Prochnow Auditorium Stage Rigging Structural Analysis

GAT

Structural Engineering Firm

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Project Introduction

Figure 1: Stage Rigging [1]

Purpose of Rigging:

- Structural system used to suspend curtains, lights, speakers, screens

Purpose of Project:

- Conduct a Condition Assessment
  - Existing plans, condition, loads, capacity
- Future Loading Plan
  - Additional loads, placement, maintain code
- Technical report to client at H&M

Prochnow Auditorium

Satellite View

Figure 2: NAU North Campus Flagstaff, AZ [2]

Stage View

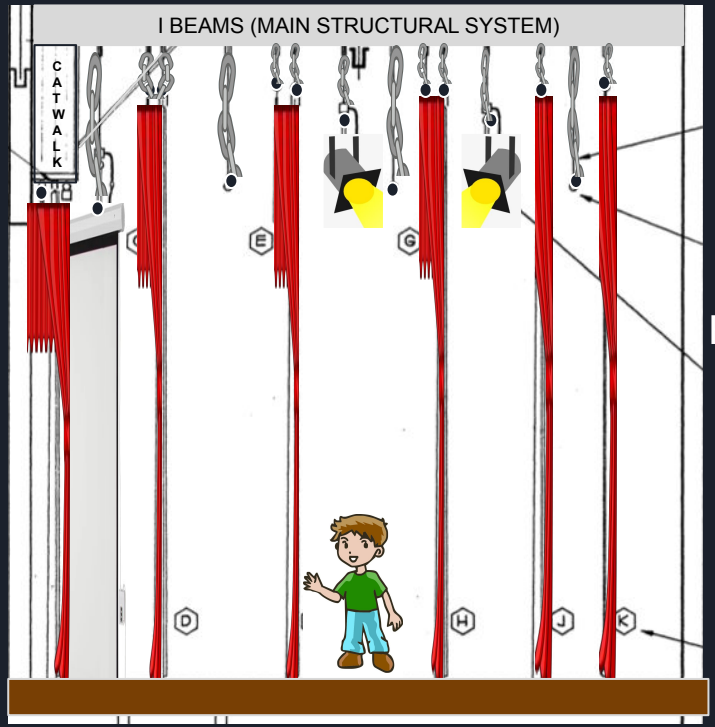
Figure 3: Prochnow Auditorium Stage [1]

Street View

Figure 4: Street View of Prochnow Auditorium [2]

Prochnow Auditorium Rigging

FRONT OF STAGE



BACK OF STAGE

Figure 5: Rigging Example

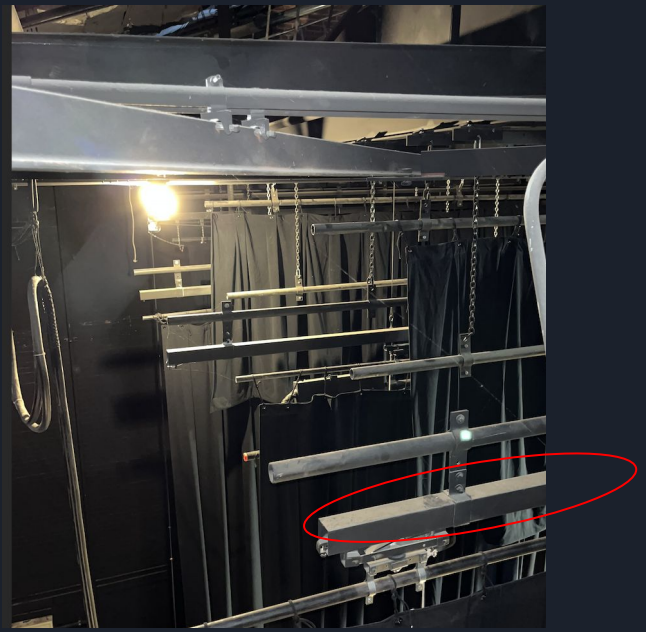


Figure 6: 17 Battens [1]

Clients & Stakeholders

Clients:

Joshua Spears (Facilities Project Manager)

Thomas Charles Eberly (Vice Pres. of Campus Operations)

David S. Merrell, P.E., S.E. (Hubbard Merrell Eng.)

Other Stakeholders:

Staff, Performers, Customers

Dr. Tuchscherer (Grading Instructor)

Dr. Dymond (Technical Advisor)

Client: Joshua Spear

TA: Dr. Ben Dymond

Plan Review

Figure 7: Original Plans in Vault [1]

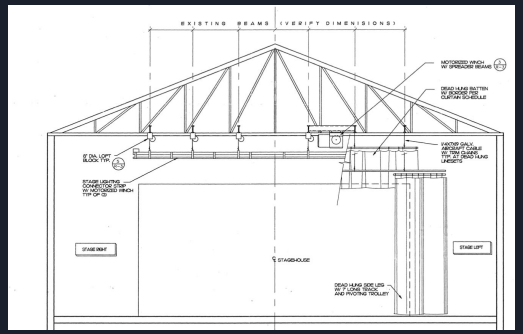


Figure 8: 1994 Plans Profile View [3]

Auditorium was built 1951

Rigging was renovated in 1994

- ‘94 design plans had the most information about the rigging
- Some dimensions were not included which required field verification
- Schedules were used as a guide for product data

Site Visit

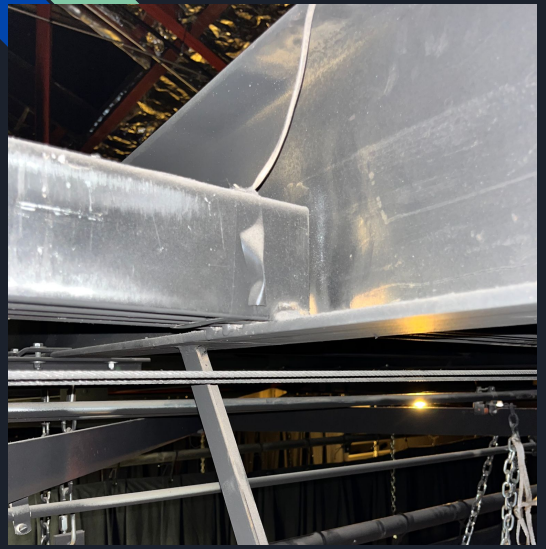


Figure 9: Documented Connection [1]

Figure 10: Jose & Theo on Catwalk [1]

- Compared design plan to existing conditions
- Took measurements
- Photographed connections
- Identified loads
    - Location and quantity

Site Visit Dates (4)

- February 14th
- April 4th
- April 18th
- April 23rd

Site Visit

- Minor deflection in the cross section of L3”x2”x ¼” angle
- Number of chains were documented
- Items not included in plans were noted
- Truss did not match plans

Figure 11: L 3”x2”x¼” Cross Brace [1]

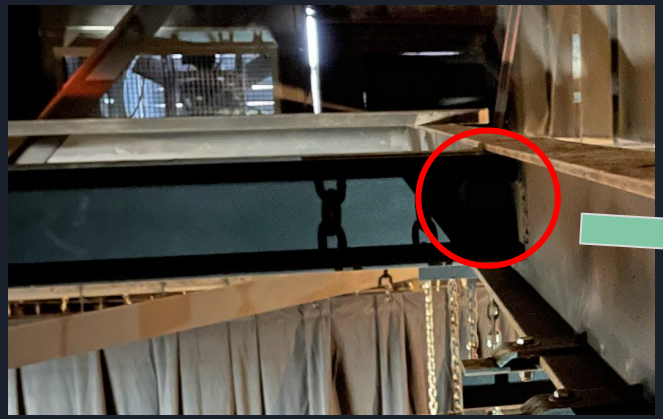


Figure 12: W 6X9 Connects w/ W 8X15 [1]

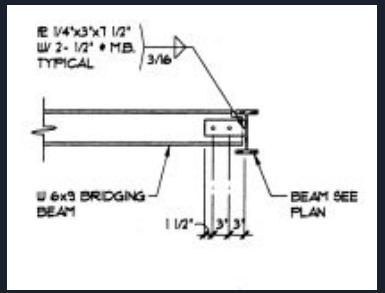


Figure 13: Beam connection from plans [3]

Truss Above Rigging

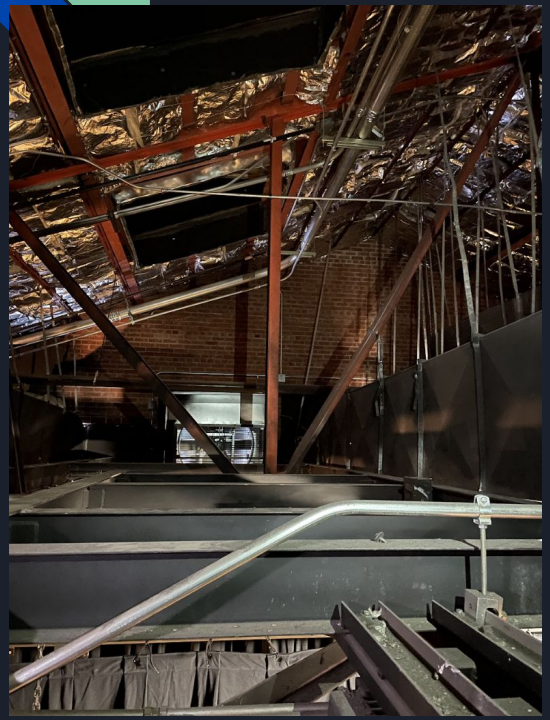


Figure 14: Truss [1]

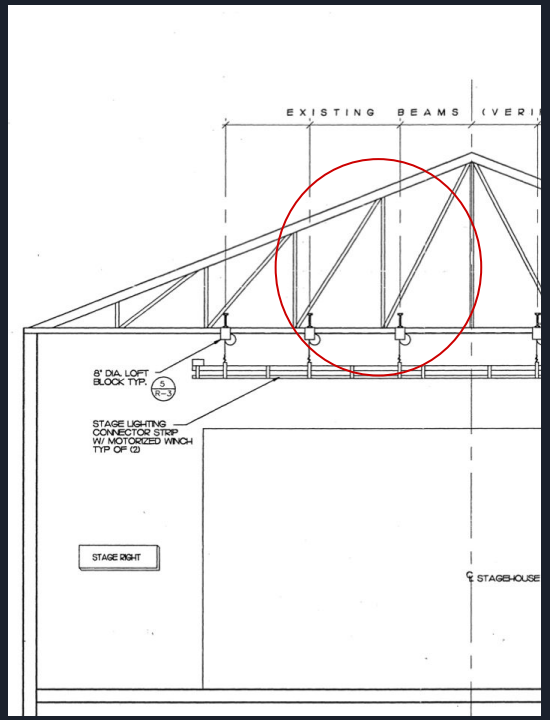


Figure 15: '94 Truss Drawing [3]

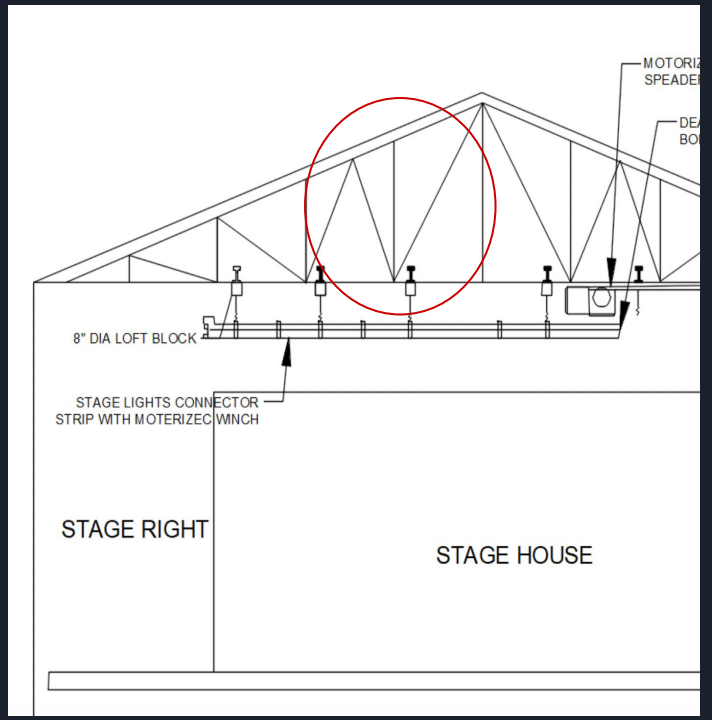


Figure 16: Updated Truss [3]

As-Built Drawings

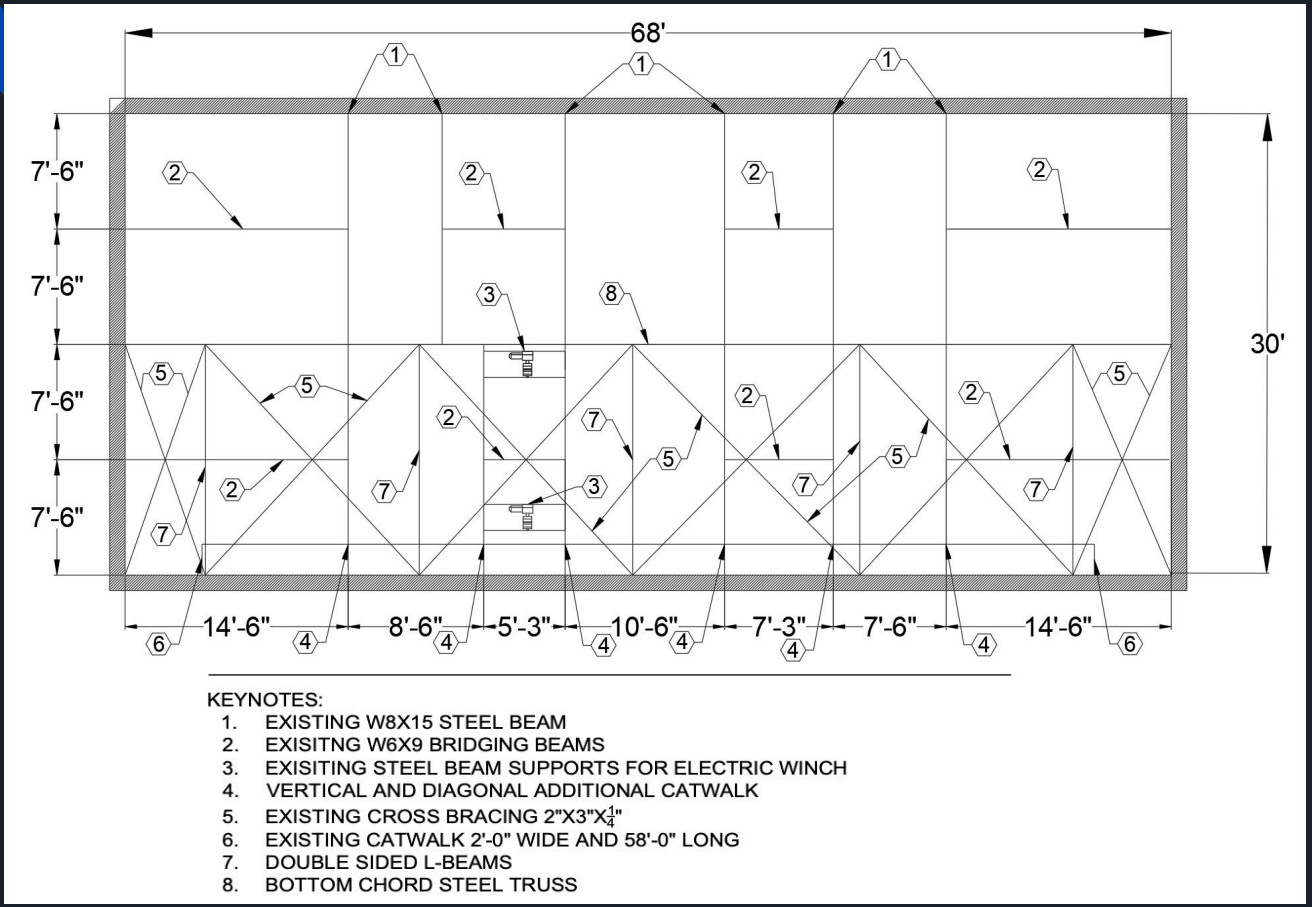


Figure 17: Rigging Beam Plan [1] [3]

Team found many differences between plans and actual conditions

- Document all differences
- Update as-builts and model accordingly
- Ensure accurate dimensions

Load Determination

LOADING SCHEDULE (ALL LIVE LOADS)							
Cases		Number of Loads	Loading Case Specifics		Total Weight (lbs)	# of Chains	Total Weight @ Chains (kips)
Batten Loading			Unit Weight (lb/ft)	Area (sqft)			
1	Valence Curtain	3	0.0208	215	169	9	0.0188
2	Main Traveler Curtain	3	0.0208	864.5	276	9	0.0307
3	1st Electric	5	-	-	254	9	0.0282
4	Projector Screen	1	-	1227	1059	2	0.5295
5	1st Border	3	0.0208	215	169	9	0.0188
6	1st Side Leg	3	0.0208	151.4	162	9	0.0180
7	General Purpose 1	1	3	-	138	9	0.0153
8	2nd Border	3	0.0208	215	169	9	0.0188
9	2nd Side Leg	3	0.0208	151.4	162	9	0.0180
10	2nd Electic	5	-	-	254	6	0.0423
11	General Purpose 2	1	3	-	138	6	0.0230
12	3nd Border	3	0.0208	215	169	6	0.0282
13	3nd Side Leg	3	0.0208	151.4	162	6	0.0270
14	3rd Electic w Light Boxes	4	0.0278	-	254	6	0.0423
15	Cyclorama	2	0.0139	554	226	6	0.0377
16	Commando Cloth Curtains	2	0.0139	1227	240	6	0.0400
17	General Purpose	1	3	-	138	6	0.0230
Winch Loading			Self Weight (lbs)	Capacity (lbs)			
		2	60	1300	2720	2	1.36
				Total Weight	6862 lbs		

Table 1: Loading Schedule (All Live Loads!) [1] [3]

Figure 18: Leg Curtain Label [1]

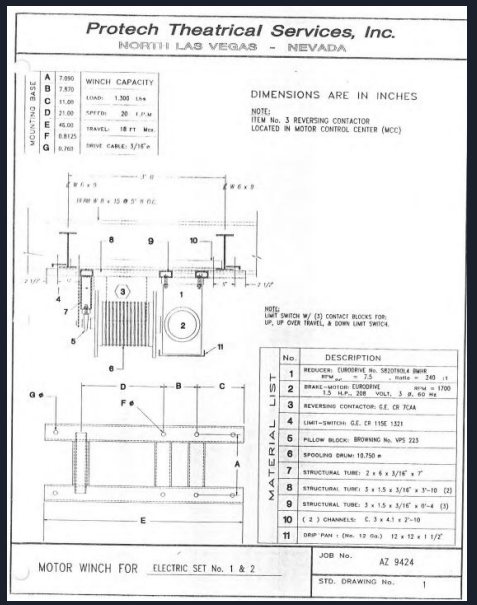


Figure 19: Winch Specs [3]

Model Created on Risa 3D

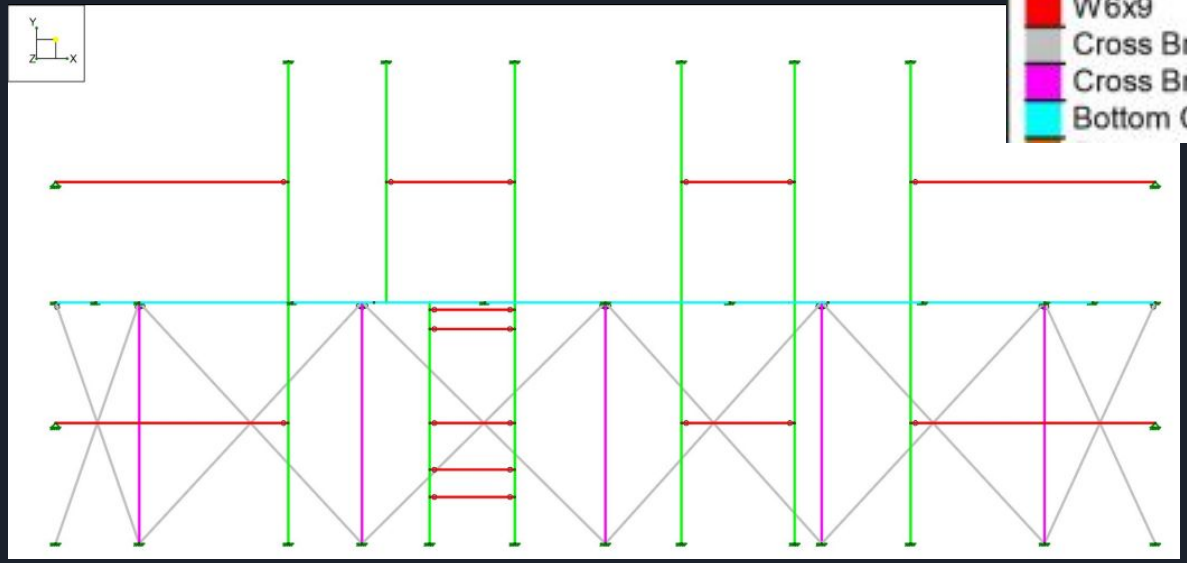


Figure 20: Color Coded Rigging Structure [7]

- W6x9 and W8x15 make up top layer of rigging
- Cross braces and lower truss chord make up lower section
- Assume A36 steel grade for all beam members
- All beam to beam connections are bolted (pin node reaction)

Existing Loads Modeled

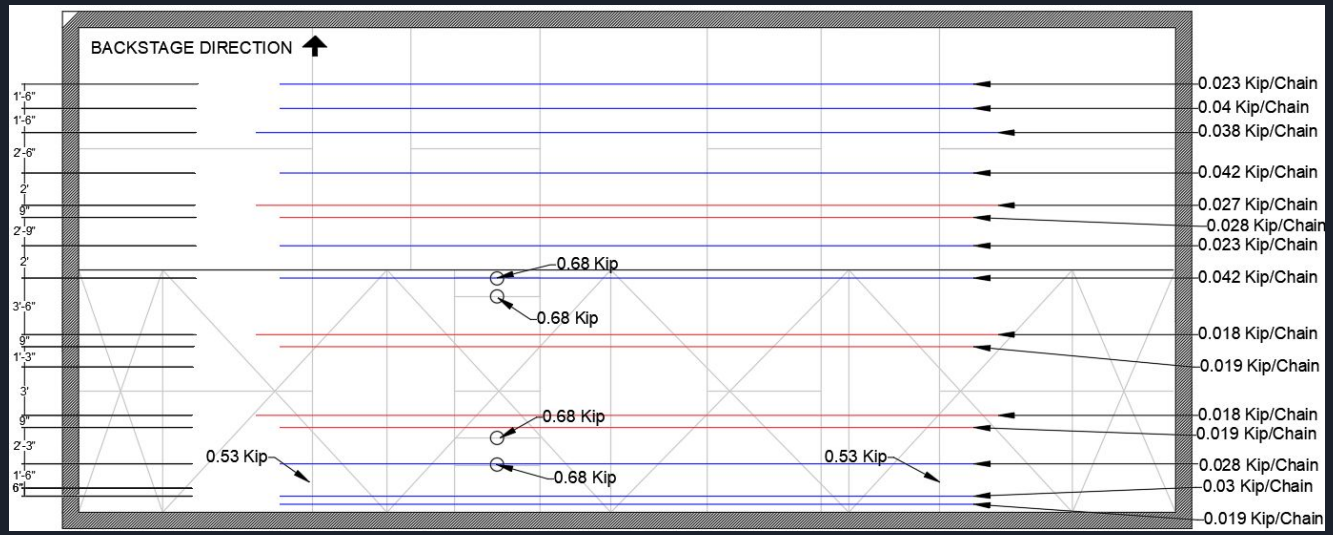


Figure 21: Load Case 1

- Two load cases modeled
- Load Case 1: Curtains fully closed
- Load Case 2: Curtains fully open (modeled as 2 point loads instead of 6+)

Profile View

- Helps support the roof of the prochnow auditorium plus the rigging
  - Rigging sits on lower chord of truss
  - Roof dead load = 20 psf and snow load = 50 psf [8]

$$DL_R = 20\ psf \times 15\ ft = .3\ kip/ft$$
$$SL_R = 50\ psf \times 15\ ft = .75\ kip/ft$$

- Rigid member links transfer applied forces from W-beams to lower chord of truss

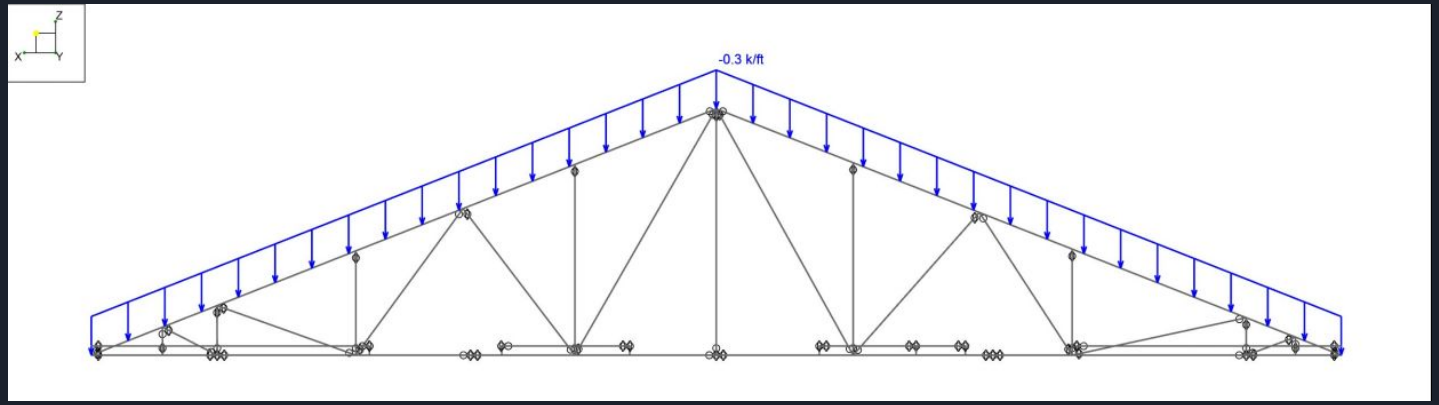


Figure 22: Profile View of Roof Truss w/ Roof DL [7]

Isometric View of Rigging Structure

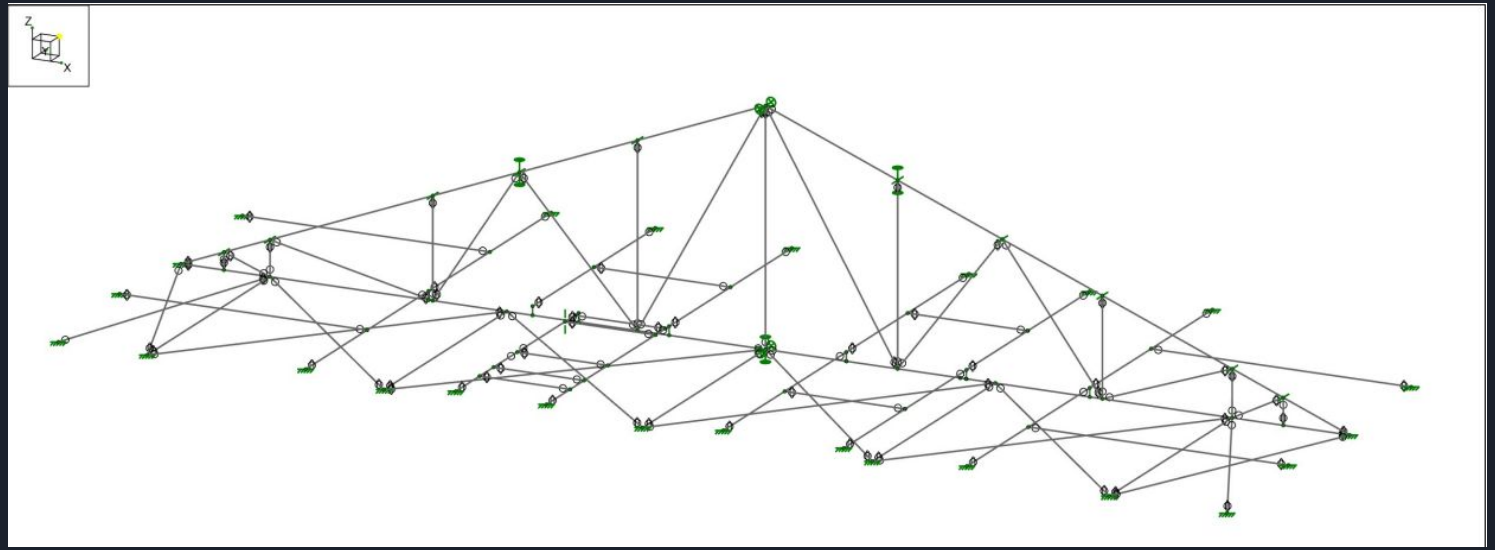


Figure 23: Isometric View of Model w/ BC's [7]

- Made alteration with to fix instability issues
- Roller connections on top of truss to prevent lateral movement

Load Combinations for Analysis

Table 2: Pertinent Load Combinations [5]

Type	Load Combination
Serviceability	DL+0.75SL+0.75LL
Ultimate	1.2DL+1.6SL+0.5LL

Table 3: Load Combinations Key

Key	
DL	Dead Load
SL	Snow Load
LL	Live Load

- Serviceability used to assess structures capacity under “normal” loads expected under service conditions. Used primarily to calculate deflections values
- Ultimate used for assessing strength and stability under extreme load scenarios. Used for comparing applied stresses to capacities.

Unity Check for Load Case 1

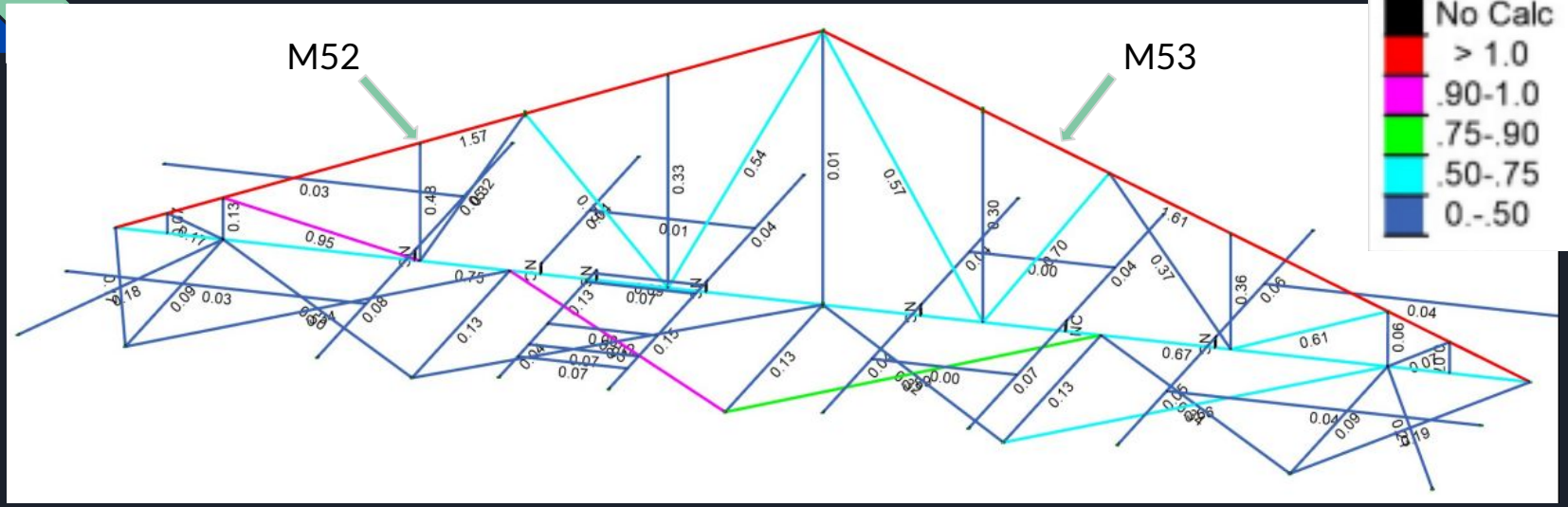


Figure 24: Unity Check for LC1 (curtains are fully open) [7]

- Ratio of applied stresses to member capacities (AISC 360-16)
- ≤1.0 considered safe and stable
- >1.0 considered in a state of failure

- Critical Members: Top chords of roof truss (M52 & M53)

Design Constraints

1. Minimum of 6 optimal load placements (per client request)
2. Potential loads applied to W8x15 beams due to lowest unity factor
3. Deflection must not exceed L/240. Considering all lengths of the W8x15 beams are 15 ft, the max deflection at these members should not exceed 0.756 in
4. Critical members stresses must not exceed by an additional 5% (per code requirement)

The “5% Rule” - IEBC 2018: Chapter 12

Historic Building --→ 1006.1 Live Loads:

- Change in Occupancy
- Maintain Previous Live Loads or IBC Requirements

Exception: Structural elements whose demand-capacity ratio considering the change of occupation is not more than 5 percent greater than the demand-capacity ratio based on previously approved live loads [6].

Optimal Load Placements

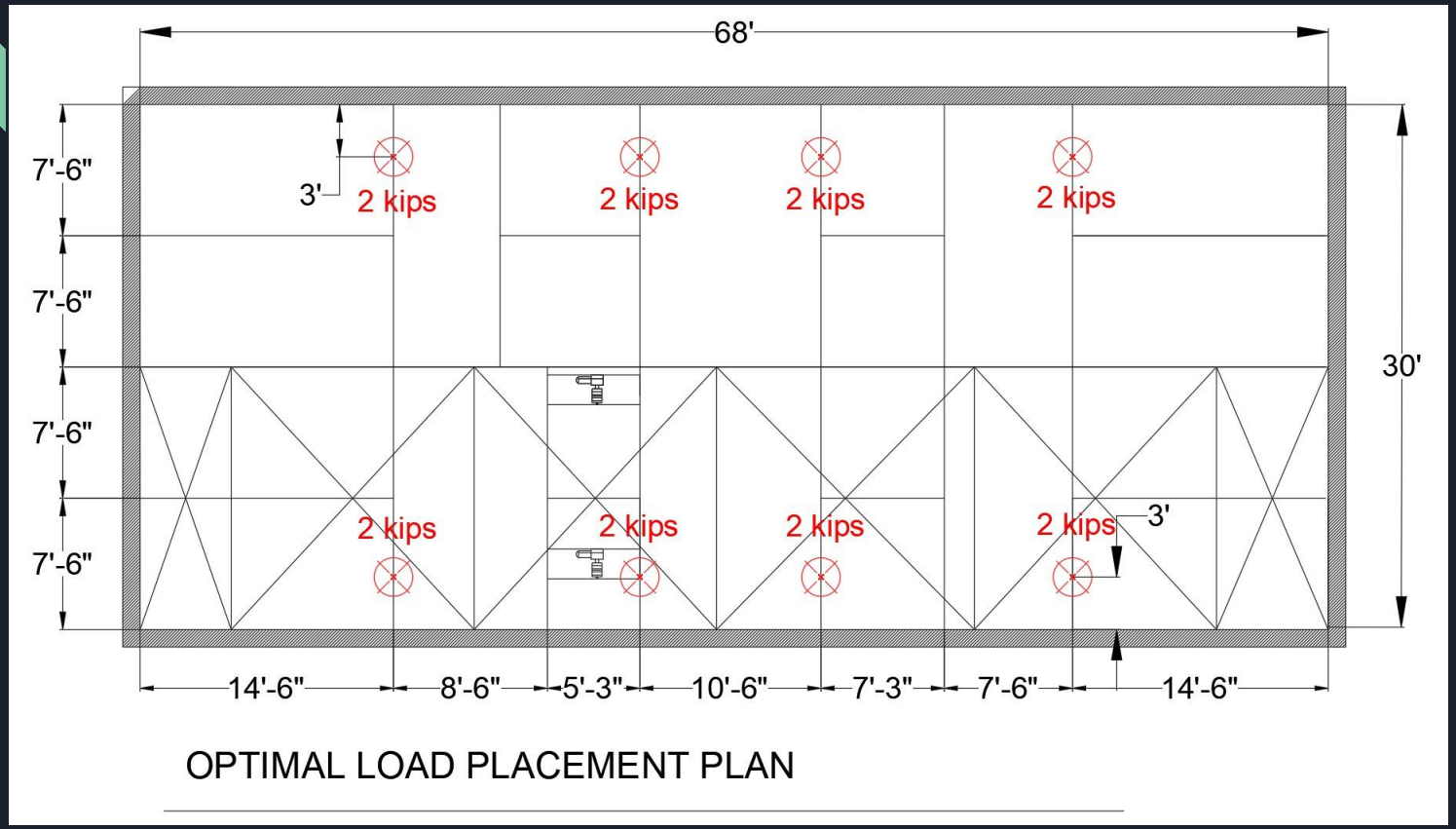
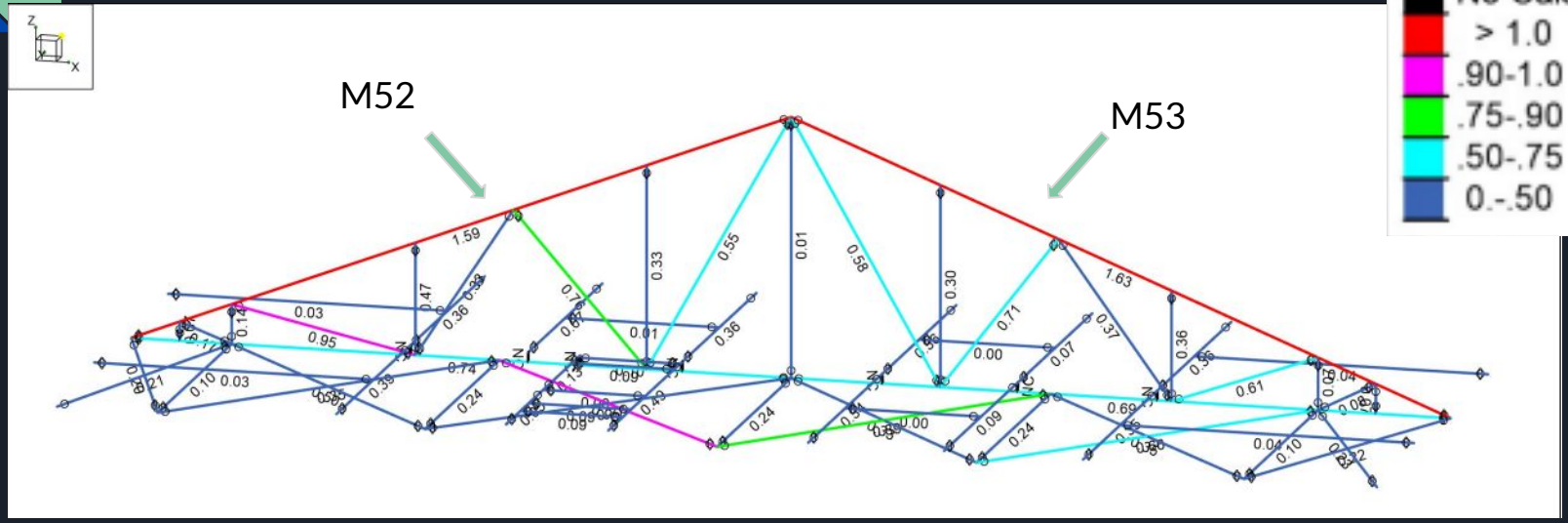


Figure 24: Loading Placement on Rigging

Unity Check For Optimal Load



	Unity Factor
M52	1.59
M53	1.63

Figure 25: Unity Check for Optimal load [7]

Results of Optimal Loads Placement

Table 4: Percent Change of Unity Ratio [7]

	Existing	Proposed	% Change
M52	1.57	1.59	1%
M53	1.61	1.63	1%

- Percent change below the allowable 5%
- Deflection values do not exceed max allowable per member
- Max tension values well below yield strength

Project Impacts

Environmental

- Use existing materials
- Increased life-span

Societal

- Avoid obstructive construction replacing rigging
- Improve safety
- Serving cultural needs of community

Economic

- Able to use existing rigging
- Fewer repairs

Conclusion

- Conducted a Condition Assessment Successfully
  - Double Checking with Clients
  - As-Builts Penning
- Met client’s quota of a minimum of 6 loading locations
  - To IEBC “5% Rule” Code
- Meeting With David Merrell
  - Assumptions Communicated
  - Considering Capacity of Entire Structure
  - Technical Report Penning

References

[1] *Site Visits To Prochnow Auditorium on Northern Arizona University*. O.A.T Engineering, 2023.

[2] *Google maps*. [Online]. Available: https://maps.google.com/. [Accessed: 02-Feb-2023].

[3] GLHN, “1994 Stage Rigging Renovation.” Flagstaff, 26-May-1994.

[4] ASCE, Minimum design loads and associated criteria for buildings and other structures 7-16. Reston, VA: American Society of Civil Engineers, 2017.

[5] AISC, *Steel construction manual*. Chicago, IL: American Institute of Steel Construction 2017.

[6] 2018 IEBC: International existing building code. Country Club Hills, IL: International Code Council, Inc., 2018.

[7] J. Espinoza, “Risa-3D 20.0 Model Outputs.” Northern Arizona University, Flagstaff, 25-Apr-2023.

[8] J. Portillo-Wightman, “Meeting(s) With David S. Merrell,” Discussion of Risa and Project.

Thank you!