STRUCTURAL ENGINEERING FOR EXISTING STRUCTURES
Seismic Retrofit • Historic Preservation • National Historic Landmarks

A Report on Structural Roof Framing at The McCelvey Center

York, South Carolina

Submitted to:
Culture & Heritage Museums

Thursday, May 12, 2022

Bennett Preservation Engineering PC
17 Lockwood Drive, Suite 500
Charleston, SC 29401

www.BennettPE.com
843-577-8850

In May 2021, Sara Johnson of Culture & Heritage Museums asked Craig M. Bennett Jr. of Bennett Preservation Engineering PC to determine shoring locations for the southern truss at the McCelvey Auditorium in York, South Carolina, for safe access for future investigation of the roof framing.

Bennett Preservation Engineering (BPE) conducted construction contract administration of the shoring and stabilization phase. In March 2022, BPE reviewed the shoring in person once it was in place.

In March 2022, once the truss shoring was in place, Bennett and Andrea C. Williams, also of this firm, examined the roof framing above the stage and the auditorium. The examination was visual with the addition of previously made as-built and shoring drawings from laser scans, photo documentation, and measurements of members and connections. Minimal finishes were removed for structural examination.

In addition, using the information collected from scans and measurements, BPE has done a gross structural analysis of members in the stage truss and a typical auditorium truss, member checks on the two trusses, fine structural checks on the internal member connections of the two trusses, and checks on the supporting masonry walls.

This report contains Bennett's findings, conclusions, and recommendations.

A brief history of the McCelvey Center in York, South Carolina, is summarized in the following text from the Culture & Heritage Museums website.

"*The McCelvey Center is the original site of the Yorkville Female College founded in 1852 and includes the 500-seat Lowry Family Theater. Noted for its remarkable acoustics, the historic theater has a warm ambiance and hosts the annual Southern Sound Series. The mission of the Lowry Family Theater is to present the unique heritage of the Carolina Piedmont through the performing arts while maintaining a quality venue for community enrichment."*

An additional history of the McCelvey Center is summarized in the following text from a 2008 report titled *Historic Architectural Survey of the City of York* by Brockington Cultural Resources Consulting.

"The new influx of rural families into Yorkville brought about a need for public schools. Following a period of private schools, the Yorkville Graded School system was inaugurated in 1888 and was the second public school system in South Carolina. The school opened in 1889, was rebuilt after a fire in 1902, and after a series of name changes, closed in 1987. Following the school's closure, York School District One turned over ownership and operation of the building and one acre of land to the non-profit organization McCelvey Center, Inc., for use as a community and performing arts center. In 2001 the York County Culture and Heritage Commission took over operation of the site plus the 11.5 acres of land behind the facility.

Now a community center housing the Historical Center of York County, the McCelvey Center has been a center for education in York since the antebellum period. The site originally housed the Yorkville Female College and Institute, opened in 1856 by the Bethel Presbytery. The school was closed during the Civil War but reopened as the York Graded School in the late nineteenth century. When the original building burned in the early 1900s, a new structure was constructed in 1904 on the stone foundation of the Yorkville Female College and Institute. The building was expanded into the present building in 1922 and was later renamed McCelvey Elementary School, after a former principal. In 1988 the building was deeded to York citizens for use as a community center."

The McCelvey Center is currently owned by York County and overseen by the Culture & Heritage Museums.

Findings by Observation

Built in the early 20th century, the McCelvey Center is a three-story brick masonry wall with a large auditorium. The naming convention used in this report is as follows: each truss is labeled numerically from south to north, starting with the truss over the stage as Truss 1.

Observations of Truss 1 from Below

The truss above the stage is approximately 60 feet long (60’-2” measured on the scan drawings) from inner face to inner face of the masonry walls.

There is a break in the truss east of the center shoring tower, near the end of a steel plate that joins the two truss pieces at or near the center. The plate could not be seen for its full length, but it appeared to be approximately 4 to 5 feet long. BPE could not determine whether or not the connection plate was centered on the joint. See Figures 1 through 3.

Sara Johnson, of the Culture & Heritage Museums, informed BPE that the chord might have been broken for over a decade, since some roof sagging was reported during a past construction roofing project, approximately 10 to 15 years ago. See Figure 4 for a recent view of the roof sag. BPE suspects that the break in the truss was far more recent than that, because there would have been significant deflection in the truss before it broke, enough to be of concern to a roofer. BPE further thinks that the debris found on the stage, just before the local engineer was first called in, likely fell when the truss bottom chord broke.

The break in the truss was, not unexpectedly, at a bolt. It appears that the bolt, with a diameter of approximately 3/4 of an inch, was a horizontal bolt near the bottom of the bottom cord, approximately an inch above the bottom edge of the bottom cord. It appears to have been a smooth bolt rather than a threaded rod. See Figure 3.

The bottom cord was notched at a few locations on each side of its center. It appears these notches were created to attach a steel plate with bolts to connect the bottom chord splice in the center of the truss. The remaining wood appears to be roughly 7 1/2 inches wide minus a 1 1/2 inches to 2 inches on each side leaving a width of roughly 4 to 4 1/2 inch. See field sketch in Figure 5. It is clear that the truss has failed here.

The cut in the south face of the bottom chord appears to be an inch and a half deep, causing us to wonder, without being able to see clearly from below, if the member might have been made up of multiple pieces of wood. When the break was seen from above, BPE determined the chord was a single piece.

Observations of Truss 1 from the Attic

The bottom chord of Truss 1 seems to be cut the same way as Truss 4, however, instead of a wooden side piece, the side pieces are made up of thin metal plates along each side with thicker plates in the notches. See Figure 6. See Figure 22 for sketch of Truss 4's wooden side pieces.

No termites were visible in Truss 1 from the attic.

The break in the truss east of the center rod can also be seen from above in the attic. See Figures 7 through 9.

Running from the middle of the truss going south to the south wall, is a girder. This girder is supported at the middle panel point of the truss. On each side of this girder are small ledgers which support joists running east-west in the attic, which in turn support the beadboard ceiling over the stage. See Figures 10 and 11. As the girder dropped with the truss bottom chord, the ledger on the east side of the girder was pulled away from the girder by the joists which are attached to it. See Figures 12 through 15. As the bottom chord of the truss broke, the joists running parallel to the truss and bearing on the girder moved away from the girder, pulling the ceiling boards open and allowing debris to fall onto the stage below. Some of the ceiling boards south of the truss have separated from one another approximately 6 1/2 inches. See Figures 16 and 17. ***Note that access in the attic in this area is extremely dangerous.***

The exterior east and west walls of the south end of the building at the stage have been pushed outward by the failure of the bottom chord of the truss. The east wall is approximately 10 3/8 inches out of plumb and the west wall approximately 3/8 of an inch out of plumb. In addition, the roughly 9 inch deflection of the middle of the truss has caused the diagonal rafters, attached both to the truss and the south wall, to push the south wall out of plumb by approximately 3 inches. These values were pulled from BPE's laser scan point cloud of the McCelvey building.

Observations of Truss 4 from the Attic

Truss 4 in the attic, the second truss south of the north wall, is observed as a typical condition of the five trusses over the auditorium (all trusses besides Truss 1 over the stage).

This truss cannot be simply classified. While it might appear to be a parallel to a Pratt or Howe truss, in reality it has wooden members intending to act in tension and other wooden members clearly acting in compression. The wooden tension members are, unfortunately, connected at their ends with compression-only connections, making these wooden tension members useless. Therefore, the truss ends up acting as a Howe truss with only the wooden compression members effective as shear carrying web members. To further complicate matters, the compression members are cut away where they cross the wooded tension members, forcing an eccentric compression load into the remaining half section. There are, however, tension rods at the approximate quarter points and at the center. Truss 4 has a tension king post threaded rod in the center of the truss approximately 1 inch in diameter. See Figures 18 and 19.

The bottom chord of the truss is made up of two 8x10 timber members, each half the length of the truss and joined in the middle, under the king post rod. The truss members are joined by a wooden side plate let into vertical dadoes cut into the sides of the bottom chords. See sketch in Figure 22. Bolts are used to hold the bottom chord and the wooden side pieces on the north and south faces of the chord together. See Figures 20 and 21.

Findings by Calculation

Assumptions on Loading

The International Building Code 2018 and ASCE 7-16 were used for this analysis. It is assumed that there is no increase in loading and no decrease in structural capacity of structural framing. It is also assumed that wind loads control over earthquake loads for this structure, although, because the structure was found to be already grossly overstressed under dead load plus live load, there was no need to run wind or seismic loading cases or combinations.

Design Criteria

- Auditorium/Stage Roof Live Load................20 psf
- Auditorium/Stage Roof Dead Load..............16 psf
- Auditorium/Stage Attic Live Load................20 psf
- Auditorium/Stage Ceiling Dead Load...........28 psf

Wind

- ASCE Ultimate Design Wind Speed: 118 mph
- ASCE Nominal Design Wind Speed: 92 mph
- Risk Category: III
- Exposure: B
- Applicable Pressure Coefficients:
- External [Cp]: +0.80, -0.4, -0.70
- Internal [GCpi]: +/-0.55
- Gust [G]: 0.85
- Ultimate Wind Pressure [p]: 50.7 psf
- Nominal Wind Pressure [p]: 30.5 psf

Findings and Conclusions by Simple Couple Analysis of Trusses 1 & 4 Under Dead Load & Live Load

For Truss 1, the truss over the stage that has already failed, early couple analysis showed that the truss bottom chord carries an approximately 38 kip tension load under dead load alone and an approximately 72 kip tension load under a dead plus live load. If the dimensions of the middle cross section at the break are taken as 4 1/4 inches by 6 inch and the areas above and below the bolts are taken as 7 1/2 inches by 5/8 of an inch, the remaining cross-sectional area of the truss is approximately 34.9 or 35 square inches. Based on these figures, the dead load tension stress would be approximately 1070 psi. The dead plus live load tension stress would be approximately 2050 psi.

If the wood were modern day Southern Pine, allowable tension stresses would be 900 psi for No. 1 and 550 psi for No. 2. If the wood were Hemlock, allowable stresses would be 875 psi for No. 1 and

375 for No. 2. Under all likely assumptions about the species and grade of wood, the applied stress under dead load plus live load grossly exceeds the allowable stress. Even under dead load alone, depending upon the species and grade of wood, the applied stress could be significantly greater than the allowable. The surprising thing is not that the truss failed but that it did not fail sooner.

For Truss 4, the tension load in the bottom chord under dead load alone is approximately 23 kips and under dead load plus live load is approximately 44 kips. Because Truss 4 has not yet failed, we were not able to determine the exact measurements of the cross-section within the dado connection, but were able to take measurements that we believe are reasonably accurate. Based on a remaining cross section of approximately 4 x 9 1/4 inches less 2 bolt holes of 4 x 5/8 inch, we calculate a cross-sectional area of 31 square inches. This cross-sectional area would give tension stresses of approximately 750 psi under dead load and approximately 1430 psi under dead load plus live load.

RAM Model Assumptions and Procedures

In spite of the fact that the simple couple analysis above showed gross overloads of Truss 1 and Truss 4, with Truss 4 being representative of all trusses over the auditorium, BPE has additionally modeled the trusses in RAM Elements as a check on the simple couple analysis.

As above, Truss 1 was modeled to represent the southernmost truss over the stage. Truss 4 was modeled to represent a typical condition of the trusses over the building's auditorium. The geometries of the two trusses were based on the scans and hand measurements BPE collected during its two site visits. The exact wood species of all the roof framing is currently unknown. BPE assumed, for modeling purposes, the wood species and grades of all members in both trusses to be No. 1 Southern Pine.

For Truss 1 and Truss 4, the center portion of the bottom chord was modeled to a thinner width than the rest of member to match its current effective width due to significant notches. These notches were made for side members meant to connect the east and west pieces of both trusses' bottom chords. This reduced the member width in the center of the bottom chord to approximately half of the width of the rest of the member.

A similar method was used at the centers of the diagonal members of Truss 1 and Truss 4 where the two diagonals intersect on the east and west sides of the trusses. The diagonal members are lapped at their intersection causing a decrease in member thickness at this location.

The diagonal member running from the center of the bottom chord outward to the top chord on each side of both the trusses was removed from both the Truss 1 and Truss 4 models. As seen in Figures 23 and 24, the diagonal member has detached from the top chord and is no longer receiving any load.

RAM Model Conclusions

While simple couple analysis showed that the Truss 1 bottom chord carries 38 kips of direct tension load under dead load alone and 72 kips under dead load plus live load, the RAM Elements analysis showed tension forces of 53 kips under dead load alone and 102 kips under dead load plus live load. The more accurate RAM analysis on Truss 4 showed tension forces under dead load alone of 27 kips and 51 kips under dead load plus live load. For Truss 1 the computed forces are 39-42% higher than simple couple analysis showed, and for Truss 4 the forces are 16-19% higher.

Even though the trusses were already showing over stress under simple analysis, for the sake of completeness we have calculated stresses under the RAM Elements analysis. These analyses show even worse over stress than the simple analysis showed. All results are summarized in the table below.

Description	**Couple Analysis Truss 1**		**Couple Analysis Truss 4**		**RAM Elements Analysis Truss 1**		**RAM Elements Analysis Truss 4**	
Truss location	Stage		Auditoriu m		Stage		Auditoriu m	
Truss span	62	ft	52	ft	62	ft	52	ft
Dead Load Alone								
Tension force in bottom chord	38	kips	23	kips	53	kips	27	kips
Area of bottom chord at connection	35	sq in	31	sq in	35	sq in	31	sq in
Applied tension stress	1,086	psi	742	psi	1,514	psi	871	psi
Allowable tension stress	900	psi	900	psi	900	psi	900	psi
Ratio of Applied/Allowable	1.21		0.82		1.68		0.97	
Overstress	21	%	-18	%	68	%	-3	%
Dead Load + Live Load								
Tension force in bottom chord	72	kips	44	kips	102	kips	51	kips
Area of bottom chord at connection	35	sq in	31	sq in	35	sq in	31	sq in
Applied tension stress	2,057	psi	1,419	psi	2,914	psi	1,645	psi
Allowable tension stress	900	psi	900	psi	900	psi	900	psi
Ratio of Applied/Allowable	2.29		1.58		3.24		1.83	
Overstress	**129**	**%**	**58**	**%**	**224**	**%**	**83**	**%**

Under all conditions of loading and analysis, and all assumptions about species and grading of wood, both Truss 1 and Truss 4 are grossly and unacceptably overstressed.

The following are Bennett Preservation Engineering's recommendations for long term stabilization and rehabilitation of the McCelvey Center. These recommendations are intended to serve as a guide for both architectural and structural design work but are not intended, by themselves, to be used for construction.

Most importantly, we recommend that the owners take care of life safety. The current shoring must remain in place and only minimal service occupancy allowed in and around the building until the roof trusses can be replaced or strengthened.

Options

York County, as owners of the McCelvey Center, should consider multiple options for the replacement or strengthening of the structural system supporting the roof. First, our assumption is that the McCelvey Center is fundamentally adequate for the purposes for which it is used. With this assumption, the challenge then becomes one of either strengthening the roof framing system or completely replacing it. It is our fundamental belief that the system can be strengthened and brought up to current code for dead load, live load, and wind load for a significantly lower cost than it can be replaced. For that reason, our recommendations are focused exclusively on strengthening of the existing truss systems.

Specific recommendations

In order to strengthen the truss systems to meet current building code requirements for structural life safety, we recommend the following construction:

- Protect all aspects of the interior of the McCelvey Center in preparation for construction, including removing the seating.
- Shore all trusses over the auditorium.
- Additionally shore the east and west ends of the stage truss (Truss 1).
- Shore the north-south girder currenting tying into the center of the stage truss (Truss 1).
- Starting at the northernmost truss over the auditorium, lift the truss enough to remove the tension stress from the bottom chord. This will likely require lifting the truss approximately 20-50% of the amount it has deflected.
- Sister all members of the truss. This will likely mean sistering the compression top chord and the diagonal web members with laminated veneer lumber (LVLs) and sistering the bottom chord with LVLs, likely two layers, or strengthening that chord with a single layer of LVL and additional steel rods or plates.
- Strengthen all member connections, in most locations with steel plates fitted to the specific location.
- If the exterior masonry walls of the auditorium beneath the truss bearing area are not adequate for carrying the load imposed by the end of the truss, strengthen that wall with additional buttressing or partial brick replacement near the top of the wall.

- Tie the ends of the truss down either to the masonry wall or to new straps and perhaps buttresses to adequately protect against wind uplift.
- Move south in the auditorium making the same repair in each truss.
- After all of the auditorium trusses have been strengthened, make the same repairs at the stage truss (Truss 1).
- Rebuild the east and west walls under the stage truss and tie the stage truss down to the rebuilt areas.
- Pull the south wall back into plumb again and tie it to the framing system.
- Repair all finishes and other systems, including mechanical systems, damaged by or removed for this work and repaint all painted surfaces on the interior of the auditorium.
- Reinstall all historic seating and other interiors removed for construction.
- Thoroughly clean the whole auditorium.
- Replace all landscaping damaged by the construction.

The above list is an outline of work to be done but is not all-inclusive. As part of the scope of our work under contract for the McCelvey Center, Bennett Preservation Engineering is developing conceptual drawings reflecting this scope of work and is having that work priced out. Those conceptual drawings and the conceptual cost estimate will be provided as a future appendix to this report.

The findings, conclusions, and recommendations in this report have been written and reviewed by Andrea C. Williams and Craig M. Bennett, Jr. PE of Bennett Preservation Engineering PC. We have based this report on information available to us at this time. If conditions change or more information becomes available, we would like to have the opportunity to reevaluate our conclusions and recommendations.

We understand that the information submitted in this report could require additional explanation. We welcome the opportunity to review this information and to answer any questions. We appreciate the opportunity to present this report and look forward to presenting the conceptual design and cost estimate.

Sincerely,

Andrea Cooper Williams, E.I.T.
Bennett Preservation Engineering PC

Craig M. Bennett, Jr., PE, SE
Bennett Preservation Engineering PC

Figure 1: View of break in Truss 1 from below

Figure 2: View of break in Truss 1 from below

Figure 3: View of break in Truss 1 from below

Figure 4: Condition of roof sag in March 2022

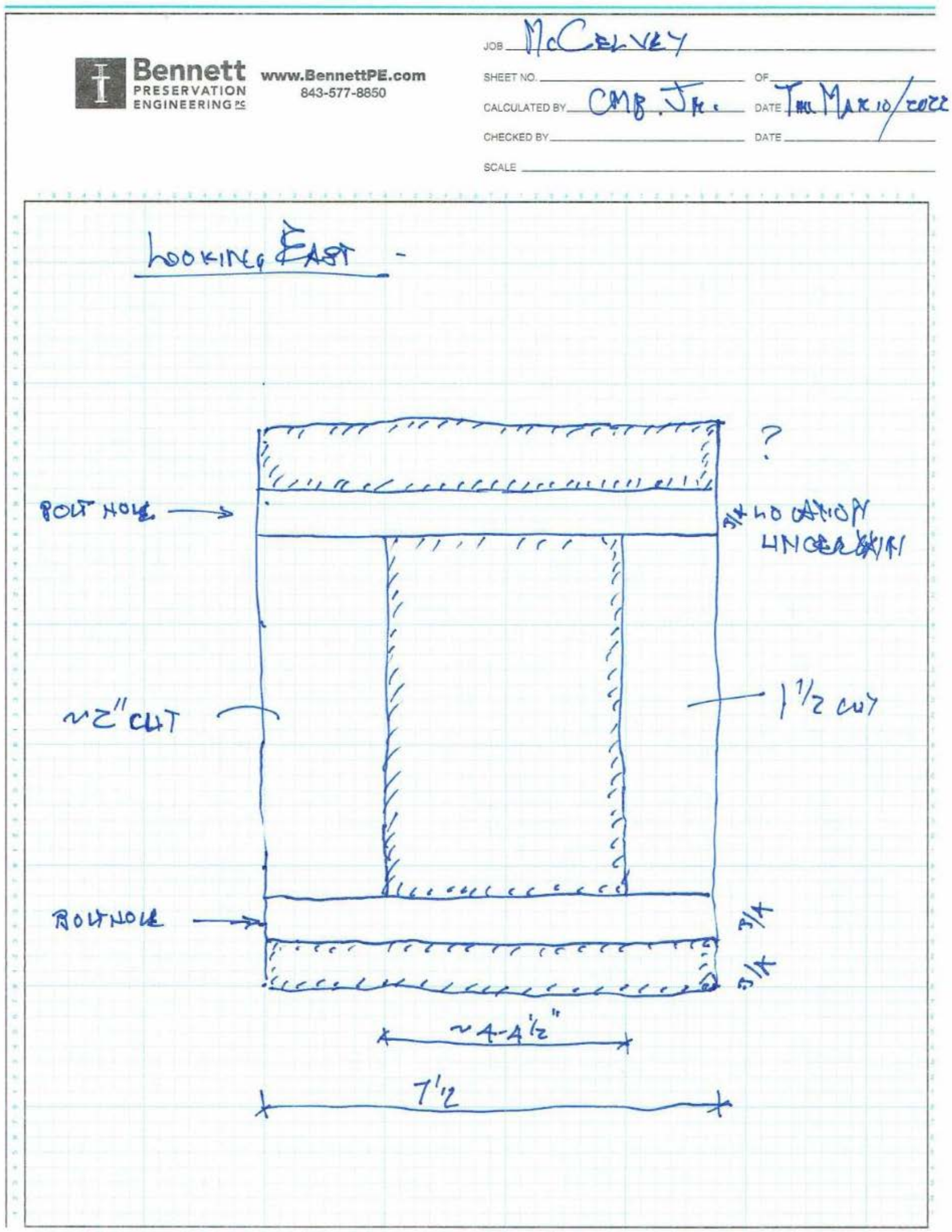


Figure 5: Truss 1 cross section field sketch

Figure 6: Metal plate side pieces at Truss 1 bottom chord

Figure 7: View of break in Truss1 from above


Figure 8: View of break in Truss1 from above


Figure 9: View of break in Truss1 from above

Figure 10: Girder running from Truss 1 to south wall

Figure 11: Girder running from Truss 1 to south wall

Figure 12: Ledger pulling away from north-south girder

Figure 13: Ledger pulling away from north-south girder

Figure 14: Ledger pulling away from north-south girder

Figure 15: Ledger pulling away from north-south girder

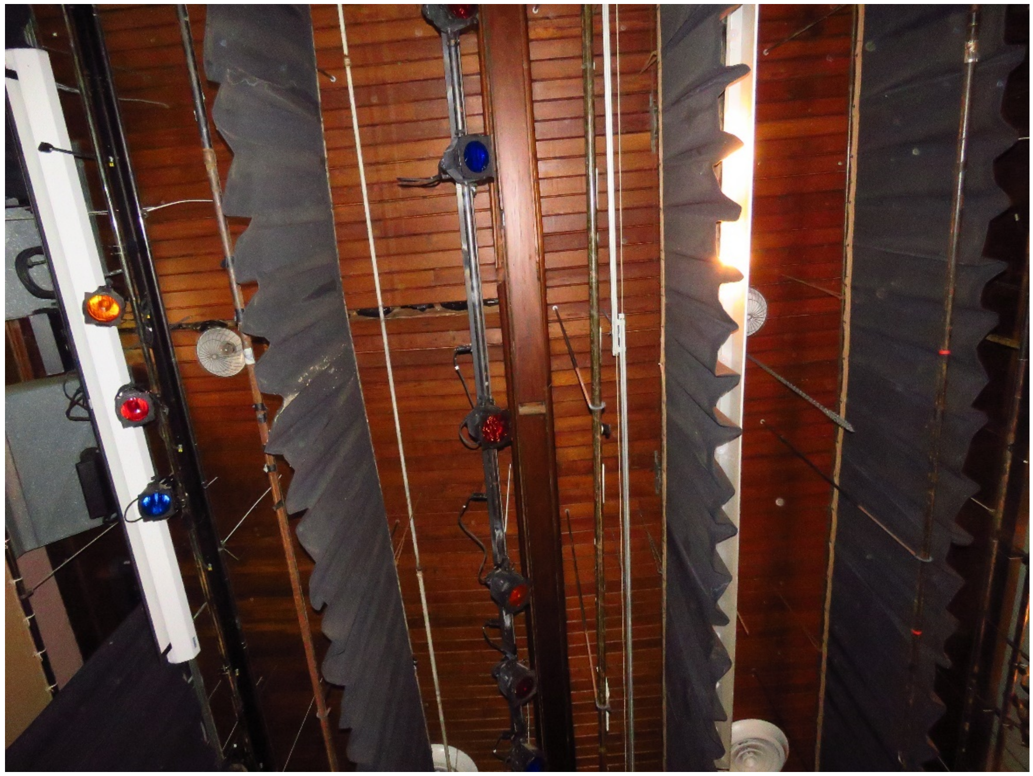


Figure 16: Open ceiling boards south of Truss 1

Figure 17: Open ceiling boards at Truss 1

Figure 18: Quarter point rod on east side of Truss 4

Figure 19: Center rod of Truss 4

Figure 20: Center rod and bolts at Truss 4 bottom chord

Figure 21: Bolts at Truss 4 bottom chord

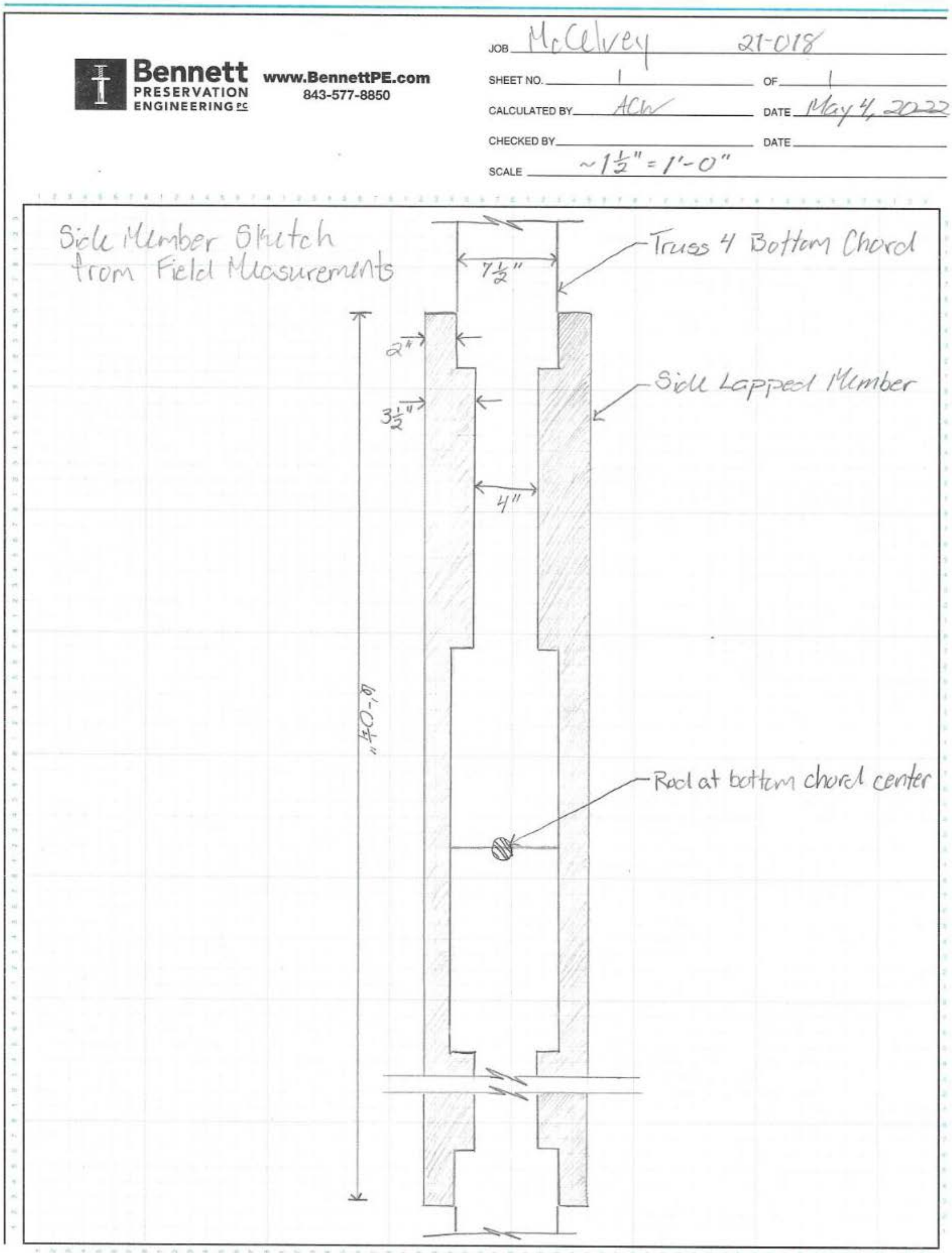
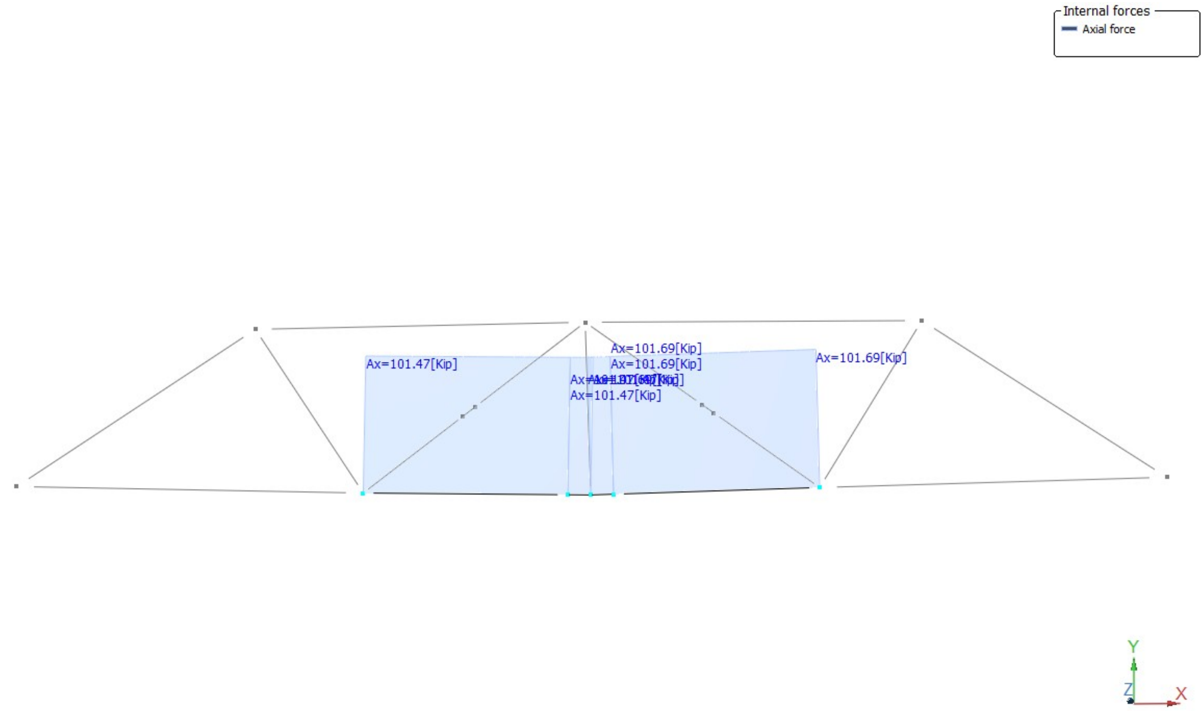


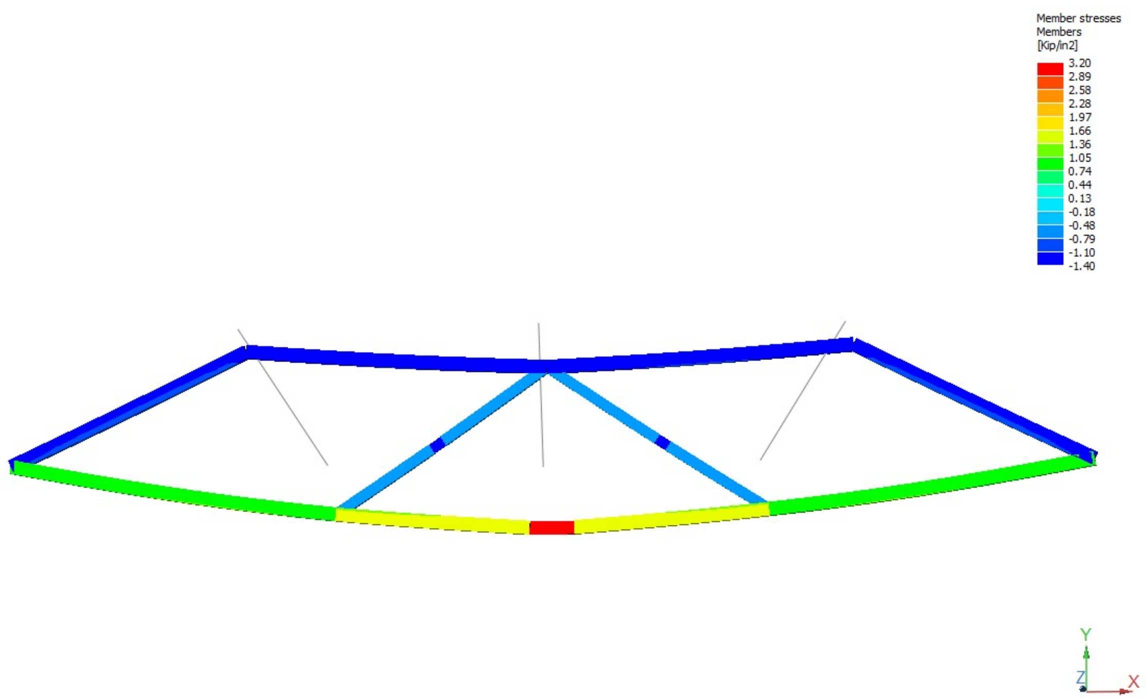
Figure 22: Plan view of wooden side pieces at Truss 4 bottom chord (bolts excluded)

Figure 23: Disconnected diagonal at Truss 1

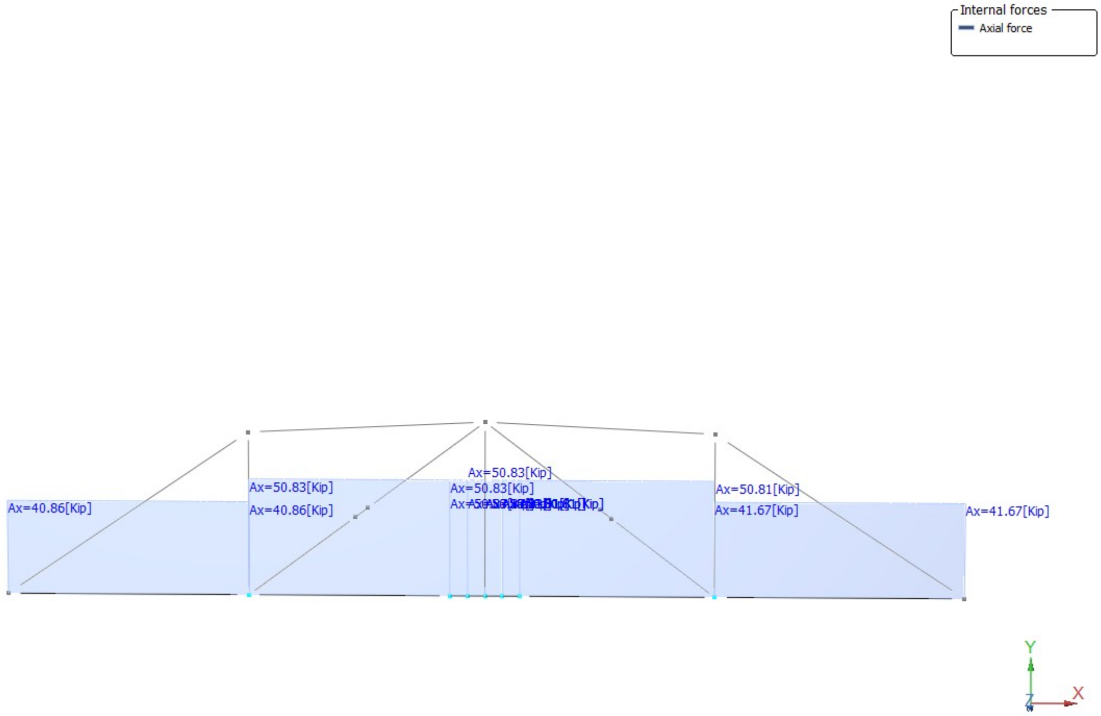
Figure 24: Disconnected diagonal at Truss 4



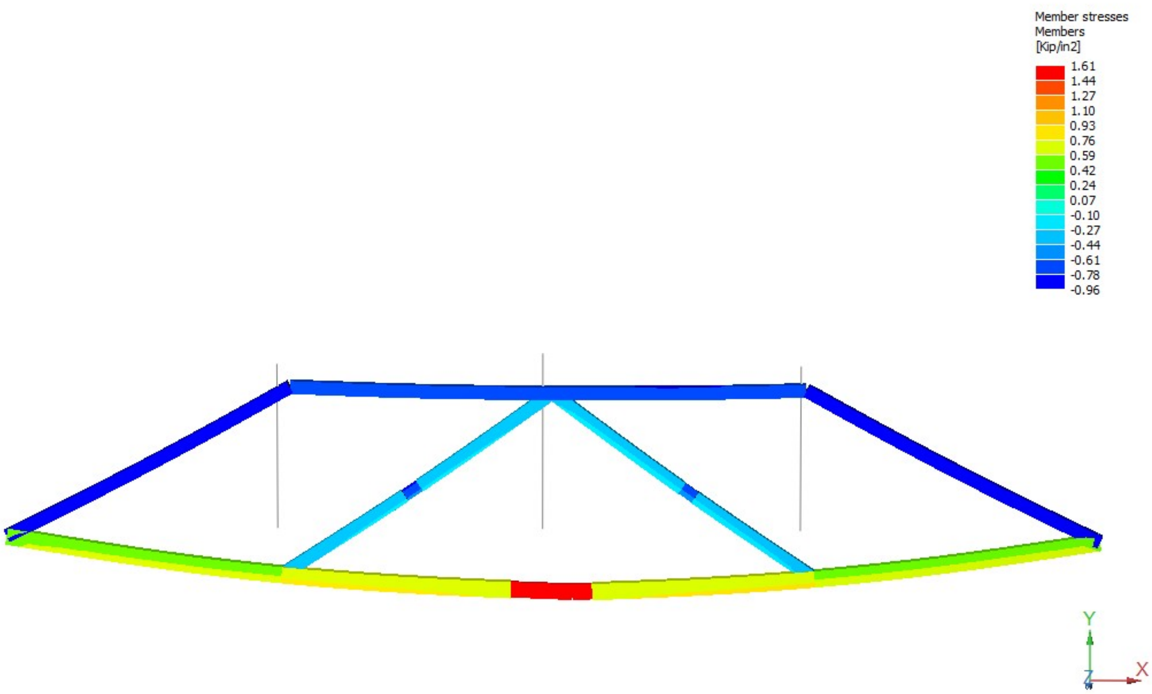
Truss 1 Axial



Truss 1 Stresses



Truss 4 Axial



Truss 4 Stresses