

# Design and Construction of the Great Tabernacle Arches

*Elwin C. Robison with W. Randall Dixon*

The genesis of the idea for the structure of the Great Tabernacle was heavily influenced by Brigham Young's contracting for road bridges. North Temple Street crosses the Jordan River about two miles west of Temple Square in Salt Lake City. In 1849, the single-lane bridge was a prominent feature on the landscape.<sup>1</sup> By 1860, the bridge was judged an "ill-shaped, ill-contrived and ponderous concern" that was costing the territorial government hundreds of dollars in maintenance. Accordingly, the territorial legislature appropriated fifteen hundred dollars for construction of a new bridge on the condition that the city and county appropriated the same. Acting as general contractor, Young hired Henry Grow, a "scientific bridge builder," to design and build the new bridge.<sup>2</sup>

Grow had worked in Philadelphia for the Remington Company, which owned the patent rights for a lattice truss.<sup>3</sup> The most important lattice truss patent was granted to Ithiel Town on January 28, 1820.<sup>4</sup> Town's lattice truss design consisted of diagonal timbers pegged together in a lattice form, with half of the timbers slanting forward and half slanting rearward. Grow used the Remington Company's patent rights to build lattice truss

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1. James William Ure, Statement, November 16, 1908, typescript, Church History Library, The Church of Jesus Christ of Latter-day Saints, Salt Lake City.

2. "The Jordan Bridge," *Deseret News*, November 14, 1860, 292, col. 2.

3. Stewart L. Grow, "A Historical Study of the Construction of the Salt Lake Tabernacle" (master's thesis, Brigham Young University, 1947), 78.

4. Town's January 28, 1820, patent was amended in April 3, 1836, to include multiple lattice and chord layers (U.S. Patent x0003169-001).

This chapter is excerpted from *Gathering as One: The History of the Mormon Tabernacle in Salt Lake City*, by Elwin C. Robison with W. Randall Dixon, forthcoming in 2013 from BYU Press. Hundreds of photos in this book tell the story of this magnificent edifice.

*Contents:*

The Great Tabernacle

Worship Spaces in the Early Church

Boweries in the Great Basin

The Old Tabernacle

Design and Construction of the Great Tabernacle Arches

The Great Tabernacle—Architectural Finishes

Acoustics

The Organ

Alterations to the Tabernacle

Services and Events in the Tabernacle

The 2006 Seismic Upgrade—Engineering

The 2006 Seismic Upgrade—Architectural Changes

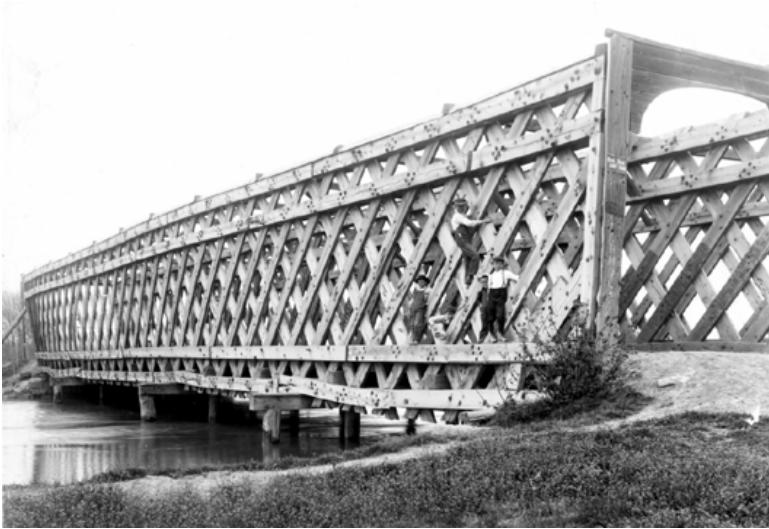
A Meeting Space for the Twenty-First Century

Looking Back

designs in Utah.<sup>5</sup> One of Young's daughters explained the relationship: "A convert by the name of Henry Grow arrived in the city from Philadelphia. He had been working for the Remington Company, who owned a patent right for slat bridge construction, and as a compliment to him the company gave him the privilege of using it in Utah, which fact he made known to the authorities upon his arrival here."<sup>6</sup>

5. Although Henry Grow's business card mentions a "Remington Patent of Lattice Bridges," there is no Remington patent for a building truss design in the U.S. Patent office records. Traditionally, writers have confused historical statements about the Remington Company and Grow's relationship to that company to mean that Grow was using a new, patented truss type. However, in reality he was granted the right to use the truss design in Utah, which rights the Remington Company had apparently purchased.

6. Clarissa Young Spencer with Mabel Harmer, *Brigham Young at Home* (Salt Lake City: Deseret Book, 1961), 281.



**FIGURE 1.** The Jordan River Bridge, also called the White Bridge, built by Henry Grow in 1861, contracted by Brigham Young. Used by permission, Utah State Historical Society. All rights reserved.

Despite the moniker “scientific,” lattice trusses were not calculated the way professional engineers were just learning to do in the nineteenth century.<sup>7</sup> Instead, lattice trusses tended to be built on rule-of-thumb principles. The multiple diagonals provided multiple load paths for forces through the truss, and the trusses in essence designed themselves, with forces running through the diagonals that matched the load path of the bridge. This resulted in many of the wood diagonals in a lattice being lightly loaded, making the form inefficient. Nevertheless, a carpenter without specialized engineering skills could build a strong truss. The depth of the truss was determined by proportion to its length and by the performance of previous bridges. Connections were typically made by wooden pegs, a decided advantage in the iron-poor territory of Utah.

Young was directly involved with the construction of the Jordan River Bridge (fig. 1). Given his practical bent and lively interest in building—plus the fact that his money was at risk if the bridge did not succeed—he

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7. Squire Whipple was one of the first American engineers to publish a rational method for the calculation of trusses in 1847. See Squire Whipple, *A Work on Bridge Building: Consisting of Two Essays, the One Elementary and General, the Other Giving Original Plans and Practical Details for Iron and Wooden Bridges* (Utica, N.Y.: H. H. Curtiss, 1847).

became very familiar with both Grow and the lattice truss design. In fact, the bridge was assembled in Young's walled compound near his home, then partly dismantled and re-erected on site.<sup>8</sup>

The bridge had a three-truss arrangement with the central truss dividing the driving lanes. According to Lorenzo Brown's diary, it appears that the diagonal lattice and bottom chord (the planks fastened to the bottom of the lattice) were launched across the river, probably floated and pulled by ropes, and then raised into position. The upper chords were then drilled, pegged, and wedged in place. Brown also talked of setting string pieces, or stringers as they are more commonly known today—the transverse beams that support the roadbed.

The bridge on North Temple lasted until its replacement in 1908.<sup>9</sup> Given their relatively slender shape (like a wooden yardstick), the planks bowed out when placed into compression, and the planks worked their way off the wooden pegs.<sup>10</sup> Importantly, in the Great Tabernacle, Grow later doubled the number of pegs at intersections and drove wedges into both ends of the pegs. Although in a dilapidated condition by the twentieth century, the bridge performed very well before weathering compromised the connections and vehicle weights increased beyond what its designer had envisioned.

It is significant that the clear span of the bridge over the Jordan River is similar to that of the clear span of the Great Tabernacle. In the absence of numerical theory on which to base structural design, precedent governs. Of course, a straight truss is not the same as a trussed arch, and those with practical building experience such as Grow and Young understood that. However, the proven performance of the truss at one hundred thirty feet served as a powerful starting point in imagining a suitable congregational space for the Saints.

Young could have chosen to have Grow design a series of straight trusses to support the roof of the Great Tabernacle, as many convention centers and sports arenas do in the twenty-first century. However, he

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8. Lorenzo Brown, *Journal of Lorenzo Brown*, 2 vols. (Provo, Utah: Brigham Young University, 1960), October 30, 1860, microfilm copy in Church History Library.

9. "Famous Old Landmark Wrecked This Morning," *Deseret News*, November 7, 1908, 1.

10. Close examination of the photograph shows that some lattice intersections were reinforced with an iron bolt, which would restrain the planks from working off the pegs. Since only isolated connections are reinforced with the iron bolts, it is assumed that these were installed as a later repair.

had several years' experience speaking under the arched ceiling of the Old Tabernacle. While he might not have understood wave propagation theory and reverberation times, he would have known what worked acoustically and what did not. The curved apse and curved plaster ceiling of the Old Tabernacle possessed excellent acoustic properties for speaking, and those who had addressed congregations there would have understood how well their voices carried by the reaction of the congregation. The design of the Great Tabernacle can be thought of as a combination of these two successful ideas—the wood trusses of Henry Grow and the acoustical properties of the curved ceiling of the Old Tabernacle.

The distinctive shape of the Tabernacle roof was chosen early in the planning process. Grow's son related that Young came to his father and asked him how large a roof he could construct. Grow reportedly replied, "150 feet wide and as long as it is wanted."<sup>11</sup> Grow was absolutely correct in his answer—once the system of arches was established, the only limits to the length of such a building were time, money, and functionality.<sup>12</sup> Young's question to Grow implies that Young had already decided on the curved shape of the Great Tabernacle. Young's daughter Clarissa reconstructed the following conversation between her father and Grow:

Henry, I am desirous of constructing a building for our people, anticipating the future numbers, and I have been wondering what plan we should use, for I have built many buildings and no two alike, and I am anxious that this should be different to anything else. What do you think about the Remington construction? Henry, I had an egg for breakfast this morning, cooked hard, and in lieu of chopping it through the center, I cut it through end-wise and set it up on tooth-picks. I was strongly impressed that we might use this plan for the building.<sup>13</sup>

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11. Grow, "Historical Study of the Construction," 76; Scott Esplin, ed., *The Tabernacle: An Old and Wonderful Friend* (Provo, Utah: Religious Studies Center, 2007), 154. Note that Kate B. Carter, *The Great Mormon Tabernacle* (Salt Lake City: Utah Printing Company, 1967), 10, repeated the story but reported a span of one hundred feet. Since the original statement was a reminiscence, it was the confidence and bravado that were of interest, not the exact span.

12. Brigham Young, *The Office Journal of President Brigham Young, 1858–1863, Book D*, ed. Fred C. Collier (Hanna, Utah: By the editor, 2006), 200 (January 28, 1861).

13. Spencer with Harmer, *Brigham Young at Home*, 281–82. Although Clarissa was only three years old when the reported event occurred, she spent much time with her father, since she lived in the Beehive House and commonly breakfasted with him. Presumably, her reconstructed conversation is based on later recounting by her father.



**FIGURE 2.** A stone pier footing. Photograph by Arnold Angle taken during the 2006 seismic upgrade.

The main support for the soaring Tabernacle roof is a series of forty-four stone piers three feet wide, nine feet deep, and of varying height to accommodate the terrain's gentle slope to the west (fig. 2). It is not known how big a crew was used in digging the foundations for the new piers, but Samuel Fletcher was remembered as the first man to break ground for the Tabernacle.<sup>14</sup> Digging the forty-four holes in the ground by hand would have taken significant effort because of the relatively dense gravel on which the Tabernacle is built. Stone footings were placed underneath the piers, broadening the contact with the soil.

The great arched wood trusses are as deep as the stone piers so that the top chord of the truss (the uppermost line of planks) lines up with the outside face of the pier, while the bottom chord of the truss lines up with the interior face (fig. 3). Massive wood sleepers bear on the top of the stone piers, transferring their load to the stone below. The builder's intention was probably for the trusses to bear along the nine-foot length of the piers. However, after 140 years of service, the only point of contact between the wood arch and stone pier occurred at the inside face of the pier. During

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14. "Recent Deaths, Fletcher, Samuel," *Deseret Evening News*, February 17, 1910, last edition, p. 3, col. 4. "He had the honor of being the first man to break ground for the foundation of the Salt Lake Tabernacle and at one time was one of Brigham Young's bodyguards."



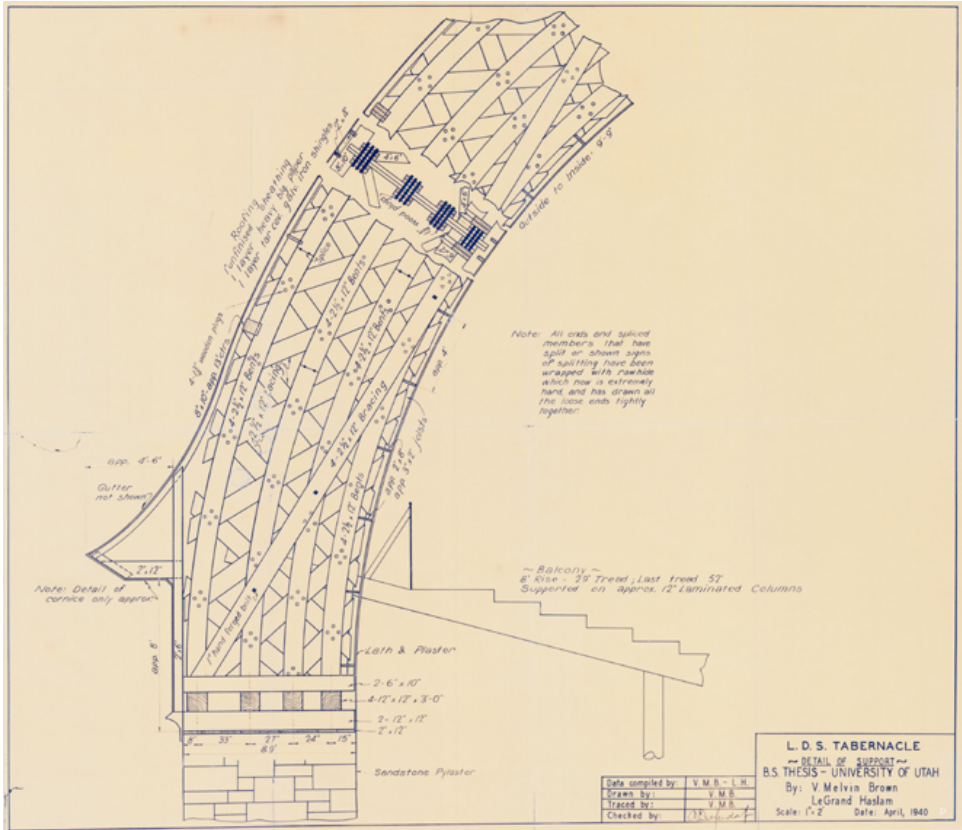


FIGURE 3. A section drawing showing the intersection of a wood lattice truss bearing on a stone pier, from V. Melvin Brown and Le Grand Haslam, “Engineering Investigation of the Great Mormon Tabernacle,” University of Utah thesis, 1940.

the seismic upgrade in 2006, engineers removed the wood trim at the top of a stone pier to look for a positive connection (such as iron bolts) fastening the arches to the stone piers. They found that they could slide a piece of paper underneath the arch at the outside face of the pier.<sup>15</sup> The tremendous horizontal thrust from the arch had pushed the stone pier and rotated it outward.<sup>16</sup> The slight rotation lowered the outside edge and

15. Correspondence with Craig Wilkinsen of Reaveley Engineers and Associates, July 15, 2010.

16. Earlier statements on the Tabernacle arches failed to reflect the knowledge gained through modern engineering investigations. For example, Earl Olson stated that “the method of construction on the roof, although a great weight was involved, was such that the roof could not spread at its base as all

raised the inner edge so that only the inner timbers of the wooden arch were in contact with the stone pier. Ironically, rather than being detrimental, this deflection of the wood arch trusses and stone piers resulted in a stable structural system.

### Half-Arch End Sections

Grow's son related an interesting aspect of the Tabernacle design. He said his father walked the floor at night for two weeks attempting to arrive at a solution of how to arch the end sections.<sup>17</sup> The Tabernacle is not a simple barrel vault (or half cylinder). Rather, the building has semicircular ends to the east and west that give the Tabernacle its turtle-shell appearance. These ends were formed of half arches that are oriented radially from the center of the last full arch to stone piers on the east and west. The weight of all these radial arches bears on that last full arch (commonly called the king arch), loading it much more heavily than the center arches (fig. 4). Grow was concerned about how to make the connection at the top, but another concern might have been creating equilibrium between the two sets of radial trusses at the east and west.

Grow understood that half arches at the east and west ends of the Tabernacle push inward at the top, for he inserted a large ridge truss at the top of the roof between the east and west half arches. Under gravity loading, the push from each set of half arches is equal, resulting in equilibrium between the two ends. As long as there is no significant

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the weight was exerted straight down toward the center. The strain on the great timbers served only to intensify their union because of the way they were fastened together." Quoted in Carter, *Great Mormon Tabernacle*, 13. This erroneous understanding of the Tabernacle structure, plus other factual errors, might have come from an article preserved in the Journal History on November 14, 1915, from the *Salt Lake Tribune*: "A notable fact is that architects and constructors who know or are informed of the methods employed unanimously agree that the great dome cannot spread at its base. So far-seeing was the arrangement of timbers that every ounce of weight exerts its pressure on the plumb line, precisely in accord with the law of gravitation—directly toward the earth's center. They say that a sufficient load could be put in that roof to crush it, but not to spread its base." In reality, although gravity pulls only straight down, the transfer of that gravitational force from the center of the span to the stone piers resulted in substantial horizontal forces at the arch supports. Had the stone piers not been as deep as they were, they would have been pushed over, and the wood lattice truss would have cracked and splintered due to the increased stress.

17. Grow, "Historical Study of the Construction," 79; Esplin, *Tabernacle*, 156.





**FIGURE 4.** Trusses seen from the top of the Tabernacle, with the roof sheathing removed during the 2006 seismic upgrade. Here the half arches (radiating to the left in the photo) and the king arch intersect. Note how the top chord of the king arch (marked by arrows) bows five inches to the right, toward the center of the building, the result of 140 years of stress. A temporary safety railing and tarp are in the right of the photograph. Photo by Elwin C. Robison.

settlement or rotation of the stone piers which support the lower ends of the half arches, the half arches and ridge truss would form a stable structural system, and no significant weight would bear on the king trusses. This is likely the way Grow envisioned the roof system to behave, for the king trusses are not bigger or stronger than the arch trusses in the center of the building. Unfortunately, as was discussed above, the stone piers did not remain perfectly in place, having rotated slightly outward. More seriously, skylights cut into the roof to illuminate the interior of the Tabernacle inadvertently cut Grow's ridge truss, eliminating the compression member between the two sets of half arches that push in toward the center. As a consequence, the half arches have transferred much of their weight onto the king trusses.



**FIGURE 5.** Wooden lattice truss arches of the Tabernacle. Note the new steel members, fire sprinkler piping to the right, and new steel strapping to prevent splitting of wood planks. Photo by Elwin C. Robison.

When the roof was removed and the bow in the king trusses was discovered, engineers placed temporary struts across the skylight, joining the original wood ridge truss to the radial trusses until a new steel ridge truss could be installed.

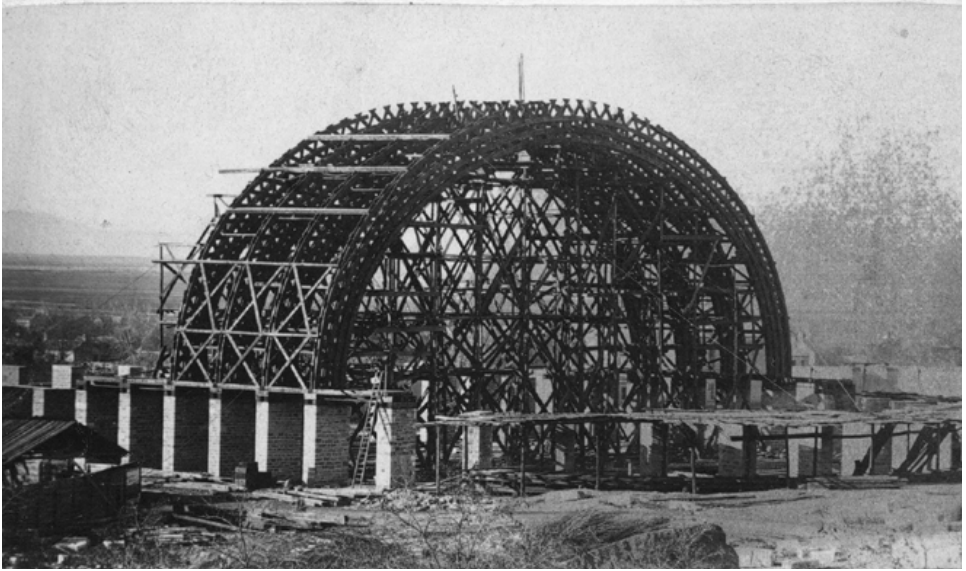
### **Construction of the Great Arches**

Despite the urgency to complete the structure, Young insisted that the stone piers be allowed to sit a season and let the mortar cure and harden before construction of the massive arches that bore on them. Construction of the great arches was a formidable task, for the scaffolding had to extend to the height of a five- or six-story building. The arches

were formed from heavy pine planks pegged and bolted together (fig. 5). The planks are about twelve inches deep and vary from two and a half to almost three inches thick. Most early sawmills could not produce dimensional lumber with greater accuracy than that. Each arch has four chords that follow the curve of the arch and that are spaced roughly equally from the top to the bottom of the arch. These four chords are made of four thicknesses of wood held together by the nine-foot-high lattice to which they are fastened by wood pegs. Joints in the chords are staggered to provide continuity along the chords.

The erroneous claim that nails were not used to build the Tabernacle has been repeated often.<sup>18</sup> In reality, tens of thousands of nails were used in construction, although procuring nails was challenging at the time.

18. For example, "Ancient Lighting Systems Gradually Give Way to New Units," *Salt Lake Tribune*, July 12, 1929: "A modern touch to Salt Lake's historic tabernacle, meeting place for pioneers as well as present-day folk, is added by the installation of an entirely new lighting system . . . in the building, which has gained world wide fame for its acoustic qualities and its construction without nails."



**FIGURE 6.** The Tabernacle during construction, c. 1865. Church History Library. Trusses for the arches were cut and laid out under the covered area in the front.

Many cut nails from the Tabernacle were saved during the 2006 seismic upgrade (fig. 7). These cut nails feature square-sectioned, tapered shafts and machine-made heads.

At the time the Tabernacle was constructed, there were at least two nail machines operating in the Salt Lake Valley. A. W. Sabin built one machine and later sold it to George J. Taylor.<sup>19</sup> Taylor advertised nails for sale in the newspaper, but along with his offer of goods was the plea, “Bring on your iron!” He was just as concerned with securing a supply of raw material as he was with selling the finished product.<sup>20</sup> Another nail machine was made by Jon Pugmire and operated in Young’s blacksmith shop.<sup>21</sup> The nail machines in Utah were relatively simple and consisted

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19. Taylor, Autobiographical Notes. Taylor explained that he owned a “machine in Utah for several years. Used to make nails out of wagon tires and sell them for 50 to 60 cents a pound. The nail machine (now in my possession) was made principally of wrought iron by a man named Sabin, one of our earliest and most competent mechanics. I remember the rollers used for rolling out the metal were wore much and I had a new pair made by James Lawson, who hammered them out of tire iron on his anvil.”

20. George J. Taylor, “Nails!!!” *Deseret News*, February 25, 1863, 280.

21. Historian’s Office Journal, February 21, 1859, 171.



FIGURE 7. Cut nails removed during the 2006 renovation. Photograph by Arnold Angle.

primarily of a set of rollers and a shear cutter. Iron was first heated and passed through rollers to produce a sheet of the desired thickness, typically about one-eighth to three-sixteenths of an inch. This plate was cut to the desired length of the nail and fed into a cutting machine that produced a slight taper on the shaft. The first nail machines cut only the shaft, leaving the head to be formed by hand in a blacksmith

shop. Later, Salt Lake City businessman Daniel H. Wells introduced the first machine that actually formed a head on the nail.<sup>22</sup> The tapered shafts were fed into a machine that clamped down on the shaft and formed the malleable iron into a head. During the seismic upgrade, the authors observed only nails with machine-made heads in the Tabernacle. This evidence indicates that by the time construction commenced on the arches in 1865, nails with machine-made heads were readily available. Although newspaper accounts reported finding handwrought nails during previous renovations,<sup>23</sup> reporters probably assumed any nail that was not a modern wire nail must have been hand produced. In reality, no serious production of handmade nails had taken place in most of the United States since the 1820s.<sup>24</sup>

What was unique about the nails of the Tabernacle was the source of the iron used in their manufacture. Young was eager to find local

22. "Utah Early Nail Making," *Deseret Evening News*, May 4, 1897, 1, col. 6. Adams said this machine was shipped across the plains by wagon in 1859 and set up in the old Sugar House Mill. A. R. Whitehead worked the machinery for Wells. See "First Nails Made in Utah," *Deseret Evening News*, May 3, 1897, 8, col. 3.

23. "Wrought Spikes Are Found in Frame under Choir Seats," *Salt Lake Tribune*, December 2, 1933, 24. The article states, "Tradition that the L. D. S. tabernacle was built without the use of a single nail—a story which has received credence the world around—was proved ill founded during the past week when a number of sturdy hand-wrought spikes were found in the original framework beneath the choir seats."

24. Lee H. Nelson and Penelope Hartshorne, "Nail Chronology as an Aid to Dating Old Buildings and Paint Color Research and Restoration," *History News* 19, no. 2 (1963).



sources for needed commodities to prevent bleeding the region of currency and capital. He sent a group to Las Vegas to mine lead, but that venture was unsuccessful due to contaminating impurities in the lead, which others later found to be silver. He even established a colony in Iron County with skilled members being called as “iron missionaries” to mine ore and smelt the metal. Although the Saints produced some iron near present-day Cedar City, the quantities consumed by large-scale construction would have taxed their production capabilities.<sup>25</sup>

According to the nail makers, their primary source of iron came from the government wagons of the United States Army, which had marched on Salt Lake City in 1857–58. The heavy military wagons that accompanied the army had thick iron hoops around the circumference of the wooden wheels and heavy chains and bolts used with brake levers, axles, and wagon trees.<sup>26</sup> Many of these wagons had been burned in Wyoming by Lot Smith during his campaign to slow the army’s progress toward Utah.<sup>27</sup>

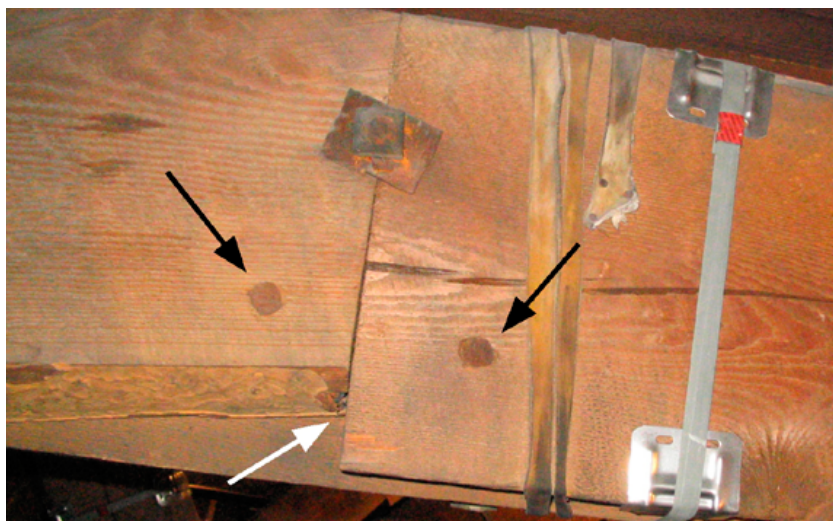
In addition to the iron needed for nails, iron was needed for bolts. In the Tabernacle, long iron bolts attach the chords of the timber arches to the lattice. Thousands of bolts fasten the arch chords where the planks abut each other. These bolts vary between one-half and three-quarters of an inch in diameter. Some are over twenty-three inches long, running through the lattice arch chords and stiffeners. Other bolts are shorter, fastening only the chords and lattice planks, or just fastening two planks where they butt together. The bolt heads are square and typically of substantial size. The shaft of the bolt and the head were visibly welded together by blacksmiths. The heavy, square bolt heads and nuts were made by shearing through one- to one-and-a-half-inch-thick stock material, which would have required heavy machinery not easily

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25. See Morris A. Shirts and Kathryn H. Shirts, *A Trial Furnace: Southern Utah’s Iron Mission* (Provo, Utah: Brigham Young University Press, 2001), 379, xix–xx.

26. Hope A. Hilton, “*Wild Bill*” *Hickman and the Mormon Frontier* (Salt Lake City: Signature Books, 1988), 73, quoting army soldier Eugene Banal: “On the east side of the Green River we found ironworks of 25 burned wagons—chains, axles, and other wagon parts—covering the trail, on the west side of the Green River, the remains of fifty more wagons.”

27. LeRoy R. Hafen and Ann W. Hafen, eds., *The Utah Expedition, 1857–1858: A Documentary Account of the United States Military Movement under Colonel Albert Sidney Johnston, and the Resistance by Brigham Young and the Mormon Nauvoo Legion*, The Far West and the Rockies Historical Series, 1820–75, vol. 8 (Glendale, Calif.: A. H. Clark, 1958), 220–46.



**FIGURE 8 (top).** A butt connection in one of the chords of the wood lattice-truss arches showing the half-inch-diameter wood pegs (black arrows), a hole drilled but missing a bolt (white arrow), a rawhide strip to control splitting, a new steel strap to supplement the rawhide, and a square bolt with a washer.



**FIGURE 9 (bottom).** A bolt with an ox shoe washer with a shoe nail still left in a hole. Note the bolt head, which has been hammered and welded on to the shaft by hand. Photos by Elwin C. Robison.

transported across the plains before the arrival of the railroad. That, together with the quantity of bolts used, suggests that they were purchased in the East. By the time the arches were being raised, residents of Utah Territory would not have had to travel all the way to the Missouri River to buy bolts. The transcontinental railroad started construction in 1863, about the same year as the Tabernacle. However, the railroad did not come to Utah until early 1869, two years after the completion of the roof structure of the Tabernacle. Although newspapers mentioned “trains” during the construction of the Tabernacle, this term referred exclusively to wagon trains. Still, the bolt supply inched closer to the Great Basin with each mile of track that was laid. In fact, it seems likely that many of the bolts used in the Tabernacle were purchased from railroad inventories.



Mute testimony to the expense and difficulty of obtaining these bolts is the fact that many bolt holes, drilled at the junction between the lattice truss chord junctions, never had bolts installed in them (fig. 8). Typically two bolts were intended to be placed at each junction, but especially in the half-arches at the ends, many of these bolts are missing. Since the loads carried by the end arches were considerably less than those borne by the complete arches over the central portion of the building, it may have been a conscious decision on the part of Grow (and Young)

to economize in areas where loads would be reduced. Of the approximately six thousand holes drilled for bolts, my survey of the roof structure shows that only about three quarters had bolts installed.

The source of the bolts was rather different from that of the washers used underneath them. Virtually all of these washers were scavenged and reused pieces of iron. Many of these were ox shoes, with a characteristic wide crescent shape and nail holes on the outer perimeter. In a few cases, a nail that held the shoe on the animal's hoof still dangled from the washer (fig. 9). Most ox-shoe washers had the tail end of the shoe (to the right in the figure) cut off, presumably thrown into the scrap heap to be reused in the blacksmith shop. Another class of washer was a square iron plate, sometimes generically referred to as wagon iron. Most of these were crudely hammered flat, indicating they had been reused (for example, the washer in figure 8). Finally, there were irregular-shaped plates of relatively thin iron used as bolt washers. Some of these trapezoidal shapes might be the ends of plates left over from nail manufacture. While the bolts probably were purchased in the East and transported west by wagon, the washers used on the bolts definitely were not.

The "no nail" Tabernacle myth likely stemmed from the use of wooden pegs that fastened together the arch lattice planks (fig. 10). Although pioneer economy and scarcity of iron encouraged the decision to use wood pins, a much tighter fit is possible using wood pegs. For example,



**FIGURE 10.** A pegged connection showing the wedges driven into the pegs perpendicular to the grain. Photo by Elwin C. Robison.

the wedge driven into the peg expands the peg to ensure a tight fit and prevent the peg from working itself out of the hole. Discarded pieces of wood pegs found in the attic of the Tabernacle are turned dowels with very smooth surfaces. Young reported that “the pins are of well seasoned timber, turned to about the 32<sup>nd</sup> part of an inch larger than the holes, they were well greased and driven home with sledges and wedged at each end.”<sup>28</sup> A blunt taper was turned into one end of the peg. Workers always drove the wedge into the peg so it expanded in the direction of the grain and not across the grain. Had the workers done the latter, each plank in the arched lattice truss would have split. This was an especially critical detail because the lumber available from local canyons to build the tabernacle was not of high quality. Most planks have many knots in them that interrupt the grain of the member, reducing their strength. Such knots also increase the susceptibility of the member to splitting. Some arch planks are split in the zone of the pegs, but because of the orientation of the wedges in the peg, this condition is relatively rare.

The tightness of the peg in the hole was critical for two other reasons. First, any slack, or “play,” in the pegs would have caused the arch lattice trusses to sag even before any load was applied. Second, shifting winds and eddy currents can blow first from one direction and then another. Any play in the connections would wear the timbers and cause eventual failure. Instead, the installation of the pegs was such that, even after 140 years, the arched lattice trusses are still sound and able to carry their loads.

If wood pegs were so efficient, then why did the Tabernacle have several thousand iron bolts? While the pegs form a secure shear connection (two planks sliding against each other), bolts are superior when used in tension (two planks being pulled apart). The bolts were used exclusively at the ends of the planks to keep their butted surfaces from spreading apart. With large compressive forces in the arch members, there would have been a tendency for the butted joints to buckle out of plane, which would have caused the arch to fail. To prevent this outcome, two iron bolts with large iron washers were installed at each butt joint. Note that the bolts are not preventing the planks from sliding past one another—it is the butted connection that does this. Instead, the bolts act in tension, holding the planks in place and preventing them from spreading outward.

Inspection of the Tabernacle trusses shows that most of the butt connections in the main trusses over the central section of the building

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28. Brigham Young to Frank Low, May 4, 1872, Letterbook 13:58–59.

have two bolts installed at each connection; but, as was noted above, many bolts were not installed, especially in the half arches. Where a bolt is missing, chord members have warped so that there is not an even transfer of forces across the cross section of planks. Half-inch-diameter wood pegs installed to aid in positioning the planks during construction are present at the butt joint, but they do not have sufficient tensile capacity to prevent warping of the wood planks when a bolt is missing.

### Completed Shell

As the heavy construction phase ended, control of the building site shifted from Grow to Truman Angell, the Church's architect. However, Grow continued as a foreman even after the main structural work was done and architectural elements were being installed. This arrangement highlights the fact that assigning credit for the design and construction of a large building to any single individual is a forced convention that does not tell us everything about the building or its history.<sup>29</sup> As the shell of the Tabernacle was finished, Grow took a secondary role, while Angell took the lead.

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29. An example of a discussion on this subject is Nathan D. Grow, "One Masterpiece, Four Masters: Reconsidering the Authorship of the Salt Lake Temple," *Journal of Mormon History* 31 (Fall 2005): 170–97.