The Church of Jesus Christ of Latter-day Saints addresses the nearby fault with a seismic upgrade to its iconic Tabernacle.

Iconic Upgrade

BY CRAIG WILKINSON, P.E. AND JEFF MILLER, S.E.

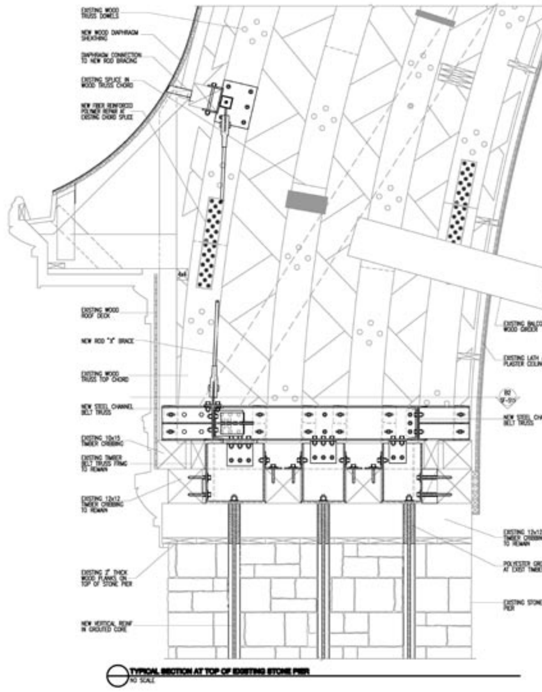
THE TABERNACLE IN SALT LAKE CITY has been a treasured piece of history for the members of The Church of Jesus Christ of Latter-day Saints since 1867. However, with the Wasatch fault that runs along the foothills of the Salt Lake Valley, the Church wanted to protect its occupants and preserve the Tabernacle if and when a major earthquake occurs. Hence, nearly a century and a half after its completion, a seismic upgrade was performed on this home for the Mormon Tabernacle Choir.

The structure of the Tabernacle is composed of sandstone piers and wood trusses. There are 44 piers in all around the perimeter, each supporting a long-span timber arched truss. Each pier is 3 ft wide by 9 ft long and the piers vary from 12 to 21 ft in height. The roof is framed with nine identical wooden arched trusses spanning between the stone piers over the main "barrel" section of the roof. At each end are 13 half-arch (radial) trusses that are supported by the last arched truss, the king truss, at the top and stone piers at the bottom. The existing trusses are 9 ft deep and the full arches span approximately 150 ft. These trusses are composed of four chords of four 2½-in. × 12-in. tim-

Steel segments for the truss had to be sized to fit through small hatches in the attic of the building.

opposite page and below: The new steel king truss complements an old wooden truss system, which had become overstressed and fractured over the years.

Images: Courtesy of Reaveley Engineers + Associates



above: A detail of the new belt truss system.

below: The exterior of the Tabernacle is composed of sandstone piers.

bers. Each chord, consisting of two timbers on each side of a lattice web, is constructed of similar sized timbers.

These trusses have had problems over the years with overstressed chord members fracturing and requiring repair. The king trusses were found to be severely overstressed due to the loads imposed on them by the radial trusses.

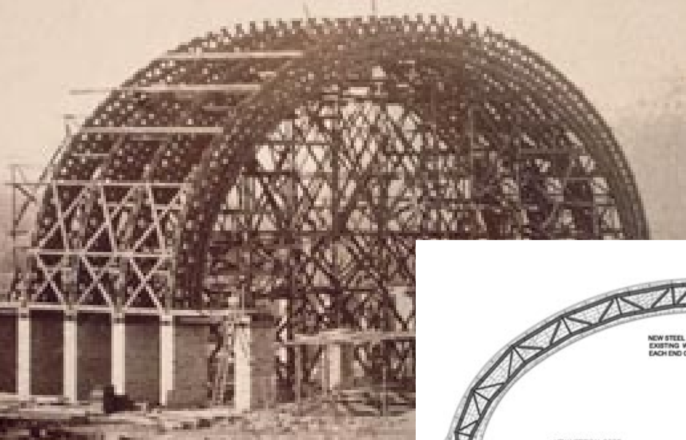
Steel in Sandstone

The major challenge was to seismically upgrade the structure while still preserving the historic integrity of the building, and several complex conditions had to be met with innovative structural engineering solutions. One of the biggest deficiencies of the structure in resisting seismic loads was that the timber members were not tied together or tied to the stone piers. A steel "belt truss" composed of over 380 steel members with steel channel chords (MC12 × 35) and steel double angle webs (2-L3½ × 3½ × 5⁄16) was designed. This oval-shaped truss rests upon the stone piers and extends around the entire perimeter of the roof structure. This belt truss, with a total inside "circumference" of about 620 feet, ties all of the existing timber trusses together and connects them to the sandstone piers.

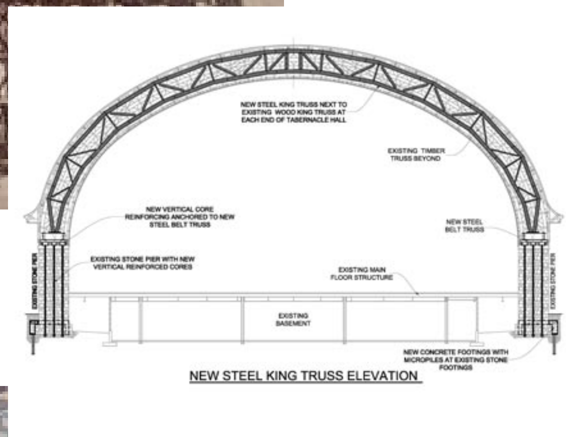
This truss was designed to be constructed in segments small enough to be lifted in place through existing 30-in. × 30-in. attic hatches. The truss pieces were assembled via bolting, as cutting and welding in the highly flammable dry timber surroundings was not feasible. Precise measurements were required to ensure that all of the bolted connections would fit.

New steel king trusses were designed and installed adjacent to the original timber king trusses due to a high level of overstress in these trusses. The new trusses were used to lift the existing trusses and re-support their load. Each of the new steel trusses is approximately 7 ft, 1 in. deep and spans 140 ft. Similar to the belt truss, the design and fabrication had to be very precise as the finished trusses had to be assembled together in the attic, again without welding or cutting any members in place. Small sections of the roof were temporarily opened to insert the pieces of steel truss without disturbing the existing trusses. This process was undertaken in several phases to ensure no harm was done to the existing structure.

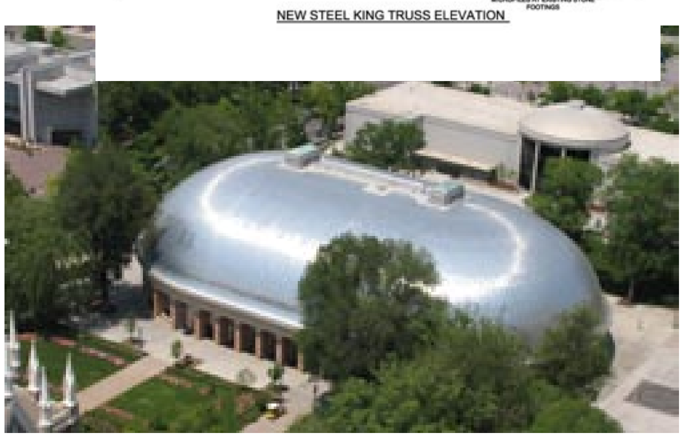
The design of the steel king truss presented two major engineering challenges. The first was controlling the amount of horizontal thrust imposed by the arch on the supporting structure. With the shape of the arch being constrained to fit within the envelope of the attic, the truss could not be reconfigured to reduce the thrust. Through extensive modeling and analysis, it was found that allowing the base of the arch to spread outward was an effective means of allowing the new arch truss to "relieve some stress"



above: **above**: The framing of the Tabernacle as it appeared in 1867.



below: Present-day framing of the new steel king truss.



right: The Tabernacle has been an icon of The Church of Jesus Christ of the Latter-day Saints for a century and a half.

Images: Courtesty of Reaveley Engineers + Associates (right); Courtesy of The Church of Jesus Christ of Latter-day Saints (above)

and reduce the thrust. The design was optimized to allow each support to move 3 in. outward before being restrained and locked into place. The top and bottom chords of the truss were designed to intersect at a single point and placed on Teflon slide bearings that were restrained from being able to move more than the 3 in. allowed.

The second challenge was detailing the top of the truss where the existing timber trusses were to be lifted a small amount. The lifting of the existing trusses was essential to guarantee that their load was captured by the new steel trusses. A detail was developed which allowed the new truss to deflect downward, while the existing truss was lifted slightly upward. Hydraulic jacks were used to lift the existing trusses and load the new truss. The sliding mechanism was then "locked" to permanently support the load and the jacks were removed.

When it came to the piers, each was strengthened by coring vertical holes and reinforcing them with grout and high-strength steel threaded rods. The sandstone foundation for each sandstone pier was also strengthened by encasing them with reinforced concrete and adding micropile foundations.

Numerous constructability and sequencing reviews with the team were critical to designing and specifying the improvements to the Tabernacle in a way that would allow the construction team to achieve maximum efficiency, while at the same time staying within the strict project constraints to preserve the historic fabric and protect the building. Today, the structure retains all of its majesty with the added bonus of being seismically safe. MSC

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