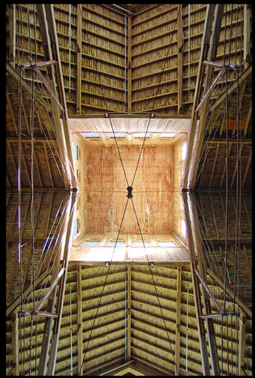


# Structural Repair of the Breeding Barn at Shelburne Farms



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## Volume I: Report Narrative

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# Contents

# Acknowledgements

This completion report on structural repair of the Breeding Barn at Shelburne Farms, presenting the results of preservation analysis and treatments that took place from 2005-2010, was accomplished through the contribution, support, and professional expertise of many public, educational and not-for-profit institutions, private firms and individuals. This most recent work was made possible by major grant support from the Getty Foundation, the Forrest and Frances Lattner Foundation, and the 1772 Foundation. A substantial grant was also secured from the U.S. Department of Housing and Urban Development with the help of Senator Patrick Leahy and made available through the Vermont Housing and Conservation Board. Additional generous support was provided by the MSST Foundation, Cruise Industry Charitable Foundation, and the Oakland Foundation.

On a technical level, developing and implementing treatments for the Breeding Barn required critical and in-depth analysis of the significance, condition, and technological complexity of the structure by a multi-disciplinary team of specialists and consultants. Key to this process was the project engineer, David Fischetti, who's structural modeling and analysis not only proved the elegance and strength of the barn's structural system as originally designed by Robertson in 1890s, but also guided the repair design. Sadly, Dave passed away during the writing of this report, but his legacy will continue through all of his work at each of the important sites he touched, and will be visible to each person who looks up in awe at the original Barn trusswork.

We are extremely grateful to Ron Anthony for his analysis and synthesis of the data on the timber repair mockups and testing, and the conclusions presented in this report, and to Jan Lewandoski who was involved in the initial assessment work as part of the Timber Framers Guild, participated in the rigging of the load tests, and whose company was awarded the contract for the timber frame repairs. We are also deeply thankful to Julie Edwards, Shelburne Farms Curator of Collections, for her documentary research and for providing us with invaluable historic images, maps, and reports.

Neil Dixon of Yankee Imaging served as the official project photographer; he documented the repair process and took spectacular rectified photos of the barn ceiling and trusswork. Report photos were contributed by all of the principal project team, and by Marshall Webb of Shelburne Farms. Special thanks are also owed to Keri Stevenson of Conservation Associates for preparation of the as-built drawings.

We cannot forget our colleagues at Shelburne Farms for their constant and unfailing support over the past five years in everything from administrative work to direct involvement in the repairs, and to what was surely a colossal effort to empty the barn prior to repair.

Last but certainly not least, we acknowledge all the craftspeople whose skill and professional expertise on the Breeding Barn project helped preserve an extraordinary National Landmark. The list is long and there will almost certainly be substantial omissions for which we apologize in advance. They are the timber-framers (Mike Cotroneo, Doug Porter, Paul Ide, Jan Lewandoski, Jason Norris and Chris Patton); masons (Rae Berolzheimer, Lindsay Foreman, Matthew Holtz, Ryder Owens, John Wastrum, Chris Gregory, Matt Tarvell, Kai Vormer, Leo Yonderdota, and Dylan Eustace); and conservators (Angelyn Bass, Doug Porter, Liisa Reimann, Sebastian Renfield).

We recognize and thank all of our contributors for their participation and collaboration in this project and helping to fulfill Shelburne Farms' commitment to cultivating a conservation ethic for a sustainable future.

# Executive Summary

Shelburne Farms is a 1400-acre working farm and National Historic Landmark District located on the eastern edge of Lake Champlain in Vermont, U.S.A. A model farm and country estate developed by founders Dr. William Seward and Lila Vanderbilt Webb, Shelburne Farms is a nationally significant cultural landscape typical of the picturesque country estates that appeared in the U.S. in the late nineteenth century. The architecture and landscape design represent significant achievements by architect Robert Henderson Robertson and landscape architect Frederick Law Olmsted, Sr. The farm is currently operated by a non-profit sustainability organization.

The Breeding Barn (1891), the center of Dr. Webb's effort to develop an improved horse breed, consists of a timber-framed main block 107 feet wide by 418 feet long, with a two-story annex. The riding ring at the center of the building, approximately 72 feet wide and 375 feet long, is spanned with composite trusses based on a design by Camille Polonceau having timber top chords with wrought iron braces and ties.

After decades of neglect, the barn is the focal point of a multi-phase stabilization and repair project. This completion report describes the structural repair of the barn that took place from 2009-10, which posed several interesting challenges. Analysis of the principal truss indicated overstresses in iron ties. Augmentation or replacement of the ties was unacceptable because of the adverse effect on historical integrity. Furthermore, decayed valley members in each of the large dormer pairs that dominate the roof required extensive repair work. Because of difficulties associated with removing such long timbers (36-54 feet), it was necessary to make most of the repairs *in situ* and without removing the roof covering.

In an effort to maintain the historic character of the barn, the multi-disciplinary project team conducted an investigation to discover the nature and condition of materials and connections and assign realistic design values, using laser scanning, resistance drilling, strength testing, and metallographic analysis. Modeling, load testing, and plane-frame analysis were used to determine the stress distribution in roof frame elements. Through modeling and analysis, it was determined that factors of safety for each of the principal elements of the riding ring truss were acceptable, and that the focus of the stabilization and repair project would be on repairing deteriorated elements and reinstating those that, for one reason or another, had been removed.

A modest testing program allowed the project team to assess the effectiveness of various *in situ* repairs. The investigation led to the development of repair strategies for roof frame elements that included the scarfing of new timbers, and inserting engineered lumber (by segmental infill) to replace decayed material. Repair designs achieved a balance between risk and integrity to ensure public safety while respecting the historic materials and design, and preserving the Breeding Barn within the cultural landscape of Shelburne Farms.

This report is divided into two volumes, the first consisting of a narrative description of the structural repair of the Breeding Barn; the second volume includes the results of lab analyses, consultants' reports, and the drawings produced for the structural repair of the barn. Volume 1 presents a brief history of the farm and its development in the late-19th century, the history of repairs and alterations made to the Breeding Barn, and conservation planning for the future re-use of the barn and surrounding buildings and landscape. This is followed by a description of the Breeding Barn and its chief structural components with respect to condition assessment, materials testing, structural analysis, design, and repair implementation. The narrative focuses on foundation stonework, characterization of iron and timber, and the assessment and repair of perimeter wall woodwork; aisle roof, wall and floor frames; riding ring columns; and riding ring roof frame.

Repairs are presented in greater detail with respect to location, the individual elements affected, and repair geometry in the as-built drawings prepared for this report. As-built drawings are included in Volume 2. The project also involved review of architect Robert Henderson Robertson's original drawings of the barn, as well as development of HABS-level drawings, and a set of design drawings for guiding the repair of the building, all of which are bound in this volume. Volume 2 also includes appendices devoted to the geotechnical survey, analysis of historic mortar, characterization of historic iron, the wood assessment, repair mockups and testing results, structural modeling and analysis, and the primary materials used in the repair of the building. The assessment, testing, structural analysis, and repair decisions made for stabilization of the Breeding Barn serve as a demonstration of sound preservation technology practices, and are the topic of several published papers and conference presentations. These are compiled in Appendix K.

The landscape at Shelburne Farms still reflects the division of the estate into farmland, forest, and parkland by celebrated landscape architect Frederick Law Olmsted Sr. Photo courtesy of Marshall Webb.

# Historical Background and Building Significance

Shelburne Farms, originally the agricultural estate of William Seward and Lila Vanderbilt Webb, is a 1400-acre National Historic Landmark District located on the eastern edge of Lake Champlain just south of Burlington, Vermont. The property is owned and operated by a non-profit organization devoted to the cultivation of a conservation ethic through education and the stewardship of natural and agricultural resources.

The Webbs built the estate between 1886 and 1905, as part of a grand experiment to develop innovative new approaches to land use and farming. They began acquiring land on Shelburne Point in 1886, and eventually purchased 32 small farms totaling approximately 3800 acres. Early in the process of acquiring the land, W. Seward and Lila Webb consulted with celebrated landscape architect Frederick Law Olmsted, Sr. (1822-1903) to develop a landscape design for their growing estate. In his c.1887 design, Olmsted proposed a plan dividing the estate into farmland, forest, and parkland, combining the pastoral and picturesque in the tradition of the great "ornamental farms" of nineteenth-century Europe.

While Olmsted's plan was never fully implemented, his influence on the landscape is evident today. Fences dividing individual farms were removed, unifying the estate. Roads were oriented to provide grand views of Lake Champlain and estate architecture across farm fields planted with hay, corn, oats, wheat, rye, and barley or pastures full of grazing cattle and sheep. Clearly defined woodlands were established on previously cleared farmland, with native species supplied from a nursery stocked with more than 100,000 maples, pines, hemlocks, and spruce trees. The parkland section included a golf course, and mature elm trees were brought in from as far as fifteen miles away and transplanted to the Shelburne House lawn and used to line roads near the north and south gates of the estate.[1]

The estate architecture was designed by New York architect Robert Henderson Robertson (1849-1919), a prominent nineteenth-century designer of monumental architecture. Robertson worked in the office of George B. Post before opening his own practice in New York City in 1871. Over the course of his career, his stylistic interests included Queen Anne and other of the Victorian styles, as well as the Romanesque revival made popular by H.H. Richardson. His designs include Witherspoon Hall at Princeton University, the Madison Avenue Methodist Church (1884), the Mott-Haven Railroad Station, the Academy of Medicine (1889), the Corn Exchange Bank Building (1892), and the American Tract Society Building (1894). Robertson was an early designer of skyscrapers and today he is best known for his Park Row Building (1896-1899), which at 27 stories was the tallest building in New York at the time of its construction.

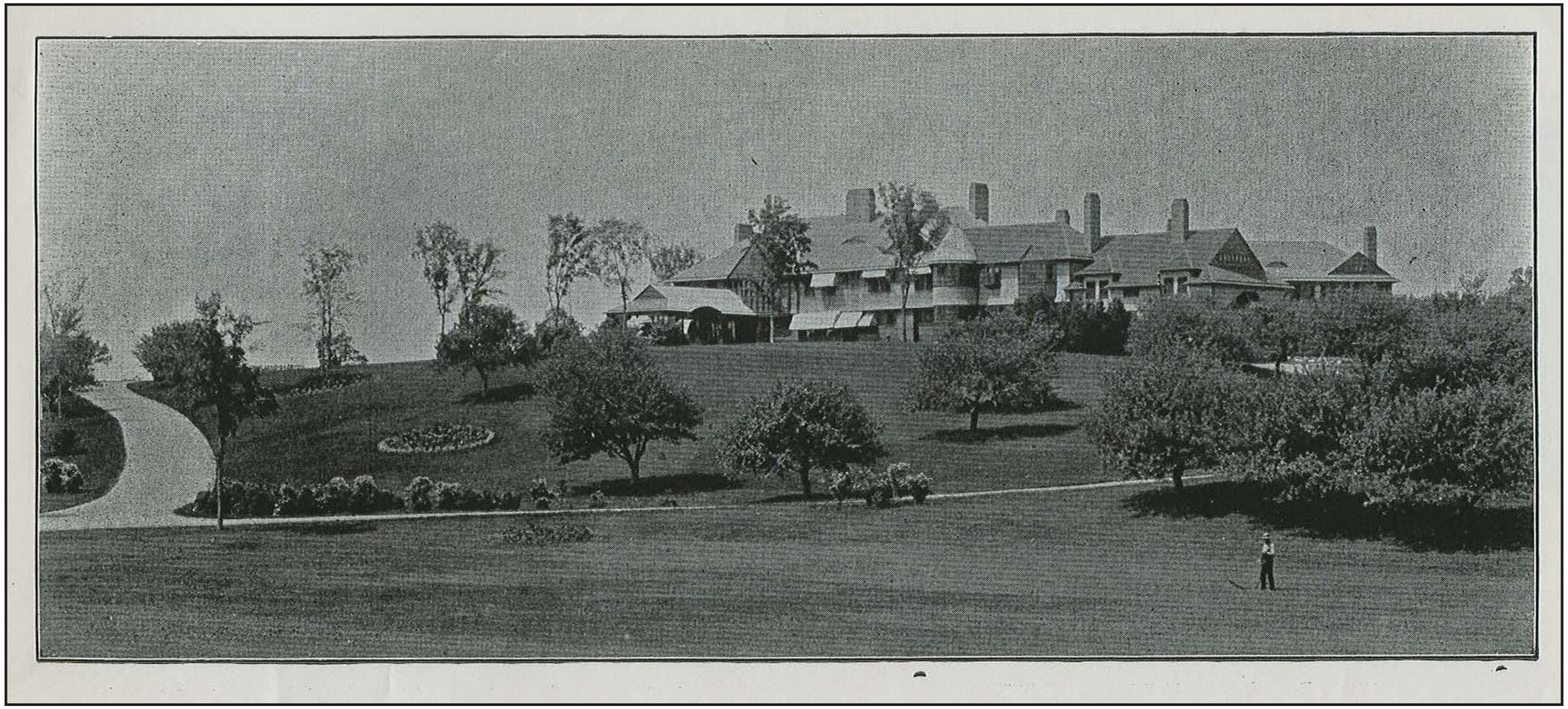
The buildings at Shelburne Farms represent Robertson's most significant estate commission. In general, the buildings combine the Queen Anne and Shingle styles and are characterized by extraordinary workmanship and design. The buildings feature gabled and hipped roofs with multiple towers, dormers, and ventilators, wide overhanging eaves supported on elaborate brackets and rafter-ends, multi-textured wall surfaces covered in shingles, clapboards, and pseudo half-timbering, and foundation stonework of estate-quarried red Monkton quartzite.

Robertson worked at Shelburne Farms for twenty years, and sixteen of his buildings survive, constructed between 1886 and 1905. The buildings are arranged on the estate in clusters or groupings according to function and consistent with Olmsted's division of the landscape into farmland, forest, and parkland. The groupings are anchored by four enormous buildings, centerpieces around which life and work on the model estate revolved. They include Shelburne House (1888, with significant renovations by 1900), a Tudor Revival mansion which served as the Webb's country residence; the Farm Barn (1888-1890), which was the agricultural headquarters of the estate; the Coach Barn (1902), the transportation center of the estate and one of Robertson's last major efforts; and the Breeding Barn (1891), which served as the center of Dr. Webb's horse-breeding efforts.

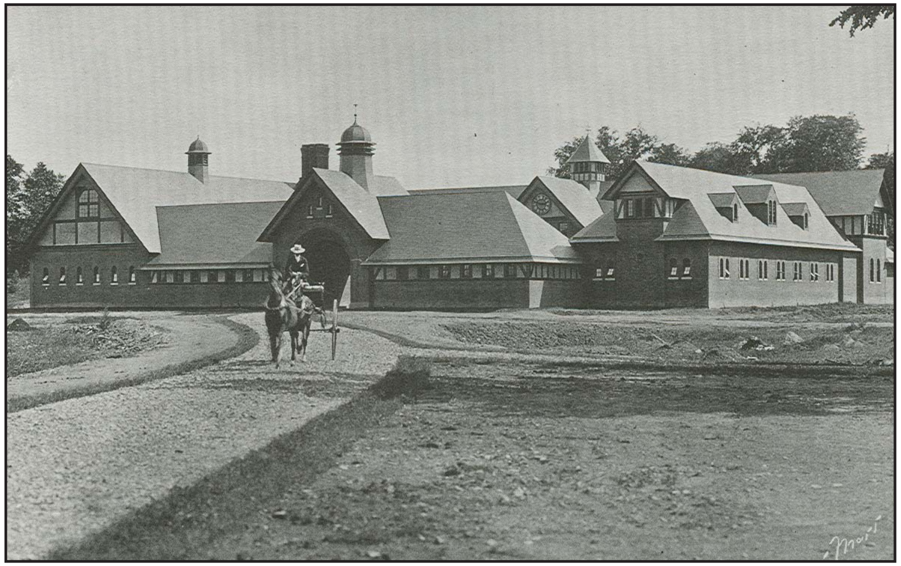
The Breeding Barn is the principal building of the Southern Acres portion of the Farm, and was built in part to fulfill Seward Webb's dream of breeding a line of strong and elegant draft horses especially suited to Vermont.[2] The building was originally called the Ring Barn, named for the riding ring that occupies the largest interior space. Construction of the barn was

[1] Donnis, E.H. 2010. The History of Shelburne Farms: a Changing Landscape, an Evolving Vison. Barre, Vermont: The Vermont Historical Society, pp. 35ff.

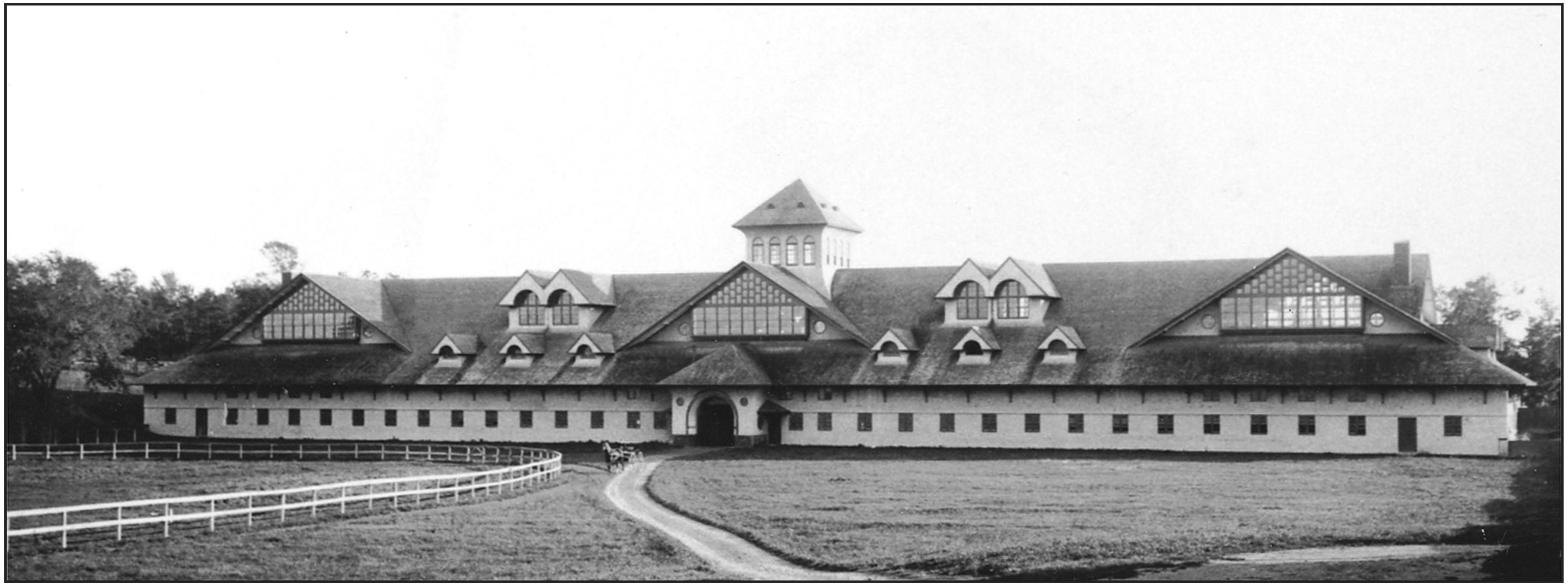
[2] Southern Acres is the traditional name for the southern portion of the farm, used primarily for the horse breeding operation.



Robertson organized the estate architecture around Shelburne House (top), the Farm Barn (bottom left), the Coach Barn (bottom right), and the Breeding Barn (overleaf).

The Breeding Barn at Shelburne Farms, a National Historic Landmark, is dominated by its complex-sloped hipped roof, nearly two acres in area, with multiple dormers and an enormous central lantern.



begun in 1890 and completed in 1891. At the time, the barn was said to be "probably the largest and best-appointed building of the kind, not only in the United States, but in the world. Those who have seen it call it one of the wonders of America".[3]

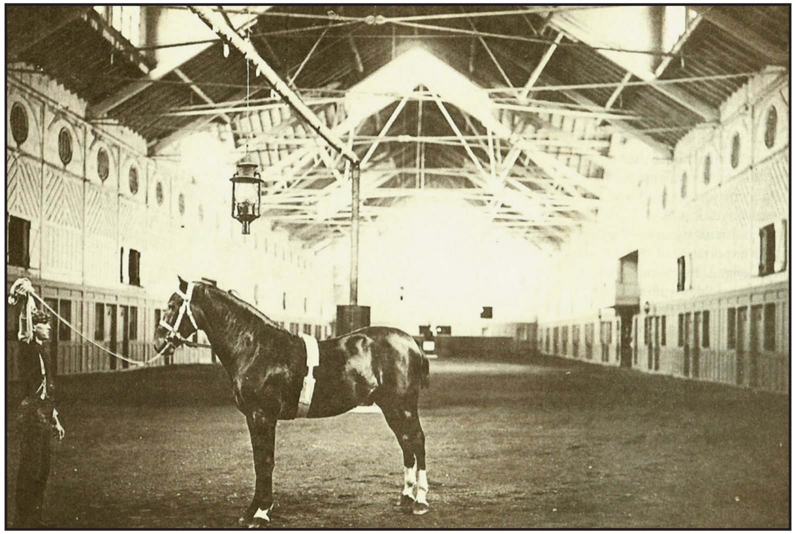
The main block of the building is approximately 107 feet wide by 418 feet long, with a two-story annex centered on the rear façade. The building is timber-framed, supported on a rubble stone foundation, and clad in wooden shingles. Building elevations are dominated by the complex-sloped, two-acre hipped roof with multiple dormers and an enormous central lantern. The walls are clad in wood shingles punctuated by scores of multi-pane windows that admit light and ventilate the interior space. A hip-roofed arched entry is centered on the front façade.

At the center of the building the riding ring, used for exercising horses throughout the year, encloses an enormous volume measuring approximately 72 feet wide, 375 feet long, and 55 feet high to the roof ridge. The ring is lit by glazing in the gables of eight large dormers and the lantern, which is supported on wooden purlins nearly 50 feet above the floor. Framed aisles on all four sides that once housed stalls at ground level and loft space above surround this central space. The annex, added sometime after initial construction of the main block, originally housed grooming operations, a tack room, and machinery for processing oats. Most of the building interior, with the exception of the aisle lofts, is finished with wood-paneled walls, cased window and door openings, and neat chamfers on exposed frame elements.

Framing of the aisles, walls, and annex is fairly typical of heavy timber construction of the day, but Robertson borrowed from contemporary railroad design in iron to create the beautiful and highly efficient roof structure over the riding ring.[4] Here, a series of fourteen principal trusses of timber and iron support the roof expanse. Each truss has wooden (Southern yellow pine) top chords trussed with wrought iron tension members and struts; a raised bottom chord of wrought iron completes the truss form. At the lower end, principal rafters are captured in cast iron housings that also receive the ends of tension members. Housings are fastened to timber plates at principal post locations. Columns are set 12-feet on center (at the corner of each stall); every other pair supports a truss. Trusses support a deck of purlins and common rafters. The surrounding aisles have shed roofs with king-rod and queen-rod trusses supporting timber purlins across which common rafters are lodged.

[3] *Frank Leslie's Popular Monthly,* September 1892.

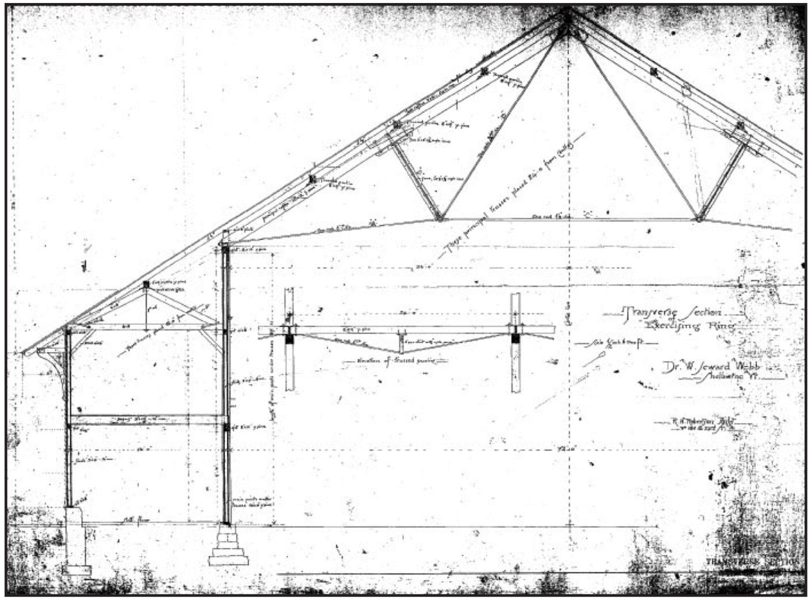
[4] Unwin, W. Cawthorne. 1869. Wrought Iron Bridges and Roofs. London: E. & F. N. Spon.



(Clockwise from top left) Construction was begun in August of 1890, and by December 1891 the building was nearly complete. The barn was the center of Webb's horse breeding operation at Shelburne Farms, one of the largest in the country. The riding ring, an enormous open space surrounded by stalls, dominated the building interior. It was used to exercise horses boarded at Shelburne Farms in any sort of weather.

Robertson adapted a truss designed by French engineer Camille Polonceau for framing the riding ring roof. Robertson's transverse section (left) of the riding ring, showing the composite truss, trussed purlins, and aisle framing. Note the tapered scarf in each top chord member, located over the struts. Ironwork in the historic photo (right) is being painted (note the painters suspended from the center tie in the background).

Originally, the purlins and valley rafters at each of the large dormers were trussed with wrought iron tension members and cast iron struts. The iron elements of the Breeding Barn roof frame were fabricated by Post & McCord, one of the largest iron and steel fabricators in New York City in the early 20th century. With truss ironwork painted white and receding from view in the limewashed riding ring, Robertson accomplished a very streamlined frame, elegant in its economy of material, and enclosing an enormous volume below the rafters.




There have been at least two major structural interventions in the riding ring roof frame. As originally designed by Robertson, a single truss was installed to support inboard dormer framing for major dormer pairs located at the east and west ends of the ring. Sometime subsequent to original construction, but early in the history of the building, a second truss was added at each inboard dormer location to support dormer framing not carried on the end walls. Top-bottom chord connections are still made at cast-iron housings, though these differ in profile from the originals. In the newer trusses, the raised center elements of the lower chords are equipped with turnbuckles, unlike their counterparts in the original trusses. Because of the proximity of cross-brace ties to the original trusses, the newer trusses were installed between columns and required additional bracing in riding ring walls. The level of craft displayed by these new trusses is roughly equivalent to that of the original construction.

A second intervention, which probably took place several decades later, was focused on structural augmentation of the valley rafters associated with the major dormer pairs. Originally, valley rafters at each of the large dormers (including at the lantern) were trussed with wrought iron tension members and cast iron struts. Sometime in the twentieth century trusses

on the lantern valleys were removed. Steel channels were added to either side of the valley members at the lantern and at dormers at east and west ends of the riding ring. Addition of the steel channels necessitated removal of the iron bridles that carried purlins, and some of the purlins were shortened to make room for the steel. Following installation of the steel channels most of the purlins were tied to valley rafters using bolted bent plates, except at dormer locations. Here purlins were removed and never replaced, leaving long top chord elements located at the centers of each major dormer pair unbraced.

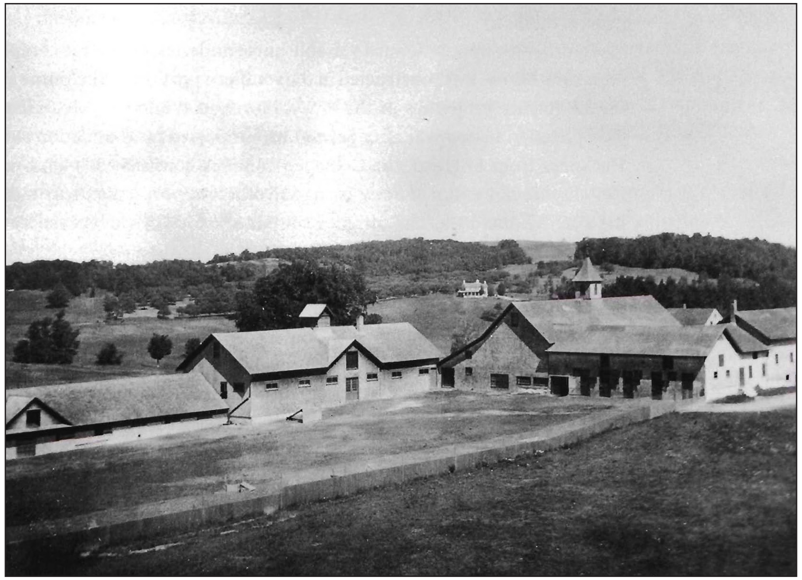
Webb intended the farm to be one of the largest and most important horse breeding operations in the country, and by the time the Breeding Barn was completed in 1891, the Shelburne Farms Stud (the name of the breeding business he operated) numbered 219 horses.[5] The Breeding Barn and surrounding horse barns[6] included a total of 150 box stalls and 70 standing stalls for the horses. Webb specialized in imported English hackneys, and by the mid-1890s was considered “the most successful amateur hackney breeder

Sometime after initial construction of the barn trusses were added on the inboard sides of east and west dormer pairs (left). Truss construction differs from the original configuration, though the quality is very high. Location of the additional trusses away from columns required additional structure in the riding ring walls (right). Steel channels were added to valley members ca. 1930. Purlin bridles were replaced with bent strap connections (bottom right).

[5] Donnis, p 71

[6] The Shelburne Farms Stud operated in a C-shaped complex of horse barns and other structures that, along with the Breeding Barn, surrounded a central paddock. The buildings that survive are known as the Breeding Barn Complex and include the Breeding Barn, Old Dairy Barn, Tracy Barn and the Wood Shop. Attendant buildings include the Tracy House, the Breeding Barn Cottage and the Vineyard Cottage.

The Breeding Barn Complex originally included several horse barns; the northwest corner of the complex appears in this historic image. Only a few of the buildings survive.



on this continent".[7] He offered low-cost breeding services to Vermont farmers in the hope that cross-breeding of Vermont Morgans with the hackneys would result in a light draft horse more aptly suited to the demands of New England farming. But the Shelburne Farms Stud was never profitable, and by 1894 some of the Breeding Barn complex was converted to house sheep. Sale of the breeding stock began in the late 1890s, and by 1903 the breeding operation was essentially discontinued.

The Webbs deeded Southern Acres to their oldest son J. Watson Webb as an early inheritance in 1913. Watson, his wife Electra Havemeyer Webb, and their sons managed the Southern Acres property, including the Breeding Barn complex, as a separate country estate and farm until 1986 when the property became part of the Shelburne Museum. During Watson's ownership, the Breeding Barn stabled a few ponies and horses that were kept for the Shelburne Hunt, was used as an interior polo field, stored hay and equipment, and housed a beef cattle operation and the University of Vermont Dairy Farm's replacement herd, which lasted until 1994. Modifications to accommodate cattle operations in the mid-20th century included demolition of most of the stables that surrounded the exercise ring. Attempts to address movement of foundation stonework associated with manure removal resulted in the addition of concrete counterwalls against some foundation stonework, particularly on the north façade.

The main Shelburne Farms estate continued its operations within the general scope of the Webbs' initial vision until c.1936, when Lila Webb died. After her death, there was a decline in activity on the estate. From 1936 to 1984, successive generations of the Webb family preserved and maintained the core property, buildings, structures, and landscape features in a manner consistent with their means and the estate's character as a working farm. While Seward and Lila's son Vanderbilt (1891-1956), and his son Derick (1913-1984) owned the main estate, they managed a smaller, diversified farming operation. In 1972, six great-grandchildren of the Webbs founded a nonprofit organization called Shelburne Farms Resources to promote environmental education and conserve the farm, its buildings and landscape. Derick Webb gave the three major buildings located on the main portion of the estate to Shelburne Farms Resources in 1976 and bequeathed the balance of the estate to the nonprofit in 1984. Shelburne Farms Resources reacquired the Southern Acres, including the Breeding Barn complex, from the Shelburne Museum in 1994 and since that time has utilized the property for limited program and maintenance related uses, and for employee housing.

Shelburne Farms was listed on the National Register of Historic Places in 1980; the designation was elevated to National Historic Landmark status in 2001. The property is significant for its architecture and landscape architecture and its associations with the Webb and Vanderbilt families, as well as to architect Robert Henderson Robertson, and landscape architect Frederick Law Olmsted Sr.

[7] "New Blood for the Horse Show", New York Herald, Nov 12, 1899. As quoted in Donnis, p 71

By 1903 the breeding operation was essentially discontinued and the barn was used for the Shelburne Hunt through the 1930s.

## Future Use/Reuse

The farm is operated by a non-profit organization committed to sustainable rural land use, environmental education, and local food production.[8] In this sense, its current use is consistent with the Webbs' original vision of a model farm for development of innovative agricultural practices for the benefit of the public. To that end, the farm maintains a Brown Swiss dairy herd and is one of Vermont's leading producers of artisanal cheese. Management of the farm's forest resources produces several thousand board feet of lumber each year for preservation of the buildings and programmatic use by the farm. Shelburne House (1886/1900), the estate mansion, was rehabilitated for operation as an inn and restaurant in 1987 and opened to the general public. The Coach Barn (1902), the last of Robertson's monumental buildings to have been constructed at Shelburne Farms, was rehabilitated in 1993 as a special events facility. The Farm Barn (1890) continues to serve as the business center of the farm, housing administrative offices, the cheese-making operation, and educational facilities.

As the principal buildings are rehabilitated, they are used to support Shelburne Farms program activities. From left to right, Shelburne House, the Farm Barn, and the Coach Barn (overleaf).

Under the reuse scenario developed by Shelburne Farms for the Breeding Barn, the building will be used seasonally for special community events. With continued rehabilitation of the Breeding Barn Complex, and the growing need for space to conduct the farm's educational activities planned for the Southern Acres, it is anticipated that use of the Breeding Barn will intensify. There are no plans to heat the building, minimizing fabric impacts associated with insulating; however, with increased use, the portable bathroom facilities may become impractical. In that event, Shelburne Farms will consider installing accessible restrooms in the aisle area at one end of the building where impacts on fabric and character-defining spaces will be minimized.

Shelburne Farms is developing plans to rehabilitate portions of the Breeding Barn Complex for its educational programs. As with past undertakings, such as the rehabilitation of Shelburne House in 1987 and of the Farm Barn and Coach Barn in 1993, Shelburne Farms' rehabilitation of the Breeding Barn Complex buildings will result in reuse by the public of

[8] *Shelburne Farms conducts educational, agricultural, and cultural programs in the belief that the quality of our living environment depends on the conservation of natural resources, a healthy agricultural base and a striving for cultural excellence.* (Shelburne Farms Long Range Plan, May 1985, in folder "Long Range Plan 1984-1985", Shelburne Farms Resources Collection)

currently underutilized historic resources. Concepts for the rehabilitation of the Southern Acres Dairy Barn as a Residential Learning Center have been developed and consist primarily of interior renovations that will include the construction of guest rooms and classrooms within existing framing bents, and a sensitively designed and sited addition at the rear of the building to accommodate mechanical and kitchen needs.

The Tracy Barn and Woodshop will likely be rehabilitated as supporting facilities for the Residential Learning Center. Interiors of these buildings may be adapted to new uses; however, changes to the exteriors will be minimized to preserve the integrity of the historic setting. With the Complex integrated into more active and flexible use, the farm can provide a place of exceptional architectural and natural beauty for imaginative new partnerships and far-reaching collaborations with community, environmental, educational, and agricultural organizations and practitioners.

Aerial image of the Southern Acres with the Breeding Barn Complex.

# Conservation Planning

After decades of disuse and deferred maintenance, the Breeding Barn was in an advanced state of deterioration. Since reacquiring a portion of Southern Acres in 1994, Shelburne Farms has focused efforts on emergency treatment of the major buildings including structural stabilization of the Dairy Barn, installation of temporary roof coverings on the Dairy Barn and Tracy Barn, and reroofing of the Tracy House. Work to date on the Breeding Barn includes stabilization of the foundation along a portion of the north wall, repair/replacement of deteriorated structural elements, installation of a copper roof, upper story window repair, and installation of a fire detection and suppression system.

The Breeding Barn during emergency stabilization in 1994.

Shelburne Farms has been engaged in a planning process to address issues associated with reuse of the buildings. Reports on conservation planning for the Breeding Barn and associated landscape include:

1. Civil Engineering Associates. *Shelburne Museum Breeding Barn: Structural Evaluation.* 1990. This document includes a detailed conditions assessment and structural evaluation of the barn prior to transfer of the building to Shelburne Farms in 1994.

2. Hunt, V.R., O'Donnell, P., Tierney, M. *Shelburne Farms Historic Resources Assessment Report* and *Long –Range Conservation Plan for Historic Resources*, both based on information gathered during a 2001 farm-wide assessment (funded by a conservation grant from the Institute of Museum & Library Services). The studies provided general conditions summaries and identified priority projects for each building in the complex. The report further identified the need for more comprehensive analysis and documentation of all buildings as the next step in conservation planning for historic resources at Shelburne Farms.

3. Heritage Landscapes. *Shelburne Farms Landscape Stewardship Plan* (2004) built on the comprehensive assessment provided in *Shelburne Farms Historic Resources Assessment Report*, to develop a comprehensive plan for landscape stewardship and incremental recapture of scenic and historic landscape character.

4. Smith, Alvarez, Sienkiewycz. *Shelburne Farms Breeding Barn Complex Conservation Plan.* 2004. With the help of a Getty Conservation Grant, a detailed conservation assessment of the buildings and landscape of the Southern Acres complex was assembled that included historic documentation, detailed structural and conditions surveys, architectural and technical drawings, conservation plans, and preservation recommendations which helped to identify conservation needs of the Breeding Barn and six other buildings in the area.

# Conditions Assessment

The 1990 engineering assessment of the Breeding Barn called attention to overstress in the truss elements and identified several areas of deterioration, including decay in most of the valley members in the large dormers at the lantern and at either end of the riding ring, and in jack rafters and plate timbers in their vicinity.[9] The assessment called for repairs of deteriorated elements but stopped short of recommending augmentation of overstressed elements because of the impacts strengthening would have on historical integrity. Beginning in 1997, emergency stabilization measures were implemented that included repair or replacement of some of the structural iron and timber elements in the roof frame, replacement of the roof covering with standing seam copper, and installation of a fire suppression system.

Condition assessment of the riding ring roof, 2005.

Following completion of *Shelburne Farms Breeding Barn Complex Conservation Plan* in 2004,[10] a project team was assembled to conduct a detailed structural assessment of the building and prepare plans for its augmentation and repair. Goals of the structural investigation included determining as-built conditions and subsequent changes to the building structure and fabric, as well as current levels of deterioration. Specifically, investigators hoped to establish reasonable design values for structural ironwork, quantify section losses in decayed valley members, and address overstresses in the truss elements. The initial building inspection was preceded by a thorough examination of available archival resources, which include architect Robertson's original construction drawings of the building, historic photographs, and original specifications for related buildings on the estate.

The inspection team included the project manager, the project structural engineer, and three timber framers associated with the truss research group of the Timber Framers Guild. Data collected in this initial survey included information on element dimensions, species, quality, and condition, and graphic recording of deterioration and damage conditions.

The survey revealed that more detailed examination was necessary to determine the current condition of foundation stonework, the quality and condition of several of the iron structural elements, and the extent of decay in several of the timber elements. The team was most concerned with deterioration of several of the valley rafters and the columns around the riding ring and building perimeter resulting in local settlements, as well as the capacity of unbraced top chords in the major dormers. Valley rafters in particular exhibited varying levels of loss associated with decay, and in two cases there appeared to have been some dislodging of the timbers from their original positions at rafter apexes.

## Laser Scanning

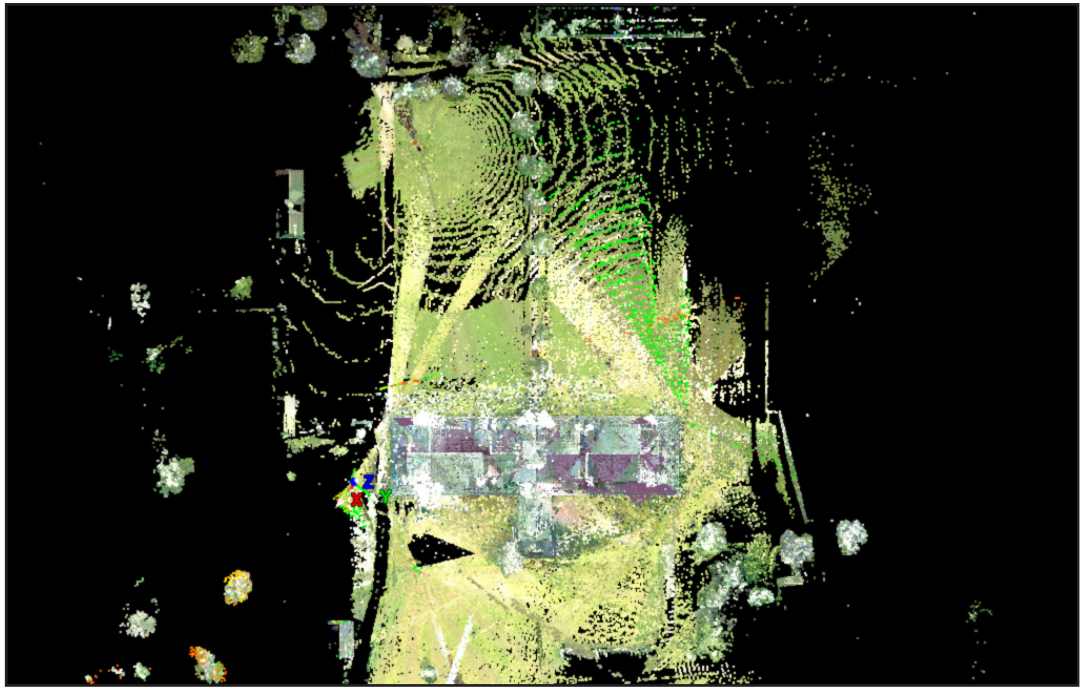
The design team felt it important to produce a set of HABS-level drawings to accurately record building displacements and differences between the building "as-built" and the original drawings. The Breeding Barn was scanned with a Leica HDS3000 3-D laser scanner at 4 mm resolution at a 3 m distance. Targets were placed to register overlapping common points and to combine data from several scanner locations. High-resolution panoramic photographs were taken to record the surfaces from each scanner location. A Sony D90 or D200 high definition camera and tripod were used to capture a 360° spherical image. Animations were created for each scanner location, and the HDR images were mapped to data surfaces to provide highly detailed 360-degree panoramas.

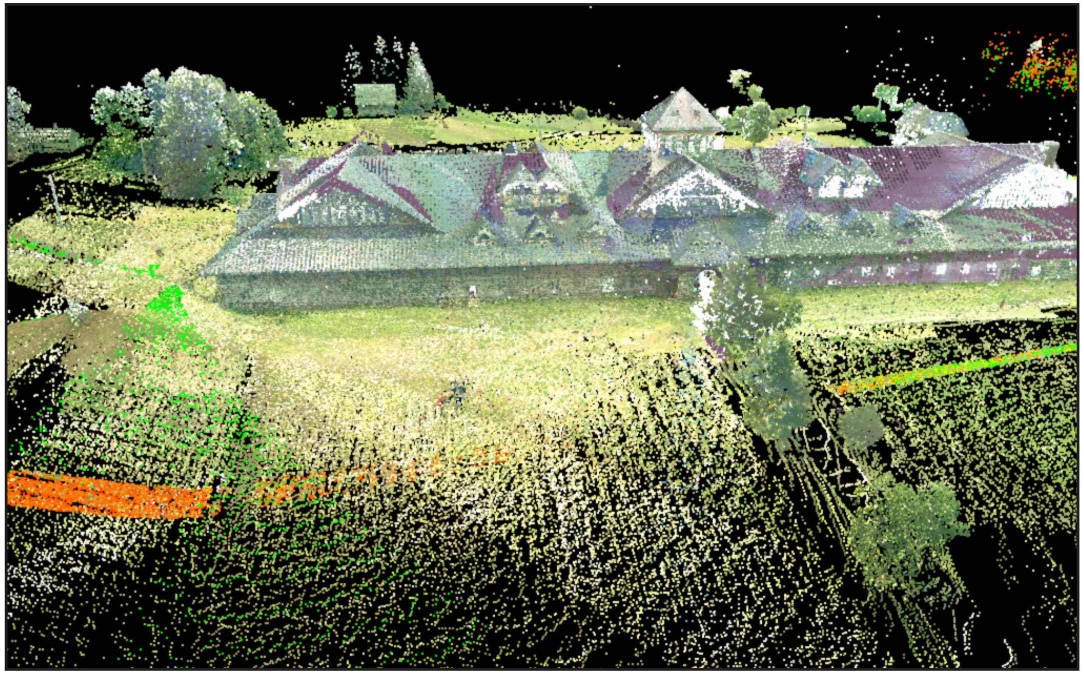
[9] Civil Engineering Associates. Shelburne Museum Breeding Barn: Structural Evaluation. 1990

[10] Smith, Alvarez, Sienkiewycz. Shelburne Farms Breeding Barn Complex Conservation Plan. 2004.

Cyclone software was used to align the separate scan data files and combine them into a single file. The combined data set was a measurable three-dimensional visualization of the interior spaces. A polygonal mesh surface was created from the point cloud data and the panoramic images were mapped on the surface. From the final data set for each space, volumetric, surface and distance information was extracted. Measured drawings were created and transferred into AutoCAD. The final documentation drawings were archived in the Library of Congress, Prints and Photographs Division [Appendix C].

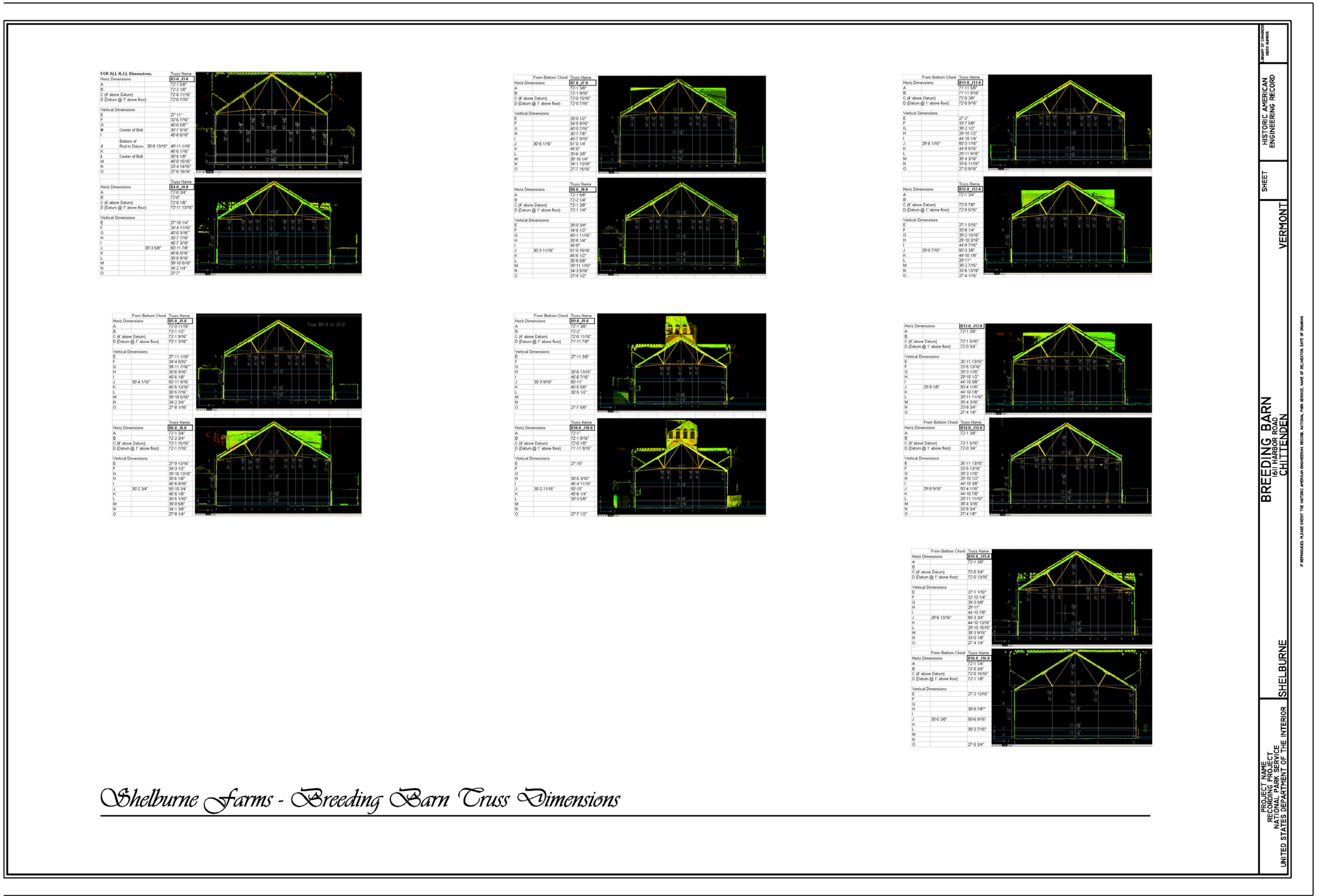
The data was provided to the project team in the form of section cuts at each truss with dimensions quantifying deflections; these provide a benchmark against which future structural movements can be measured. Deflections of iron lower chord elements were plotted against theoretical maximum deflections to calculate tensile stresses associated with dead loads.





Data cloud images of the Breeding Barn site (top) and north façade (bottom).

Point cloud sectios at each truss location with deflections.



## Foundation Stonework

The building foundation is of rubble or uncoursed ashlar construction, laid in a Portland-lime-sand mortar. Stonework consists primarily of red Monkton quartzite that may have been extracted from the quarry on the farm, with the inclusion of random fieldstones, particularly in the lower courses. Foundation layout was completed in August 1890,[11] and it is assumed that trenching and construction followed soon after.

Investigation of the foundation stonework began in 2006 with a condition assessment that revealed the stonework on the annex and on the east, west, and south façades of the main block to be in fair to good condition. Stonework on the northeast had been replaced with reinforced concrete above grade. On the northwest façade, a reinforced concrete counterwall had been added to the original foundation sometime in the 20th century. The counterwall was poorly detailed, and encased the timber sills and the bottoms of columns and studs. Most of the encased timber was decayed as a result, and there were visible displacements in the north wall frame.

Foundation settlement has been minimal. Test pits were dug on north, south and west sides of the main block to inspect subsurface conditions. In general, foundation stonework was placed bedrock or ledge at varying depths (typically 3-5 feet). Working with a consulting engineer and geotechnical faculty at the University of Vermont, foundation construction was documented, site soils were characterized, strength-in-shear was determined, and building loads were calculated [Appendix E]. It was determined that original foundations are substantial enough to support required loads.

Since construction of the barn, there has been one partial repointing campaign. Samples of the earliest pointing mortar were characterized (ASTM C1324) chemically and petrographically [Appendix F]. Mortar constituents are Portland cement, hydrated lime, and sand; volumetric proportions are calculated as 1.0 : 2.2 : 9.4 (Portland cement : hydrated lime : sand). Condition of the mortar ranged from good to poor, with losses concentrated in above-grade stonework at corners and below the many valleys in the dormered roof. However, it did not appear that the stonework on most of the building had ever been repointed, and it was the judgment of the design team that the mortar was reasonably durable, given the long period of performance.

Condition assessment of the barn foundation included test pits for subsurface inspection of foundation stonework, and the collection of geotechnical data.

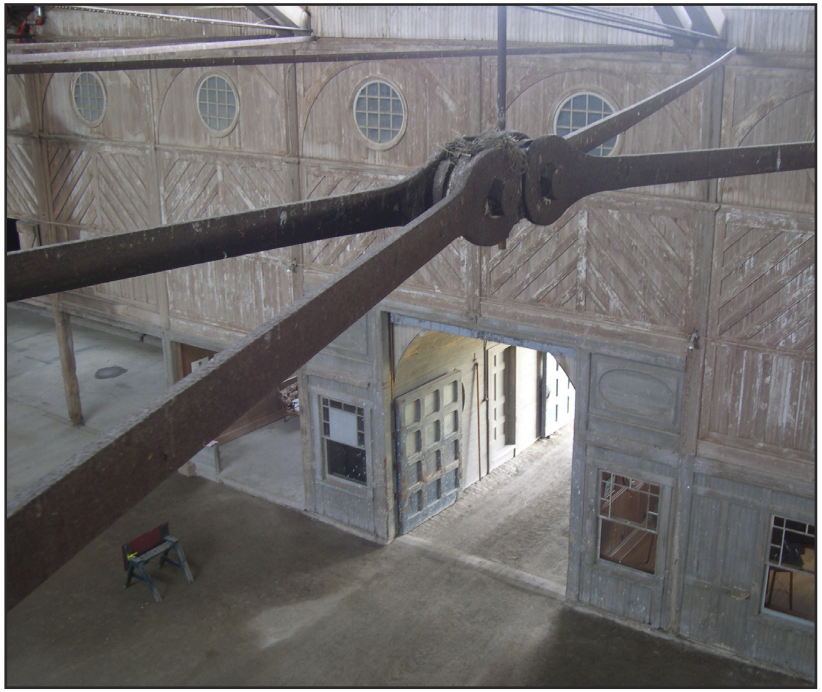
[11] Burlington Free Press, Aug 26, 1890

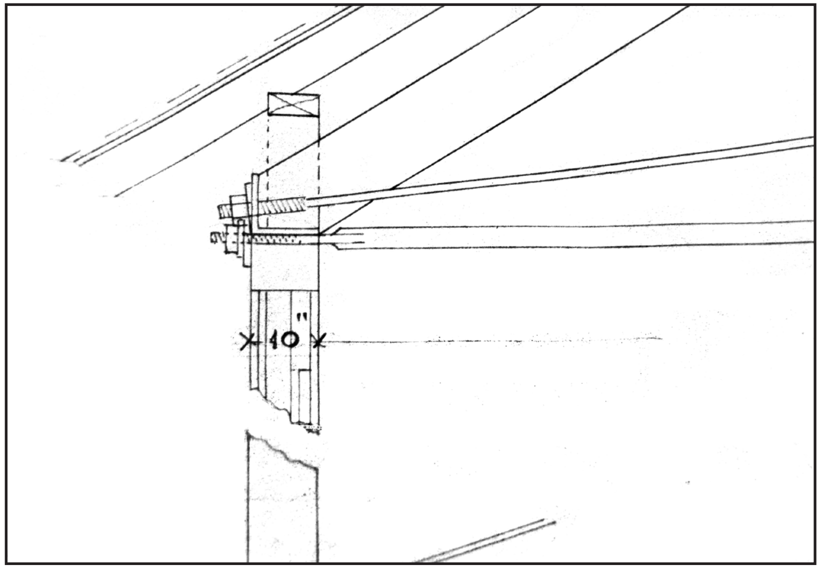
Clockwise from top right: cross-brace ties installed between each pair of trusses; section through the cast iron shoe at the heel connection of the truss; the strut-lower chord connections in the truss

## Iron Characterization

The CEA engineering analysis (1990) and the engineering update done for the 2004 conservation assessment both called attention to overstresses in iron tension elements in the principle truss and trussed purlins. Both studies were apparently conservative in assigning strength values because basic characterization of the iron and timber elements had never been completed.

Investigators hoped to establish reasonable design values for structural ironwork, and address overstresses in the truss elements. Each truss has wrought iron tension members and struts; a raised bottom chord of wrought iron completes the truss form. Tie connections consist of eyes that are forge-welded to the ties and pinned with iron, except at truss heels. Here, principal rafters are captured in cast iron housings that also receive the ends of tension members, which are threaded and captured with nuts. Tension across the lower chord can be adjusted to some extent by tightening or loosening the nuts. Threads and eyes are upset (larger in diameter than the bars to which they are attached) to counter stresses at connections, while being economical of material and reducing dead loads.[12]





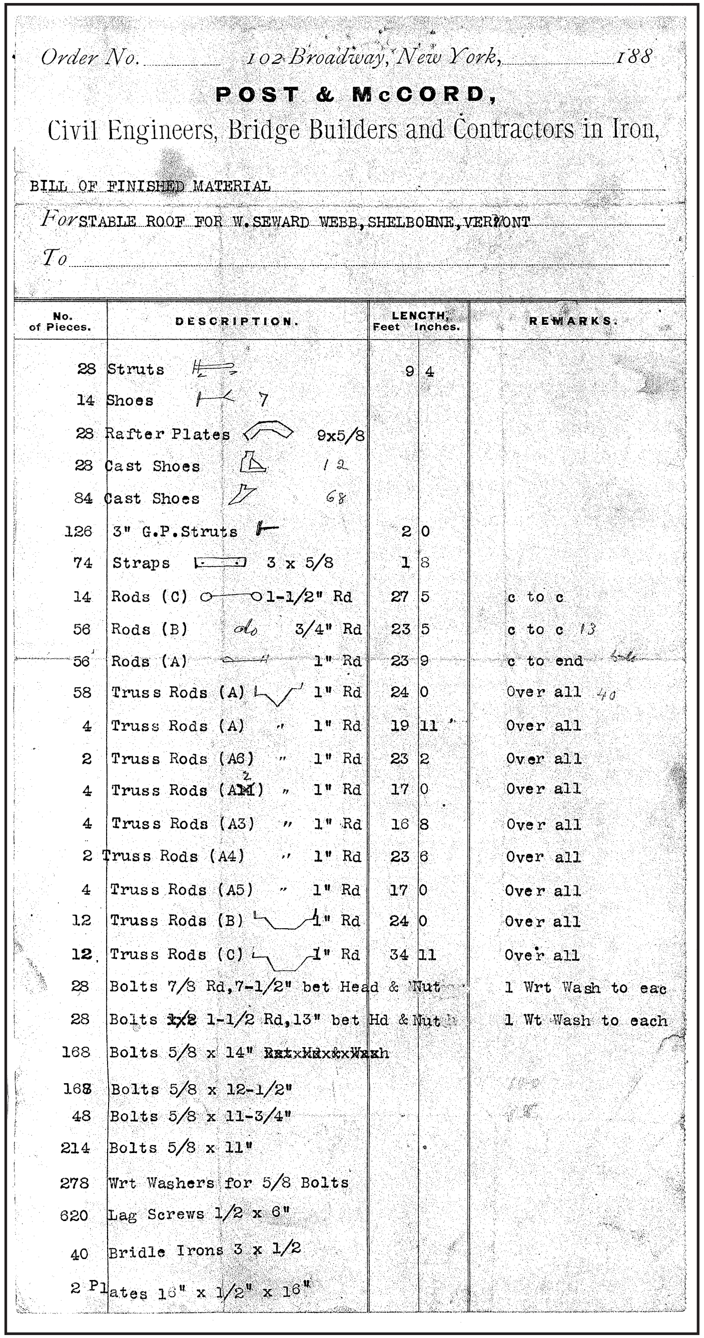

[12] Phoenix Iron Company. 1885. Useful Information for Architects, Engineers, and Workers in Wrought Iron. Philadelphia: Phoenix Iron Company, p. 90.

There are iron cross-brace ties between every principal rafter pair. These ties, made of rolled iron bars 3/4-inch by 3-inches, have upset threaded connections that terminate in cast iron shoes fastened to plate timbers behind truss heel connections. The cross-brace ties can be pre-tensioned by adjusting nuts at the connections.

Purlins and valley members are trussed with wrought iron ties across one (king-rod) or two (queen-rod) pipe struts. Tie rods have termination plates that are L-shaped in section and forge-welded to tie bars. Termination plates are let into dadoes plowed across trussed timbers and lagged. Pipe struts are threaded into bases, and tension in the truss rods can be adjusted by turning struts in or out of the base housings. Aisles have wrought iron king-rod and queen-rod trusses supporting timber purlins across which common rafters are lodged.

The firm of Post & McCord, one of the largest iron and steel fabricators in New York City, supplied the iron elements of the Breeding Barn roof frame. The firm was involved in the construction of a number of skyscrapers, including the Metropolitan Life Insurance Company Tower (1907-9) and the Empire State Building (1929-31), and the first firm in the world to use steam-powered derricks to raise iron in the construction of tall buildings.[13] Drawings and bills of materials produced by the company for the Breeding Barn project survive in the Shelburne Farms archives [Appendix B].

With the exception of angled struts and bolsters installed on top chords, dimensions of installed iron elements are the same as those specified in the original construction drawings. Visual inspection by the team metallurgist confirmed that forge welds in the



Order No. ........ 102 Broadway, New York, ........ 188

**POST & McCORD,**

Civil Engineers, Bridge Builders and Contractors in Iron,

BILL OF FINISHED MATERIAL

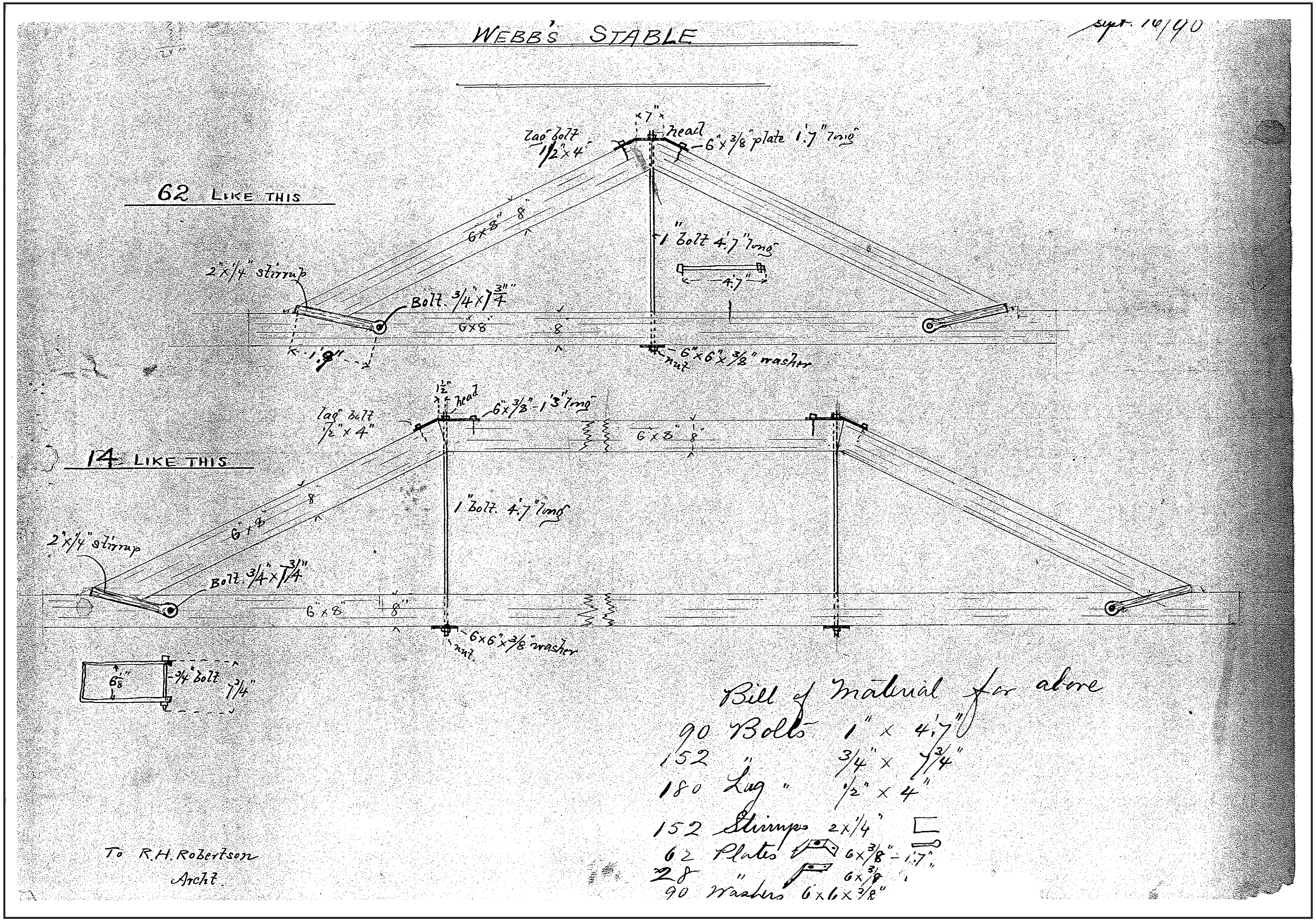
For STABLE ROOF FOR W. SEWARD WEBB, SHELBOHNE, VERMONT

To

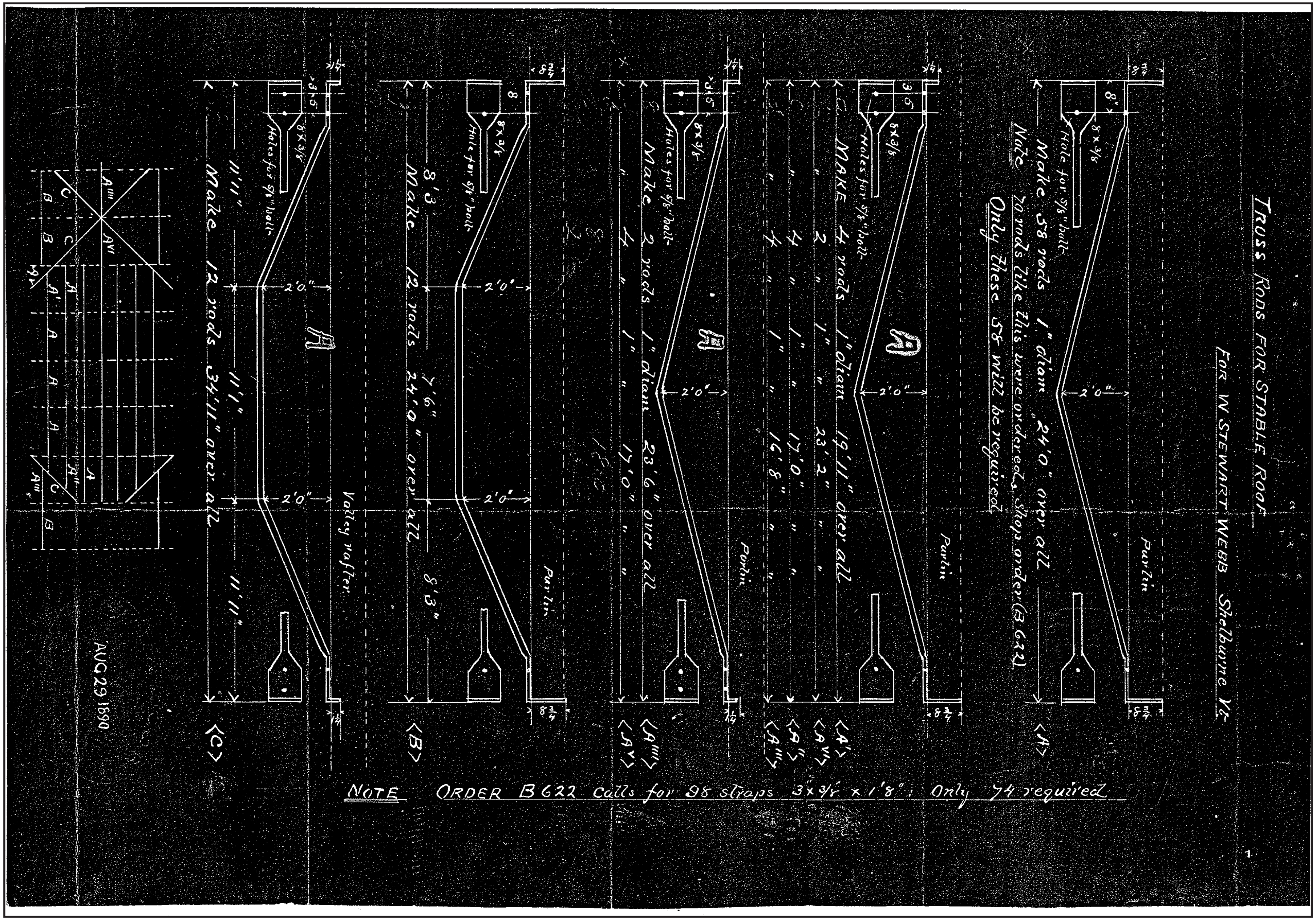
| No. of Pieces. | DESCRIPTION. | LENGTH, Feet | Inches. | REMARKS. |
|---|---|---|---|---|
| 28 | Struts | 9 | 4 | |
| 14 | Shoes 7 | | | |
| 28 | Rafter Plates 9x5/8 | | | |
| 28 | Cast Shoes 12 | | | |
| 84 | Cast Shoes 68 | | | |
| 126 | 3" G.P. Struts | 2 | 0 | |
| 74 | Straps 3 x 5/8 | 1 | 8 | |
| 14 | Rods (C) 1-1/2" Rd | 27 | 5 | c to c |
| 56 | Rods (B) do 3/4" Rd | 23 | 5 | c to c 13 |
| 56 | Rods (A) 1" Rd | 23 | 9 | c to end |
| 58 | Truss Rods (A) 1" Rd | 24 | 0 | Over all 40 |
| 4 | Truss Rods (A) " 1" Rd | 19 | 11 | Over all |
| 2 | Truss Rods (A6) " 1" Rd | 23 | 2 | Over all |
| 4 | Truss Rods (A~~1~~2) " 1" Rd | 17 | 0 | Over all |
| 4 | Truss Rods (A3) " 1" Rd | 16 | 8 | Over all |
| 2 | Truss Rods (A4) " 1" Rd | 23 | 6 | Over all |
| 4 | Truss Rods (A5) " 1" Rd | 17 | 0 | Over all |
| 12 | Truss Rods (B) 1" Rd | 24 | 0 | Over all |
| 12 | Truss Rods (C) 1" Rd | 34 | 11 | Over all |
| 28 | Bolts 7/8 Rd, 7-1/2" bet Head & Nut | | | 1 Wrt Wash to eac |
| 28 | Bolts ~~1x2~~ 1-1/2 Rd, 13" bet Hd & Nut | | | 1 Wt Wash to each |
| 168 | Bolts 5/8 x 14" ~~RatxHdx&xWash~~ | | | |
| 168 | Bolts 5/8 x 12-1/2" | | | |
| 48 | Bolts 5/8 x 11-3/4" | | | |
| 214 | Bolts 5/8 x 11" | | | |
| 278 | Wrt Washers for 5/8 Bolts | | | |
| 620 | Lag Screws 1/2 x 6" | | | |
| 40 | Bridle Irons 3 x 1/2 | | | |
| 2 | Plates 16" x 1/2" x 16" | | | |

Order form (left) and shop drawings (overleaf and following page) from Post & McCord, the New York firm that supplied ironwork for the Breeding Barn

[13] Landau, Sarah Bradford and Condit, Carl W. 1996. Rise of the New York Skyscraper 1865-1913. New Haven, CT: Yale University Press, p. 39.

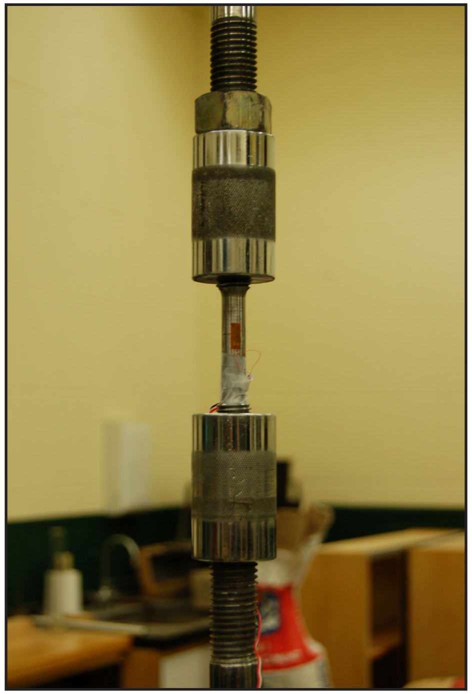


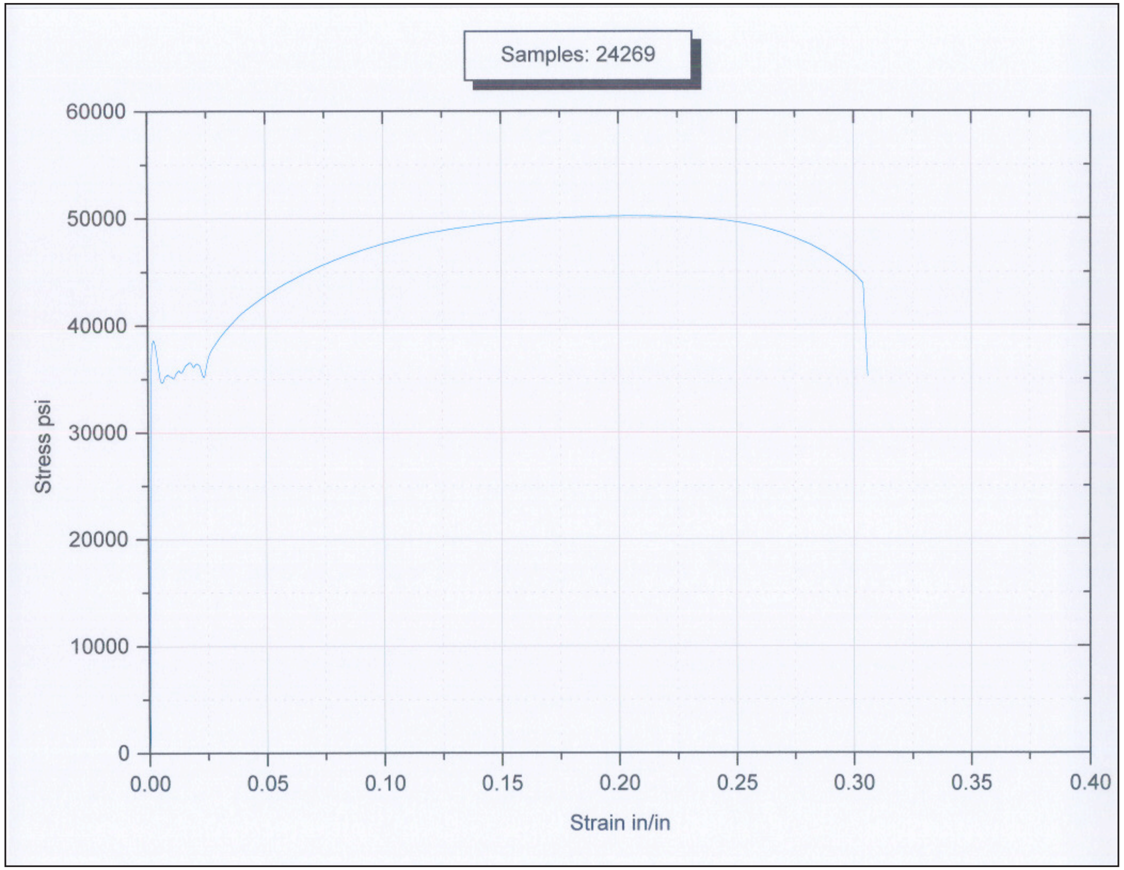
WEBB'S STABLE
Sept. 16/90
62 LIKE THIS
Lag bolt 1/2" x 4"
head
6" x 3/8" plate 1.7" long
6x8" 8"
1" Bolt 4.7" long
4.7"
2" x 1/4" stirrup
Bolt 3/4" x 7 3/4"
6x8"
1.9"
6" x 6" x 3/8" washer
nut
14 LIKE THIS
Lag bolt 1/2" x 4"
1 1/2"
head
6" x 3/8" - 1' 3" long
6x8" 8"
1" Bolt 4.7" long
2" x 1/4" stirrup
Bolt 3/4" x 7 1/4"
6 x 8" 8"
6x6" x 3/8" washer
nut
6 1/8"
3/4" bolt
7 1/4"
Bill of Material for above
90 Bolts 1" x 4.7"
152 " 3/4" x 7 3/4"
180 Lag " 1/2" x 4"
152 Stirrups 2 x 1/4"
62 Plates 6 x 3/8" - 1.7"
28 " 6 x 3/8"
90 Washers 6 x 6 x 3/8"
To R.H. Robertson Archt.

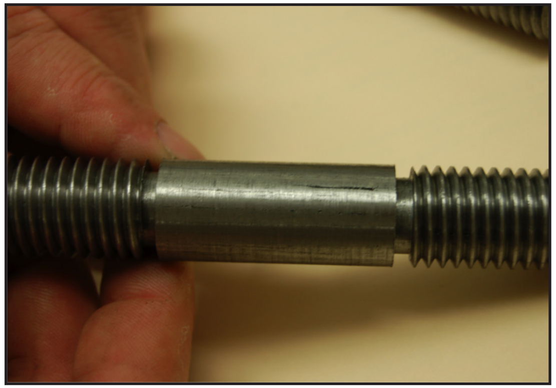

TRUSS RODS FOR STABLE ROOF
FOR W. SEWARD WEBB Shelburne Vt.
Make 58 rods 1" diam. 24'0" over all
Note 70 rods like this were ordered, shop order (B 632)
Only these 58 will be required
MAKE 4 rods 1" diam 19'11" over all
" 2 " 1" " 23'2" " "
" 4 " 1" " 17'0" " "
" 4 " 1" " 16'8" " "
Make 2 rods 1" diam 23'6" over all
" 4 " 1" " 17'0" " "
Make 12 rods 24'0" over all
Make 12 rods 34'11" over all
Holes for 5/8" bolt
Purlin
Valley rafter
NOTE ORDER B622 calls for 98 straps 3"x3/8" x 1'8": Only 74 required
AUG 29 1890

Strength-in-tension tests were conducted in the Materials Lab, School of Engineering, University of Vermont on sample coupons collected from the Breeding Barn roof

tension elements were generally in good condition, and that heel connections were intact and in good condition. Samples were obtained from iron truss rods that were shortened when trusses were added at east and west dormer locations. The samples were large enough for conducting strength-in-tension tests (ASTM A 370-97a) of the iron at the Materials Lab in the School of Engineering at the University of Vermont. Values obtained for the four samples tested indicated an average yield strength of about 33.2 ksi, an average maximum tensile strength of 47.3 ksi and a MOE of 30.2 Mpsi, which compare relatively well to design values in period codes and design manuals.[14]





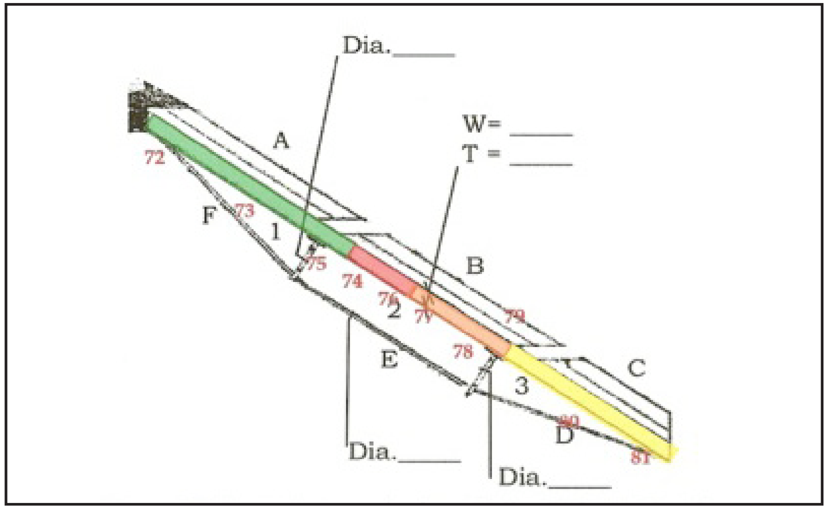
[14] cf., Tredgold, Thomas. 1860-1. Practical Essay on the Strength of Cast Iron and other Metals. London: John Weale. Also, Hudson, Ralph G. 1939. The Engineer's

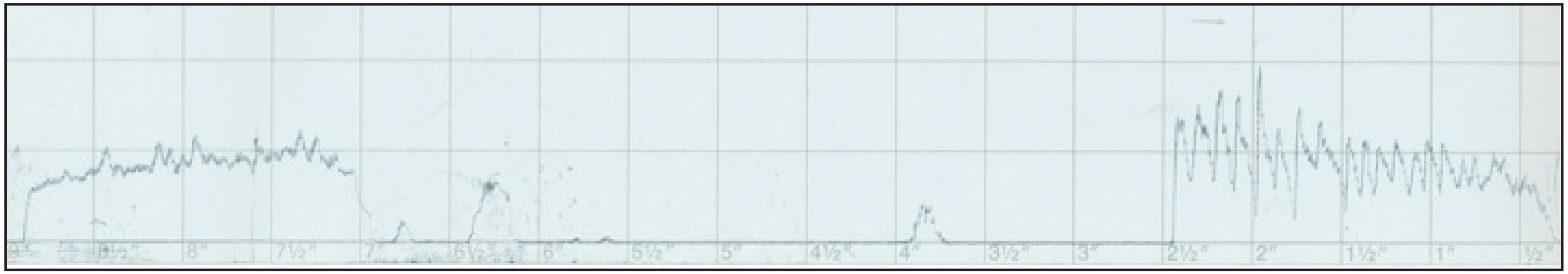
## Timber Investigation

Deterioration of timber elements in the roof frame was caused by failure of the roof covering, particularly around the main dormer valleys. Valley members were affected, as well as columns supporting them and proximate aisle framing. Given the decay patterns, it is likely that water entering the building along main dormer valleys followed rafters to plates and column joinery below. In an earlier repair campaign, steel channels were installed on the valley members as a strengthening measure. Addition of the steel channels necessitated shortening of purlins terminating at the valleys. Most of the purlins were reattached using bolted plates, except at dormer locations. Here, purlins were removed and trusses located at the centers of each major dormer pair were left without bracing. The steel channels bolted to either side of each valley member prevented direct examination of those surfaces.

To quantify the extent of deterioration, a systematic survey was conducted using a resistance drill (IML-RESI System). Resistance drilling is a quasi-nondestructive technique for determining the relative density of wood, identifying discontinuities and quantifying the extent of section loss in the process. The drill measures and records the torque encountered by the motor as a small-diameter needle advances into the wood. The needle does not remove material in the manner of a drill bit; rather, only a small amount of wood fiber is displaced as the needle is pushed through the wood. In most cases the drill sites are difficult to locate once the needle has been removed. Resistance drilling was especially useful in evaluating valley members, where installation of reinforcing steel channels prevented direct examination.
Timbers were drilled in the radial and transverse directions along their length in order to characterize decay patterns and quantify section loss. Of the twelve timbers examined, five had substantial section losses due to decay. With three of the valley members, losses appeared as decay channels located in the upper half of the timber section, probably the result of water leaking through the roof and finding its way into drying checks. Two of the members were severely deteriorated at rafter heels, where they bear on timber plates in the walls surrounding the riding ring.

Results of resistance drilling tests indicating the extent of section loss at each of the drill sites were expressed graphically and in tabular form. Color-coding the graphics allowed for easy identification of problem areas in each timber. By locating and quantifying material loss, resistance drilling permitted detailed design of timber repairs prior to dismantling the affected portions of the building [Appendix H].

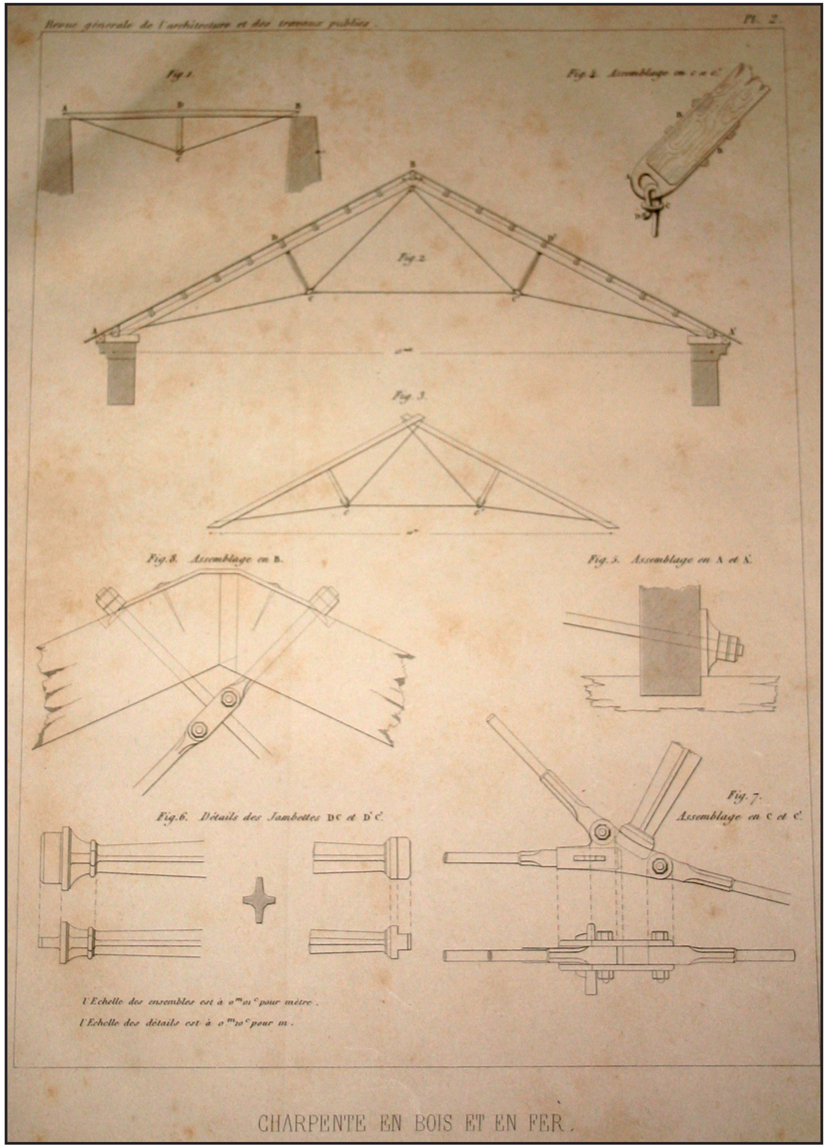



The investigator is using a resistance drill to locate and measure voids in a valley member (top). Note the steel channels that prevent drilling except at the top and bottom of the member. The sample resistograph strip (bottom) indicates a void about 4½-inches in width near the middle of the member. Graphic presentation of resistance drill results for the valley member at 11.0 South (left). The color-coding indicates levels of damage.

# Modeling and Analysis

Designed for the Paris-Versailles Railroad in 1837, Polonceau published a monograph on the truss form under the title “Notice sur nouveau système de charpente en bois et fer,” (Revue Générale de l’Architecture et des Travaux Publics). This plate appeared in the original publication and details the adjustable connections at the ridge and rafter ends.




The procedure for evaluating the Breeding Barn involved applying current code-mandated snow, live, and wind loads to various component systems, assuming that no deterioration has occurred. In this way, the original structure could be tested with specific design load criteria, against reasonable allowable design values with the amount of overstress tabulated for various elements.

We performed plane frame computer analyses, where the stiffness in the various components was included, resulting in accurate theoretical deflections. The computed dead and live load deflections were then compared to current code-mandated limits for roof structures. As-built capacities as determined through structural analysis were collated with findings of the condition assessment (field observation, measurement, and testing) and, using engineering judgment, the capacities of the various components were tabulated accounting for deterioration.

The production of a set of measured drawings of the structural elements, based on the original R.H. Robertson drawings and data collected by 3-D laser scanning of the building, established the original configuration of the building “as built”. The team reviewed the original plans to determine the impact on the analysis of various elements, and field-verified the dimensions of individual elements. The structural elements of primary interest in the Breeding Barn are the principal trusses, purlins and valley rafters.

For the riding ring roof Robertson selected a truss form originating with Camille Polonceau, and commonly used in railroad construction during the latter half of the 19th century. Designed for the construction of the Paris-Versailles railroad, the truss form featured economy in the use of wood, room below the raised center chord, lightness, ease of assembly, and could be adjusted by tightening nuts at the heel connections.[15] The truss came to be very popular for medium to large spans[16] and by the late 19th century, graphical analyses of the truss form were common in books on roof and bridge trusses.

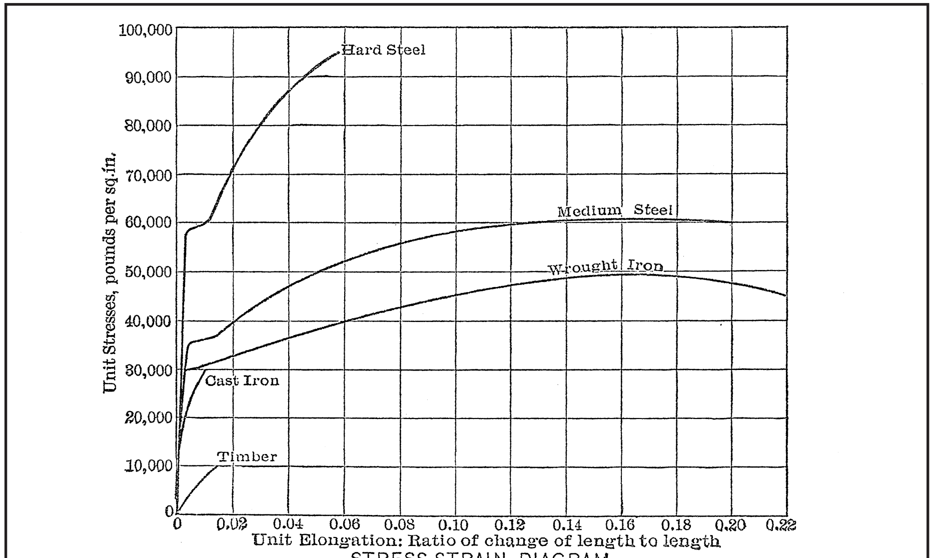
Among the advantages associated with the use of the truss in the Breeding Barn are the lightweight construction considering the span, the amount of light reaching the barn floor, and the incredible volume of this room. At the time Robertson completed his design, the truss was thought to be “more economical of material than any other form”[17], a characteristic the architect was able to put to good use. With the ironwork painted white and receding from view in the limewashed riding ring, he was able to convey the impression of a traditionally framed timber building with an enormous open volume below the timber rafters.

[15] Polonceau, C. Notice sur nouveau système de charpente en bois et fer. Revue Générale de l’Architecture et des Travaux Publics. 1840.

[16] Holzer, Stefan. The Polonceau roof and its analysis. *International Journal for the History of Engineering and Technology*. Vol. 80 No. 1, January 2010. 22-54.

[17] Unwin, p.122

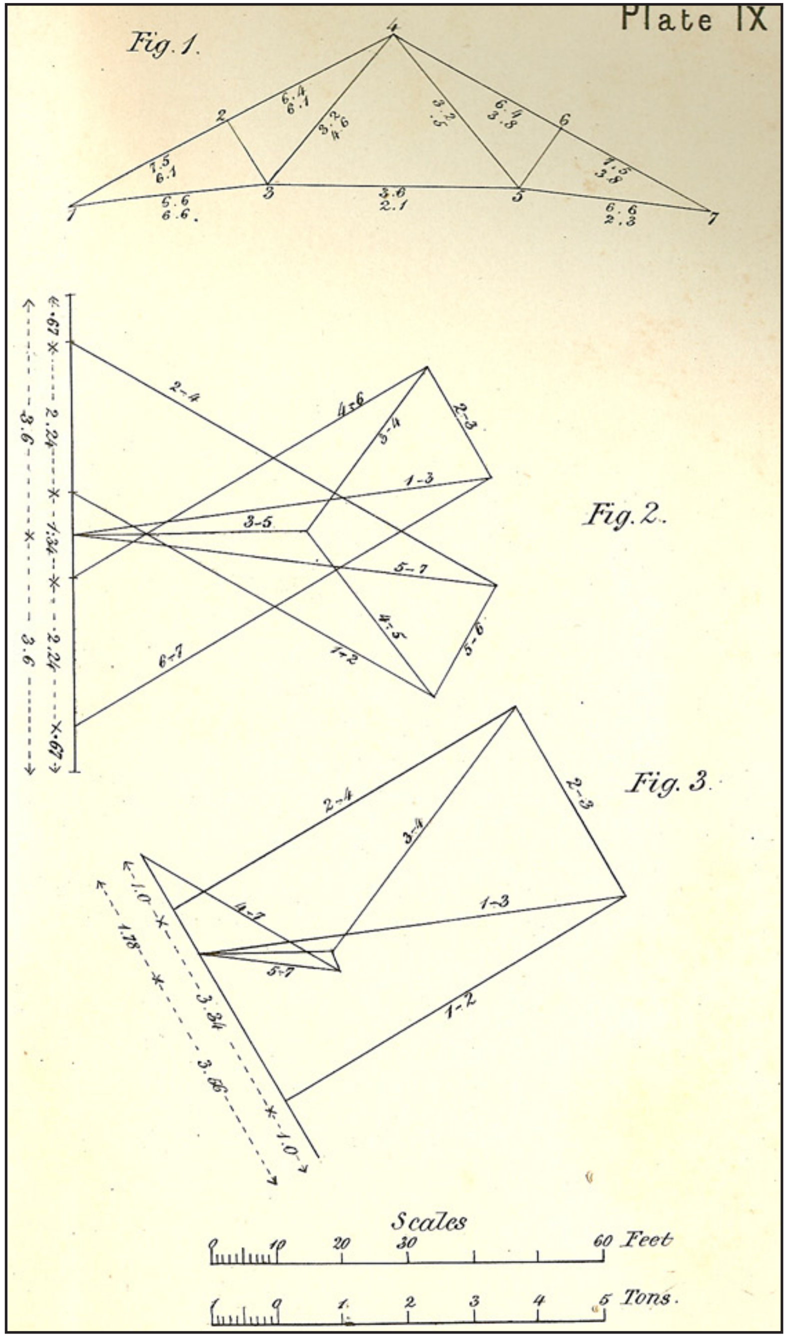
Preliminary analysis of the principal truss was performed with a 30 psf snow load and 15 psf dead load. The analysis indicated that there are overstresses in the top chord as well as the truss rods that extend from the heel supports to the struts. It is possible that the original designer may have failed to predict overstress in the 10-inch by 12-inch top chord by analyzing the truss using graphical means (a force diagram and string polygon). First developed in the United States by Col. Stephen H. Long in the 1840s, this method of analysis provides only axial member forces and is fairly accurate for trusses where purlin loads are applied to panel points. In the case of the Breeding Barn, however, the top chord on each side of the principal truss has reactions from purlins applied midway between panel points.[18] Apparently, this truss evolved from a simple truss analyzed by graphical means, to one with purlins located between joints. The computer analysis has tremendous advantages over traditional methods of analysis. Stiffness and continuity of various truss members can be accounted for as well as slight variations in truss geometry where the centroids of members do not converge at a single joint.



STRESS-STRAIN DIAGRAM

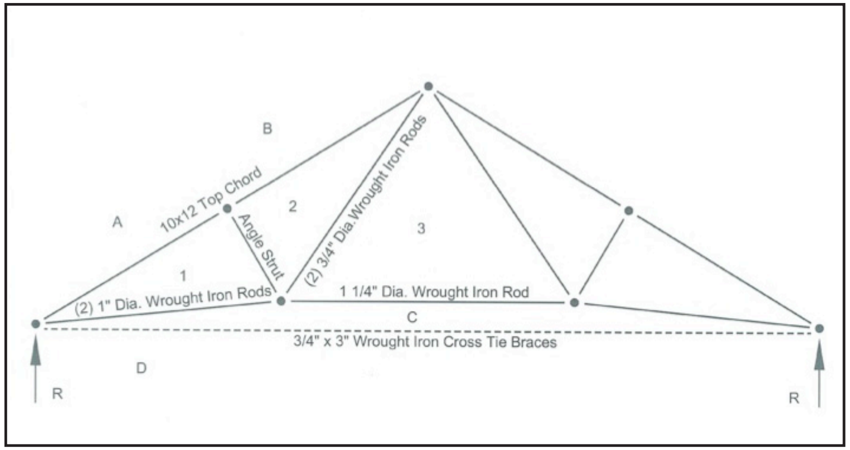
[18] To analyze the truss as component in its simplest form, certain assumptions are required for graphical analysis, the method of joints, and the methods of moments and shears. Primary axial stresses are obtained on the basis of simplifying assumptions, producing an ideal truss with members having only axial forces. The following assumptions are made to allow the truss to be analyzed:

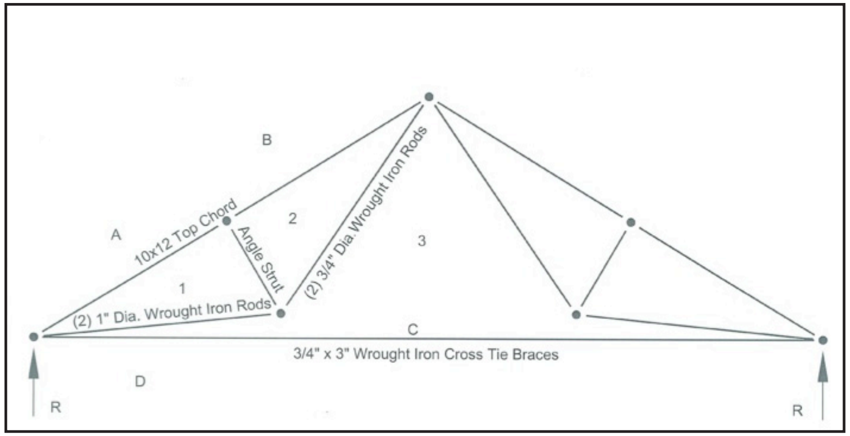
- The truss members are connected together with frictionless pins.
- Truss members are straight and the axes of the members intersect at joints.
- Deformations under load do not excessively change the basic truss geometry.
- Loads and reactions are applied only at joints.




Test values for the iron compare relatively well to design values in period design books (left); By the time Robertson designed the Breeding Barn, graphical analyses of the Polonceau truss appeared commonly in design books, like this one from Unwin (right).

Computer models were constructed of the truss alone (top), and of the truss with the cross-brace tie substituted for the center tie (bottom). Analysis of the primary truss indicated overstresses in bottom chord elements. Adding the cross-brace tie, which Robertson apparently did sometime during construction, reduced stresses in iron and timber elements.




In a simple plane frame analysis of the truss only, the 1-inch diameter rods are stressed to a $f_T$= 36,057 psi [Appendix J]. This is very high when compared to a tabulated elastic limit of 30,000 psi and ultimate strength in tension of 50,000 psi.[19] Although the stresses for wrought iron components are high, all but one component are close or within range of the 25,000 psi to 30,000 psi elastic limit published in period handbooks.

By using ultimate published values for clear wood specimens [20] reduced by a factor of 4.0, the top chord of the truss almost checks out with 6% overstress. The static bending modulus of rupture and the maximum crushing strength in compression parallel to grain for clear straight-grained specimens of Loblolly pine, divided by a factor of safety of 4.0 will yield values of Fb=3,200 psi and Fc=1,782 psi.

The wrought iron angles used to bolster the spliced top chord is an interesting detail. These may have been added as an afterthought, sometime during design, to reinforce the top chord acting as a two-span beam supporting purlins at the midpoint of both spans. Although it certainly was possible to obtain southern pine in 40-foot lengths to produce a two-span continuous top chord, the designers chose to splice the top chord directly above the bolster angles.

Given the high stresses in some of the iron truss rod elements, the primary issue in analyzing the principal truss was to determine the path of the horizontal tensile force in the roof. This was also the goal of load tests of the truss at gridline 11.0.[21] A second computer model was constructed, substituting the very substantial cross-brace ties that connect every truss pair for the center iron tie in the truss. Member forces derived from analyses using the same unit loads were compared to the results of the load test.

[19] Results of strength-in-tension tests of four samples collected from the barn yielded an average elastic limit of 33,150 psi and an average ultimate strength in tension of 47,330 psi. These samples were collected from cut-offs of truss rods installed in the original construction of the barn roof.

[20] Wood Handbook: Agriculture Handbook No. 72, USDA, Forest Products Laboratory. 1987.

[21] Load test data is included in Appendix J.

[22] A set of Robertson's drawings for the Breeding Barn survive in the Shelburne Farms archives; copies of the originals are included in this report [Appendix B]. This drawing set includes a roof framing plan and a transverse section that do not portray the cross-brace ties, as well as a roof framing plan and section at the lantern that include the ties. The cross-brace ties do not appear on the surviving order for truss and purlin ironwork placed with Post & McCord, the iron supplier, in December 1890. However, it is clear that the cross-brace ties were installed as part of the original construction campaign and appear in the earliest photographs of the unfinished barn interior. It seems possible that Robertson amended the drawing set during construction, perhaps in response to unacceptable deflections in the frame.

The load tests employed two loading scenarios consisting of 1000-lb. and 2000-lb. (force) unit loads suspended from purlins and panel points. Vibration testing and strain gauge measurements were used to measure changes in strain in bottom chord elements. In both loading scenarios, measured strains were substantially lower than values based on the original model, tending to confirm modeling scenarios in which horizontal forces are managed by cross-brace ties (supplemented by aisle framing). The test added credence to the thesis that R. H. Robertson added the cross-brace tie rods to the basic truss configuration sometime during construction,[22] thus reducing horizontal and vertical deflection and reducing the stresses in both the original wrought iron elements and timber top chord.

Axial loads in lower chord members and cross-brace ties were also measured using vibration testing.[23] Tensile forces were calculated on the basis of resonant frequencies measured in each member. Cross-brace ties were found to have significant tensions in dead load conditions. Computer models were used to predict member forces associated with snow load. While factors of safety were found to be low for some members, so long as the stresses in wrought iron members are within the elastic limit when reasonable design loads are applied, the Breeding Barn is not in danger of collapsing. In addition, factors of safety for the cross-brace ties are reasonably high.

**Table 5.15: Factors of safety for principal truss #11 members predicted by adding the experimental dead loads to the 2-D snow model results**

| Member # | Principal Truss Axial Load (lbs) | | | | Yield FOS |
|---|---|---|---|---|---|
| | Experimental | VA 2D | Superposition 2D | Yield | |
| 11 E,W | 5,000 | 16,450 | 21,450 | 24,350 | **1.14** |
| 12 | - | 20,400 | - | 54,780 | **-** |
| 13 E,W | 4,750 | 16,700 | 21,450 | 24,350 | **1.14** |
| 15 E,W | 4,500 | 7,400 | 11,900 | 13,695 | **1.15** |
| 16 E,W | 3,750 | 7,100 | 10,850 | 13,695 | **1.26** |

**Table 5.16: Factors of safety for principal truss #11 members predicted by adding the experimental dead loads to the 3-D snow model results**

| Member # | Principal Truss Axial Load (lbs) | | | | Yield FOS |
|---|---|---|---|---|---|
| | Experimental | VA 3D | Superposition 3D | Yield | |
| 11 E,W | 5,000 | 3,845 | 8,845 | 24,350 | **2.75** |
| 12 | - | -3,200 | - | 54,780 | **-** |
| 13 E,W | 4,750 | 3,910 | 8,660 | 24,350 | **2.81** |
| 15 E,W | 4,500 | 5,700 | 10,200 | 13,695 | **1.34** |
| 16 E,W | 3,750 | 5,750 | 9,500 | 13,695 | **1.44** |

**Table 5.17: Factors of safety for principal truss #11 members predicted by adding the experimental dead loads to the 1-side loaded 3-D snow model results**

| Member # | Principal Truss Axial Load (lbs) | | | | Yield FOS (1 sided loading) |
|---|---|---|---|---|---|
| | Experimental | VA 3D (1-sided loading) | Superposition 3D (1-sided loading) | Yield | |
| 11 E,W | 5,000 | 4,965 | 9,965 | 24,350 | **2.44** |
| 12 | - | -1,100 | - | 54,780 | **-** |
| 13 E,W | 4,750 | -600 | 4,150 | 24,350 | **5.87** |
| 15 E,W | 4,500 | -85 | 4,415 | 13,695 | **3.10** |
| 16 E,W | 3,750 | 5,900 | 9,650 | 13,695 | **1.42** |

**Table 5.18: Factors of safety for the x-brace members predicted by adding the experimental dead loads to the 3-D snow model results**

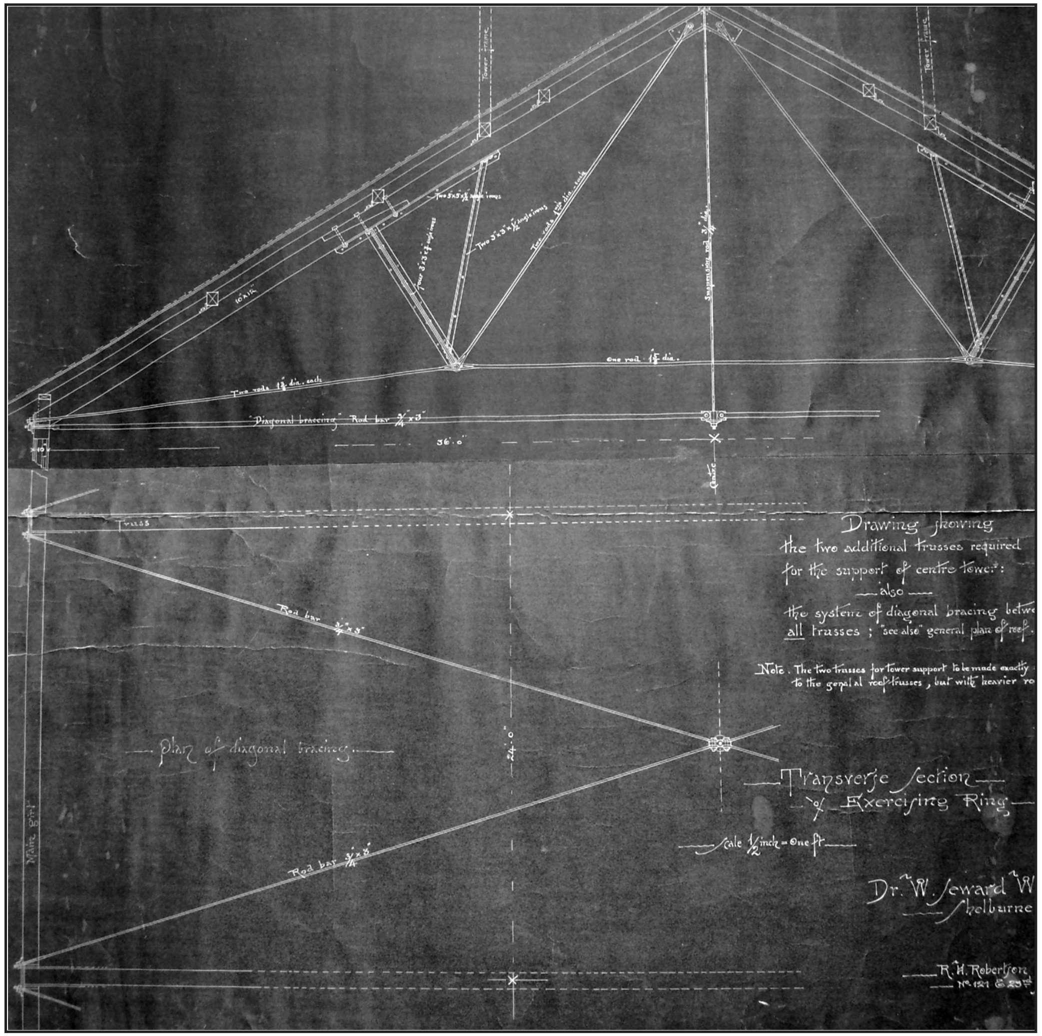
| Member # | X-Brace Member Axial Loads (lb) | | | | Yield FOS |
|---|---|---|---|---|---|
| | Experimental | VA 3D | Superposition 3D | Yield | |
| 1 | 9,000 | 10,800 | 19,800 | 69,750 | **3.52** |
| 2 | 10,500 | 10,200 | 20,700 | 69,750 | **3.37** |
| 3 | 10,000 | 10,200 | 20,200 | 69,750 | **3.45** |
| 4 | 8,500 | 10,700 | 19,200 | 69,750 | **3.63** |
| 5 | 9,500 | 10,800 | 20,300 | 69,750 | **3.44** |
| 6 | 9,400 | 10,200 | 19,600 | 69,750 | **3.56** |
| 7 | 11,500 | 10,200 | 21,700 | 69,750 | **3.21** |
| 8 | 8,300 | 10,700 | 19,000 | 69,750 | **3.67** |

[23] Ernst, M. Assessment of the Breeding Barn roof structure using truss member resonant frequencies and computer modeling. Master's thesis, School of Engineering, University of Vermont. 2009.

Load tests and direct measurement of axial loads in iron truss elements and cross-brace ties confirm that lateral stresses in the roof frame are resisted by the cross-brace ties that Robertson added sometime during construction.

The addition of ¾-inch thick by 3-inch high cross-brace ties to the building, apparently during construction, provides another path for the tensile force to be resisted. By including the cross-brace ties in the analysis of the building cross section, the center tie bar of the truss becomes a zero force member.

Computer analysis of the roof truss using the appropriate section properties and material stiffness reveals that immediate horizontal deflection under dead load only would have been a total of 2 inches. This deflection of the trusses would have manifested itself in bending of the 10-inch by 10-inch post from a point at the horizontal chord of the roof trussed above the side aisle to the 8-inch by 10-inch girt (sill) at the heel of the truss, a distance of about 8 feet. Certainly, a horizontal movement of 2 inches would have been observed in the posts. If the annex had already been built or partially framed, it would have provided some restraint, pushing most of the deflection towards the posts along the north side of the building, which certainly would have been observed by workmen. The answer was to provide additional ties to limit the movement that is natural in a truss with a raised bottom chord. In providing these ties R. H. Robertson transformed the building cross section into a tied A-frame with trussed rafters.




Robertson's transverse section at the lantern, apparently added to the drawing set sometime during construction, showing the addition of cross-brace ties and modest upsizing of lower chord elements in the lantern trusses. For additional information on the drawing sequence, see Appendix B.

## Conservation Philosophy

The Breeding Barn is in a jurisdiction subject to the Boca National Building Code/1999, which allows for performance-based compliance exceptions in the case of historic buildings. The code has been used in establishing required live loads for the building. In managing the historic landscape and buildings of the estate and adapting them to new uses, Shelburne Farms is broadly guided by the Secretary of the Interior's Standards for Rehabilitation. Because of the significance and integrity of the Breeding Barn, and its importance in the history of the development of structural form (modern use of light-weight trusses for large spans, modular framing, and use of iron in structural applications), the project team was additionally guided by the ICOMOS Principles for the Preservation of Historic Timber Structures, and the ISCARSAH Principles and Guidelines.

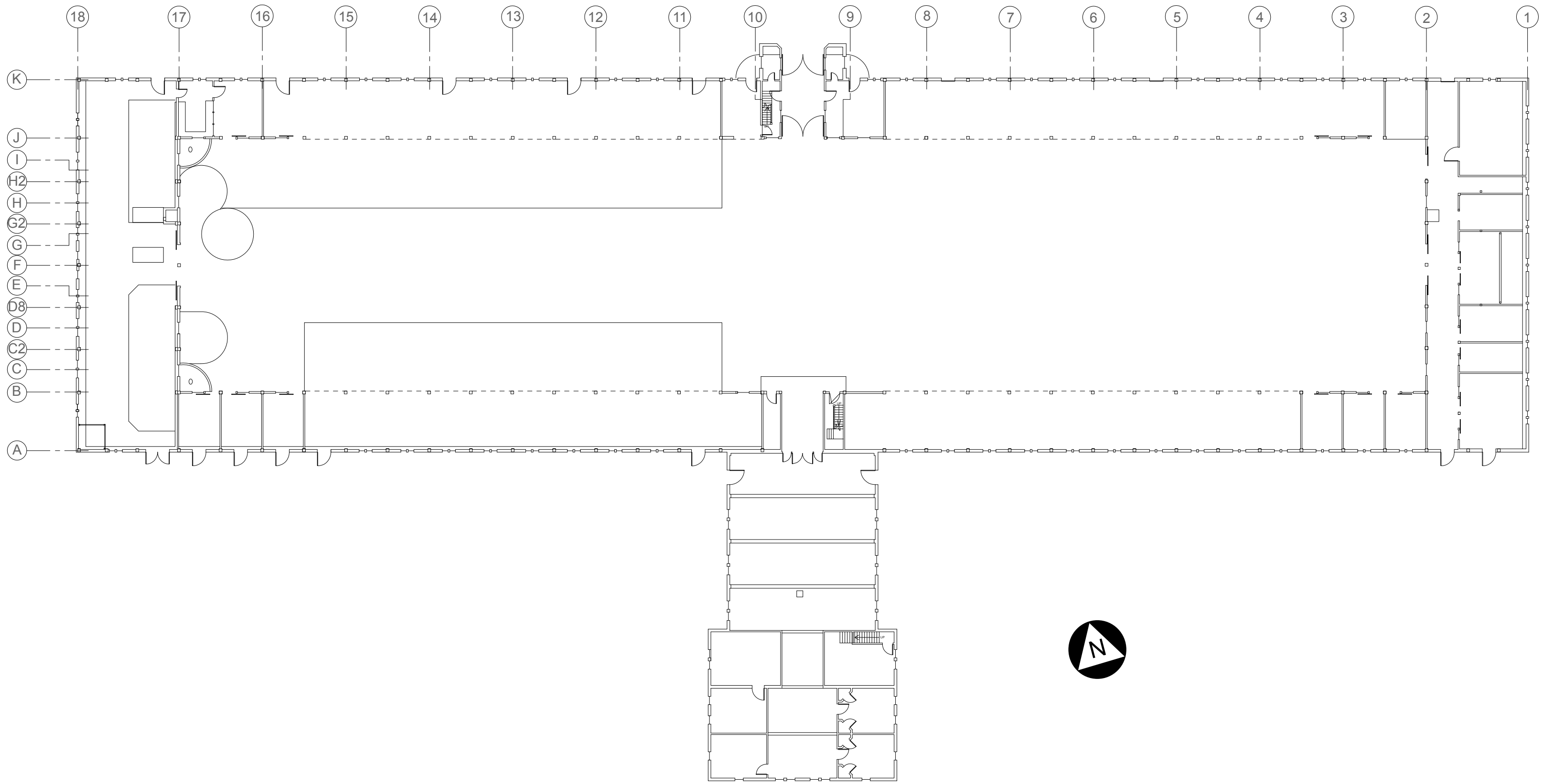
In conducting our investigation and developing repair strategies, the project team determined that fabric interventions should be as conservative as possible, the historic structural system should be preserved to the fullest extent possible, and that traditional repairs with proven and predictable performance records are preferable to introducing new materials and technologies so long as public safety requirements are met. To design an intervention program that meets structural goals and guarantees public safety while having the smallest possible impact on surviving fabric, the project team focused on accurate and detailed examination of surviving fabric to discover the nature and condition of materials and connections;

- Characterization of timber and metal elements using non-destructive and quasi non-destructive testing techniques to the fullest extent possible;
- Rational selection of design values based on the conditions survey, materials testing, and review of the original construction documents and original design methodologies;
- Reduction of factors of safety through exhaustive study and knowledge of the building systems and materials;
- Identification of overstresses through detailed modeling and analysis;
- Careful consideration of programmatic solutions to address structural deficiencies to minimize fabric interventions;
- Development of a HABS-level documentation (to be contributed to the Library of Congress upon completion of the project).

# Repair Strategies

Structural analysis of the Breeding Barn reveals that the building was originally well designed, so that stabilization efforts could focus primarily on repair and conservation of deteriorated fabric and reinstatement of missing elements. The principal conservation methods address repair and conservation of historic stonework, repair of deteriorated structural woodwork, retention of original roof frame elements, and reinstatement of missing iron elements.[24]

Ground level plan with grid overlay




[24] Beginning in 1995, Shelburne Farms undertook emergency stabilization of the Breeding Barn that included replacement of the roof covering with standing seam copper, and repair of upper level windows, dormer and tower siding, and woodwork above eaves level. As a result, rates of deterioration have been enormously reduced. Below the eaves, building envelope elements have not been maintained in decades. These include shingles and other siding, windows, doors, and casings and wood trim. As part of the building investigation, treatment strategies were developed for these elements; implementation is scheduled for a subsequent phase.

### Foundation Stonework

On the barn site, the depth of a rocky subsurface layer suitable for placement of building foundations increases from west to east. On the west façade, and for much of the north and south façades, foundation stonework is placed directly on bedrock. To the east, stonework is placed at sufficient depth to resist frost, and vertical movement has been negligible. Displacement of foundation stonework seemed to be largely the result of damage caused by snowplows and farm machinery. The worst example of this condition was found at the northwest corner of the building, where several of the large cornerstones had been dislodged.

During the latter half of the 20th century, significant changes were made to the foundations on the north façade. East of the main entrance (K 1.0-9.0),[25] above-grade stonework was replaced with a reinforced concrete grade beam placed directly on the original subsurface stonework. West of the entrance, a reinforced concrete counterwall was added to foundation stonework on the building exterior, above and below grade, and a concrete curb was added against the timber sill on the interior. The counterwall and curb (K 10.0-17.0) encased structural woodwork and created a route for funneling water into the building. Sills, posts, and studs on the northwest perimeter wall were severely decayed as a result and there were visible displacements in the north wall frame.

Principal constituents of the original mortar are Portland cement, hydrated lime, and sand; volumetric proportions are calculated as 1.0 : 2.2 : 9.4 (Portland cement : hydrated lime : sand).The original mortar performed relatively well, with the most extensive repointing having occurred on the annex. But since Portland cement-gauged mortars are prone to early failure where the cement-lime ratio is less than 0.5 : 1.0[26] a new repointing mortar was formulated using natural hydraulic lime and local sand. It approximates the original mortar in appearance and hardness [Appendix F].

**Repair strategies developed for building foundations include:**

***1. Relaying displaced stonework***
Minimal restacking of foundation stonework was required at the northwest corner of the building. The affected volume was less than 4 cubic yards. The repair design called for relaying of original masonry and matching the original mortar with respect to hardness, permeability, and visual characteristics.

***2. Removing the concrete counter-wall***
Since the counterwall is not a characterizing feature of the building, and is the primary cause for decay of original woodwork along this section of the wall, the above-grade portions of the concrete counterwall were removed from the northwest perimeter wall. Since complete removal would have resulted in total loss of original stonework, the repair design called for retention of the below-grade portions, treating them as a spread footing on which to lay a replacement stem wall.

***3. Restoring the stone stem wall on this façade***
Reinstatement of the stone stem wall using stone collected from the historic quarry and bedding it in a mortar of natural hydraulic lime and sand.

***4. Spot repointing on all sides of the building.***
Spot repointing was selected as the most appropriate strategy for protecting period stonework from the ingress of water while maximizing the retention of early fabric. Spot repointing was carried out with a mortar that matched the original with respect to hardness and visual characteristics.

### Perimeter Wall Woodwork

The sill on the northeast perimeter wall was replaced with a dimensioned lumber sill in an earlier repair campaign and is in good condition. The sill on the northwest perimeter wall was encapsulated in a reinforced concrete counterwall, along with the bases of posts and studs. The counterwall, apparently added to afford some protection from farm machinery, formed a shelf outside the building envelope and funneled rainwater to wooden elements. Posts and studs from K10.0-K17.0 were decayed as a result and losses appeared as displacements at eave level.

Decay of perimeter wall framing at A 4.5-5.0, K 7.5-8.0, and K 11.0-11.5 extended above aisle floor level, and affected rafter tails, plates, columns, studs, ledgers, window lintels, and sills.

[25] Grid coordinates refer to the grid overlay in the plan on p. 36.

[26] Teutonico, J.M., McCaig, I., Burns, C., Ashurst, J. The Smeaton Project: factors affecting the properties of lime-based mortars, In *APT Bulletin*, Vol. 25, No. 3/4 (1993), pp. 32-49.

## Aisle Roof, Wall, and Floor Frames

Roof leaks coupled with hay storage in the aisles resulted in decay of aisle roof, wall, and floor frames, particularly below valleys associated with the three major dormer pairs of the riding ring. Plates and supporting columns were decayed where water has run through leaking roof coverings, along valley rafters, to plates and into column joinery below. This type of deterioration was concentrated at B14.5, J4.5, and J14.5.

Upper level floors are wood decks over wood girts and joists. The floor decks and joists are generally in good condition, except below major dormer valleys on the southeast (gridlines 4.0-5.0; gridlines 7.0-8.5), the southwest (gridlines 14.0-15.0), the northeast (gridlines 4.0-5.0; 7.0-8.0) and the northwest (gridlines 10.5-11.5; 12.5-13.5), where earlier roof leaks (that are no longer active) have resulted in decay of the floor deck and several joists.

Primary roof loads are supported on riding ring columns. The columns are supported on limestone piers, and floor elevations in many places are level with the tops of piers due to the addition of concrete floors over the original floors of clay. Nearly every column[27] along the riding ring is decayed at its base.

Repair strategies include scarfing new timber to replace decayed portions of roof and wall elements, and replacement in kind of decayed floor joists, bridging, and decking. Strategies for column repairs include scarfing new column bases and adding new stone plinth blocks to elevate column bases above concrete floors added in the 20th century.

## Riding Ring Roof Frame

Through modeling and analysis of the roof frame, it was determined that factors of safety for each of the primary elements are satisfactory. This was the central goal and key accomplishment of the building investigation. In earlier engineering assessments of the Breeding Barn, it was thought that overstresses in principal trusses, purlins, and valley rafters required structural augmentation. Under the repair scenarios developed in these earlier studies, recommended treatments would have resulted in locating loads in new elements, bypassing the historic structural system. Through comprehensive archival and structural survey and in-depth analysis of the building, unnecessary and invasive additions to the structural system were avoided.

Roof leaks at dormer valleys and chimneys resulted in decay of valley members and gable rafters. In an earlier repair campaign, steel reinforcing channels were added to valley members, and some of the original truss elements were removed. The applied reinforcing steel was poorly detailed and contributed to further decay.[28] Repair strategies include removal of reinforcing steel channels; repair of valley members and rafters; reinstatement of missing trusswork, purlin bridles, and braces; and repair of common rafters and roof deck.

Quantification of decay in deteriorated elements through resistance drilling enabled the design team to focus efforts conservatively on only those elements that absolutely required repair. Significant section loss was discovered in five valley rafter timbers[29] (8.0 South, 11.0 South, 14.5 South, 17.0 South, and 14.5 North), as well as in timber plates and column joinery below these rafters. A sixth valley member (11.0 North), replaced in a previous repair campaign, consisted of three pieces of timber bolted between steel channels. Valley members at 2.0 South and 14.5 South had partially slipped from lodgings over the dormer apexes.

In addition, the north rafter timbers in each gable end of the riding ring were partially replaced in a previous campaign in response to decay resulting from roof leaks at each chimney. Repairs were incomplete, splices were fastened with undersized lagged shear plate connectors, and on the west gable temporary shoring of the repaired rafter was left in place.

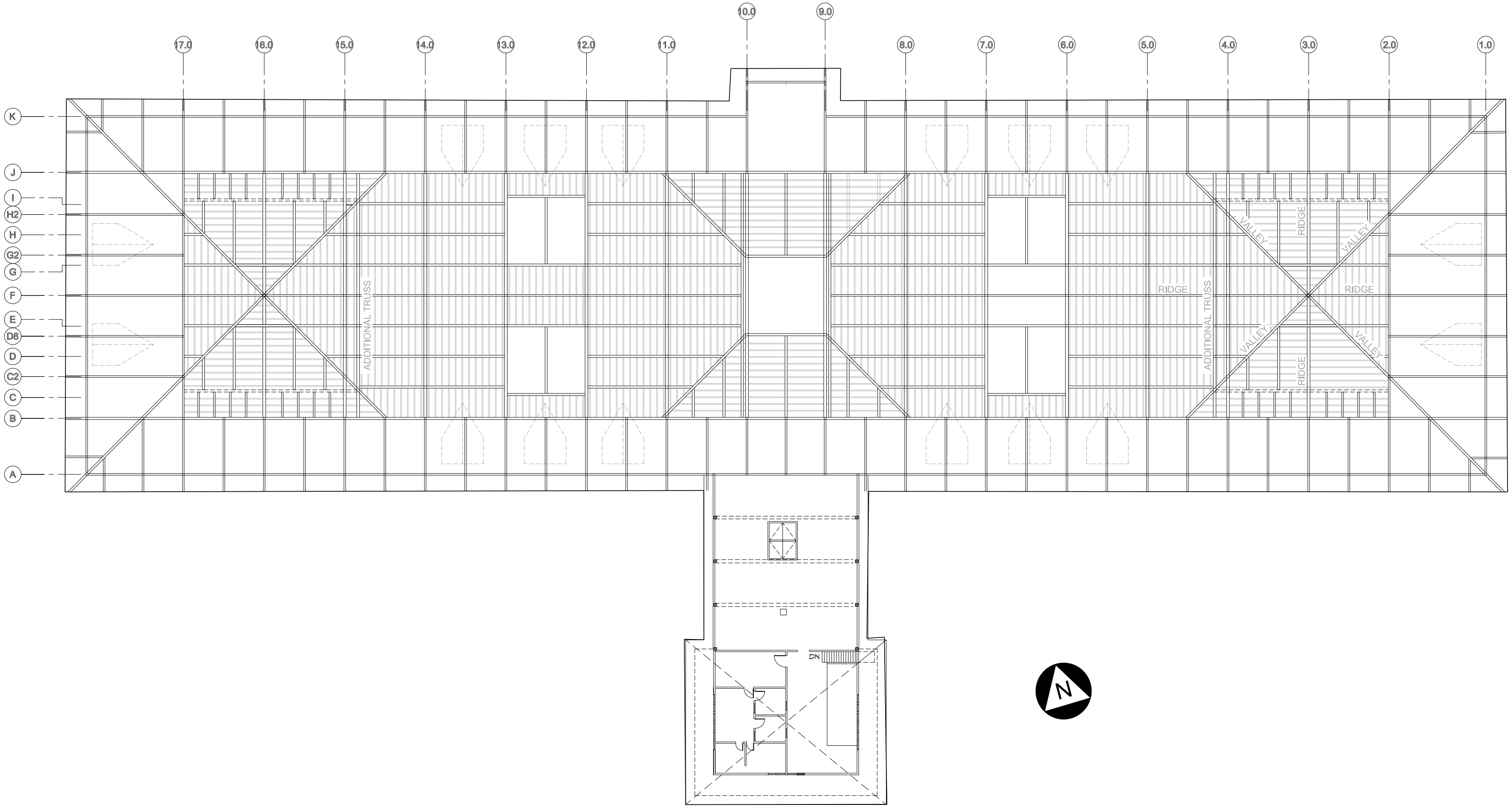
Iron truss elements were found to be in generally good condition, and require minimal treatment to address low levels of corrosion.[30] Unfortunately, iron truss work was removed from each of the valleys at the central lantern location (8.0 South, 11.0 South, 8.0 North, 11.0 North) in a previous repair campaign.

27 For a complete list of deterioration conditions, please consult the table included in the design drawings, Appendix D.

28 While the addition of the reinforcing steel occurred c.1930, the steel channels cannot be considered characterizing features of the building, bear no relationship to the designers from which the building derives its significance, and certainly cannot be considered the work of a master. As a strengthening strategy, the addition of the steel channels to the wooden valleys was poorly detailed in terms of the transfer of loads from one element to another, and accelerated the decay of the valley members.

29 The grid coordinates indicate the locations of valley-plate connections (framing plan p. 39); north and south indicate on which side of the ridge timber a particular valley lies.

30 Corrosion of historic ironwork has caused rust and minor scaling of many of the elements, but has not resulted in significant section loss. Historically, ironwork in the riding ring was painted. Conservation of period iron will require blast cleaning to remove dirt, rust, and scale. As part of the building investigation, a specification was developed for blast-cleaning of corroded iron surfaces, priming with a galvanic zinc-rich primer, and painting with aliphatic polyurethane enamel Munsell-matched to the original paint color. Painting of the ironwork will take place in a subsequent phase of work.




Roof framing plan with grid overlay

Repair strategies developed for valley members and gable rafters included:

- ***Removing steel reinforcing channels from valley rafters***. These channels were only marginally effective in carrying rafter loads because of inadequate connections between steel and wood elements, and inhibited the drying of rafter timbers, accelerating their deterioration.
- ***Scarfing new timber into historic members*** in areas where bending moment is low or where scarf joints receive support from other members of the frame. Scarfed repairs have a long tradition of use, do not result in the introduction of material discontinuities, and the repairs have predictable service lives.
- ***Installing laminated veneer lumber dutchman repairs in decay voids*** using a gap-filling epoxy adhesive. Replacing decayed material by segmental infill has the advantages of removing minimal material, concentrating material removal in the areas of greatest deterioration, and minimizing the effects of combining dissimilar materials.

Repair strategies developed for structural iron components included:

- ***Reinstatement of missing truss rods and pipe struts on lantern valleys.***
- ***Installation of modified iron bridles for valley rafter / jack rafter connections.***

# Repair Implementation

Repointing of foundation stonework involved cutting damaged joints to provide key for the replacement mortar. Burlap was used to control drying.

[31] While Shelburne Farms was under construction, Webb established a quarry to provide stones for building and paving.  The quarry is no longer a part of Shelburne Farms, but on an adjacent property owned by Tom Cabot. He donated the stone for the project.

Analysis of the overall building structure indicated that it was originally very well designed, so our treatments focused on conserving deteriorated elements and reinstating missing elements. These included restoring foundation stonework, repairing woodwork along perimeter walls, in the aisles (including roof frames, walls, and floor systems) and riding ring, and reinstating missing iron trusswork.

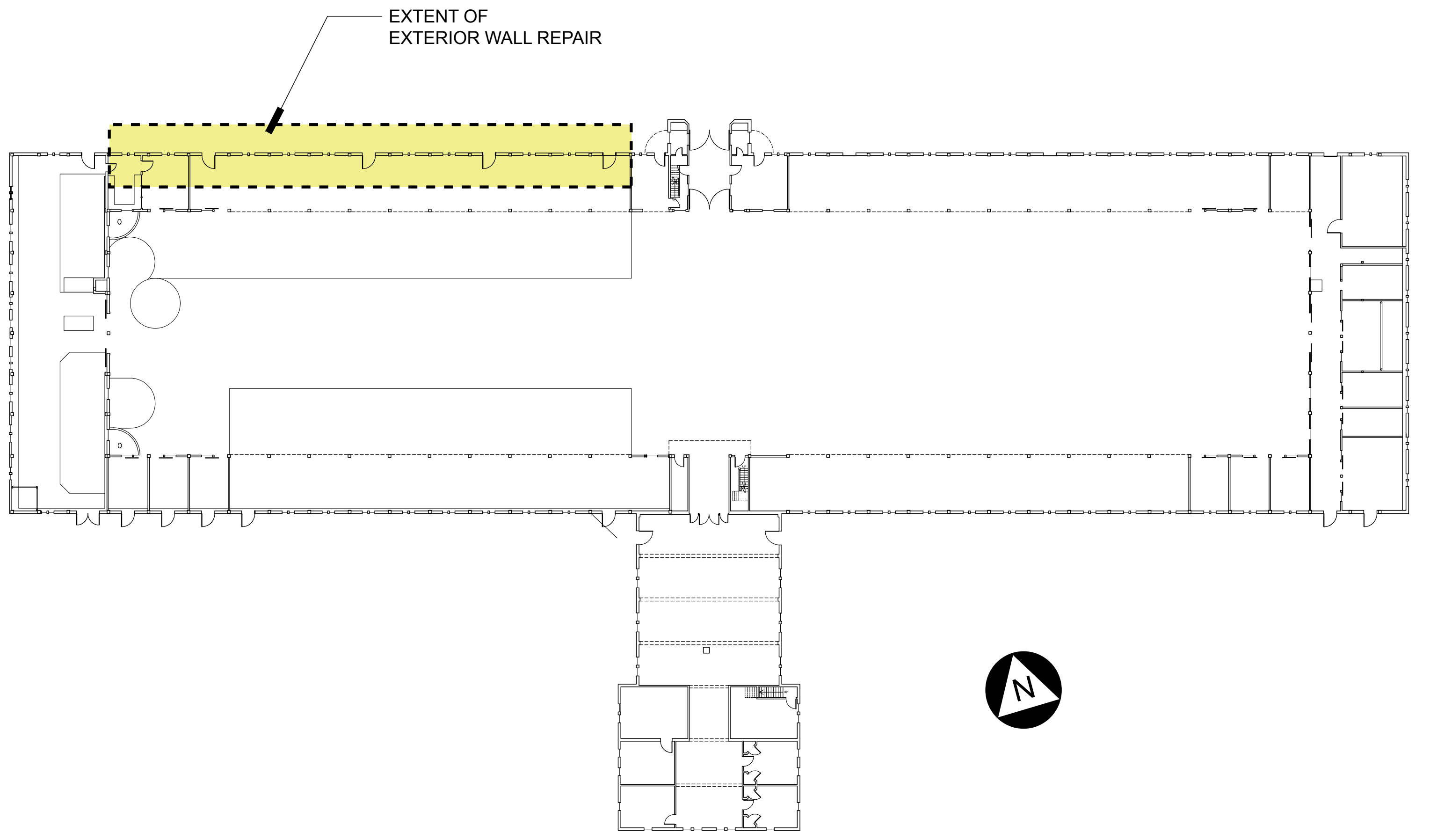
Spot repointing of the south, east, and west foundation walls was completed in 2008. Walls were excavated to a depth of approximately 18 inches to address subsurface deterioration. Excavation of the east wall, where the grade is highest, reached a depth of three feet. Spalling and deteriorated mortar was removed; joint depths were adequate to achieve proper keying of the replacement mortar. Stonework at the northwest corner of the building that had been struck by farm machinery was partially dismantled and relayed.

Historic mortar constituents included Portland cement, hydrated lime, and sand; volumetric proportions are calculated as 1.0 : 2.2 : 9.4 (Portland cement : hydrated lime : sand) [Appendix F]. The mortar had performed relatively well, with losses concentrated under roof valleys and at building corners. However, Portland cement-gauged mortars are prone to early failure where the cement-lime ratio is less than 0.5 : 1.0. For this reason, a repointing mortar was formulated using natural hydraulic lime and local sand to approximate the original in appearance and hardness. New joint profiles match the original. During installation, foundation walls were shaded, and new work was covered in burlap and wetted twice daily for at least one week following repointing.

Stonework at the building entrance consisted of coursed ashlar with rusticated surfaces that had been extensively repaired. Hard replacement mortar had cracked away from masonry units, exposing the wall interiors to water. This mortar was removed entirely, and stonework reset where necessary. The entrance was repointed with a hydraulic lime : sand mortar to match the rest of the building.

In 2009, replacement stone was obtained from the historic quarry[31] for reinstatement of the stone foundation wall on the northwest façade. Following cribbing of the northwest wall, the concrete counterwall was removed from the interior and exterior of the building to a depth of approximately six inches below grade. Subsurface concrete was retained to preserve as much of the

First floor plan highlighting location of foundation and perimeter wall repairs

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FOUNDATION REPAIR, KEYED FIRST FLOOR PLAN

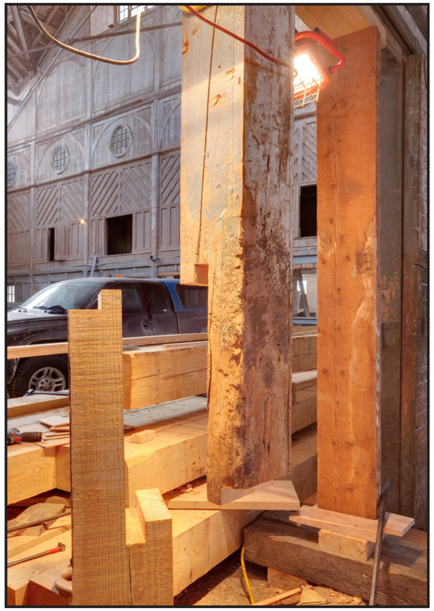
SCALE: 1/32" = 1'-0"

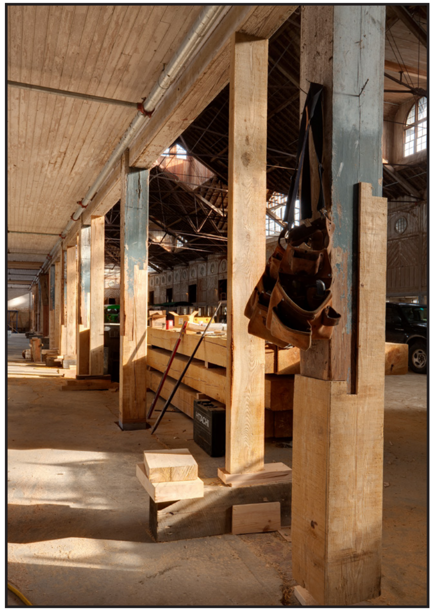
The concrete counterwall on the northwest façade was removed to a depth of approximately six inches below grade, and a new stone stem wall was constructed to support replacement sills.

historic foundation stonework as possible, and the assembly treated as a spread footing for supporting a reinstated stone stem wall.

The top surface of the remaining concrete was detailed to shed water. Following repair of the structural woodwork on this wall, a new stone stem wall was constructed on top of the surviving wall and to sill height. The stone salvaged for this purpose was shaped by hand to replicate the spacing and finish of the original stonework. Stone was laid in a hydraulic lime : sand mortar tooled to match original work. A polyethylene barrier was placed between the new stonework and the existing floor slab, to facilitate the eventual removal of the slab. A foundation drain was installed on the building exterior and tied to an existing drainage system.

Repair of the timber frame began in October 2009 with cribbing of the northwest aisle, where concrete counterwalls resulted in decay of perimeter wall wood-



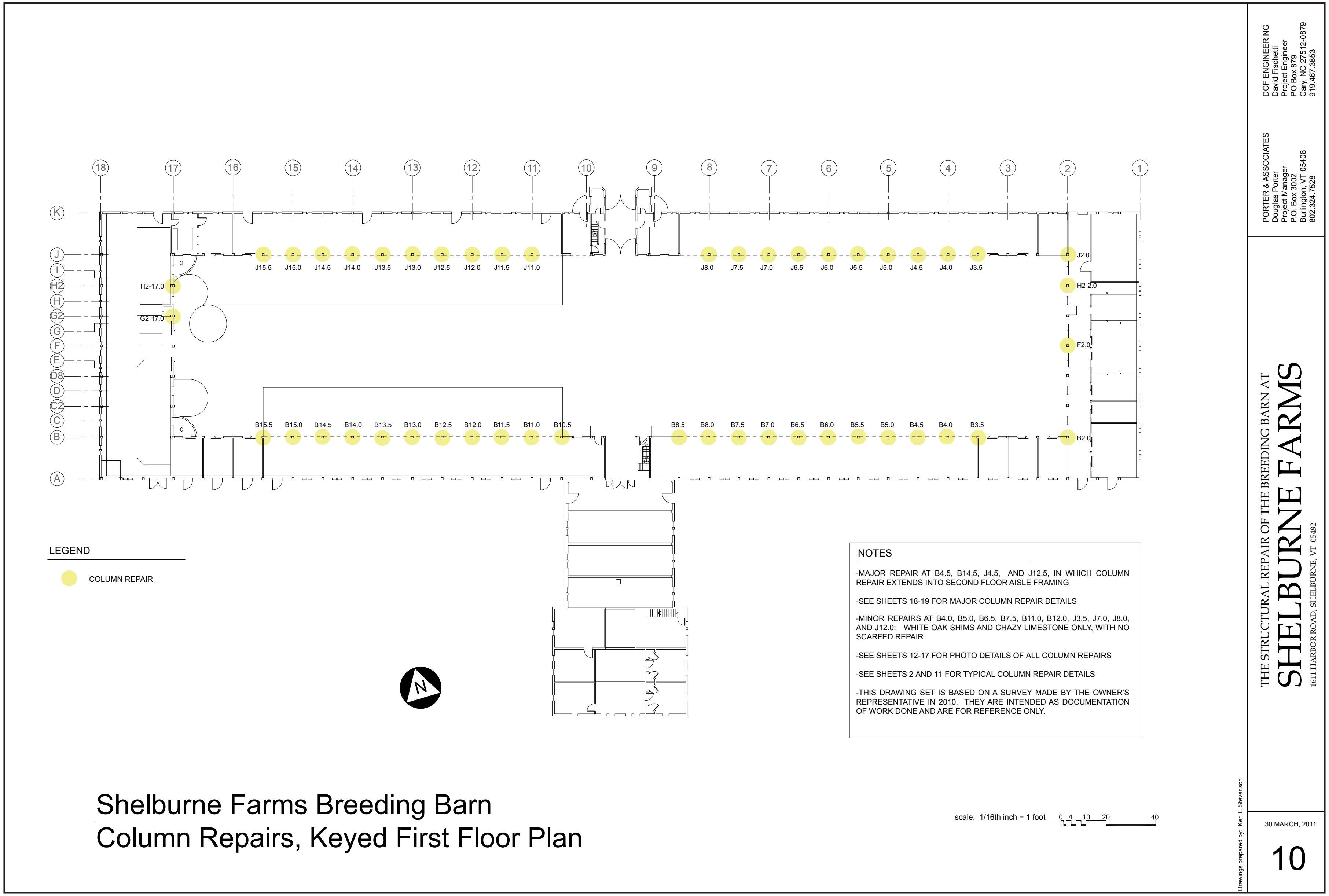
work. New column bases were scarfed into decayed posts, studs were scarfed or sistered, and sills were replaced. Most of the columns along this wall had been repaired once before, and in most cases it was possible to use existing scarf locations for the new repairs. Sills were placed on new stone stem walls, and the wall, approximately 200 feet long, was leveled to the extent possible. Sills on the north façade are especially close to grade, and to improve the decay resistance of this vulnerable element, replacement sills were made of locust.[32]

Of the 70 columns surrounding the riding ring, nearly 50 of them were significantly decayed at the bases, partly due to installation of concrete floors in the mid-20th century. In addition, several columns were damaged by animals and agricultural machinery.

Riding ring columns were repaired by scarfing in new timber to replace decayed portions, using a nosed scarf form found elsewhere in the barn. New column bases were placed on limestone plinths and white oak shims, elevating them above a concrete floor installed in the mid-20th century.

[32] Robertson's plans called for sills of Southern yellow pine, but also show foundation wall heights of approximately 2 feet above grade on the north façade. Plans were apparently changed during construction, and foundation stonework was terminated at interior floor level and within 10-12 inches of grade. None of the original sill timbers survive on the north building façade

First floor plan highlighting locations of column repairs

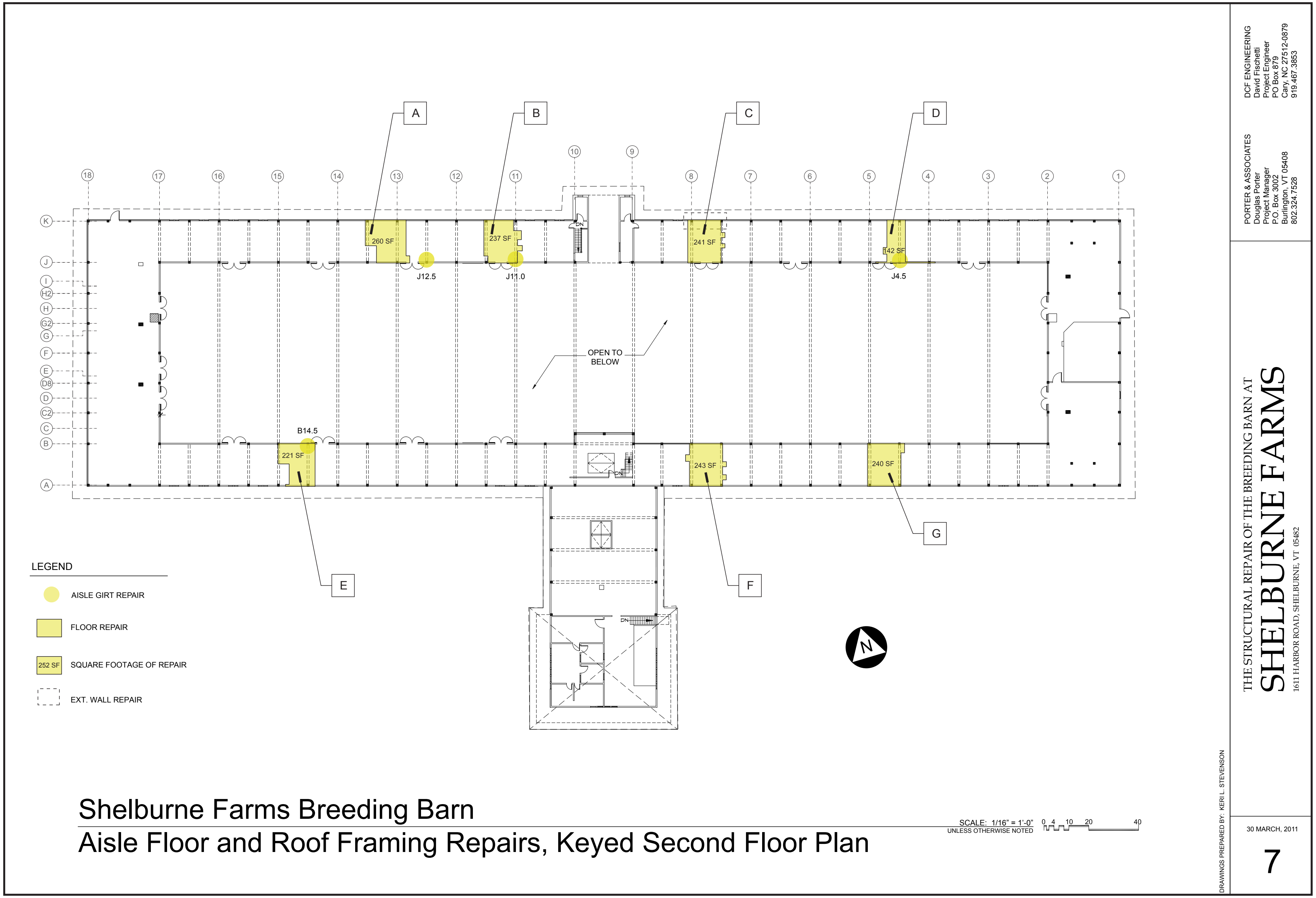


Repairs typically included the scarfing of new column bases to replace decayed material, and the addition of sheet lead damp proofing, limestone plinth blocks (matching the historic limestone piers), and white oak shims nested across the entire width of each column base. The scarf form used for most of the repairs replicated an historic form found in the building. In most cases, replacement pieces were at least 2 feet long below the lowest shoulder to prevent splitting when loads were returned to the columns. By jacking three to four columns at a time, framers were able to bring aisle girts and plate timbers to a nearly level position.

Four of the column repairs (B4.5, B14.5, J4.5, and J12.5), associated with roof leaks at the dormer valleys, extended into the aisle level. In each case, the columns had been repaired at least once before, and misalignment of shoulders in the scarfed splices had resulted in buckling of the columns above the aisle floor. At J4.5, floor girts on either side of the repaired column were replaced. New repairs included appropriate dimensioning of scarf joints and installation of free tenons or splines to replace missing joinery that supported aisle floor girts.

Four of the columns located below dormer valleys required repairs extending into the aisle level. Here, a new column base is raised into position (left) and is shown installed with replacement girts (right).

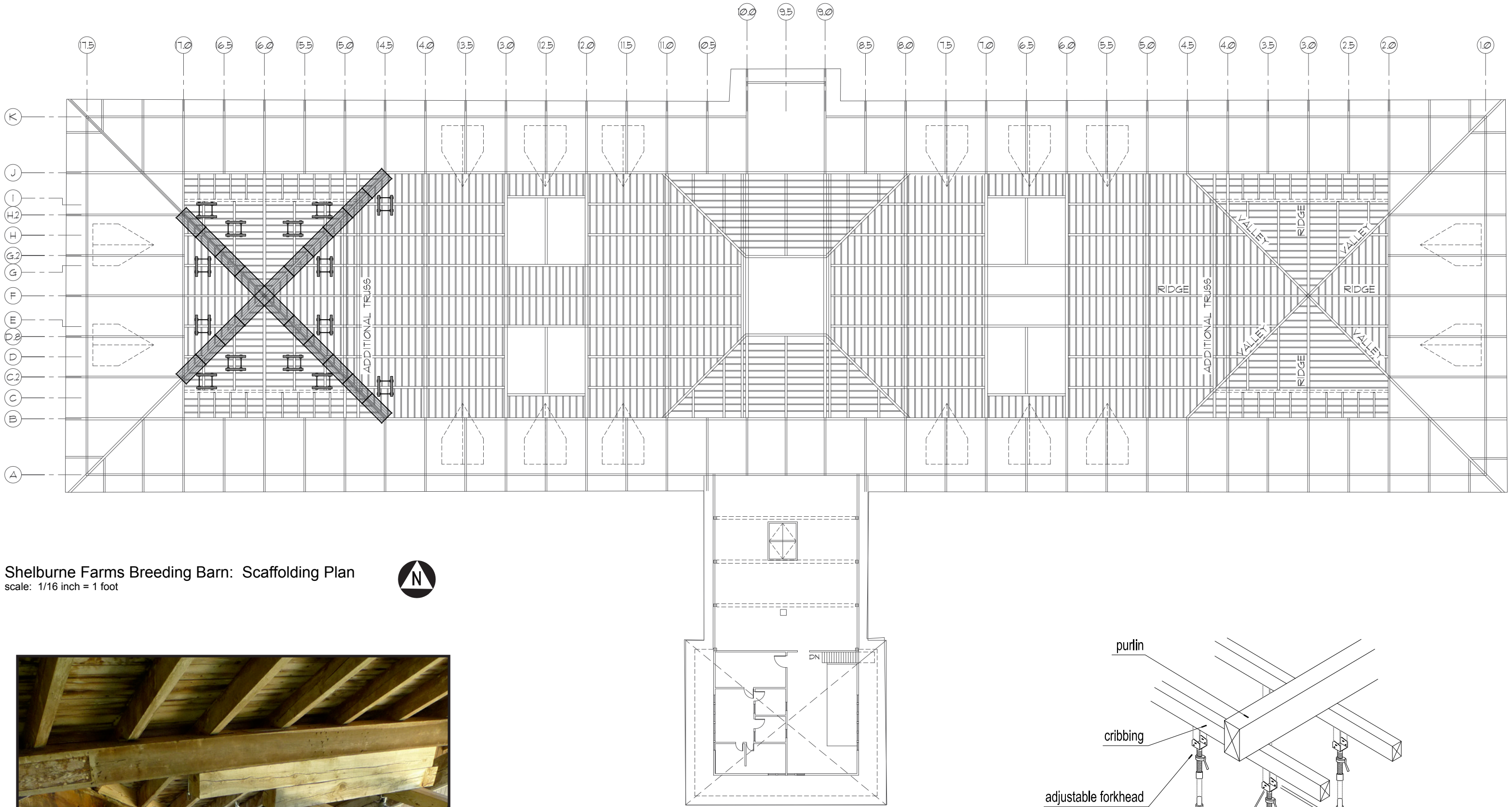
Second floor plan highlighting the locations of aisle roof, wall, and floor repairs



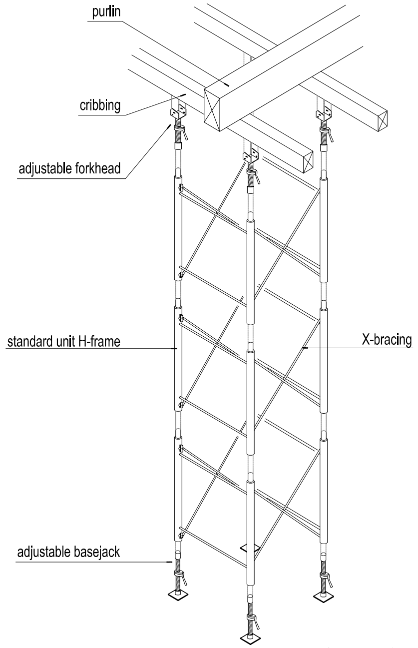
Repairs in the aisles included scarfing of new timber in roof trusses (bottom right), wall plates and studs (top right), and floor joists, ledgers, bridging, and decking (left). In the photo at left, note the temporary truss installed to support the plate during wall repairs.

Additional repairs were made to the aisle roof, wall, and floor frames at each of these locations. Aisle truss repairs typically consisted of scarfing new rafter and tie beam ends, and replacing decayed tenons with free tenons. Wall repairs included scarfing of perimeter wall plates to replace decayed portions, dutchman repairs of adjacent common rafters, scarfing of studs and columns, and replacing decayed window lintels. Floor system repairs typically consisted of replacement in-kind of decayed ledgers, joists, bridging, and decking.

Crews erected scaffolding and structural staging for roof frame repairs beginning in March 2010. Universal scaffolding was installed directly below each of the four valley members in the west dormer pair, X-shaped in plan, and with scaffold decks descending from the apex at the center to plate timbers on the north and south. Overall height of this construction was approximately 35 feet at the plates to 50 feet at the center of the dormer pair. This provided framers with a work platform. Sixteen towers of structural staging were added to this construction to support purlins at purlin-valley connections.



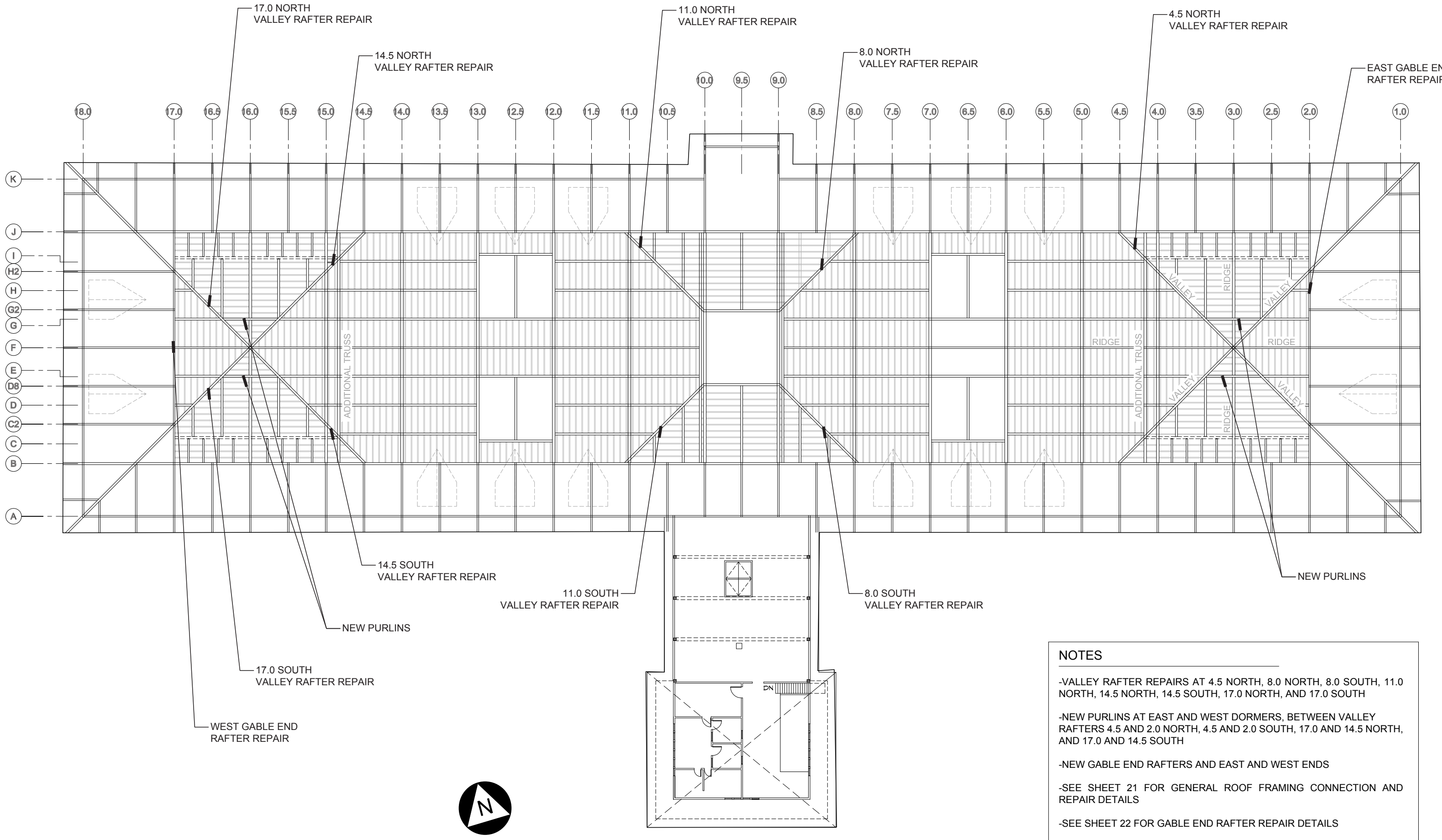

Shelburne Farms Breeding Barn: Scaffolding Plan
scale: 1/16 inch = 1 foot




3/16 inch = 1 foot

Scaffolding and staging for roof repairs included universal scaffolding set in an X-pattern below valleys with structural staging towers to support purlin loads.

Roof framing plan indicating locations of roof frame repairs




NOTES

-VALLEY RAFTER REPAIRS AT 4.5 NORTH, 8.0 NORTH, 8.0 SOUTH, 11.0 NORTH, 14.5 NORTH, 14.5 SOUTH, 17.0 NORTH, AND 17.0 SOUTH

-NEW PURLINS AT EAST AND WEST DORMERS, BETWEEN VALLEY RAFTERS 4.5 AND 2.0 NORTH, 4.5 AND 2.0 SOUTH, 17.0 AND 14.5 NORTH, AND 17.0 AND 14.5 SOUTH

-NEW GABLE END RAFTERS AND EAST AND WEST ENDS

-SEE SHEET 21 FOR GENERAL ROOF FRAMING CONNECTION AND REPAIR DETAILS

-SEE SHEET 22 FOR GABLE END RAFTER REPAIR DETAILS

-SEE SHEETS 23-29 FOR VALLEY RAFTER REPAIR DETAILS

# Shelburne Farms Breeding Barn
## Roof Framing Repairs, Keyed Roof Framing Plan

SCALE: 1/16" = 1'-0"
UNLESS OTHERWISE NOTED
0 4 10 20 40

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THE STRUCTURAL REPAIR OF THE BREEDING BARN AT
SHELBURNE FARMS
1611 HARBOR ROAD, SHELBURNE, VT 05482

30 MARCH, 2011

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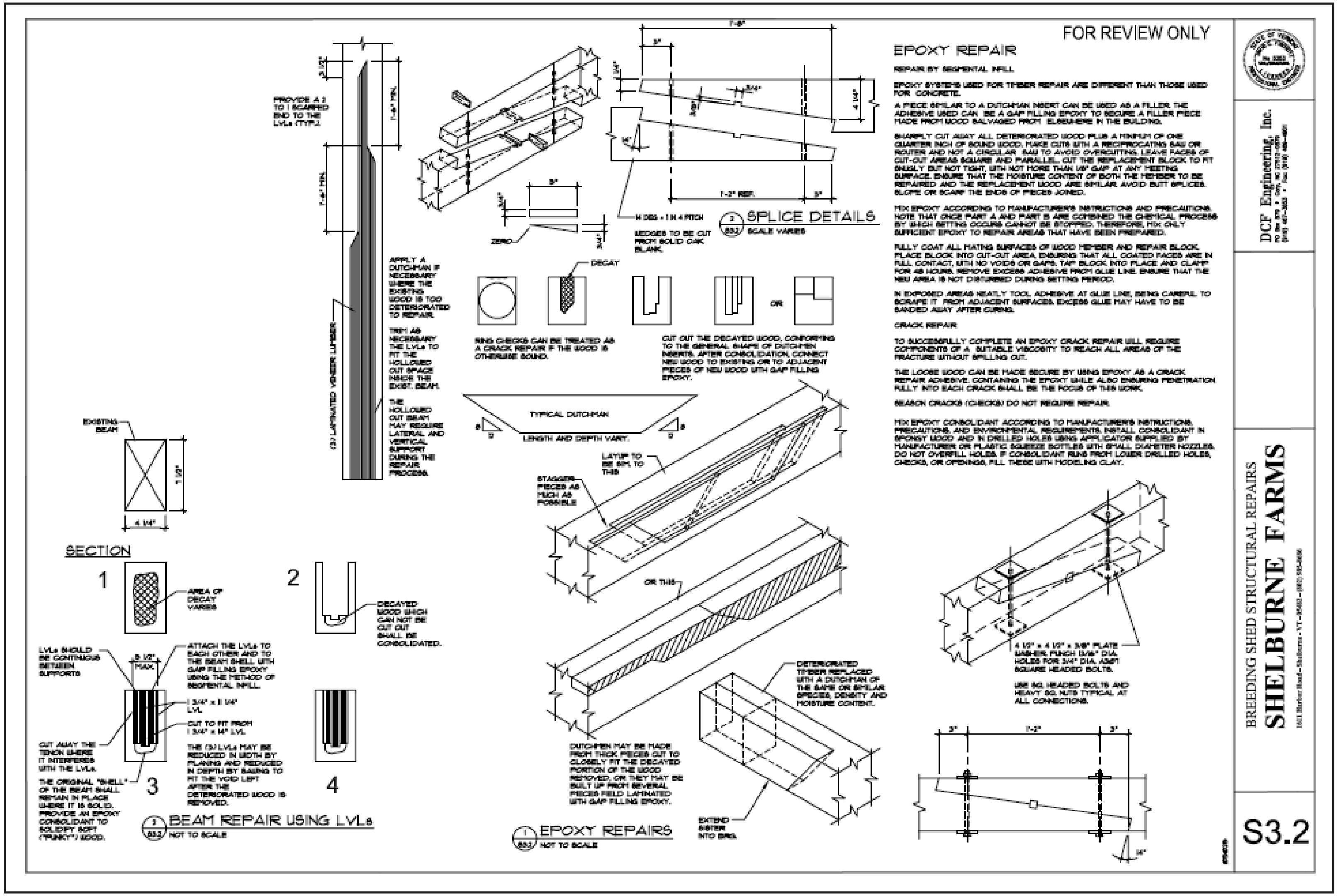



Repairs for valley members included segmental infill of long decay voids using engineered lumber and the scarfing of new timber to replace decayed timber.

Once roof loads were transferred to the structural staging, steel channels bolted on either side of each valley member were removed. These channels were added to valley members c.1930, apparently in an attempt to address deterioration of the timbers, but connections between the channels and timbers were poorly designed and the channels promoted decay of the wooden elements.

Repair strategies for valley members included: 1) scarfing new timber into historic members in areas where the bending moment is low or where scarf joints receive support from other members of the frame; and 2) installing laminated veneer lumber dutchman repairs in decay voids using a gap-filling epoxy adhesive.

Bending tests were conducted on repair mockups and solid controls to compare repair strategies for valley members.

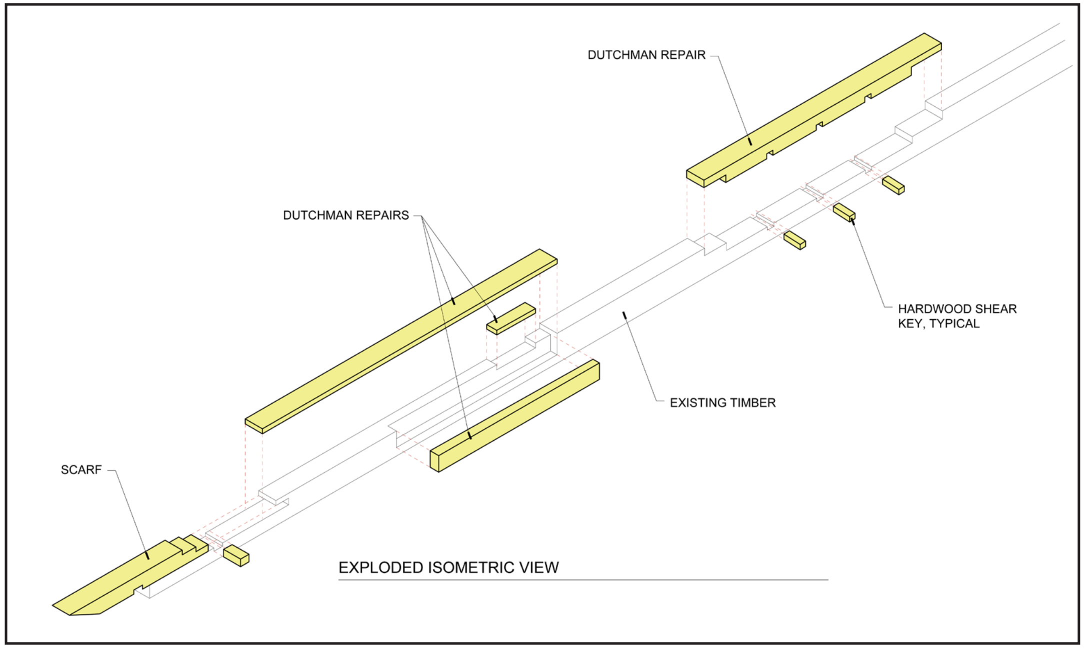
A testing program was undertaken to select adhesives, determine the relative strength of dutchman repairs, and compare the performance of different scarf profiles. Two candidate adhesives[33] were selected based on temperature requirements, gap-filling properties, pot life, clamp time, and curing time. Each epoxy was used to edge-glue ten panels under ambient temperature and humidity conditions. These were evaluated informally for ease of mixing and application, curing, and strength. Of the evaluated adhesives, the repair team selected West System 105 epoxy resin with West System 206 hardener because of better bulking and curing properties given ambient conditions in the barn.

[33] The epoxy resins tested were Shell Epon 828 with #3460 hardener and West System 105 epoxy resin with West System 206 hardener

To compare the strength of repaired timber to undeteriorated solid timbers, the team conducted a series of bending tests. The test protocol was established to replicate the field conditions under which the repairs would be made. As such, strict adherence to an established testing standard would likely have limited the project team's ability to determine the optimum repair strategy for the timbers in situ. All tests were conducted using a three-point bending test.

The tested repairs included nosed, keyed, and bolted scarf joints, and laminated veneer lumber (LVL) dutchman repairs installed in grooves plowed into simulated deteriorated timbers. The ultimate bending strength and mode of failure was recorded for each test. Results were compared to solid timber control specimens. Based on the results (as well as the ability to implement the repair *in situ*), the LVL dutchman repair provided the optimum repair strategy for long unsupported spans. Scarf joints were acceptable where they receive support from other parts of the frame, or where bending moments are low.

For valley members 14.5 South and 14.5 North, decay in the lower third of the length of the members (near their intersections with trusses at gridline 15.0) was repaired by scarfing in new timber; scarf joints were




The valley member at 11.0 South with decayed material removed in the upper half of the span (left). Note the shear block mortises cut in the member and in the timber dutchman on the scaffolding behind the valley timber. The extent and location of the damage necessitated a change in the types of repairs employed (bottom).

located near intersections with trusses and were reinforced with bolts and structural washers. For valley members 11.0 South and 8.0 South, scarf repairs were made within 7 feet of the plate timbers, where the bending moments are low. Valley member 11.0 North was replaced in an earlier repair campaign by three butt-joined timbers bolted to the steel channels. This assembly was replaced with a scarfed member (installing a single full-length timber was not feasible without removing a portion of the roof) with the scarf joint located near the lower queen strut, where the bending moment is low.

Valley members 17.0 South, 17.0 North, 11.0 South, and 8.0 South were characterized by long decay channels in the upper half of the timber section, apparently the result of water from roof leaks accessing drying checks on the upper surface of each timber. These were repaired by removing decayed material to leave a long dado that was then filled with a segmental engineered lumber dutchman adhered with a gap-filling epoxy. In some instances (as at 11.0 South and 8.0 South) it was possible to drop the timber to the scaffold deck for treatment; in others (as at 17.0 South and 17.0 North), cutting and assembly were done *in situ*.

Resistance drilling was focused on valley members, where decay was extensive and timbers could not be visually inspected effectively because of the framing on top surfaces and steel channels bolted to the sides. In most cases, drilling results corresponded well to actual conditions and the drill sur-

Resistance drilling results typically corresponded well to actual conditions and the drill survey proved to be a powerful tool in anticipating the extent and types of the repairs. For example, the color-coded graphic indicates the portion of the valley member at 14.5 North most severely affected by decay (top left), and the section drawing roughly indicates the size and shape of the decay channel near the intersection of the valley with the rafter at gridline 15.0 (bottom right). The photo taken during construction (top right) demonstrates a close correspondence between the section drawing based on drill results and actual conditions.New timber was scarfed into the valley member at 14.5 North where both timbers receive support from truss rafters. The length of the replacement timber is approximately 21 feet.

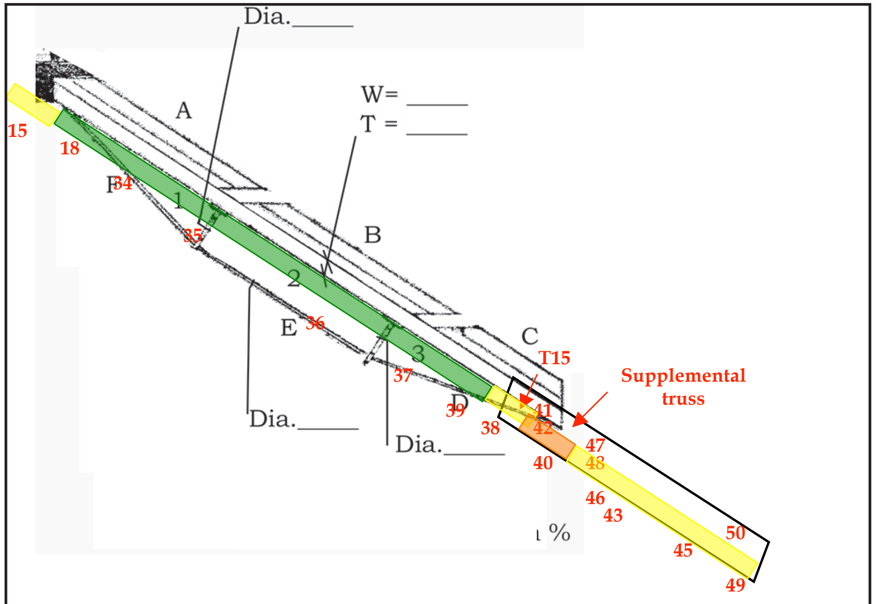



**Figure 31.** Inspection results from Valley Rafter 14.5 North

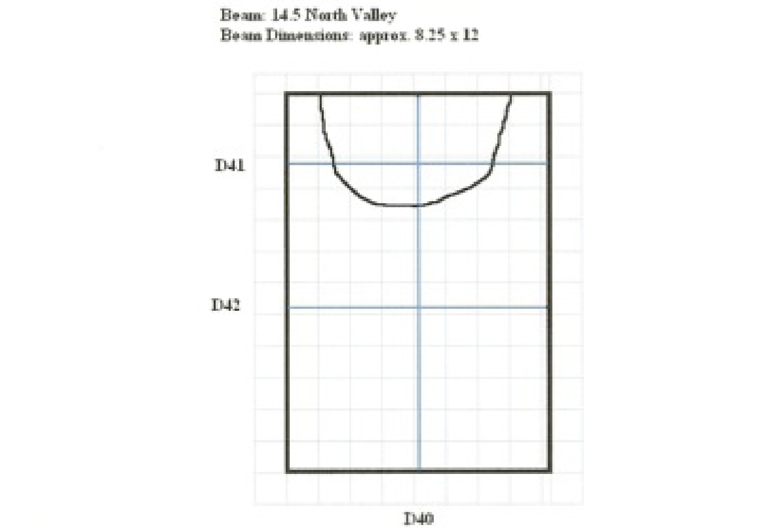



**Figure 35.** Diagram showing channelization pattern in Valley Rafter 14.5 North near the supplemental truss.

vey proved to be a powerful tool in anticipating the extent and types of the repairs. In two cases, however, framers encountered significant damage that did not appear in the assessment documentation. In both instances, there were large areas of decay that appeared to originate at the surfaces where steel channels were attached. These did not appear in the drill survey results in part because the steel channels limited access to those areas. While the presence of decay along the interface between the timbers and steel reinforcements was expected, the extent of decay in these two valleys came as a surprise. For the valley member at 11.0 South, decay along both surfaces was so severe that the repair specification had to be changed. This limitation of resistance drilling should be considered when conducting a condition assessment where access to the full timber is restricted.

When the steel reinforcing channels were removed from valley members in the lantern and in the east and west end dormers of the riding ring, there was a buildup of rust, corrosion crusts, and dirt left on the surface in patterns that corresponded to the shape of the channel. The accretions were caused by migrating water that had become trapped between the metal and the wood. Approximately 720 square feet of the valley members' surfaces were cleaned to remove the encrustations and stains where possible; three valleys were treated in the lantern and four each at the east and west ends. Rust and dirt buildup was concentrated in the lower end of the rafters, but there was also heavy soiling in patches along their lengths and anywhere water accumulated. Though the rust was often thick and scaly, it was primarily localized on the surface and generally did not penetrate deeply into the wood.

To remove the thick accretions, the wood was first dry-cleaned with paint scrapers and synthetic fiber sponges. Areas with historic limewash and little corrosion or staining were not treated. Stains were wet-cleaned with water and scrubbed with soft-bristle brushes, ultra fine-grained sanding sponges, and plastic mesh scouring cloths. Heavily soiled areas were additionally washed with a 1% Vulpex in water. Care was taken when

Steel channels left scaly rust deposits and stains on timber surfaces. Cleaning involved use of a nonionic detergent and water

Purlins were extended with loose tenons and jam blocks and supported on custom-made replacement bridles (top). Gable-end rafters were decayed at chimneys and were repaired by scarfing in new timber. Scarfs received support from wall framing (bottom).

scrubbing to work with the grain. Water was applied through an air-brush, which allowed a steady stream to flow down the wood, which lifted the soiling and soap and was absorbed with sponges. The goal of the cleaning was to remove as much of the staining as possible, but not to restore the surface to a pristine state. From the ground, 35-55 feet below, most of the rust stains are not visible and some of the whitewash finish is now apparent.

Upon completion of repair and cleaning, missing truss elements were reinstated, and purlins were reconnected to valley members. All of the valley members at the lantern location at the center of the barn (8.0 South, 11.0 South, 8.0 North, and 11.0 North) required new truss work. Truss rods and pipe struts were fabricated[34] in steel (historic examples are of wrought iron) to match the profiles and dimensions of the originals. The iron bridles that connected purlins to valleys were lost when the steel channels were installed, and purlins appear to have been shortened to make room for the steel. Ghosts left on the woodwork allowed fabricators to replicate original bridle profiles, and extra-deep replacement bridles (to engage the shortened purlins) were fabricated of 5/16-inch steel plate. Where purlins were too short to adequately engage the new bridles, loose tenons were installed. Blocks were installed at purlin ends to provide bracing for the valleys, and roof loads were returned to valley members.

At either gable end, principal rafters were repaired by scarfing in new timber to replace decayed sections; scarf joints receive support from gable wall framing. Scarf joints were modeled on joints cut in each top chord element and are typically tapered, at least 4 feet in length, and reinforced with bolts and structural washers. For the repair at the west gable end, the replacement piece was spliced to the existing rafter at an historic scarf joint near gridline J.

[34] Leo's Welding, Morrisville, Vermont

# Training Program

Conditions assessment, structural investigation and evaluation, and repair of the Breeding Barn created several opportunities for training. The initial condition assessment of the building was organized as an educational workshop in partnership with the University of Vermont. The assessment crew included the project architectural conservator and structural engineer, timber framers associated with the truss research group of the Timber Framers Guild, and student trainees selected from the Civil Engineering and Historic Preservation programs at the University. Trainees were paired with professional team members and assigned a portion of the building to survey. With three teams working from lifts, and two teams working in the aisles, conditions survey of the barn took three days, and identified issues and areas of deterioration to be addressed in the ongoing building investigation.

A student intern from the School of Engineering at the University of North Carolina was involved in the nondestructive evaluation of decayed wooden elements. Her work, funded in part by a grant from the National Science Foundation, formed the basis for a state-of-the-art report published by RILEM Technical Committee 215 on "In-situ assessment of structural timber".

Student interns from the College of Architecture were a part of the Texas Tech University team that performed laser scanning of the building. Students participated in the fieldwork and helped to prepare a set of two-dimensional HABS drawings of the building based on the collected data.

Graduate students from the School of Engineering at the University of Vermont participated in the geotechnical investigation, strength testing of period iron, and load testing of trusses. Five students, under the supervision of a consulting engineer and University faculty, were involved in the geotechnical investigation, which included condition assessment of subsurface foundation stonework, soil indexing, and shear testing of foundation soils.

The timber-framing workshop included a day devoted to design for historic timber buildings (above left), followed by a week-long session focused on shoring, cribbing, and joinery.

Strength-in-tension tests (ASTM A 370-97a) were conducted on samples of wrought iron salvaged from the Breeding Barn roof (additional testing was done in an independent testing lab). Two graduate students and a Barrett Scholar assisted with load testing of the trusses. The graduate students went on to complete thesis projects on the use of resonant frequencies in determining axial loads in metal truss elements. Students worked under the direction of project team members, university faculty, and consulting engineers. [Appendices G and J]

Repair implementation also created training opportunities. Two apprentice-level masons were paid members of the crew responsible for repointing the Breeding Barn foundation stonework. A portion of each workday was devoted to their training, and trainees participated in joint preparation, mortar mixing, and repointing. The training period lasted approximately 16 weeks. Similarly, two intermediate-level timber framers were selected to work with the timber framing crew. These trainees participated in all of the activities undertaken by the crew, including jacking and shoring, and *in situ* repair of deteriorated woodwork. Their training period lasted approximately 48 weeks.

A week-long training session targeted at mid-career timber framers and design professionals working with existing timber buildings was co-hosted by Shelburne Farms, the Preservation Trades Network, and the Timber Framers Guild. The training session was organized in two parts, including a one-day workshop directed at designers, and a week-long workshop focused on developing repair skills.

The one-day workshop covered the investigation, analysis, design, in situ repair strategies, and the role of traditional trades in implementation, using the Breeding Barn as a case study. Workshop presentations were made by Douglas Porter (project manager), Ronald Anthony (Anthony & Associates, a wood science consulting firm), David Fischetti (project structural engineer), Jan Lewandoski (Restoration and Traditional Building, timber frame contractor), and Rudy Christian (Preservation Trades Network). The session was attended by 14 A&E professionals and 13 timber framers; participants received 8 contact hours/AIA-CEUs.

Timber framers attending the week-long workshop participated in several aspects of *in situ* heavy timber repair, including jacking, cribbing, and scarf joint repairs. The course instructors were Jan Lewandoski and Paul Ide (both of Restoration and Traditional Building), and Rudy Christian (Preservation Trades Network).

Additional repairs are planned as part of a project involving conservation, repair, and reinstatement of building envelope elements below eaves level. Securing the building envelope will further protect the building against the ingress of moisture, will help to ensure the longevity of structural repairs, and is the next critical step in preparing the building for reuse. Building envelope repairs will follow structural stabilization as soon as funding permits. The project team is currently engaged in documenting the envelope elements and has developed a preliminary scope of work that involves:

**1. Conserving windows and doors on the building perimeter.** Repair options include:

- ***Woodwork and resin repairs of sills and bottom rails***. Resin repairs can be made to restore small losses. Dutchman repairs can be made to restore larger losses, including joinery.
- ***Reinstatement of sash joinery at meeting rails and bottom rails*** using loose tenons, dutchman repairs of relish in mortised elements, and traditional fasteners.
- ***Reglazing using original and early glass where it survives.*** Original glazing putty contains asbestos and is in friable condition.
- ***Repair / replacement-in-kind of damaged and missing hardware***
- ***Reinstatement of paint finishes.*** Early paint schemes will be recreated using modern emulsion paints.

**2. Conserving/restoring exterior siding and trim.**

Many of the siding elements are missing or have simply reached the end of their service lives. Repair options developed for exterior siding and trim are focused on traditional materials and technologies and include:

- ***Reinstatement of missing shingles at roof bracket locations*** replicating the quality and exposure of original elements.
- ***Removal of corrugated metal from the south façade*** to facilitate drying of the woodwork.
- ***Replacement of missing shingles and clapboards on south façade*** replicating the quality and exposure of original elements.
- ***Dutchman repair of damaged casings, moldings, and exterior trim***

It is anticipated that the Breeding Barn Complex will become the new educational center of Shelburne Farms, with educational programs hosted in the Residential Learning Center at the Dairy Barn. The Breeding Barn will continue to function as a seasonal special events facility in support of educational and community activities. Future conservation projects will include repair of interior windows, doors, and woodwork, and conservation/reinstatement of some (though perhaps not all) painted finishes. At present, project planning for this phase of work is purely conceptual.

# Conclusion

The structural investigation of the Breeding Barn was conducted over three years, costing just under 20 percent of the total repair costs. The time and effort spent on materials characterization, load testing, modeling, and analysis were offset by vastly reduced impacts on historical integrity and significance of the building. Resistance drilling proved to be an effective way to anticipate the extent of repairs needed in the valley members, provided designers with the lead time necessary to design repairs that were conservative of original material while meeting public safety requirements, and helped to prevent expensive delays in construction. The modest testing program focused on repair performance gave designers the data necessary for proper detailing and repair of valley member *in situ,* and gave craftspeople an opportunity to select repair materials best suited to conditions in the building. Furthermore, evaluation of the efficiency of various *in situ* repair options through mechanical testing are invaluable in the discussion and exchange of ideas on repairing and extending the service life of a historic timber structure using best practices.

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