Napa County HISTORIC Courthouse

By Luke Wilson, S.E.,
Brett Shields, P.E.,
and Kevin Zucco, S.E.

Figure 1. Entry showing damage; taken the morning of the Earthquake.

AT 3:20 AM, August 24, 2014, the Napa County Historic Courthouse was severely damaged in the magnitude 6.0 South Napa Earthquake, which induced nearby ground motion readings indicating spectral accelerations ranging from 0.4g to 1.7g for low period structures. Most obviously, the top of the south east corner at the front of the building (east face), along with its attached dental cornice, collapsed outward to the sidewalk below (*Figure 1*). The Initial review also revealed a partial collapse of the exterior brick wall on the north elevation. At one corner of the building, the top two to three feet of brick wall fell inward, collapsing the ceiling framing above the jury room (*Figure 2*). There was significant additional damage throughout the exterior and interior masonry walls and the building frequently appeared in news coverage as a prominent downtown public building affected by the Napa Earthquake. The Courthouse was subsequently red-tagged by the City of Napa (the building was deemed unsafe for occupancy or entry, except as authorized by the local building Authority Having Jurisdiction per Applied Technology Council, ATC 20-1), beginning the long process to assess the damage, repair, and reoccupy the historic structure.

History

The Napa County Historic Courthouse was constructed in 1878, with an estimated $51,000 construction cost equivalent to approximately $1.3 million in 2019 dollars. It was added to the National Register of Historic Places in 1992. Before this building was built, two previous courthouse buildings existed on the same site. The original building was a prefabricated structure shipped to the city by barge in 1851. Just five years later, in 1856, the original building was replaced with a site-built courthouse that was ultimately deemed unsafe due to settlement and wall cracking. In 1874, construction began on the current courthouse, which has been serving the local community for over 140 years.

The current courthouse architectural design was provided by the Newsome Brothers, who also designed the Napa Opera House and the William Carson Residence in Eureka, with the assistance of local architect Ira Gilcrest. The Courthouse, along with the Hall of Records and Administrative Annex, occupies a city block bounded by 2nd, 3rd, Coombs, and Brown Streets in downtown Napa. The land for the Courthouse site was donated for use by City founder Nathan Coombs. As part of the original construction, a two-story jail was constructed west of the courthouse with a small access corridor between the two buildings.

In 1918, the Hall of Records building was constructed adjacent to the jail on the west end of the block. When the jail was demolished in 1977, a new Administrative Annex was built as infill between the Hall of Records and the Historic Courthouse to create a single-occupancy space. While the 1977 infill project is seismically separate from the Historic Courthouse, several large openings reinforced with concrete frames were added to the west wall of the Courthouse building, and multiple smaller openings were either added or infilled to accommodate new circulation patterns in the combined space. Additionally, in 1977, a seismic retrofit of the Historic Courthouse was performed with concrete pilasters added in the north and south exterior walls and the interior hallway corridor walls, and out-of-plane wall anchorage hardware was installed throughout. In 2003, a tenant improvement to the court clerk's office added an approximately 25-foot-long concrete infill shear wall between the first and second floors along the north corridor wall.

Figure 2. Courtroom view from the attic where brick partially collapsed the ceiling below.

continued on next page

Figure 3. Horizontal offset of brick in the attic.

Figure 4. Partially collapse of URM wall due to adjacent Administrative Annex Framing.

The Courthouse is a 15,000-square-foot, two-story, unreinforced brick masonry building with wood-framed floors, ceiling, and roof. The original construction included an octagonal bell tower with an onion dome roof that was damaged in the 1906 San Francisco Earthquake and eventually removed in the early 1930s. The roof framing consists of straight sheathing over 2x rafters and site-built, large rough-sawn timber trusses, while the ceiling framing below consists of conventional 2x framing. Roof and ceiling framing both span between perimeter and corridor bearing walls. The floor consists of assorted finishes over straight sheathing with rough-sawn 3x12 joists.

ZFA's longstanding relationship with Napa County and direct involvement with the Historic Courthouse since 2006 offered familiarization and knowledge of the building invaluable to the process after the earthquake and repair solutions beyond.

Damage from 2014 Earthquake

ZFA was brought in as part of a team tasked with completing the Courthouse repair after the building was shored under a prior contract with a separate design team. Before beginning repair design and drawings, ZFA completed an extensive damage documentation effort to reveal and illustrate the level of damage to the client and the insurance company's peer review engineer for confirmation of required repair scope.

In addition to obvious partial collapses, the building sustained significant damage at the second-floor level and along the front of the building. The front (east) façade, consisting of a series of reentrant corners stepping out horizontally towards the front entrance, experienced significant corner damage throughout. Observed damage included: diagonal cracking of walls leading to in-plane and out-of-plane horizontal wall displacements up to three inches (*Figure 3*); multiple localized or partial collapses of brick walls (*Figure 4*); failure of both the original out-of-plane government roof-to-wall anchors and the 1977 retrofit wall anchorage; and significant non-structural damage, including broken sprinkler lines that caused additional water damage.

The out-of-plane wall anchorage included failures of both the original government anchors (approximately 8-inch-diameter iron plate on the far face of the brick wall anchorage by a flat plate through the wall to the wood framing beyond) and the 1977 retrofit adhesive anchors. Observed failures included: wythe pullout, retrofit anchor adhesive bond failure, buckling of 2x diagonal braces, net tension rupture of 2x braces, and bolted connection failures in 2x members. With few exceptions, out-of-plane wall anchorage failures were concentrated at the roof/attic level.

Documenting the Damage

In lieu of traditional damage documentation methods, in which reviews are completed on a room-by-room basis, generally looking at a wall from one side at a time, ZFA employed a wholistic 3-D approach. Detailed and scaled field observations of damage on both sides of walls (cracks, deflections, displacement of wythes, localized collapses, and failures in out-of-plane wall anchorage), as-built conditions differing from the original construction, and 1977 reconfiguration documents were combined with original construction documents to create a 3-D BIM model. All observed wall cracks were modeled with different color and weight 3-D model lines. Blue lines indicated cracks occurring on the north or east faces, while red indicated cracking on the south or west faces of walls. Model line weights were also varied to depict crack size thresholds. Wall profiles were edited to show localized collapsed areas and voids.

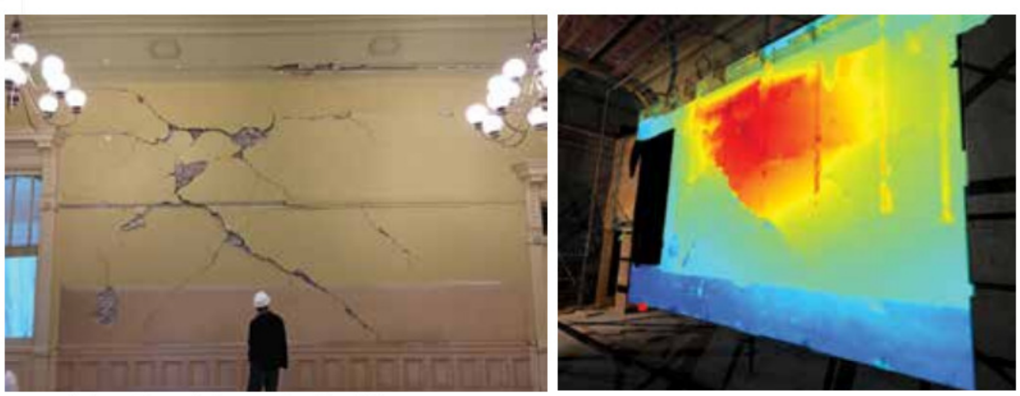

Figure 5. Site photo of damaged wall and heat map showing offset.

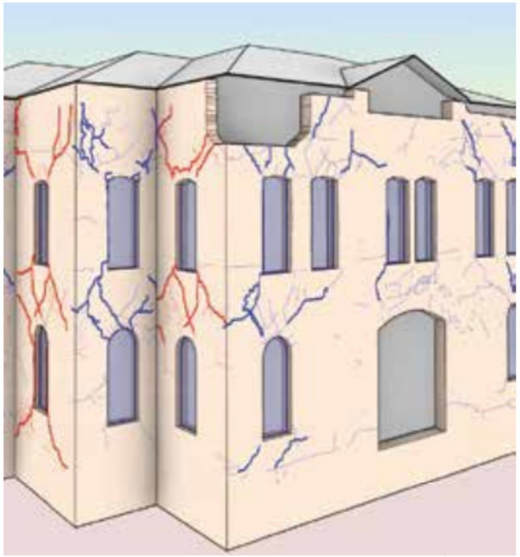

Figure 6. BIM Model showing entry damage (see Figure 1 for actual photo of area).

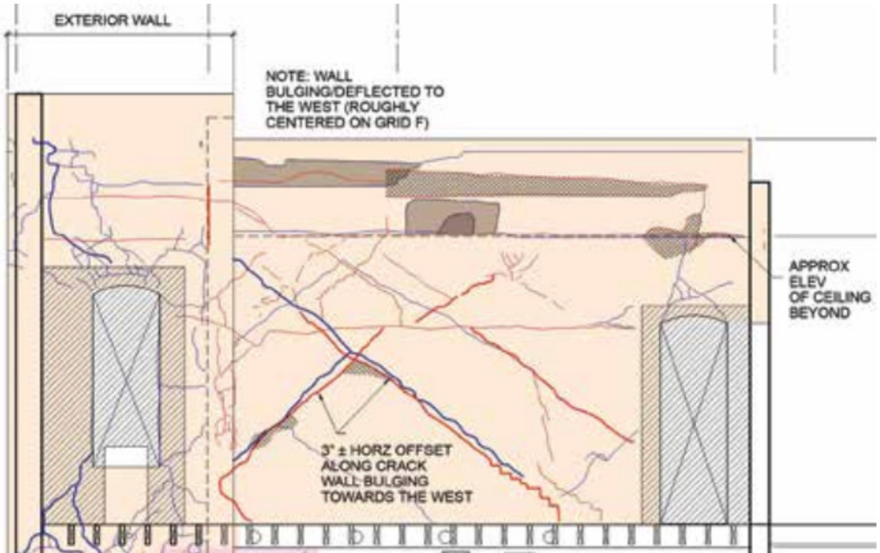

Figure 7. Example damage documentation drawings (see Figure 5 for an actual photo of the wall).

A 3-D exterior site scan was completed shortly after the earthquake for use in shoring design, and an internal 3-D scan of each room was completed during the damage documentation phase. The resulting data point cloud was linked into the BIM model to verify dimensional assumptions and aid in building deflection review and assessment. Sections were cut through the walls with the point cloud to illustrate out-of-plane wall displacements and verify wall thicknesses that were otherwise difficult to identify solely through field observations. The 3-D scans were also used to generate "heat maps" (*Figure 5*) showing relative out-of-plane displacements in a colorized gradation to augment the documentation drawings.

Using the damage documentation 3-D BIM model (*Figure 6*), two-story full-length wall elevations and 3-D views clearly illustrated crack patterns on both sides of walls (*Figures 7* and *8*). Using this whole-building approach to documenting the damage, significant two-story diagonal crack patterns were revealed that extended through wall faces, providing valuable insight into the global building behavior and resulting damage extent from the earthquake.

Assessing the Damage

FEMA 306, *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings*, was used to classify observed failure modes and provide an estimated loss of strength for each wall pier along each wall line. Typical failure patterns included wall-pier rocking, in-plane flexural cracking, and out-of-plane flexural cracking. Additionally, significant corner damage was observed due to the reentrant corner configuration along the eastern front façade, resulting in the partial collapse of two walls at the roof. In addition to the more common damage patterns documented in FEMA 306, weak pier/spandrel joint damage patterns were also observed at exterior corners and reentrant corners. The combination of the field observations, 3-D BIM modeling, and FEMA 306 analysis created a summary of the damage documentation that was used to develop a conceptual repair approach for review and discussion with the insurance company's peer review engineer.

Because of the historic materials and construction techniques, 140 years of use and modification, and the wide range of damage throughout, a single repair option was not appropriate. The repair concept, therefore, used a combination of traditional brick repair methods, repointing, grout injection, and localized areas of brick rebuild along the western portion of the building. However, the more heavily damaged eastern portion and corridor walls required a creative repair approach to save the historic fabric of the building and provide improved structural performance.

This repair approach included the use of Fabric-Reinforced Cementitious Matrix (FRCM), one of the first applications in California, and wall reconstruction with specially-detailed CMU construction to replace the walls in the areas of heaviest damage.

A more detailed review of the various repair and rehabilitation techniques utilized will appear as a future article in STRUCTURE.▪

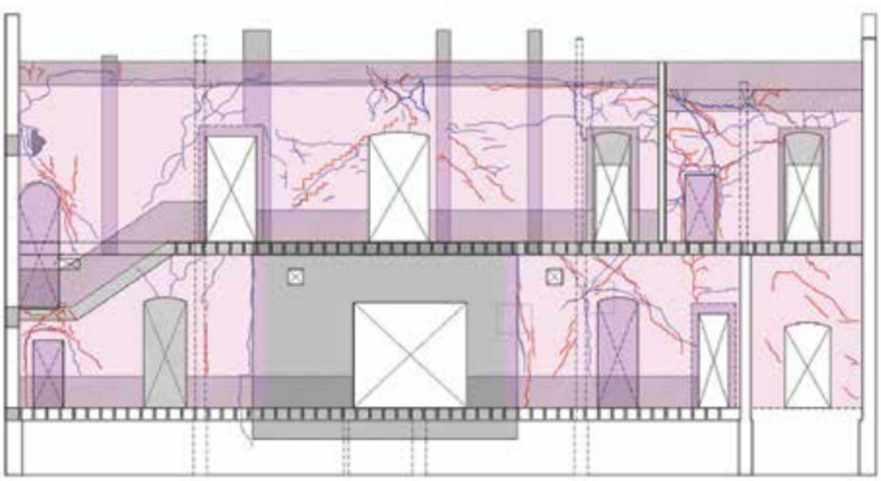

Figure 8. Two-story section through the main hallway showing damage documentation.

All authors are with ZFA Structural Engineers in Santa Rosa, California.

Luke Wilson is an Associate Principal. (**lukew@zfa.com**)

Brett Shields is an Engineer. (**bretts@zfa.com**)

Kevin Zucco is an Executive Principal. (**kevinz@zfa.com**)

Project Team

Owner: County of Napa
Structural Engineer: ZFA Structural Engineers
Historic Preservation Architect: TreanorHL
Architect: TLCD Architecture
Owner's Rep: AECOM
General Contractor: Alten Construction

Figure 1. Entry showing damage taken the morning of the earthquake.

Napa County HISTORIC Courthouse PART 2

By Brett Shields, P.E., Luke Wilson, S.E., and Kevin Zucco, S.E.

On August 24, 2014, the South Napa Earthquake left the Napa County Historic Courthouse heavily damaged with partially collapsed walls, ceilings, and extensive wall cracking (*Figure 1*). The City of Napa red-tagged the courthouse as un-occupiable, which began the extensive damage documentation effort outlined in the December 2019 edition of STRUCTURE. After documenting and assessing damage, the design team refocused efforts towards a solution to repair and preserve as much of the historic building as practical while providing improved detailing.

Construction Documents

The 140-year-old building is constructed with unreinforced brick, an "archaic" structural system. After considering the *California Building Code* (CBC) or American Society of Civil Engineers *Standard for Seismic Evaluation and Retrofit of Existing Buildings* (ASCE 41), ZFA Structural Engineers decided the *California Historic Building Code* (CHBC) was the appropriate design code for the project because it would allow reuse of the historic brick walls.

Repair Approach

An overarching goal of the repair was to save the historic brick structure in its original state utilizing the original construction, where possible, and providing modern construction techniques with ductile detailing where rebuilding or strengthening the damaged condition was required. Because of the historical materials and construction techniques, 140 years of use and modification, and the wide range of damage throughout, a single repair option was not appropriate. Repair details were approached with continuity, resilient detailing, and construction tolerances in mind. During documentation, the high level of historic brick masonry craftsmanship became apparent, particularly at the exterior of the building (*Figure 2*). Therefore, repair work was kept on the inside face of the building to preserve hand-shaped decorative brick features and trim adorning the exterior of the structure. In areas of new wall construction, these features were recreated with modern appendages and plaster to preserve the historic appearance. Additionally, the historic interior wood trim and wall wainscot were salvaged and reinstalled throughout the building.

Traditional Repair Methodology

Traditional repair methods, such as repointing mortar beds and grout injecting cracks, were used where observed damage was less extensive and cracking was limited to discrete locations. This was primarily concentrated on the first floor and the west end of the second floor that experienced smaller deformations.

Grout injecting was determined to be preferable for the repair of distinct larger cracks, but an alternative repair solution was needed in areas of numerous cracks prevalent throughout the second floor.

Fabric Reinforced Cementitious Matrix Overlay

Early in the repair design, the design team considered using traditional Fiber Reinforced Polymer (FRP) overlay on brick walls demonstrating extensive cracking. Due to surface preparation requirements and material incompatibilities of FRP (epoxy resin vs clay and mortar), the team turned to a new overlay product uniquely suited for brick masonry construction called Fabric Reinforced Cementitious Matrix (FRCM) used extensively in Europe. FRCM was used to repair brick

Figure 2. Historic exterior wall brick construction and dental cornice.

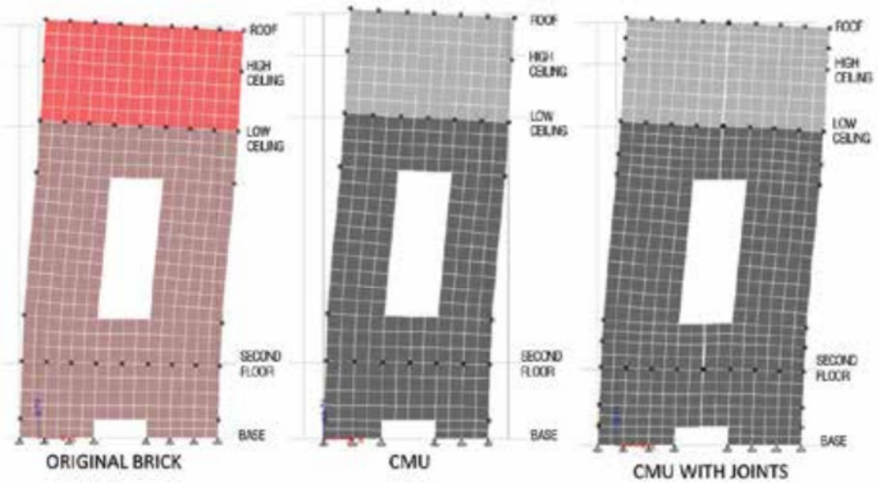

Figure 3. Analysis model showing original brick, CMU, and CMU with control joints.

Figure 4. CMU reconstruction of damaged 2nd-floor walls.

masonry walls with significant cracking but minimal permanent deformations, and to provide continuity through floors, walls, and around corners. As a new product being brought to the United States by manufacturers, including Simpson Strong-Tie, FRCM presented several challenges and opportunities from design through construction. These will be discussed in a future Part 3 article in STRUCTURE.

CMU Design

Reinforced CMU construction was used in place of brick to reconstruct areas where significant damage and permanent seismic deformations required walls to be rebuilt. These areas were primarily concentrated at the east end of the second floor. Special design consideration was taken to avoid concentrating lateral and overturning loads from relatively stiff new CMU above to the remaining historic brick below. Analytical models were created using tested in-situ historic brick material properties to determine approximate stiffnesses of existing wall piers to be replaced. The same piers were then modeled with multiple CMU construction options, including partially grouted CMU, adjusted specified compression strength of masonry (f'_m) using different grout, different block and mortar properties, and alternate block layouts to compare stiffnesses and strengths.

These adjustments did not provide the desired reduction in stiffness; therefore, strategically located control joints were added to further reduce the stiffness of the areas rebuilt with CMU (*Figure 3*). The final design included a stacked bond, in lieu of a traditional running bond and control joints located above and below windows, at reentrant corners, and regular vertical spacings in long rebuilt walls. The final layup more closely matched the stiffness of the original brick walls such that new walls work in unison with existing walls, and lateral loads are not concentrated in any one area. Additionally, many of the exterior reentrant corners, whose stiffness concentrated seismic load and deformations, were reconstructed out of CMU with control joints in the corners to decouple perpendicular walls.

Combining the CMU rebuild with existing historic brick construction presented dimensional obstacles that were addressed in detailing. The brick arches at the 1st and 2nd-floor windows of rebuilt walls were recreated with precast concrete elements to adjoin rectangular CMU with curved historic windows. CMU was aligned at the exterior face of brick to minimize furring and plasterwork on the visible historic exterior and aid in providing a flush plaster joint with the existing plaster finish. At interior walls, CMU was detailed to be centered on the brick below to limit the dimensional offset from the brick below each side for installation of FRCM continuity laps. Transitions of CMU to unreinforced brick were dowelled with alternating embedment lengths to tie the walls together and avoid creating a defined weak plane in the brick similar to those observed at the 2003 concrete shear wall interface.

The unique condition of anchoring new CMU walls to existing in-place ceiling framing allowed for cast-in-place anchorage to be located

Figure 5. Detail of CMU interface with historic brick arch.

Figure 6. CMU and precast lintel construction above the original brick wall.

accurately, avoiding the traditional difficulties associated with locating cast-in-place anchorage. Connections employed slotted holes, post-installed anchorage, acceptable dimensional ranges, shims, and acceptable offsets to allow for as much existing variability as possible, maximizing construction tolerances.

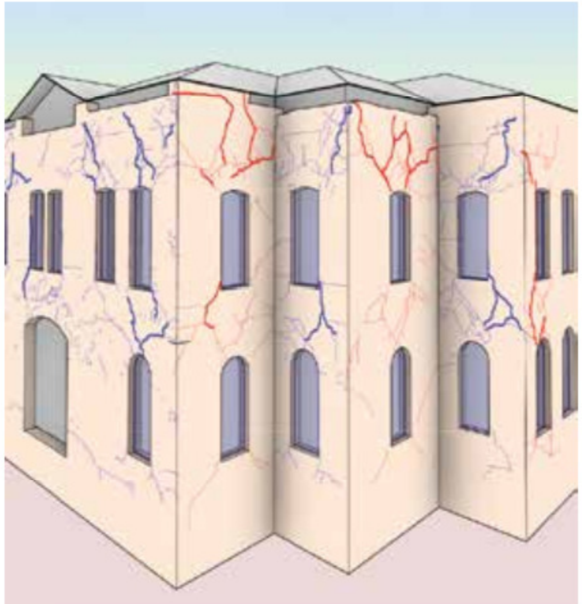

Figure 7. Example of damage documentation drawings.

Construction

As is typical for working within an existing building, multiple unforeseen conditions were discovered during construction. This included uncovering additional damage to brick walls, unknown wall voids or changes in wall thickness, minor areas of dry rot, and incomplete or changed configuration of work shown in the 1977 retrofit documents.

Damage documentation was largely completed by observing cracking in the finished plaster to assess overall damage before requiring expensive removal and reapplication of plaster. Localized areas were selected for removal to verify that plaster cracking correlated to a crack in the brick substrate. Removing plaster during construction often revealed that numerous small patterned cracks observed in the plaster typically resulted from fewer large cracks in the brick ultimately requiring grout injection. Even in areas receiving FRCM overlay, larger, open cracks were grout injected to provide a cohesive substrate for the FRCM. The process of injection uncovered a handful of unforeseen wall voids and chases that required grout filling before crack injection.

In addition to material similarities, CMU was used in the project for its adjustability to accommodate small dimensional variations in the existing structure. Modern construction procedures and metrics focus on installing materials straight, true, and plumb rather than matching existing conditions. The roof and second floor experienced small permanent displacements, which were compounded with plan dimension variations along the length and height of each wall. This created a challenge in rebuilding a new "straight" wall between two existing points (*Figure 4, page 23*) while still supporting the floor and ceiling. This condition was resolved through shimming of ledgers at small gaps and providing bearing angles at larger offsets.

While CMU has some adjustability to accommodate small existing dimensional offsets, the number of intricate interface conditions to existing construction was a challenge. CMU had to interface with historic brick arches (*Figure 5, page 23*), existing floors and ceilings, adjacent precast concrete lintels (*Figure 6, page 23*), uneven base levels, wall anchorage, and existing penetrations while adjusting to match existing walls. The result was a number of details, both planned and unforeseen, requiring a level of mason care and ability beyond that of typical construction.

Conclusions

From the beginning of the damage documentation phase in early 2016 to completion of construction, the overarching goal was to preserve the historic fabric of the building while providing improved resiliency, with modern structural design and detailing techniques woven into the project.

Due to the archaic materials, the age of the building, and the architectural layout of rooms, the extent of damage from a brief walkthrough could be easily underestimated. Extensive documentation utilizing new technologies and proven methods to create a 3-D BIM model, clearly and effectively documenting the as-built/damaged building, allowed all stakeholders to witness the entire building as affected by the earthquake (*Figure 7*). While time-consuming, this detailed process was critical to the success of the project in supporting a step-by-step agreement process in the scope of work and extent of repairs with all stakeholders.

A combination of repair strategies was used, including repointing, grout injection, localized rebuild of brick, FRCM overlay, and reconstruction of walls with CMU. Reconstructed CMU walls provided at areas of permanent deformations were designed and detailed to perform similarly to the original construction, allowing the first floor walls to remain with minimal alterations. Additionally, the CMU thicknesses closely matched the original building configuration, maintaining the architectural layout and maximizing reuse of historic trim and wainscot.

While there were challenges and unforeseen conditions along the way, the building has successfully reopened and provides the County with services in a uniquely rich environment (*Figure 8*).

The design, construction, and lessons learned of the Fabric Reinforced Cementitious Matrix overlay system will be covered in a future STRUCTURE article.▪

Figure 8. Grand opening on January 22, 2019.

All authors are with ZFA Structural Engineers in Santa Rosa, California.

Brett Shields is an Engineer. (bretts@zfa.com)

Luke Wilson is an Associate Principal. (lukew@zfa.com)

Kevin Zucco is an Executive Principal. (kevinz@zfa.com)

Napa County HISTORIC Courthouse PART 3

By Brett Shields, P.E., Luke Wilson, S.E., and Kevin Zucco, S.E.

Figure 1. Entry showing damage taken the morning of the earthquake.

On August 24, 2014, the South Napa Earthquake left the Napa County Historic Courthouse heavily damaged with partially collapsed walls, ceilings, and extensive wall cracking (*Figure 1*). The City of Napa red-tagged the courthouse as unoccupiable, which began the extensive damage documentation and repair effort. The overarching goal throughout this process was to provide a solution to repair and preserve as much of the historic building as practical while providing improved detailing.

The historic courthouse building is a 140-year-old, two-story, unreinforced brick bearing wall structure with wood-framed floors and roof, located in downtown Napa. The building had a significant remodel and retrofit in 1977 which included concrete frames for new openings, concrete or concrete masonry unit (CMU) infill of existing openings, and many other small renovations.

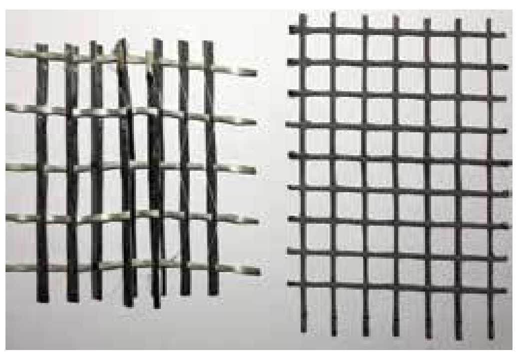

Figure 2. FRCM uni-directional (left), bi-directional (right).

The observed earthquake damage in the brick walls varied from miscellaneous small cracks to significant cracking with permanent in-plane and out-of-plane displacements in both principal directions, to the partial collapse of wall sections. The repair approach needed to provide a similarly diverse set of options to match observed conditions. Traditional brick repair methodologies, repointing, and grout injection were used in areas of minor damage where appropriate. Complete wall reconstruction using specially detailed CMU was used in areas with permanent deflections and partial collapse. However, a third repair approach was needed to address the majority of wall areas exhibiting extensive cracking and minimal displacement. The damage documentation and general repair efforts were outlined in the December 2019 and January 2020 editions of STRUCTURE.

Fabric Reinforced Cementitious Matrix

Early in the repair design, the design team considered using traditional Fiber Reinforced Polymer (FRP) overlay on brick walls that demonstrated extensive cracking. However, FRP presents challenges in a historic brick application. It requires significant surface preparation of the brick to provide a flat surface for fiber application. The finished product requires surface preparation to receive a base coat for finished plaster. The epoxy-based resin creates a sealed surface over the historic brick, restricting the brick's natural ability to breathe. Maintaining this breathability was critical for the preservation of the historic brick.

During concept design, an overlay product used extensively in Europe, Fabric-Reinforced Cementitious Matrix (FRCM), was being introduced to the California market by manufacturers including Simpson Strong-Tie. FRCM consists of either uni-directional or bi-directional carbon fiber fabric (*Figure 2*) embedded between lifts of cementitious matrix installed in ¼- to ½-inch lifts. The lifts can either be installed by hand similar to plaster, or as a spray installation similar to shotcrete. The fabric, which comes in rolls up to 77 inches wide, is pressed into the base lift before having a cover lift of matrix installed. The total thickness for one layer of FRCM is approximately 1 inch plus ½ inch for each additional layer of FRCM. As a porous cementitious material, FRCM is more homogeneous with existing brick stiffness and mechanical properties compared to epoxy-based overlays and allows the historic brick to breathe. The FRCM surface preparation only requires a surface clear of loose debris, cleaned, and saturated surface dry for cementitious matrix adhesion and curing. The FRCM can double as the base coat for plaster installation, removing an extra preparation step required for FRP.

The FRCM, combined with grout injection of large cracks in the brick substrate, was used to restore in-plane capacity to extensively cracked brick walls in place of typical traditional brick repair approaches. The matrix's tolerance in lift thickness, and its ability to locally fill voids of up to 2 inches, provided flexibility for the structure's variable (brick, concrete, and CMU) surface conditions and interfaces. Additionally, the FRCM was used to provide nominal continuity through structural elements such as floors and wall intersections using bundled splay anchor ties, laps between different materials, and nominal tension ties at reentrant corners exhibiting spandrel joint damage.

During design, Simpson Strong-Tie was in the process of gaining seismic approvals for FRCM in California. Therefore, the design process was a collaborative performance-based specification design-build approach. Simpson Strong-Tie acted as the engineer of record for the design of the FRCM product using American Concrete Institute (ACI) 549.4R-13, *Guide to Design and Construction of Externally Bonded Fabric Reinforced Cementitious Matrix Systems for Repair and Strengthening Concrete and Masonry Structures*, with direct input and oversight from ZFA. Per ACI 549.4R, there is no strengthening limit for earthquake and wind forces as they are not considered likely to damage the unprotected FRCM compared to a fire or blast loads. However, FRCM strengthening should not exceed 50 percent of the capacity of the original structure to limit force transfer to the brick. And, strengthening should be limited to 12-inch-thick walls maximum. Additionally, the combined brick and FRCM shear capacity should be compared to the limit state shear capacity of substrate toe crushing.

Based on the reduction in capacity determined in the damage documentation process, ZFA provided target minimum in-plane strengthening loads, ranging from 10 to 25 percent of the undamaged brick wall capacity, for the design of the FRCM to repair the wall to its undamaged capacity. ZFA also provided construction details for the installation of FRCM to walls and their intersections with surrounding structural elements. The design team coordinated the number of layers and directionality of FRCM on each wall face to minimize impact to significant architectural areas. The result was that each wall to receive FRCM had custom reinforcing layups, including at least one layer of bi-directional fiber reinforcing for continuity and added ductility.

Mockup

Due to the complexity of detailing and installing CMU, historic brick, wood framing, wall anchorage, and use of a new product in FRCM, the design team recommended the construction of a mockup. The mockup was intended to test installation techniques on similar conditions to the existing building and to identify potential issues before full mobilization during construction. The mockup served as a minimum quality of work example and later served as a surface for mockup of architectural finishes installed over the FRCM.

The mockup consisted of approximately 19 linear feet of a six-foot-tall wall in an 'L' configuration (plan view). It included the two typical window head configurations, an exterior corner pilaster, multiple CMU to brick interfaces, control joints, and a wood ledger to install FRCM splay anchors through. Once the structure was completed, FRCM was installed over each of the four sides on two separate days.

The mockup was completed early in the construction schedule and observed by the Design Team, Owner's Representative, General Contractor, multiple representatives from Simpson Strong-Tie, and Project Inspector of Record (IOR). The group debriefed after each installation and circulated lessons learned. Through this process, multiple installation techniques were tested to ensure ½-inch lift heights. Ultimately, the most effective process was determined to be having preset feeler gauges, spot-checking the material as it was installed and using wires to set the final depth (*Figures 3* and *4*) similar to traditional shotcrete installation techniques.

Figure 3. Mockup prior to installation of FRCM.

Construction

As one of the first installations of the FRCM product in California, there were challenges to overcome. FRCM requires the substrate to be saturated surface dry (SSD). SSD is the condition at which the wall substrate is saturated, refuses to absorb additional water, and the surface is dry to the touch. The building has been enclosed for 140 years with central heat since the 1970s, which led the walls to be dry. The walls were wetted every 30 to 60 minutes during the day and covered overnight for approximately 48 hours before the walls reached SSD. This is critical to the installation of FRCM to prevent the wall substrate from absorbing the moisture in the thin lift layers of cementitious matrix, causing the material to flash or surface tear while the contractor finishes the installation. This challenge was not identified in the mockup because the mockup was new construction and was exposed to the outside elements before the installation of FRCM.

FRCM was installed with a pump, hose, and nozzle, similar to shotcrete. Typical shotcrete lifts are three to four inches minimum, meaning there was a learning curve to install the ½-inch lifts required for FRCM. The size of the walls complicated this. The typical wall height was 16 feet on the first floor and 18 to 20 feet on the second floor, requiring multiple levels of scaffolding to access (*Figure 5*). Matrix had to be installed around scaffolding, leading to shadowing and/or thin spots at the scaffolding planks and legs and thick spots at

Figure 4. FRCM fabric being installed into matrix.

Figure 5. FRCM installation.

the corners, floors, and ceilings. These variations had to be trimmed to meet flatness requirements for future wall finishes. If the matrix was too thin, the fabric could be unintentionally moved or damaged while worked into the first lift of matrix.

Additionally, scaffolding presented an obstacle to the installation of the large rolls of fabric. The fabric could not be sharply bent without damaging the fiber bundles or disconnecting the unidirectional grid from tie strands. Therefore, the FRCM had to be installed from a rolled bundle challenging to work around scaffolding. While the mockup was an excellent proof of concept and uncovered many installation hurdles, it had size limitations that did not uncover challenges of large-scale construction means and methods.

Figure 6. Finished FRCM installation on first floor (left), second floor (right).

Conclusions

FRCMs were used to provide in-plane and out-of-plane repair/strengthening throughout the building, maximizing the amount of historic brick wall that was preserved. Its relatively thin application, substrate tolerance, material compatibility with the existing brick, and its allowance for the walls to naturally breathe were critical to providing a structural solution while minimizing the effect on the historic character of the building (*Figure 6*). FRP would have required significantly more surface preparation in comparison to FRCM, and discrete shotcrete walls would have affected room sizes and required strengthening of collectors and foundations.

While FRCM had multiple benefits, using a new product to California presented several challenges during design and construction. These ranged from working with Simpson Strong-Tie as they developed design guidelines and material information, preparation of 140-year-old brick walls, and translating installation techniques from the mockup to working within the building. A dynamic and collaborative team approach was required by all involved to overcome these challenges.▪

All authors are with ZFA Structural Engineers in Santa Rosa, California.
Brett Shields is an Engineer. (bretts@zfa.com)
Luke Wilson is an Associate Principal. (lukew@zfa.com)
Kevin Zucco is an Executive Principal. (kevinz@zfa.com)