Steel Revives Historic Structure

By Marie Ennis, P.E.

The United World College (UWC) commissioned Einhorn Yaffee Prescott to carry out the restoration and adaptive use of Montezuma Castle, a 90,000-sq.ft. structure dominating the spectacular landscape just outside of Las Vegas, NM, to house dining, student residential, recreational, administrative and conferencing facilities. The scope of work included complete upgrades of electrical, mechanical and plumbing systems, life safety upgrades, ADA compliance and façade restoration. Architecturally, public spaces with significant finishes were treated as a preservation project; other spaces were treated as a renovation project. As with most projects involving the restoration and upgrading of an old load bearing masonry and wood framed structure, there were numerous structural challenges. The scope of structural work included repairs due to prior inappropriate removals of bearing structure, the installation of a new elevator, reinforcement of floor framing to support Code required live loads and repair of deteriorated structure due to years of neglect.

The dining room measures 60 by 100′ and was originally designed as a "column free" space. Historical documents indicate steel framing in several locations in the building; however, the existing beams and trusses are wooden. The trusses are a combination of timber and dimensional lumber with wrought iron tie rods and cast iron joint fittings. The Chicago architects would certainly have been familiar with the latest construction technology, so it is possible that the previous building on this site, destroyed by fire, had steel trusses and that timber was substituted for the extant building either for expediency or cost savings.

Five trusses spanning 60′ are concealed in partition walls above the dining room. The bottom chords support the floor joists at the second floor level and the top chords at the third floor level. The presence of a corridor at the second floor precluded the use of diagonal members at the center panels of the trusses. Solid stone masonry piers at the exterior building walls support the trusses.

In 1938, seven-inch diameter steel shoring columns were added under the center of the bottom chord of each truss in the dining room down through the basement. It appears that during the installation of the shores the trusses were jacked-up slightly resulting in reverse curvature of the deflected shape. By removing the plaster concealing the trusses at the second floor, the reason for the shoring became evident: significant failure had occurred. The unevenness of the second and third floors reflected the deformation of the trusses.

The Solution

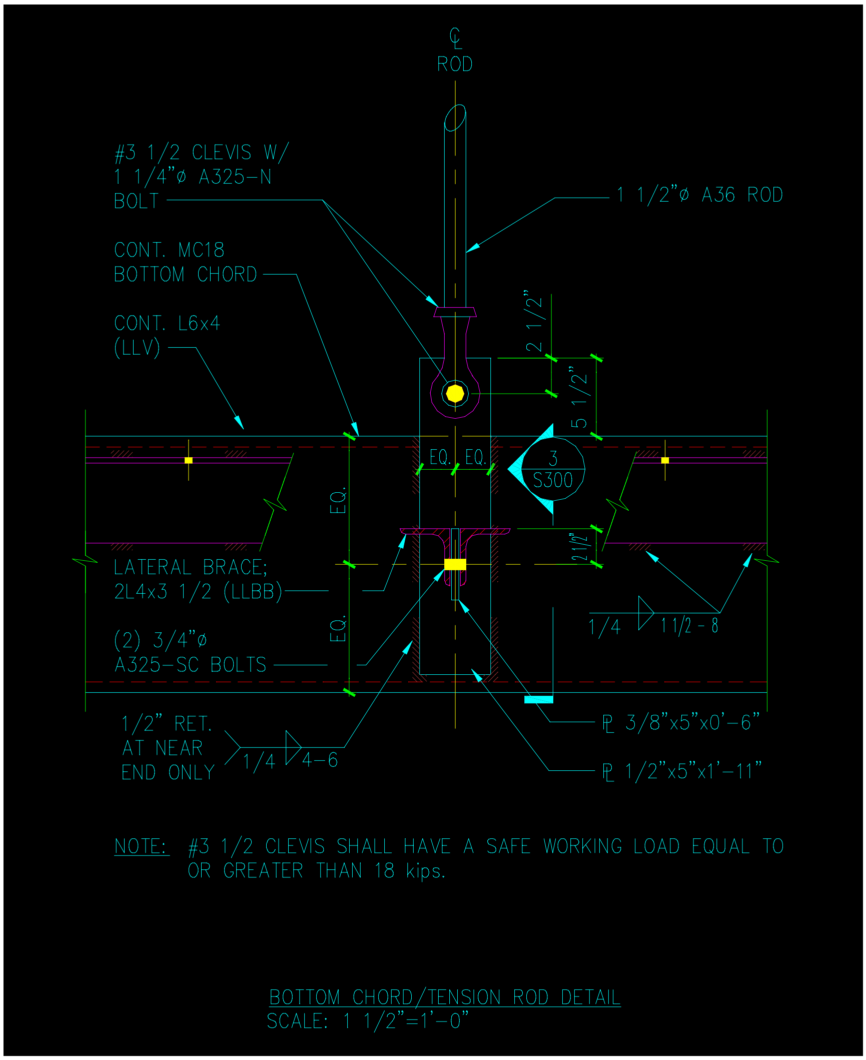
The first step for the design team was to fully document the "as-built" configuration of the timber trusses, determine what loads were originally supported by them, model the structure using RISA software and analyze the system. This exercise verified that the trusses were inadequately designed for the imposed loads that include the second and third floor framing and partitions and the roof.

The top chords are constructed of five 2″ x 12″ wood members that are through-bolted at the cast iron joint fittings; the bottom chord is similarly constructed of five 2″ x 14″ wood members. Diagonal members are 9¾″ x 11¾″ solid timbers with pairs of wrought iron tie rods, either 1¾″ or 1½″ diameter, at the four interior panel points. The nineteenth century designers had attempted to provide additional stiffness to the structure by inserting wrought iron flitch plates in the bottom chords of all the trusses for the length of the center three-panel points. The observed failure of the bottom chord occurred in a bolted connection just beyond the end of the flitch plate.

Reinforcement of the existing structure was ruled out as an option due to the variable conditions from truss to truss and the inherent difficulties of reinforcing the bolted connections. Instead, a scheme was devised to install pairs of steel trusses that would sandwich the timber trusses. All floor and roof loads would be directly transferred to new steel structure leaving the old trusses in place.

There were a number of important factors that influenced the design decisions for the repair. Because of previous fires at the site and the proximity of the new steelwork to the old timbers, the team felt it was imperative that all field splices would be bolted. Each truss had deflected in a unique pattern, and even though the project scope included some jacking of the trusses to minimize variations in the deflections and unevenness in the second floor framing, it was necessary to design the steel anticipating variable conditions. Because of this, the new steel was designed to be deeper than the original framing to allow for the noted discrepancies: up to 3″ for the top chord and 4″ for the bottom chord. Fortu-

Dining room truss during reinforcing operations.



Detail at reinforced panel point with new lateral brace.

Dining room trusses had deflected substantially by 1938, prompting the addition of columns at the mid-span of each truss. This uncovered joint reveals significant structural damage.

nately, the jacking sequence was successful removing most of the deflection from the trusses and leveling the floors above.

Yet another design challenge was related to the geometry inherent in the design of the old trusses. The timber diagonals and wrought iron tie rods could not be located with their axes aligned with a single working point at the connections; it was not possible to make the connection work with the wood, bolts and rods given required clearances. The new steel trusses were designed so that there is a single working point at each connection. Knowing that there would be some interferences, the steel design allowed for a misalignment between the abandoned timber trusses and the new truss members. In those locations where there was conflict between the steel truss tie plates and the old timber diagonals, limited shimming or offsetting of the tie plates using angles was specified.

Channel shapes were chosen to minimize the width of the members given that the trusses are bounded by door openings in the second floor and the bottom chords appear as decoratively plastered soffits in the ceiling of the dining room. The desire was to avoid significantly altering the architectural aesthetic of the space and reuse existing door openings. The channels also provided economic section properties relative to the overall weight of the new steel: MC 18s for the bottom chords, C 15s for the top chord, C 12s for diagonal members. All pairs of truss members were connected periodically with tie plates. Angles, L6 x 4 x 5/16, were shop welded to the upper web of the channels to allow for shimming to the underside of the floor joists so as to transfer the floor loads directly to the steel.

Pairs of tension rods were designed with initial selection based on the size of the original rods. Given the logistics of the site, the use of rods allowed flexibility and adjustability by the incorporation of clevises and turnbuckles. This consideration governed the size of the rods, not stress.

All new steel-to-steel connections were custom designed using using 7/8″ diameter A325-SC bolts in oversized holes. The holes were oversized to facilitate the installation of the steel and to allow for adjustments of alignment prior to tightening the SC bolts. Additional ¾″ diameter A325 bearing bolts in 7/8″ holes were provided for use in the erection process but were not needed for strength. Whereas the floor joists braced the timber trusses, lateral bracing using back-to-back angles was installed at new panel points on the steel trusses.

Given the logistics of the project site, the steel erection process was fully anticipated in the design of the new trusses. The design team anticipated the maximum lengths of steel that could be brought into the building without damaging finishes and the need for adjustability during erection.

The key to successful renovation projects is a technical understanding of archaic building materials, sensitivity to historic preservation issues, thorough investigative fieldwork, evaluation of constructibility issues prior to completing the design drawings and a creative approach to field problems during construction. The grand dining room at Montezuma Castle will once again be column free thanks to the pairs of steel trusses concealed overhead. In respect for the historic fabric, the original trusses remain but are no longer carrying loads. And, in keeping with the original design intent, steel is now doing the work.

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