UNIVERSITY OF NOTRE DAME
Campus Crossroads

By Andy Greco, P.E. and Peter Heeringa, P.E., S.E.

The Campus Crossroads Project is the largest building initiative in the history of the University of Notre Dame. The $400 million project includes construction of more than 750,000 square feet of classroom, research, student facility, digital media, performance, meeting, event, and hospitality space.

Notre Dame University is recognized around the world for its first class academics, athletics, and campus architecture. The campus buildings are notable for their collegiate gothic style.

The scope of the project includes three new buildings in addition to numerous renovations of the existing stadium envelope and interior. The new structures wrap themselves around three sides of the existing football stadium with broader University programs, such as student life initiatives located in the West Building, the psychology department and digital media in the East building, and the Department of Music making its home in the South building.

The massing of the exterior masonry was detailed aesthetically to match Knute Rockne's original stadium. The facade is layered and set back as it ascends over multiple stories. As a result, complex shaped built-up brick and block masonry walls and piers rest on multiple framed floors.

Reinforcement Detailing

Due to the complexity of the façade, sdi-structures (sdi) established a system on the structural drawings where each unique concrete masonry unit (CMU) pier was detailed and then tagged on elevation views (*Figure 1*). Altogether 65 individual piers were detailed in the East and West buildings, with each detail highlighting the CMU reinforcing requirements and the bracing requirements for CMU back to the superstructure. Red lines were included in the elevations to highlight locations of brick relief.

Masonry Pier and Wall Reinforcing Analysis

Walkcowitz Consulting Engineers (WCE), a consulting structural masonry expert, was hired by the mason contractor to conduct the final masonry backup designs, which were reviewed by sdi-structures and processed through the construction change system. Once the sub-contracts were awarded for the masonry packages, revised wind loading criteria, evaluation of the materials to be used, and a comprehensive construction document package allowed for further investigation and final design of the masonry backup systems used throughout the three building projects. WCE applied finite element analysis to approximately 25 masonry piers that were found to be generally representative of the 65 piers identified in the project structural drawings.

Figure 1. A sample of structural exterior elevation.

Masonry Anchorage to Superstructure

The CMU piers were anchored to the steel beams at each floor level. sdi-structures, in consultation with WCE on behalf of the Michigan Structural Masonry Coalition, reviewed available products for anchoring the CMU backup to the structural frame. Due to the hundreds of anchor locations, sdi thoroughly researched backup anchorage solutions that could resist the concentrated wind forces while maintaining cost efficiency and speed of installation.

The concept for the final anchor detail (*Figure 2*), which included a slotted channel and strap anchor, was commercially available but had low capacities for pull-out and compression. Given the tall floor-to-floor heights up to 16 feet, parapet heights as much as 7 feet, and discrete pier construction, the load demand on each anchor required a more robust channel-strap system than was commercially available.

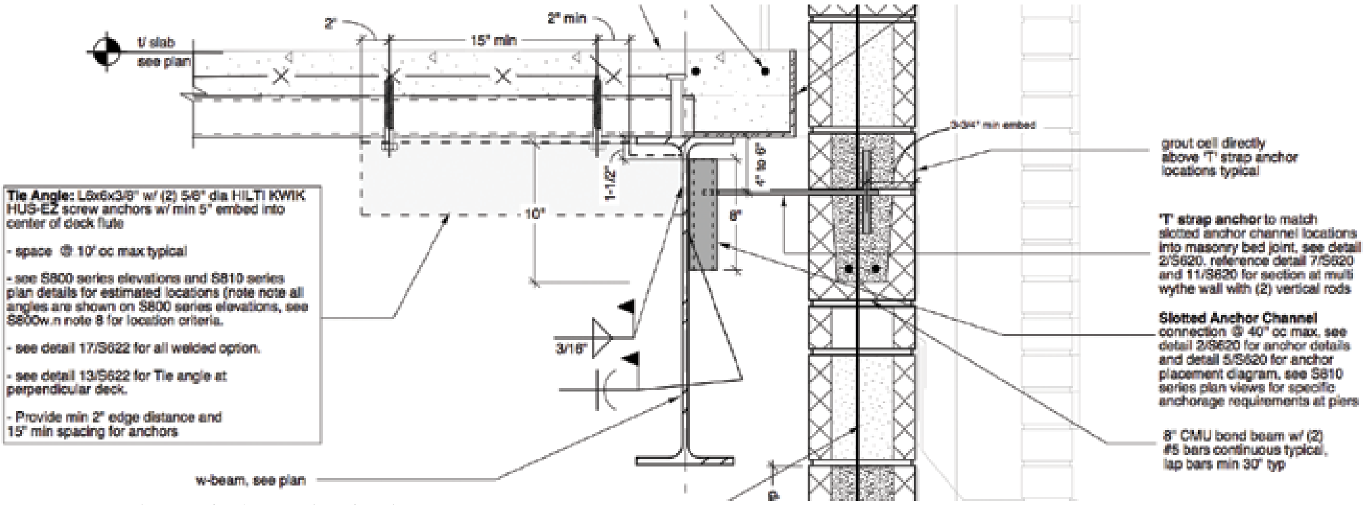

Figure 2. Typical CMU backup anchor detail.

The chosen anchor design allowed for 8 inches of vertical play to accommodate unique CMU coursing conditions at each floor. And yet, the design maintained a consistent detail. When installed, the anchor was designed to provide adequate out-of-plane bracing of the wall for wind and seismic loads while maintaining vertical slip with respect to the floor construction.

The anchor also had to have the capability to reach out over variable distances, as dictated by the layered gothic façade, to secure the walls and piers. This meant that the tee strap component of the system needed to resist buckling in compression at variable lengths. Per AISC 360-10 Table User Note E1.1, section E3 of the specification was used to evaluate the flexural buckling capacity of the strap anchors in compression. Given the uncertain level of rotational restraint at each end of the strap, a K factor of 1.0 was used to determine anchor compression capacity. The "neck" of the T-strap was sized to maintain adequate tension capacity at the slot. The geometry of the T-strap, as a whole, balanced strength requirements with constructability tolerance. Multiple thicknesses of the tee strap were designed so that the mason could choose the appropriate one based on the distance needed. The "slotted channel" was selected from a readily available HSS and fabricated with a full height vertical slot to allow for easy insertion of the tee (*Figure 3*). The contractor was given the option of using bent plate steel in place of the slotted HSS.

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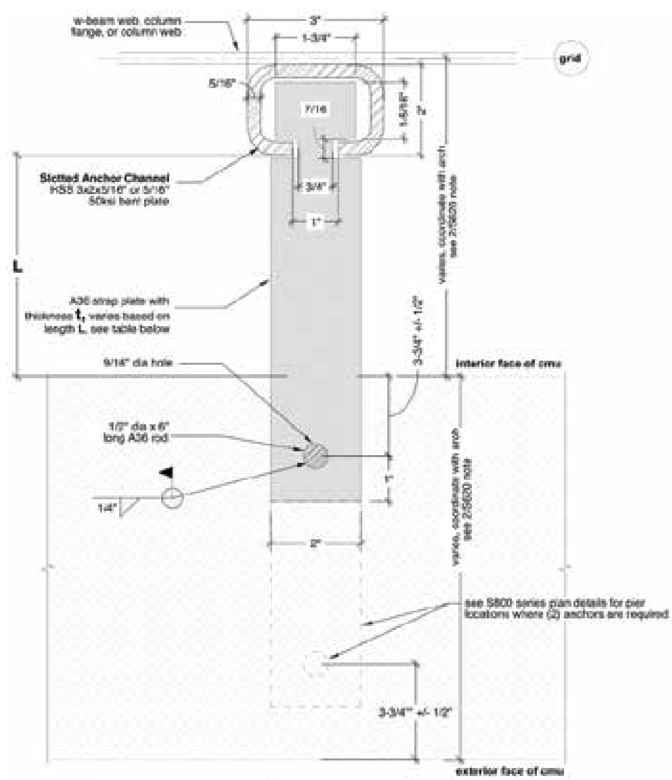

L strap unbraced length	t strap thickness
≤ 14"	5/16"
14" ∠ L ≤ 20"	3/8"
20" ∠ L ≤ 24"	7/16"
24" ∠ L ≤ 28"	1/2"

Note: Due to the range of dimensions from perimeter steel framing to interior face of CMU, and from perimeter steel framing to exterior face of CMU, there will be multiple anchor lengths and thicknesses required. The contractor should determine all necessary dimensions to meet the CMU wall anchorage requirements prior to fabricating the strap anchors, and/or provide field adjustable anchors

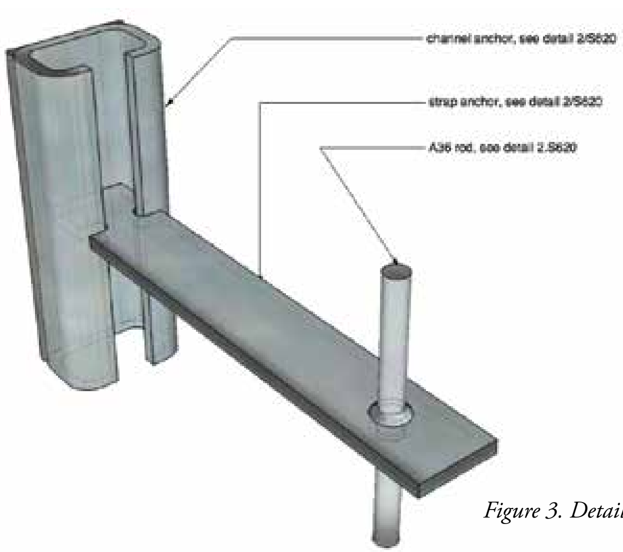

Figure 3. Details of slotted anchor channel and anchor strap.

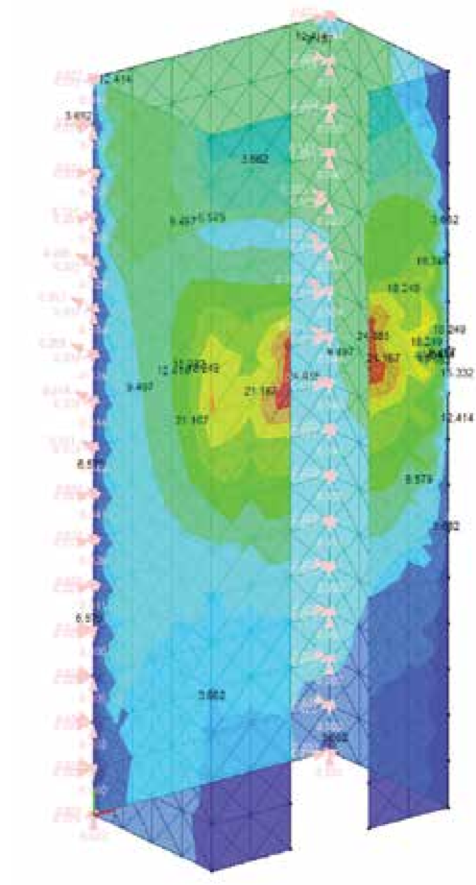

Figure 4. Von Mises results for anchor channel FEA model.

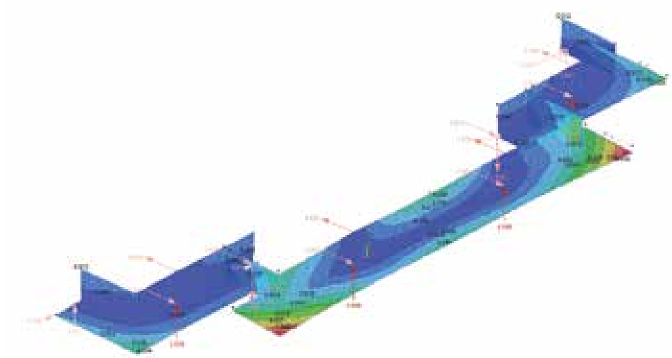

Figure 5. Sample relief angle FEA model.

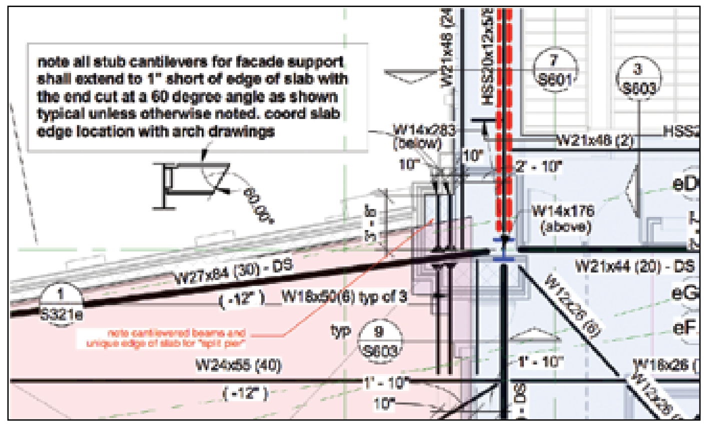

Figure 6. Sample "split pier" floor framing.

In addition to the tradition buckling analysis performed for the strap anchor (per AISC Specification Chapter E), a finite element model was used to validate the anchor channel (*Figure 4*). The model included shell elements 5⁄16-inch thick, with the element mesh kept small enough to capture local bending effects. Von Mises stresses in the plate elements were considered to evaluate the principal stresses in the plate steel due to bending and axial loads, with the final stress levels kept low enough to prevent yielding or fatigue failure of the channel. Where possible, the anchor channels were shop installed on the beam webs and delivered to the site ready for CMU installation.

To avoid conflicts with mechanical trades in the ceiling, it was also critical that the perimeter structural details did not require kickers. By locating the wall bracing connection near the top of the perimeter beams, kickers were avoided across the project and bracing was achieved with only discrete "tie angles" tight to the composite deck at each pier location.

Masonry Relief

Given the complex brick patterns, relief angle design and attachment posed a unique challenge. Relief angles were supported using a combination of post-installed epoxy anchors, screw anchors, through bolts, and welded embed plates. Cavity dimensions varied across the project to help create the layered appearance of the brick, with some cavities more than 8 inches. To limit the number of visible horizontal joints in the brick, certain relief angle assemblies supported as much as 35 feet of brick above. To determine accurate relief angle deflections and anchorage forces, sdi created finite element models of each relief condition (*Figure 5*). These models allowed the team to design with confidence and efficiency, which would not have been possible with traditional hand calculations.

The geometry of the building, with brick supported on multiple levels of the superstructure, required careful consideration of differential expansion of brick on each level. Each time brick wrapped over the top of roof levels, it was necessary to create a horizontal joint in both the backup CMU and the brick veneer. These "split piers," as they came to be known, required careful coordination of multiple items including structural steel framing, the edge of the concrete deck, and the extent of the horizontal joint to ensure the joint's performance without compromising the look of the veneer. *Figure 6* highlights a typical split pier condition as the masonry wraps over an exterior terrace on the North end of the East building. At split piers, the stub cantilevers were mitered at 60 degrees to allow the block from below to extend uninterrupted to the beam top flange. The horizontal relief joint was then created by embedding a flat plate in the masonry block coursing that was cut to the specific profile of the surrounding brick. Additionally, the plate size was set by determining the weight of CMU required to counter the overturning moment applied by the brick relief.

The Campus Crossroads masonry work is nearly complete at Notre Dame. When finished, it will stand as an example of the highest levels of tradition, elegance in design, craftsmanship, and engineering.▪

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