Homestead High School Retrofit

The comprehensive rehabilitation of a Silicon Valley high school used a composite solution.

By Nik Blanchette, SE, Steve Heyne, SE, and Chris Warner, SE

Homestead High School is in the heart of Silicon Valley, California, and has produced notable alumni like Steve Wozniak and Steve Jobs. With great innovation in its DNA, the school required an inventive, surgical retrofit to two of the campus' original buildings, which consist of concrete masonry unit (CMU) walls with precast concrete floor and roof framing. ZFA, the SEOR for the project, identified these buildings as seismically deficient, particularly the floor and roof diaphragms, and assisted the school in pursuing state funding towards seismic strengthening. These large, heavy buildings warranted a creative approach to improve performance without adding significant seismic mass or replacing substantial elements. At the same time, low ceilings, poor ventilation, and limited natural light hindered the function of the space; a rehabilitation served to drastically improve the users' experience day-to-day while also dramatically increasing the seismic resilience of the buildings.

Originally constructed in 1962, the campus comprised eight stacked-bond CMU-framed one-and-two-story buildings with precast concrete tee-beam floor and roof framing. The walls are fully grouted, steel reinforced, of various thicknesses: 8, 12, 16, and 24 inches; stacked-bond is defined as aligning mortar joints from course-to-course in lieu of offsetting them (i.e. running bond). Eight-inch walls are reinforced with a single layer of reinforcing, both vertical and horizontal, whereas thicker walls are reinforced with a double layer of rebar. Tee-beams are either 24 or 36 inches tall, reinforced with a mixture of prestressing strands, deformed bars, and welded-wire reinforcement. Heavy walls and heavy beams generate significant seismic mass, which can lead to poor seismic performance when coupled with non-ductile concrete & masonry detailing. The original scope of the rehabilitation was four of the buildings: A, B, C and L (Fig. 1), however only A and B have been modernized thus far. Buildings A, B, and C are two-stories, and L is one-story. Building L was an addition to the original campus, but it contains similar detailing to the previous structures. Bringing these buildings up to current code performance was no small task.

In 2006, California voters approved Proposition 1D to fund critically seismic deficient public-school buildings throughout the state; allocation of funding is organized through the Office of Public School Construction (OPSC) with the Division of the State Architect (DSA) reviewing and approving construction documents, including eligibility for the funding. This program is defined as the Seismic Mitigation Program (SMP). SMP provides matching funds and is a phenomenal option for school districts to improve the resiliency of their building stock for seismic hazards.

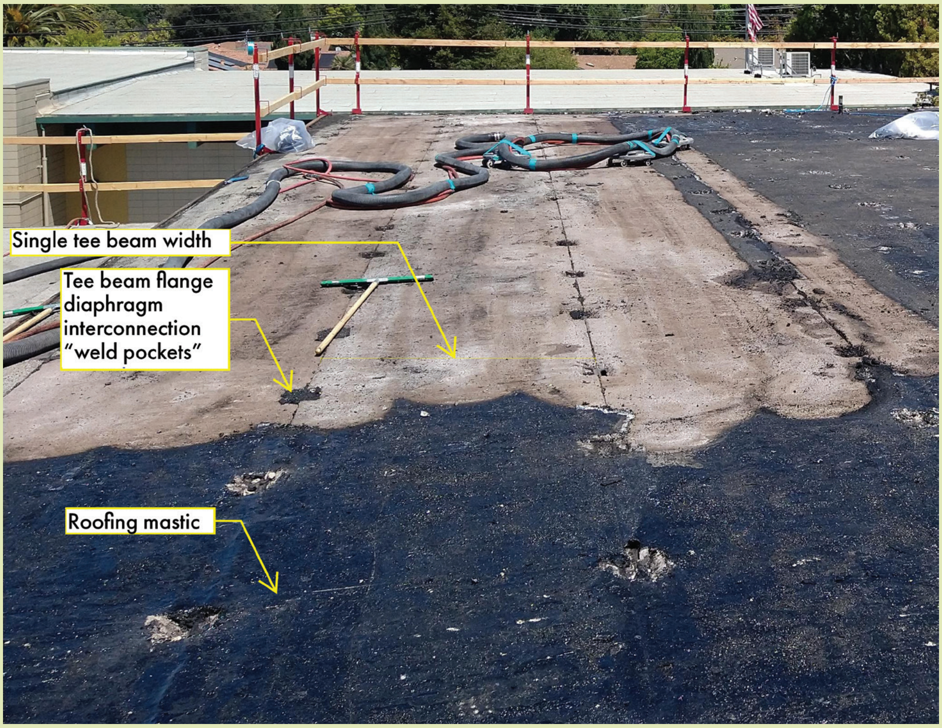
First, SMP requires an Eligibility Evaluation Report (EER) to establish qualification for the program. Qualifying buildings exhibit a critical

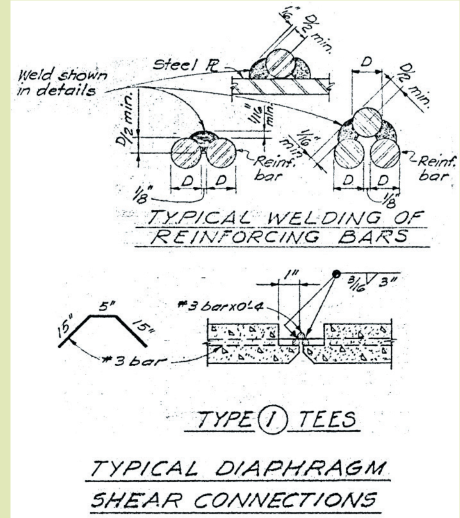
Building A post-modernization is shown here. Architecture by Quattrocchi Kwok Architects.

seismic deficiency that is expected to result in local or global collapse in the design earthquake event. Utilizing ASCE 31-03, Seismic Evaluation of Existing Buildings, DSA created a straightforward approach to screen vulnerabilities severe enough to warrant state funding: soft story, captive columns, wall anchorage deficiency, etc. The EER involves brief calculations to support the assertion of seismic deficiency. When completed, the EER is submitted to DSA for review and approval.

Buildings A, B, and C contained the same critical deficiency—inadequate concrete tee-beam flange interconnection for diaphragm action. At the roof, concrete tee-beam flanges, with no topping slab, acted as the diaphragm (Fig. 2). Without a topping slab, force transfer relies on welded connections between adjacent precast tee-beams. These connections consist of a piece of rebar welded, one side, to rebar embedded in adjacent beams (Fig. 3). This results in a one-sided weld that is dangerously subject to prying, which could be due to transverse loading, contraction and expansion, and/or differential prestress cable relaxation. Additionally, there is no positive attachment between the tee-beams and the perpendicular shear walls. At the floor, there is no positive attachment between the topping slab and the shear walls or collectors—load transfer between the horizontal and vertical Seismic Force Resisting System relied on concrete "blocking" panels physically

Fig. 1. As shown in this campus site plan, the high school rehabilitation scope included Buildings A, B, C, and L. Image credit: Google Earth





🡅 *Fig. 3. Original detail illustrating welded joint between tee beams. Credit Masten Hurd & Gwathmey Architects.*

🡄 *Fig. 2. The roof's surface is prepared prior to installation of FRP.*

interlocking the team beam stems on top of the collector line. Of course, there are other seismic deficiencies; however, those deficiencies are not considered per EER to be something that would result in local or global collapse.

Following eligibility confirmation, an important decision for the school district is rehabilitation or replacement. If the estimated retrofit cost is equal to or greater than 50 percent of the replacement cost, then the district can obtain funding to replace the existing building with new construction. To preclude inflating the comparison cost, DSA reviews the scope of the proposed retrofit to confirm it's the minimum amount of work necessary. If rehabilitation is the selected direction forward, the next step is the Evaluation and Design Criteria Report (EDCR).

Second, the EDCR is the designer's opportunity to define the design criteria for the structural safety aspects of the rehabilitation project, establishing a baseline for preparation of the construction documents. Due to the dramatically different approaches available to retrofit a building, the EDCR serves to coordinate between stakeholders and DSA before the design begins. The EDCR has several key areas: potential seismic deficiencies, both structural and nonstructural; design criteria; data collection, which includes condition assessment and material testing; and geological hazards, which includes soil effects like liquefaction as well as ground shaking. A critical decision at this point is choosing between *ASCE 7 Minimum Design Loads and Associated Criteria for Buildings and Other Structures* and *ASCE 41 Seismic Evaluation and Retrofit of Existing Building*s. Using ASCE 7 for the retrofit design requires compliance with prescriptive detailing requirements of the material reference standards, which is not typically feasible for decades-old concrete, steel, and/or masonry structures. ASCE 41 was utilized for this project due to that reason. An EDCR is required for each building individually: a total of three were prepared for this project. The EDCR specifies what Performance Objective the project will be retrofitted to, which is in accordance with California Existing Building Code (CEBC) Section 317.5. For Risk Category III structures, DSA specifies BSE-2N and BSE-1N Seismic Hazard Levels and Limited Safety and Damage Control Performance Ranges, respectively. DSA reviews and approves the EDCR—the next step is the construction documents.

Identified in the EER, the concrete tee-beams were the main culprit for poor seismic performance; various elements of the diaphragm required strengthening: out-of-plane wall anchorage, diaphragm shear & flexure, and in-plane shear transfer between diaphragm and shear wall. Several options were evaluated to improve the diaphragms: concrete overlay, horizontal steel truss, and composites. Adding new concrete would add seismic mass, which would exacerbate other seismic deficiencies. Steel would weigh less than concrete but the complicated steel connections would be costly. Composites, like Fiber-Reinforced Polymer (FRP), offer a lightweight solution to strengthening existing concrete. FRP typically consists of carbon or glass fibers combined with a liquid polymer material, such as epoxy. Simply put, adding strips of FRP to concrete acts like adding rebar, which can increase flexural strength, shear strength, and/or confine elements to improve ductility. DSA requires the approval of Alternate Design, Materials and Methods of Construction (AMM) request for the use of FRP. The engineer submits the proposed condition; a description of the requested alternate for various topics like suitability, strength, fire resistance, et cetera; and supporting documentation like preliminary calculations and manufacturer's information. One initial discussion point with DSA was unidirectional versus bidirectional fabric.

FRP fabric typically comes in either unidirectional or bidirectional weaves. As the name suggests, the difference is the orientation of the fibers. Unidirectional fabrics have fibers primarily oriented in one direction; whereas, bidirectional has primary fibers oriented in two orthogonal directions. Unidirectional fabric is a great solution for flexural reinforcing because the tension forces are oriented in one primary direction. Bidirectional is a good option when forces may occur in more than one direction, like in diaphragms. However, overlapping orthogonal layers of unidirectional fabric can achieve strengthening in those orthogonal directions as well. Ultimately, diaphragm strengthening utilized overlapping layers of unidirectional fabric due to high demands.

At the interface of the concrete diaphragm and the CMU wall, in-plane shear transfer was deficient. Bidirectional fabric in an

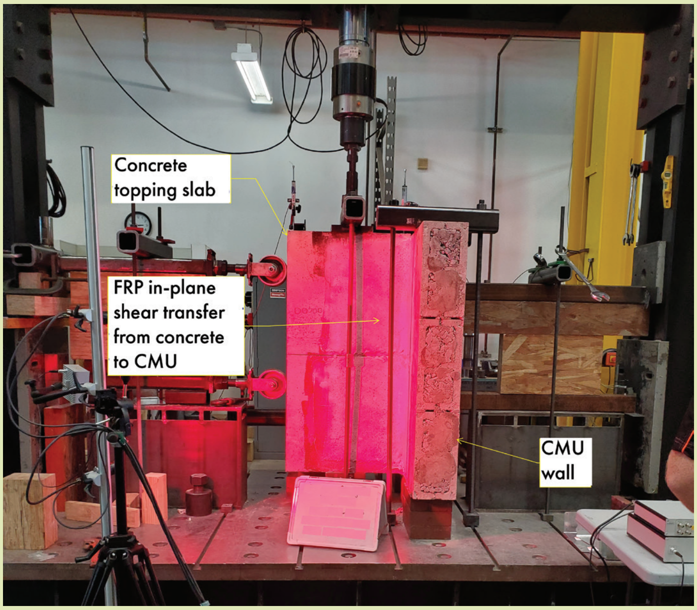


Fig. 4. FRP testing is performed for concrete topping slab to CMU wall in-plane shear transfer. Credit Simpson Strong Tie.

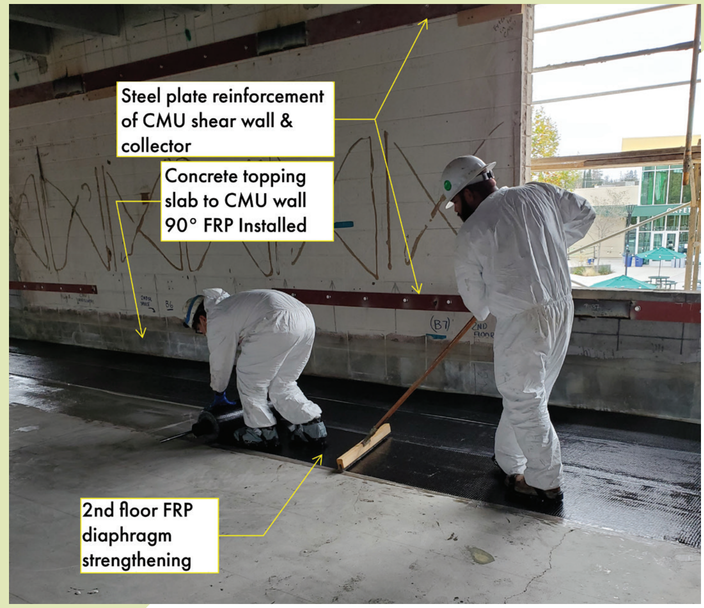


Fig. 5. Steel plates were used for CMU wall shear wall and collector strengthening. FRP diaphragm srengthening is installed by unrolling epoxy-saturated fabric.

L-shape was employed to strengthen the connection.

The two different materials present in the shear transfer connection added scrutiny to the FRP strengthening because *ACI 440.2R-17 Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures* specifies that FRP materials and specific applications are to be qualified by tests. Simpson Strong Tie (SST) is the Manufacturer of FRP solutions that was the basis of design for this project, and they had not previously tested CMU-to-concrete FRP connections. To address this condition, SST performed testing at their research and development lab in Stockton, California, to substantiate the capacity of the connection (Fig. 4). SST addressed DSA comments on their test setup and results; DSA approval would not be possible without their participation. Testing was in accordance with *AC125 Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-reinforced Polymer (FRP) Composite Systems*, which is the basis for ICC-ES approval. SST fabricated five specimens to recreate a segment of the existing CMU wall and concrete diaphragm, to which the proposed FRP connection was added. Installation of FRP matched project specifications, such as the surface preparation and the paste radius to smooth out the right angle between wall and diaphragm. Load was applied cyclically to the concrete stem, with a push-pull cycle of one kip-per-second load rate. Per AC125, load reversal was applied at increments of 25% of the anticipated ultimate failure load. Per ASCE 41, the lower bound strength calculated from the test results was the average maximum strength minus one standard deviation. For one layer of bidirectional fabric, 12.5 inches wide, this was 4.8 kips per foot of capacity, which was only a six percent reduction from calculated capacity. With shear transfer resolved, the next problem to solve was collector forces.

FRP solved a great number of challenges in the seismic retrofit of these buildings; however, another solution was utilized for strengthening of collectors and in-plane shear transfer in some locations—steel (Fig. 5). Steel was a viable option for collectors specifically due to their isolated locations, which allowed for localized swaths of material; unlike the diaphragm that involved the entire area of the floor. FRP was considered for collector strengthening but the enormous seismic mass of the buildings produced such large collector forces that steel was more economical. Steel plates, field welded together to allow the Contractor to select their splice locations, were anchored to the existing collectors with screw anchor bolts at 24 inches-on-center, to provide strengthening in both compression and tension. Similarly at transverse walls, in-plane shear strengthening was achieved using bent steel plates bolted to the diaphragm and connected to the wall with screw anchor bolts. In addition to the dramatic structural upgrades, nonstructural improvements were a crucial piece of this project.

Nonstructural connections to tee-beams warranted extreme scrutiny to avoid prestressing strands. Typical prestressing strands sweep from full depth at supports to the bottom approximately 25 percent at midspan with around 1.5 inches of clear cover, leaving little room to embed fasteners. A product relatively new at the time to receiving ICC-ES approval, Hilti HDI-P TZ drop-in anchors were extensively used due to the incredibly shallow hole depth – ¾ inch. In most nonstructural anchorage conditions, like cold-formed steel wall framing or folding partition support, the drop-in anchors allowed installation without locating the prestressing strands due to the lack of conflict. Nonstructural components like mechanical, plumbing, and/or fire protection warranted a screw anchor connection due to the larger mass; screw anchors required coordination with prestressing strands to ensure none would be cut. New penetrations through tee beams were another item that required close coordination. Vertical penetrations through tee beams were carefully located to avoid existing connections and incorporate with new FRP strengthening. Incorporating nonstructural anchorage into the structural drawings added scope of work but ultimately helped preclude unfortunate surprises in construction.

These rehabilitated buildings, standing at 62 years old, offer a phenomenal learning space for the campus. SMP provided matching funds to achieve this work, which was a tremendous opportunity for the school district to maintain the original form of the campus while achieving current code equivalent building performance. FRP demonstrated itself as an incredible solution to mitigate critical seismic deficiencies while not adding burden to any other structural elements—a key aspect of retrofitting heavy buildings. ▪

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