LDS Church Tabernacle on Temple Square

Seismic Upgrade and Renovation

By Craig Wilkinson, S.E. and Jeff Miller, S.E.

Reaveley Engineers + Associates were awarded an Outstanding Project Award in the 2008 NCSEA Annual Excellence in Structural Engineering program (*Category – Other Structures*).

The interior of the Tabernacle, showing the massive organ and the balcony, which were both seismically strengthened. Courtesy of the LDS Church.

Built with 60-foot tall arched timber trusses made of lattice-timbers that span 150 feet, the Tabernacle on Temple Square in Salt Lake City, Utah, was an engineering marvel then, just as it is today. The open assembly hall, including the balcony, seats around 4,000 people. It is home to the Mormon Tabernacle Choir and also houses the world famous pipe-organ. With the Wasatch Fault running along the foothills of the Salt Lake Valley, The Church of Jesus Christ of Latter-day Saints (LDS) wanted to preserve the Tabernacle while protecting occupants in the event of a major earthquake.

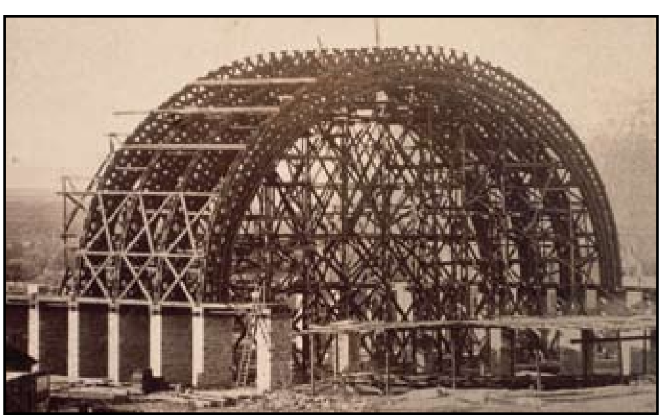
The main barrel section of the Tabernacle roof is framed with nine identical arched trusses, each 9 feet deep and spanning 150 feet between sandstone piers. At each end of the barrel roof are thirteen half-arch trusses that are supported at the top by the outermost arched truss, the king truss, and fan out radially to sandstone pier supports at the bottom. All of the trusses are built of similar construction. Each chord is built from two timbers on each side of a lattice web timber.

With the openness of the main hall, its historic finishes and unique acoustics, upgrading the building while preserving its original architecture and historic integrity proved to be challenging. The items most in need of strengthening were the stone piers, the timber arches (especially the king trusses) and their connections to the piers, and the pipe organ casework.

The forty-four sandstone piers supporting the roof were reinforced by coring holes from the tops of the piers in the attic into the ground below the piers, without moving the timber trusses bearing on the piers. Threaded steel reinforcing bars were grouted into the cores using a flowable high performance grout that was tested for the conditions encountered on the Tabernacle. Each pier was strengthened with either four or six of these vertical reinforced cores. The original stone footing for each pier was preserved and encased into larger concrete foundations supported by new 6-inch diameter micropiles embedded deep into the ground.

The original timber framing and trusses were not positively connected to each other, or to the stone piers. An oval-shaped steel "belt truss" was designed to rest upon the stone piers and extend around the entire perimeter of the roof structure. This truss is composed of over 380 members, with steel channel chords and double-angle webs. The belt truss, with a total inside circumference of about 620 feet, ties all of the existing timber trusses together and connects them to the stone piers. It is also attached to a new outer-diaphragm of the roof and to each of the vertical reinforced cores in the piers.

The belt truss was designed to be constructed in segments, small and light enough to be lifted in place through existing 30-inch square hatches in the soffit. The individual pieces of the truss were assembled with fully bolted connections, because cutting and welding in the highly flammable dry timber surroundings of the attic were not allowed.



The original tabernacle was constructed in 1867. Courtesy of the LDS Church.

Two new steel king trusses were installed adjacent to the original timber king trusses due to a high level of overstress in the timber resulting from the load from the radial trusses. The new trusses were used to slightly lift the existing trusses and permanently re-support their load. Each of the new steel trusses is approximately 7 feet deep and span 140 feet. Similar to the belt truss, the finished trusses had to be assembled within the confines of the attic. Small sections of the roof were temporarily opened to insert portions of the steel truss without removing large sections of the roof diaphragm.

The design of the king truss presented two major engineering challenges. The first was controlling the amount of horizontal thrust imposed by the base of the arch on the existing stone piers. With the shape of the new arch constrained to fit within the envelope of the attic, the truss could not be reconfigured to significantly reduce the thrust. Instead, the base of the new truss was placed on slide bearings to allow it to spread outward as it was loaded, as a means of allowing the new arch truss to "relieve some stress" and reduce the thrust. The design was optimized to allow each support to move 3 inches outward before being restrained and locked into place. The top and bottom chords of the new truss were designed to intersect at a single point that was placed on Teflon slide bearings that were restrained from being able to move more than the 3 inches.

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, simultaneously loading the new truss. The sliding mechanism was then "locked" to permanently support the load and the jacks were removed.

The casework for the historic pipe organ is a large structure in itself, and was in danger of tipping in a seismic event, potentially destroying the thousands of pipes. A bracing scheme was designed to provide support for the organ and tie it to the roof structure, without being visible in the main hall and without displacing any organ pipes. Another steel truss was designed, this one spanning horizontally, with panel points behind the largest of the towering organ pipes and supports at the radial trusses in the attic.

The Church of Jesus Christ of Latter-day Saints had strict constraints for the seismic upgrade of this facility. Today, the structure retains all of its majesty with the added bonus of protecting the occupants and preserving it for future generations.▪

The sandstone piers and their foundations were reinforced to prevent failure in an earthquake.

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Project Team:

Owner – The Church of Jesus Christ of Latter-day Saints
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Structural Engineer – Reaveley Engineers + Associates
Mechanical Engineeer – VanBoerum & Frank Associates
Electrical Engineer – BNA Consulting
Contractor – Jacobsen Construction Co.