicated team can transform devastation into opportunity for preservation, innovation, education, and stewardship.

Working for the U.S. Department of the Treasury, Bureau of the Public Debt and the Armed Forces Retirement Home, a combined design-build team was led by The Christman Company (general contractor) and included Keast & Hood (structural engineer), Quinn Evans Architects (architect), and PRESERVE/scapes (preservation consultant). The team worked collaboratively to repair earthquake damage and remediate structural conditions.

Key elements found to be crucial for success in this project include the following:

- Criteria: Research of code requirements and guidelines; definition of structural repair/retrofit criteria as well as architectural goals, especially as relates to historic fabric and significance. Incorporation of the Secretary of the Interior's Standards for the Treatment of Historic Properties.
- Survey: Survey and assessment methods including both new and old technologies; carefully selected to be appropriate to the project and construction means and methods.
- Selection: Careful selection and delineation of areas requiring reinforcing/retrofit and areas requiring repair only.
- Collaborative Design: Project delivery methods involving early collaboration with contractors and specialty trades.
- Collaborative Construction: Routine, flexible, and creative involvement of the design team throughout the construction process.
- Community Engagement: Involving the surrounding community in the reconstruction and reinforcement of the Sherman Building through education and service helped foster excitement and pride for the iconic historic structure.

At the start of the project in July 2012, the full extent of damage to the Sherman Building was not fully known. Visible conditions included hundreds of fallen and removed stones, gaping holes in the roof, collapsed retaining walls, and destroyed interior finishes. The substantial cracking and displacement of masonry were the major known structural damage concerns, see Figures 1 & 2. However, the extent of structural damage remained largely unknown.

Figures 1 & 2. Displaced masonry. (Preservescapes 2011 with permission from Preservescapes)

For a project defined by unforeseen conditions and historic significance, the team implemented an approach that allowed for the fluid development of designs and methods tailored to the building's unique historic construction and fabric. Every member of the multi-disciplinary team, from consultants to contractors, worked closely in the field, fostering a collaborative spirit and collective vision for recovery. Through this concerted effort, the team maintained a fast-track schedule and stayed within budget despite project complexities. AFRH moved back into the building within six months of the start of the design-build process, and all work was completed in just over a year.

A major component of the Sherman Building project was substantial masonry reconstruction to repair structural damage and to provide concealed reinforcements for sensitive seismic retrofit and long-term preservation. Much of this effort focused on the building's iconic clock tower; over 500 stones (20 courses) were reconstructed around a new steel frame carefully designed to be hidden within the tower's open belfry.

Understanding the Damage
Visible building distress was noted in the form of masonry displacement. Cracks in the plaster finish often indicated cracking of the masonry finish beyond.

To understand the extent of the damage, the team implemented innovative methods that serve as models for future preservation projects. The team performed a digital point cloud laser-scan survey in the field to understand the building's geometry and displacements that occurred during the earthquake. The survey ensured that the design for structural remediation was tailored to the unique geometry and conditions of the tower. Digital surveys and custom graphic tools, such as course maps and inventory elevations developed by the preservationist consultant, resulted in improved efficiency and 100 percent accuracy for the complex

reconstruction. Following an extensive team evaluation, the building required reinforcement and seismic upgrades as well as restoration.
In order to gain a better understanding of the internal structural distress, probes were conducted through existing plaster. Probes removed the plaster and chased cracks in order to establish the severity of masonry cracking and associated wall displacement (unzipping of interior walls from exterior walls). Furthermore the probes brought to light unforeseen structural elements including full height timber wall trusses.

In the attic of the structure, existing wooden roof truss distress was visually apparent, with damage related to both the earthquake and years of moisture decay and termite infestation, see Figure 3. Heel joints at the exterior walls, already weakened by earlier deterioration, subsequently failed during the earthquake and caused wall separation. The existing timber trusses required an in-depth review using non-destructive resistance drill testing. Additional building components affected by the earthquake included the building chimneys. The chimneys collapsed during the seismic activity and required new structural elements to replace the fragile and flexible masonry structure.

Figure 3. Deterioration in roof truss. (Keast & Hood 2013, with permission from Keast & Hood)

Project Approach
Based on the team's extensive evaluation, the building required reinforcement and seismic upgrades as well as restoration. Structural work included assessment, reconstruction, and seismic retrofit (where required) of retaining walls, ornamental parapets, chimneys, clock tower and timber roof trusses along with anchorage of exterior masonry walls to internal walls and diaphragms. These repair and reinforcement upgrades spanned through all phases of the original construction and required a diverse range of design solutions.

Elaborately and beautifully constructed out of mostly single-wythe stone masonry, the original clock tower's was a key comment of the project seismic retrofit and restoration. While the stone weathered well, the stone performed very poorly in the earthquake.

On the project critical path, a steel braced frame was selected to reinforce and add stiffness to the exposed bell level of the tower without adding significant weight and triggering further reinforcing or foundation upgrades below, see Figures 4 and 5. Although engineers investigated alternative reinforcement options for the towers, including shotcrete, cast-in-place concrete, and reinforced masonry, steel was chosen because it offered more flexibility for design and construction. This decision was also logical in terms of safety, scheduling, and aesthetic standpoints. Steel could be fabricated off-site and installed quickly, benefitting the project's fast-track schedule. Additionally, the steel frame's lightweight nature posed further benefits by avoiding the cost and time of reinforcing the existing foundation design. The effort represents the delicate balance of structural reinforcement and historic preservation required by the project.

Implementing RAM Elements software to design and detail the new steel structure, Keast & Hood sensitively and strategically wove roughly 10 tons of new steel framing elements into the historic building fabric, strengthening the existing structure and bracing the masonry for long-term seismic protection. It also provided necessary support to new CMU wall panels installed to offer additional strengthening of the fragile exterior stone shell, see Figure 6. The steel columns, beams, and braces of the frame were carefully located and later painted to avoid visibility from exterior views of the tower.

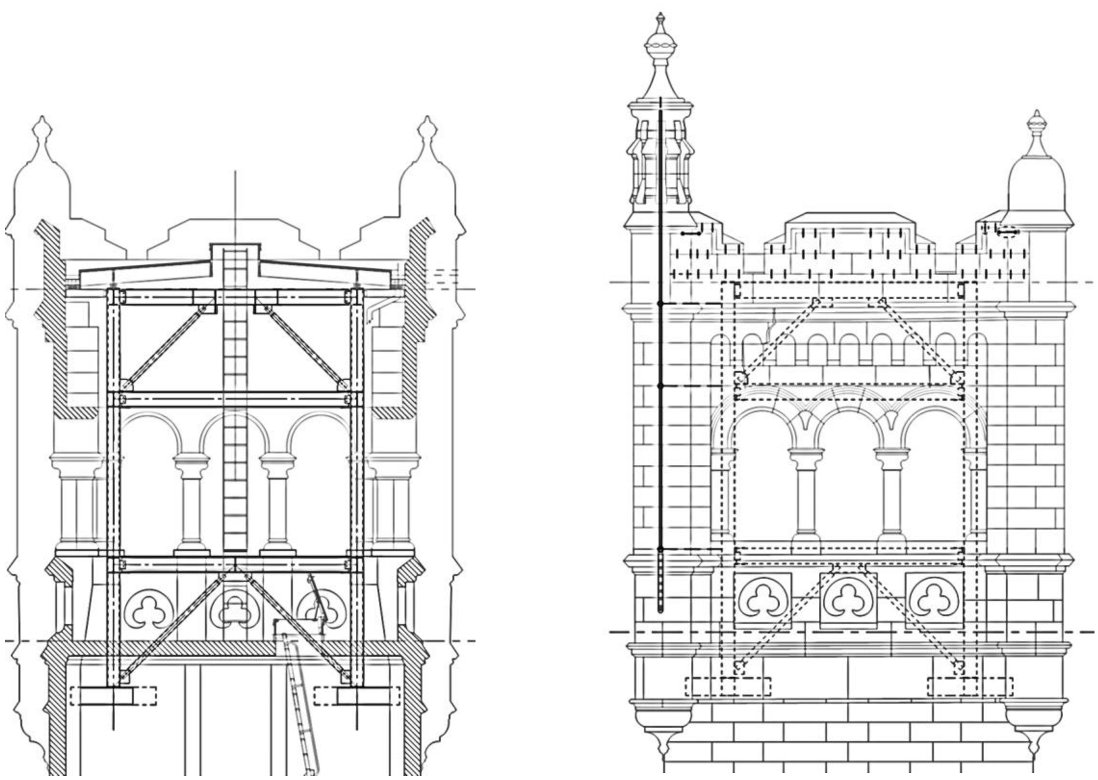
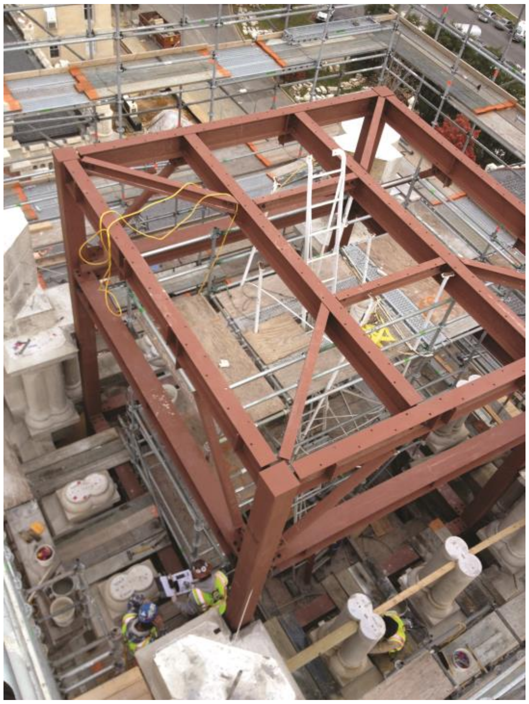


Figure 4. Steel braced frame. (Keast & Hood 2013, with permission from Keast & Hood)



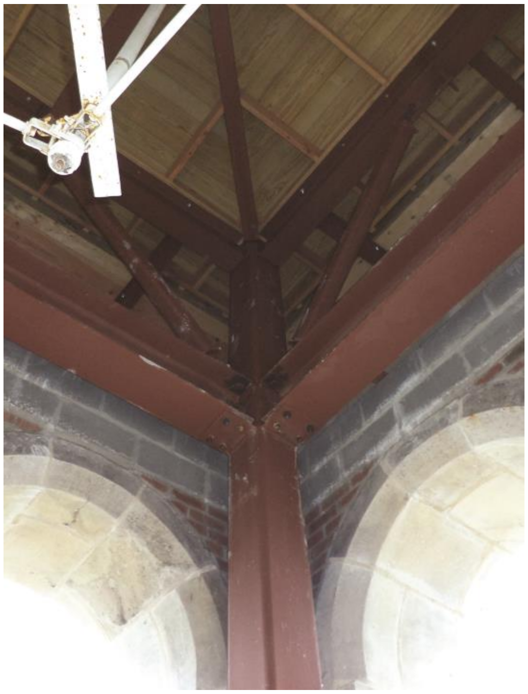


Figure 5. Steel braced frame. **Figure 6. Steel frame from interior.**
(Keast & Hood 2013, with permission from Keast & Hood)

The steel came in the form of roughly 40 pieces, most of them in the 10-to-15-ft range: W14x48, W12x53, and W6x16. The 26-ft-tall columns were made of HSS10x10x½. Angle pieces were used to create new frames for masonry support.

Limited interior stainless steel reinforcing and masonry backup were added to provide load transfer and strengthen weak points in the reconstructed stone masonry. The tower roof was constructed to match the existing form while providing capacity to brace the tower parapets and transfer diaphragm forces.

Large protruding corner turrets were repaired with a grouted sock anchor approach. Stainless steel threaded rods within fabric socks were inserted into dry core-drilled holes in the masonry and filled with cementitious grout for proper bond and compatibility with the historic fabric, see Figure 7. This solution stabilized the fragile masonry while providing permanent reinforcement for the turrets and tower. It is interesting to note no two courses were identical in stone geometry. Furthermore, the geometry of each cornerstone was unique in that no cornerstone was identical. Repairs accommodated the large variance in stone geometry.

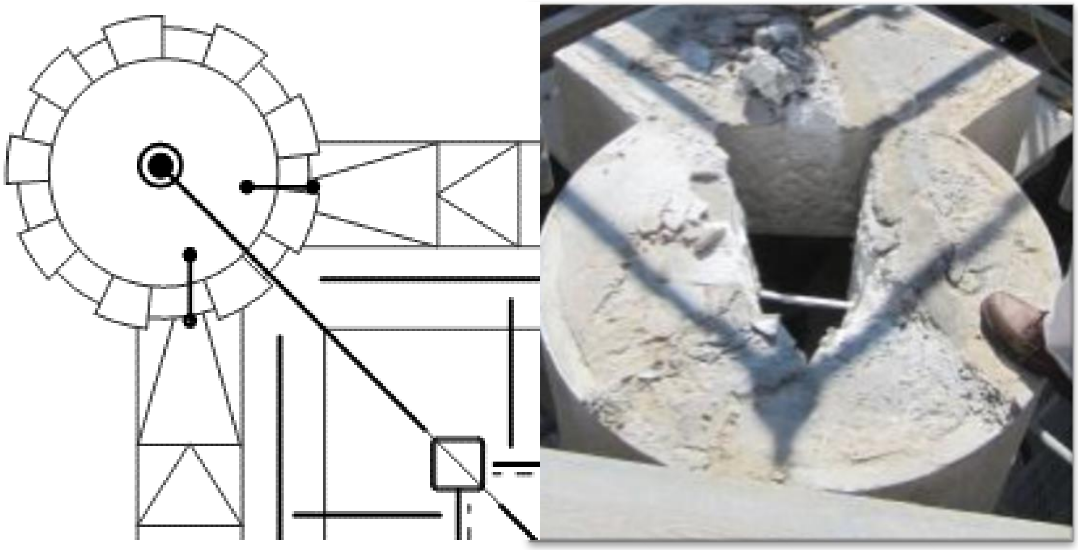


Figure 7. Masonry restraint. (Keast & Hood 2013, with permission from Keast & Hood)

Additional exterior masonry elements were repaired by similar means of grouted sock anchors with steel tie backs to the structural masonry backup (brick), see Figure 8.

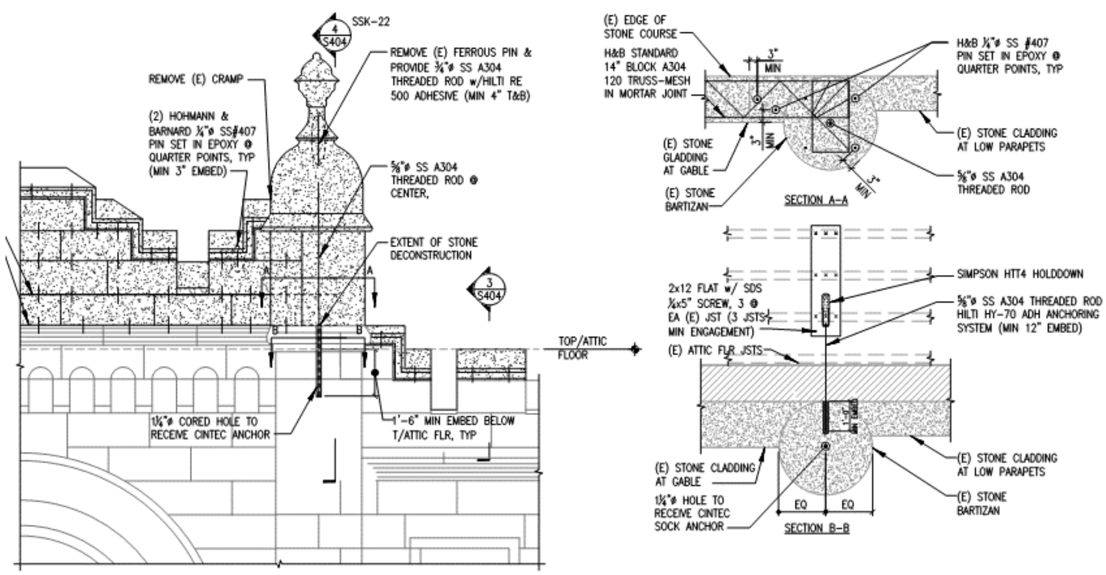


Figure 8. Masonry Anchorage. (Keast & Hood 2013, with permission from Keast & Hood)

Beyond masonry reconstruction and embedded reinforcement, engineers provided positive mechanical anchorage of the exterior masonry walls to the wood framed floors and bonded the dress stone to the structural masonry backup with concealed helical anchors and cold-formed plates where new steel strap anchors were introduced at the floor levels and exterior / interior wall intersections, see Figure 9. Positive anchorage was also provided at the original cast iron portico using concealed stainless steel fasteners.

Figure 9. Exterior / Interior Wall Anchorage. (Keast & Hood 2013, with permission from Keast & Hood)

Taking cues from the firm's past historic intervention approaches, notably Philadelphia's Academy of Music, Keast & Hood engineers designed steel reinforcements that were carefully threaded into the attic to reestablish the truss heel-joint connections with the wooden trusses. The design necessitated a detailed survey by the fabricator and meticulous installation. Carpenters worked in tandem with the fabricator to install each new piece of steel by hand. Roof truss reinforcement is pictured in Figure 10.

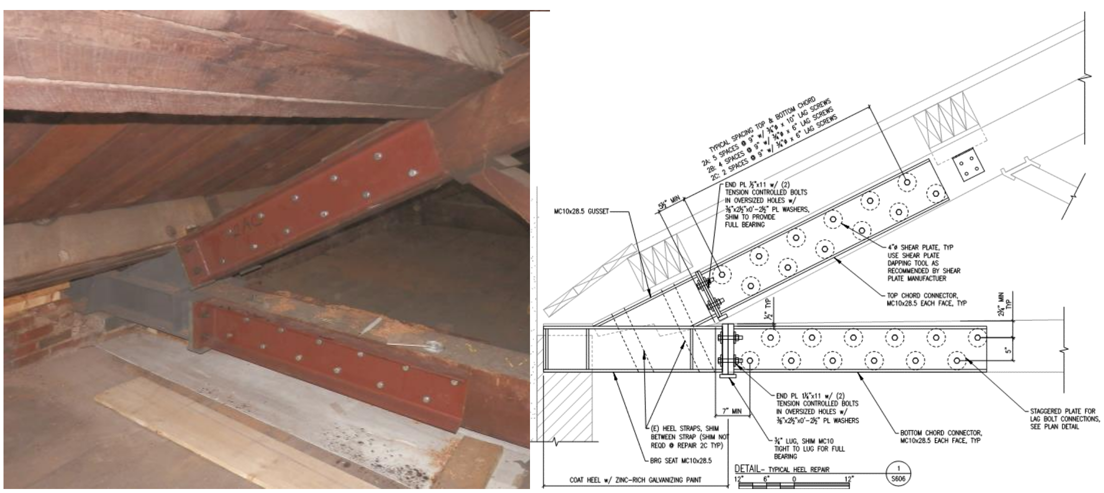


Figure 10. Roof truss reinforcement and bearing. (Keast & Hood 2013, with permission from Keast & Hood)

Due to the design-build nature of the project and the irregular building geometry, the structural solution incorporated very little conventional framing. The most common framing was block masonry and structural steel tube and wide-flanges shapes used to frame the clock tower reinforcing.

The Construction Process

The time sensitive nature of the project, in combination with not being able to foresee all structural damage, posed a unique and challenging design-build construction process. This required all members of the design and construction teams to be flexible and creative in order to respond to the obstacles the project afforded. Goals of the project were to preserve the existing appearance of the Sherman Building, while reinforcing and rebuilding the structure using as much of the original construction materials as possible. In addition, in accordance with the Secretary of Interior Standards, all repairs were designed to be for all intensive purposes reversible.

Another complexity of the construction process was replacing each individual stone back into its original position. As with any preservation project, this challenge requires careful construction methods and can often translate into a lengthy timeline. However, this project was completed within two years of the earthquake, with Veteran residents returning to the building after just six months of the start of construction.

In response to the extent and severity of the observed distresses, partial deconstruction of the tower was required. Over 20 courses (rows of bricks) of the masonry tower were dismantled and rebuilt around a new structural steel eccentric braced frame (EBF) assembly in conjunction with selective internal reinforcements, see Figure 11. Existing conditions such as rounded stone edges, tapering brick backup and the varying cuts and sizes of the original stone impacted the design.

Figure 11. Disassembly of clock tower. (Keast & Hood 2013, with permission from Keast & Hood)

Steel erection only took a few days, and installation required scaffolding the entire tower and deconstructing the tower to a working level just below the existing clock tower deck. New steel was installed using a self-erecting tower crane. A new CMU shear wall was built to support the base of the internal steel frame, see Figure 12. A scaffold system was then erected in the third floor office to the underside of the clock level. Due to the tight confines of the existing spiral stair, which was blocked by the scaffolding, a small opening was cut in the clock level floor to haul block pallets and other construction materials up into the tower.

Figure 12. Internal Masonry Shear Wall for Steel Frame. (Keast & Hood 2013, with permission from Keast & Hood)

One of the more exciting unforeseen conditions was a time capsule found during deconstruction of the tower. The time capsule artifacts, left by the original masons in 1890, were conserved and returned to the tower during a December 2012 topping-out ceremony. The discovery of the time capsule and artifacts, including original mason's markings and tools, fostered immense pride in the team's efforts to restore the legacy of the original tradesmen.

Community Engagement

The team's efforts reached beyond the building itself. The project created opportunities to engage the community and provide exposure to a historic landmark that is not open to the public. In addition to writing articles to keep AFRH veteran residents engaged in the recovery, programs were conducted with community groups, and presentations and tours were hosted for professional organizations.

Working with the nonprofit organization Live It Learn It, the team orchestrated an interactive educational program for local elementary school students. The program explained the historic significance of the Sherman Building; gave students the opportunity to play the role of engineer, architect, or builder to create a replica of the tower; and introduced students to careers they might one day pursue.

Spirit of Stewardship

In August 2013, AFRH hosted a public open house to celebrate the project's completion and created a permanent lobby display to educate staff, residents, and visitors about the building's history and recovery. The rebirth of this landmark has renewed a spirit of stewardship and preservation at AFRH, one that will surely have a lasting effect on the building and the surrounding historic campus.

Completed Restoration & Seismic Retrofit

Structural steel tower reinforcement, masonry restoration, cast-iron railing repairs, timber truss strengthening and other structural restoration efforts were made to bring the Sherman Building back from devastation, see Figure 13. More than 3,000 stones in retaining walls, chimneys and parapets were salvaged, catalogued and rebuilt using nearly 100% of the original hand-carved marble. The $14 million project not only restored the building but also reinstated the home and sense of national pride for 500-plus military veterans who reside in the Armed Forces Retirement Home and the Sherman Building.

The project as a whole highlights the successes of a true Design-Build project with a dedicated team. The existing structure presented challenges, including unique archaic structures, around each corner; however, the collaborative effort from all involved help to restore and protect this historic landmark for years to come within a tight project schedule and final completion date.

Figure 13. Restored and reinforced Sherman Building. (Keast & Hood 2013, with permission from Keast & Hood)

References

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Design-Build Team List:

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