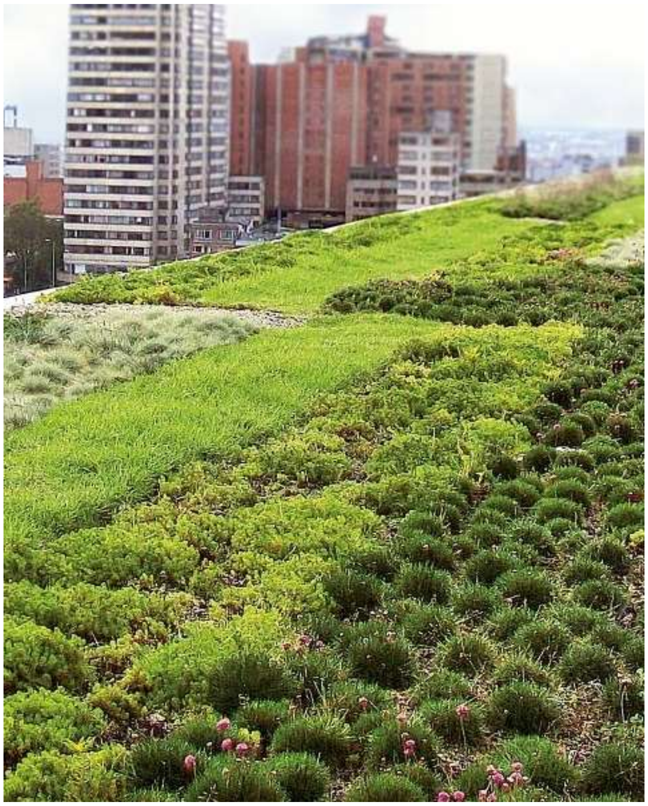


DESIGN REPORT

COOL AND GREEN ROOFS

FIVE FLAGS CIVIC CENTER
DUBUQUE, IOWA

May 10th, 2024

Section I: Executive Summary

This report presents the final design recommendations we developed for the Five Flags Civic Center Cool and Green Roof project. It contains descriptions of the project's scope of work, material choices, construction cost estimates, and loading analyses. The recommended design pertains only to the roof structure but includes features intended to optimize the space and affect the energy output of the building.

The design team is composed of four senior students from the University of Iowa's Department of Civil Engineering, all of whom have experience in structural engineering and were eager to pair structural design with modern sustainability solutions. The contract for this project began with the proposal submittal on February 2nd and has extended to the current submittal of a final design and accompanied documentation on May 3rd.

Within this period, we researched the most suitable sustainable roofing material types to fit the needs of the Five Flags Civic Center, focusing on energy efficiency, maintenance costs, ease of application, and aesthetics. The recommended final design balances the associated capital cost of the project with the return on investment from its generated energy savings and the expected longevity of the new roofing. Additionally, we have used computer software and hand calculations to ensure that the components of the recommended design can be supported by the roof structure itself. Partial areas of the roof will require additional reinforcements or replacements due to the recommended renovations. These reinforcements and their accompanying calculations are detailed in this report as well.

The designs described in this report integrate three components of sustainability into the roof structure: green roof, cool roof, and solar panels. The constraints and challenges of integrating a green roof system into a structural design include those of maintenance, extra roof weight from captured water, and remaining within the project budget. Although features like a green and cool roof add extra cost to the project, over time they can reduce energy costs and can serve as a model for the community.

The Five Flags Civic Center has three, well-differentiated sections of roof area. Roof Area 1 is the highest in elevation and is above the historic theater. Roof Area 2 is the largest in area and is above the arena. This area uses a steel truss system to support the current weight of the roof. Roof Area 3 is the lowest in elevation and second largest in area, it uses concrete planks to support the ticketing and office area of the building. In the concept development phase of the project, we presented three alternative designs. To present a wide range of options for the client to consider, these three alternatives used combinations of green roofs, cool roofs, solar paneling, and improvements to allow for roof accessibility for the public.

The first alternative uses cool roof coverage on roof area one only and green roof in all other areas. The second roof design alternative uses green roof over the largest roof area (two) but also incorporates cool roof over roof area three with solar panels on top of the cool roof material. The third design alternative allows patrons of the Civic Center access to the roof via a newly installed elevator and stairwell. The roof would utilize all three components of sustainability, green roof gardens, cool roof materials, and solar panels. The roof could have a bar/bistro and tables for patrons to sit, chat, and admire the space. This alternative generates the highest cost of the three and would need to be built to meet ADA and applicable roof safety standards.

Building upon the concept design alternatives phase of the project and with feedback from project stakeholders, we developed two different final designs. The first uses only cool roof materials and includes a replacement of roof insulation. The replacement of the insulation on all roof areas to polyurethane rigid foam board would increase the R-value from its existing 13 to 30.5. This design has less cost associated with it as it would not require reinforcements to the truss system below the arena roof. It would, however, have a longer payback period of 43 years. The second design integrates a green roof and solar panels in addition to the cool roof plans of the first design. The roof insulation would be replaced on the entirety of the roof, cool roof would be applied everywhere except where the green roof is, and the green roof would cover a portion of the roof above the arena (area two). The solar panels would be placed on the roof of the offices/ticketing area (area three), on top of the newly applied cool roof. The placements of each eco-friendly component were governed by the current and unchanging locations of mechanical equipment, and the economy of minimizing required reinforcements due to the additional weight each component carries. This second design, which uses areas of cool roof, green roof, and solar panels, would have a payback period of 46 years. This is slightly higher than the cool roof payback period due to the costs associated with reinforcing the green roof areas.

The recommended cool roof material is a rigid foam polyurethane sheeted with PVC single-ply membrane. This material was chosen for its high insulation rating and relatively long-life expectancy of 30 years. In the recommended design configuration, the green roof would be built up along the eastern edge of the arena roof and extend down the center of the roof (see Figure 8 in report for aerial image). Compatible with renovation work on an existing building and to minimize reinforcements, the design utilizes an extensive green roof, meaning the soil medium will be 6-inches deep or less.

To implement this design, the existing steel trusses of the arena roof will need to be strengthened to support the additional weight of the green roof. The reinforcement is provided by welding additional steel sections onto the existing truss to increase the area of the governing strength members. Where the green roof spans the entire length of the roof, the entire truss must be replaced to add the capacity needed to support the green roof. No reinforcement is needed to support the cool roof or solar panels, as these are light-weight features.

The total construction cost of the cool roof design is estimated to be $1,035,710. This includes the cost to remove the existing roof, replace insulation, and cover all areas of the roof with the cool roof PVC single-ply membrane material. It is estimated that with the replacement of insulation and the addition of the cool roof material, annual building energy savings will be

$19,586. The construction cost of the cool roof, green roof, and solar panel design is $1,694,541. This accounts for the cost of materials and installation of the new insulation, roofing, solar panels, and all existing member reinforcements and replacements. The estimated annual savings associated with this design is $38,628.

Section II: Organization Qualifications and Experience

1. Organization and Design Team Description

The design team consists of four engineering students with structural design experience. These members and their project roles are listed below:

Rose Schweitzer, Project Manager

Leo Islas, Structural Lead

Sara Bayas, Tech Support and Designer

Giulio Diaz-Elizalde, Tech Support and Designer

The engineers on the project team are in their final semester of the Civil Engineering program at the University of Iowa. Leo, Giulio, and Sara specialize in Structures, Mechanics, and Materials. Rose has a tailored focus area of study but has elected to take primarily structural and water-related coursework. This project is their senior capstone design project.

Section III: Design Services

1. Project Scope

The project team was tasked with developing a roof design for the Five Flags Civic Center in Dubuque, Iowa. In the concept development phase of the project, three alternative designs were created. With feedback from the project stakeholders, two final designs were developed with supporting structural analyses, material research, and cost estimates. To meet the client's goals of utilizing sustainable roofing options to provide energy savings for the building and have an aesthetic aerial view of the roof, the alternatives designed by our team incorporates three different components of sustainability: green roof, cool roof, and solar panels. Renovations to the roof will take place as a part of a larger renovation project of the entire building. The team performed an evaluation of the roof structure and generated a recommended design. Cost estimations and payback periods were also included in the final analysis of the roofing options.

2. Work Plan

The Cool/Green Roof Project contract period began on February 5th, 2024, when the proposal was submitted, and ended May 3rd, 2024, when the construction documents were submitted. Within this period, all design tasks will be completed by the project team to meet the client's goals. The Gantt chart in Figure 1 provides the chronological series in which each deliverable was completed. The estimated duration of each task and its completion date are outlined. The project can be divided into four main task items, these task items are listed below:

I. Data Collection
- A meeting with the client, a site visit, reviewal of the building blueprints, and roofing material research

II. Design Concept Development
- Roof layout, energy efficient recommendations, and loading configurations

III. Structural Design Specific and Detailing
- Loading analysis of the arena truss system and concrete planks

IV. Final Documentation and Reporting
- Generating cross-sections, cost estimates, and documenting structural analysis results

Cool/Green Roof Project Schedule

	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Element	Duration (Days)	15-Jan	22-Jan	29-Jan	5-Feb	12-Feb	19-Feb	26-Feb	4-Mar	11-Mar	18-Mar	25-Mar	1-Apr	8-Apr	15-Apr	22-Apr	29-Apr
Data Collection																	
Team - Client Introduction Call	1	x															
Site Visit	1		x														
Reviewal of Building Blueprints	5		x	x													
Roofing Material Research	10			x	x												
Design Concept Development																	
Roof Layout Brainstorming	3.00				x	x											
Energy Efficiency Research	7.00					x	x	x									
Loading of Recommended Material	7.00						x	x	x	x							
Structural Design Specifics and Detailing																	
Loading Analysis of Arena Truss	20.00								x	x	x	x	x				
Loading Analysis of Concrete Planks	5.00											x	x	x			
Reinforcement Design for Arena Truss	5.00													x	x		
Areas	5.00													x	x		
Final Documentation and Reporting																	
Generating Cross-Section Drawing Sets	5.00												x	x			
Cost Estimations	15.00												x	x	x		
Documenting Structural Analysis Results	7.00													x	x		
Presenting Final Results and Recommendations	3.00															x	x

Figure 1. Project Design Phase

Section IV: Constraints, Challenges, and Impacts

1. Constraints

Designing a cool and green roof for the Five Flags Civic Center in Dubuque, Iowa, presented several constraints that required careful considerations. For instance, ensuring compliance with local building codes and environmental regulations was crucial for achieving a successful design. These regulations encompassed factors such as safety requirements, and stormwater management standards. Moreover, the presence of mechanical equipment within the existing structure limited the available space for incorporating new elements into the design, as per the client's request. Given the condition of the building and the client's objective to minimize project expenses, we opted for an extensive green roof design due to its minimal maintenance requirements and light weight when compared to different types of green roofs. However, this choice also entailed constraints in the variety of vegetation and additional features that could have been incorporated.

2. Challenges

Balancing the high cost of sustainable features with budget constraints was a significant challenge. Due to Dubuque's varying annual climate conditions, selecting suitable plant species that could survive in this climate and sunlight exposure to ensure long-term vegetation health while requiring a minimal amount of water and maintenance were very important considerations for the design. The roof design also needed to achieve an aesthetic goal that would align with the stakeholders' needs and preferences, aiming to provide a pleasant view for tourists visiting the city and emphasize Dubuque's commitment to sustainability by reducing greenhouse gas emissions and increase renewable energy usage. These challenges required thorough planning and strategic solutions to ensure a successful outcome.

3. Societal Impact within the Community and/or State of Iowa

Cool roofs reflect a higher portion of incoming sunlight compared to traditional darker roofs, resulting in reduced heating and cooling cost for buildings. They also play a significant role in mitigating the urban heat island effect in cities. The installation of green roofs actively removes heat from the air and reduces temperatures of both the roof surface and surrounding environment, which can extend roof service life. According to an article published by the EPA (United States Environmental Protection Agency), green roof temperatures can be 30-40 °F lower than those of conventional roofs and can reduce energy use by 0.7% compared to conventional darker roofs, reducing peak electricity demand, and leading to an annual savings of $0.23 per square foot of the roof's surface. By reducing the overall energy load, green roofs contribute to a decrease in associated air pollution and greenhouse gas emissions stemming from conventional power sources. Furthermore, green roofs also offer aesthetic benefits and serve as habitats for various plants and animal species. Although the initial cost may be higher, the long-term economic benefits accrued by both the community and the Civic Center are substantial. Ultimately, with this project demonstrating leadership in a more sustainable design, it can inspire others in the community and throughout Iowa to embrace more environmentally friendly alternatives for a more resilient, enjoyable, and sustainable future.

Section V: Alternative Solutions Considered

In the process of generating the final roof design, the team developed three preliminary design alternatives with interchangeable components for the Five Flags Civic Center. Due to the existing roof having three levels, this section will reference the roof system as three separate roof areas, labeled in Figure 2. The highest level will be designated as Roof Area 1 and will reference the roof for the theatre (10,650 sq. ft). Roof Area 2 will be the second highest level and will reference the roof space above the arena (45,300 sq. ft). Finally, Roof Area 3 will reference the lowest part of the roof system accessible through the arena and currently holds most of the mechanical equipment (15,400 sq. ft).

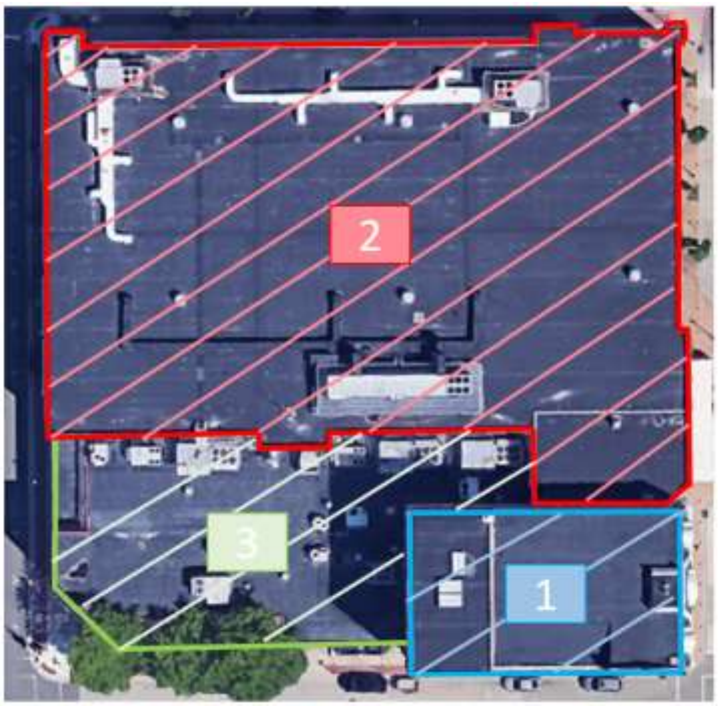


Figure 2. Reference Map of Roof

Alternative 1:

Alternative one emphasizes the green roof feature with some cool roof elements for an aesthetic and neat, but still sustainable roof option. Depicted in Figure 3, Roof Area 1 will consist of a white metal sheet layer acting as a cool roof. This sheet layer will cover all parts of roof area one including all sloping and curved elements. Roof Areas 2 and 3 will have a green roof with grass and shrubbery that is native to Iowa. The water collected from roofs can be collected and reused for non-potable purposes such as flushing toilets or irrigation and watering. The existing mechanical units and ducts will stay in place. Small paths that will cut through the greenery will provide access to the units.

With this alternative having the largest green roof area, it would have great benefits in stormwater reduction and add to the biodiversity of the area. Green roofs actively and consistently dissipate the heat island effect. With the location of this building in the downtown district of Dubuque, it would be beneficial to utilize green features. Furthermore, the cooling effect would increase with the increase in area of the green roof.

While this design alternative would allow the building to achieve a high energy efficiency rating, it would add a significant amount of load to the existing roof. The truss system supporting roof area two would need to be reinforced to have the capacity to support the green roof addition, incurring a large additional cost with this alternative compared to the others. With the greatest amount of area being green roof, maintenance costs would also be higher than in the other alternatives. In addition to energy efficiency, however, this alternative would have great aesthetic appeal, especially when being viewed from the bluffs west of the building.

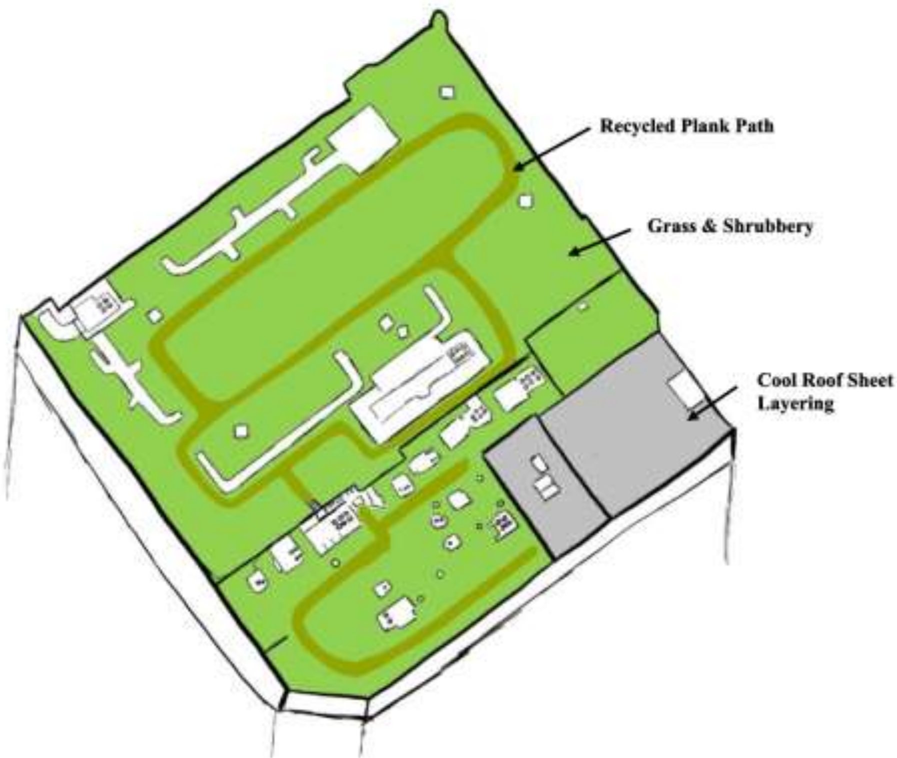


Figure 3. Design Alternative 1

Alternative 2:

Alternative 2 will involve adding solar panels to the flat parts of roof area one to not only reduce the energy use of the building, but also produce energy for the Civic Center's use. The solar panels will be faced south at a 30-degree angle for the most efficient performance. The entire area will have an underlayment of reflective materials and will go under the solar panels.

For Roof Area 2, all existing mechanical units will remain in place with the option to upgrade them. The units and ducts will be surrounded by a border of white sheet layering with a connecting path for access to each unit from the staircase between roof areas two and three. For a sustainable option, this path could be made of recycled wood material. The surrounding rooftop will have a green roof consisting of Iowa native grass and shrubbery. Roof Area 3 will maintain the location of existing mechanical units to minimize costs and an awning will cover the existing HVAC along the building wall to improve the roof aesthetic. Figure 4 shows this design alternative.

Similar to design alternative one, design alternative two would also have a high energy efficiency rating and need reinforcement to the truss system below roof area two. There is slightly less green space in this alternative, as seen in Figure 4, so additional reinforcements will not be as intensive as with design alternative one, making the alternative slightly less expensive. With the greatest amount of area still being green roof, maintenance costs would also still need to be considered. This alternative would also have great aesthetic and public appeal as it sports all three concepts of energy efficiency: green roof, cool roof, and solar panels.

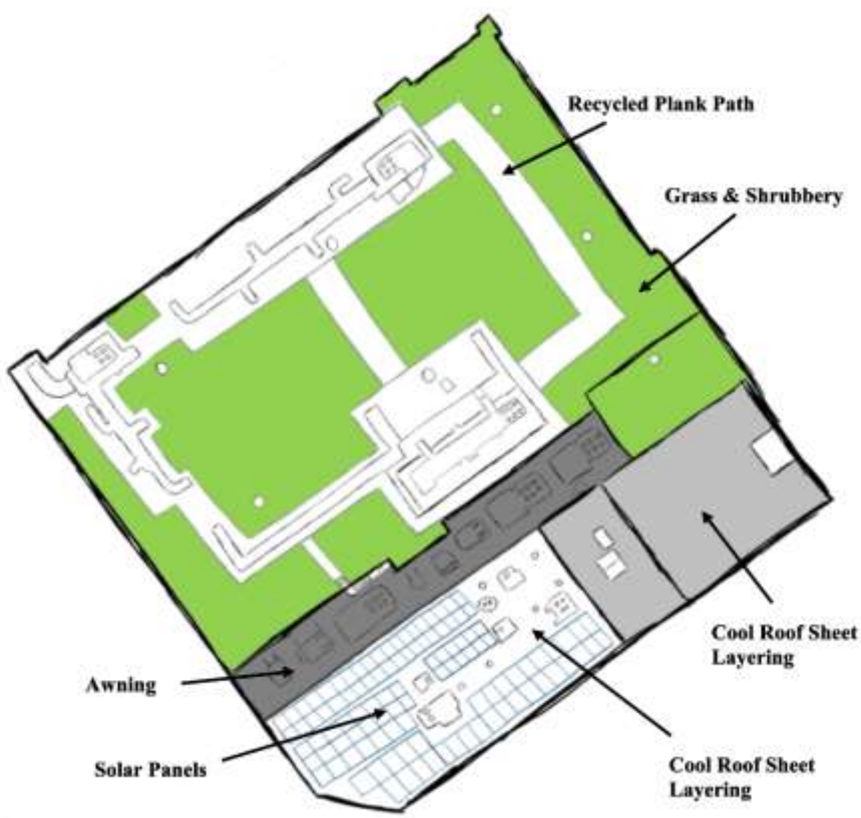


Figure 4. Design Alternative 2

Alternative 3:

Alternative 3 uses elements of both cool and green roofs while also converting the roof to an occupiable space for events, dining, and community interaction with the garden spaces. The height of the parapet walls will need to be increased to 3 feet 6 inches. As stated in alternative two, roof area one will house solar panels facing the south at a 30-degree angle to obtain the most efficient amount of sunlight while having a reflective underlayment. Roof Area 2 will include a green roof utilizing native Iowa grasses and shrubbery. The group proposes that a new mechanical system be installed to accommodate the new roof design for area 2. A bistro and outdoor gathering space with a community garden will be the main feature of the new design. A new elevator and staircase would be placed on the right side of the arena wall to allow the roof to be accessible and ADA compliant. On the roof level, these access points will be placed on either side of the bistro. All components of Roof Area 2 will be connected by paths made with recycled wood plank material. Roof Area 3 will have a reflective material to deflect ultraviolet radiation. It is proposed that a new mechanical system is to be added and that this section be closed off to the public to serve as a mechanical space. These details are depicted in Figure 5.

This alternative allows for community interaction with the green spaces, showcasing the City of Dubuque's commitment to eco-friendly development. It could also generate more revenue as patrons rent the space for events, visit the bistro and purchase food and drinks, or visit the Civic Center more frequently due to this additional, aesthetic social gathering space. It would have the benefits that were provided in alternatives one and two, stormwater and energy use reduction and solar energy production.

This alternative would be the most expensive to implement. Creating a space that can be occupied and usable requires many additional renovation projects to the existing building, some including raising the walls for safety, adding public accessibility, wiring electricity, and routing plumbing to the roof, etc. This alternative would have a similar energy efficiency rating to alternative two, but it would also interact with the public more, instilling community ideals of sustainability. There is slightly less green space in this alternative, as seen in Figure 5, so additional reinforcements may not be as intensive as with design alternative one, making the alternative slightly less expensive. With the greatest amount of area still being green roof, maintenance costs would also still need to be considered. This alternative would also have great aesthetic and public appeal as it sports all three concepts of energy efficiency: green roof, cool roof, and solar panels.

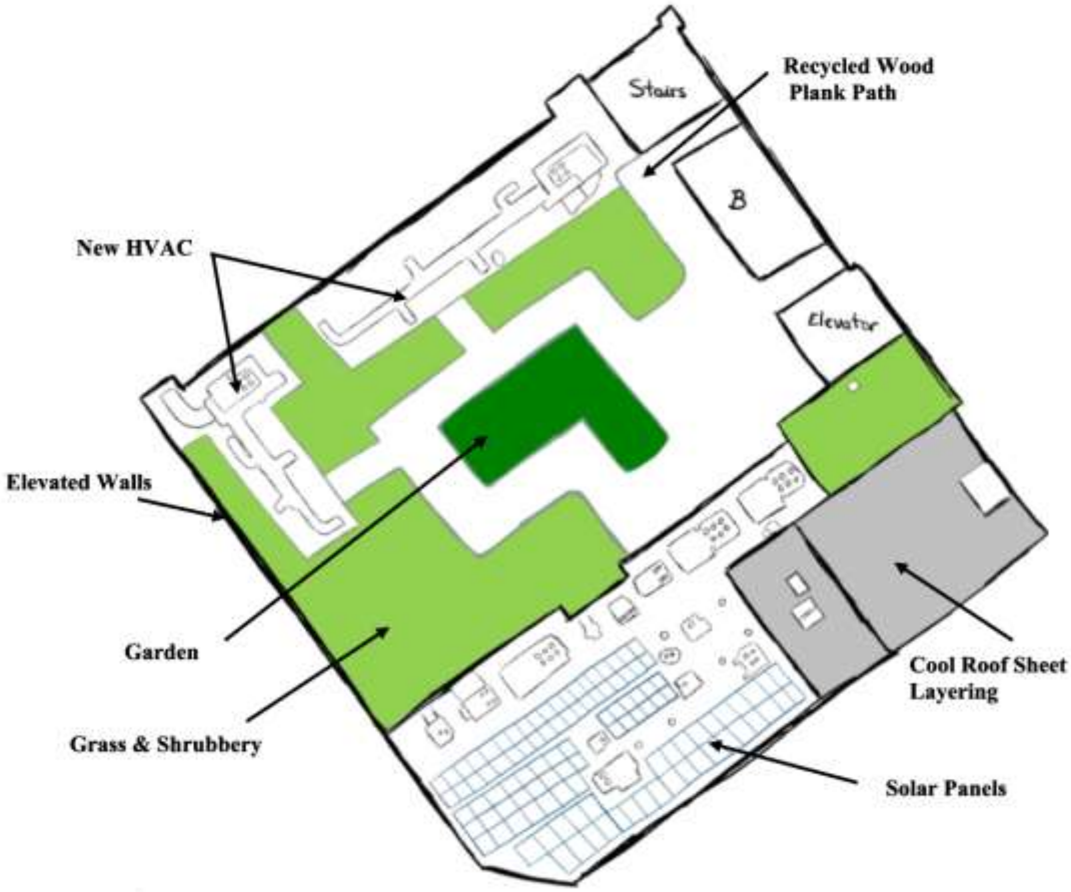


Figure 5. Design Alternative 3

Section VI: Final Design Details

Based on stakeholder feedback, we formulated two design solutions for the Civic Center roof re-design. The first alternative uses only the cool roof component while the second uses an integrated design that utilizes cool roof, green roof, and solar panel components. These two design alternatives are described in detail in this section.

Cool Roof Only Solution:

The objective was to implement a sustainable solution that not only provided thermal comfort but also aligned with the city's commitment to environmental responsibility. The selection of the cool roof material aimed to mitigate heat absorption, thus reducing the urban heat island effect prevalent in Dubuque. Additionally, the roof design incorporated features to enhance energy efficiency, such as reflective coatings and insulation, contributing to the overall building performance.

We investigated several roofing material options for the cool roof solution that would preserve the metal roof deck and increase energy efficiency. Among the alternatives explored are composite tiling, light colored paint or coating, and single-ply membrane (with polyurethane rigid foam). Composite tiles are typically a mixture of materials like plastic, rubber, and sometimes recycled materials. They are lightweight, eco-friendly, and last between 40 and 50 years. A general overview of the installation process for this material would be to remove the existing roof down to the decking to repair or replace any damage, and then add insulation and a rigid foam board in where the tile would be placed.

The light-colored paint/coating material was an attempt to offer the client the cheapest option possible. This option is the least evasive to the existing roof. The coating can either can sprayed or painted on to the existing rubber asphalt finish, and the only preparation needed for this is a proper cleaning of the existing roof surface. The recommended coating is called "555 Fibered Aluminum Reflective Roof Coasting 4.75 gal". This coating is corrosive resistant and is a waterproofing sealant to control leaks and cracks while also providing high reflective properties to extend roof life and reduce roof surface temperatures (both exterior and interior). It is recommended that all leaks and cracks are fixed before adding the sealant to offer more waterproofing protection. The patching of existing leaks was not included in the cost estimation for this cool roof alternative.

The recommended material for this design is a rigid foam Polyurethane-isocyanate sheeted with PVC single-ply membrane. PVC membrane was selected as an economical long-term solution, the material retains a solid white matte finish and is resistant to dirt, mold and wind corrosion reducing overall maintenance cost. The roofing materials can be adhered with either fasters or adhesive material for an easy installation process and with minimal required equipment. This material composition has one of the highest R-values that is commercially available and is Energy Star approved. Although the material itself is not biodegradable, it uses 85% less energy to manufacture compared to typical insulation and has a longer lifespan once applied to the roof, generating less overall long-term waste. The lifespan of the material is 30 years, exceeding the standard 20 of commercially typical roofing applications. It follows the International Building Code (IBC) Section 2603 and the International Energy Conservation Code (IECC). In addition, it is rated as a Class A Fire Protection material that can lessen the spread of fire.

As for energy efficiency, the R-Value for the new roof system was designed to be 30.5, indicating that the roof has a greater resistance to heat flow than the existing roof system (R = 13). This allows indoor temperatures to remain cool in summer and warmer during winter months. To create a durable cool roof, protection of this material is required to maximize the overall benefits of this material, specifically its waterproofing and reflectivity characteristics.

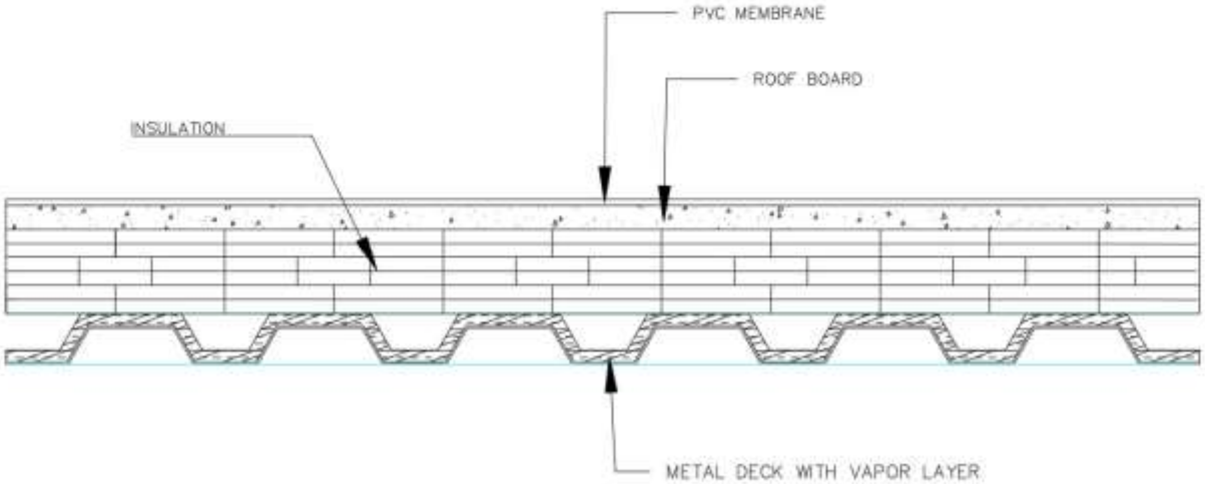


Figure 6. Cool Roof Cross Section

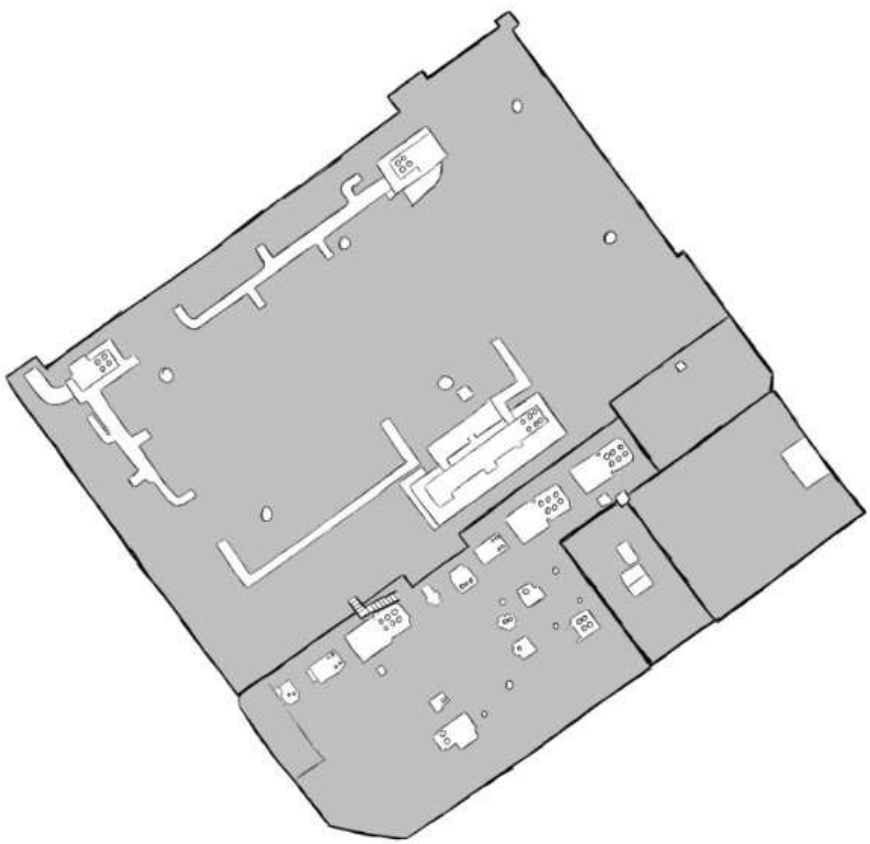


Figure 7. Cool Roof Only Design

Green Roof, Cool Roof, and Solar Energy Solution

The objective of this solution is to integrate the green roof and solar panels into the cool roof design to implement additional benefits of stormwater reduction, energy production, and aesthetics. This design minimizes the amount of roof reinforcement required while still achieving the benefits of a green roof. Each of these three components are described in detail in this section.

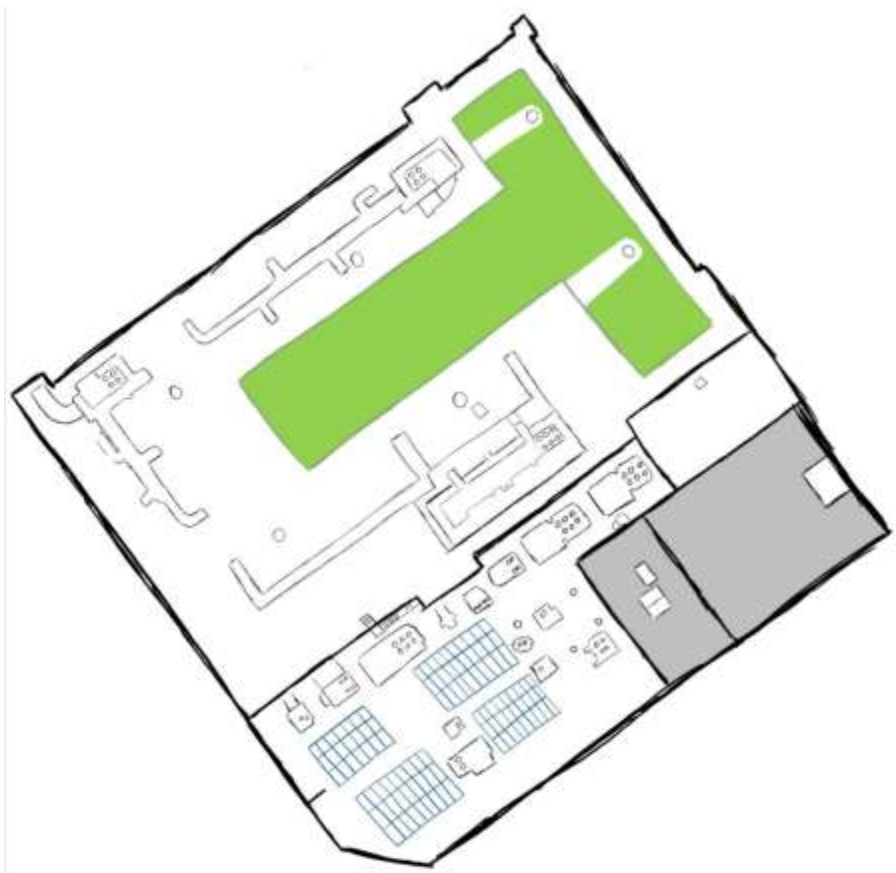


Figure 8. Cool Roof, Green Roof, and Solar Panel Design

Cool Roof:

The same roof material used in the cool roof design solution would be used for this alternative as well. It would be installed with new insulation everywhere except for where the green roof is located. The recommended material choice is a PVC single-ply membrane over a new polyurethane rigid foam insulation layer. This combination of insulation and cool roof membrane increases the longevity of the roof and the energy efficiency of the building.

Green Roof:

The design of the green roof over the arena is classified as an extensive green roof due to its lightweight and shallow build-up height. Extensive green roofs have six inches, or less, of growing medium depth and are a good fit for renovations on existing structures like the Civic Center without imposing excessive structural loads in general. This lightweight characteristic of the extensive green roof is beneficial for various reasons. For instance, it minimizes the additional weight on the building's structure, reducing the need for costly structural reinforcement. Secondly, it allows for easier installation and maintenance compared to more intensive green roof systems. Overall, the extensive green roof design chosen for the Five Flags Civic Center balances the benefits of green infrastructure with practical considerations, providing an environmentally friendly and aesthetically pleasing solution that enhances the Civic Center's sustainability profile.

In this alternative, the green roof would only cover a portion of roof area two to minimize the required truss reinforcement. The outline of the green roof area is shown in Figure 8. The planted sections of the roof would share the same insulation as the areas covered by only cool roof. The cool and green roof cross sections diverge in likeness after the roof board, where instead of the PVC membrane, the green roof has a monolithic membrane, a protection sheet, a root barrier layer, a drainage layer, and then finally the growing medium, as shown in Figure 9.

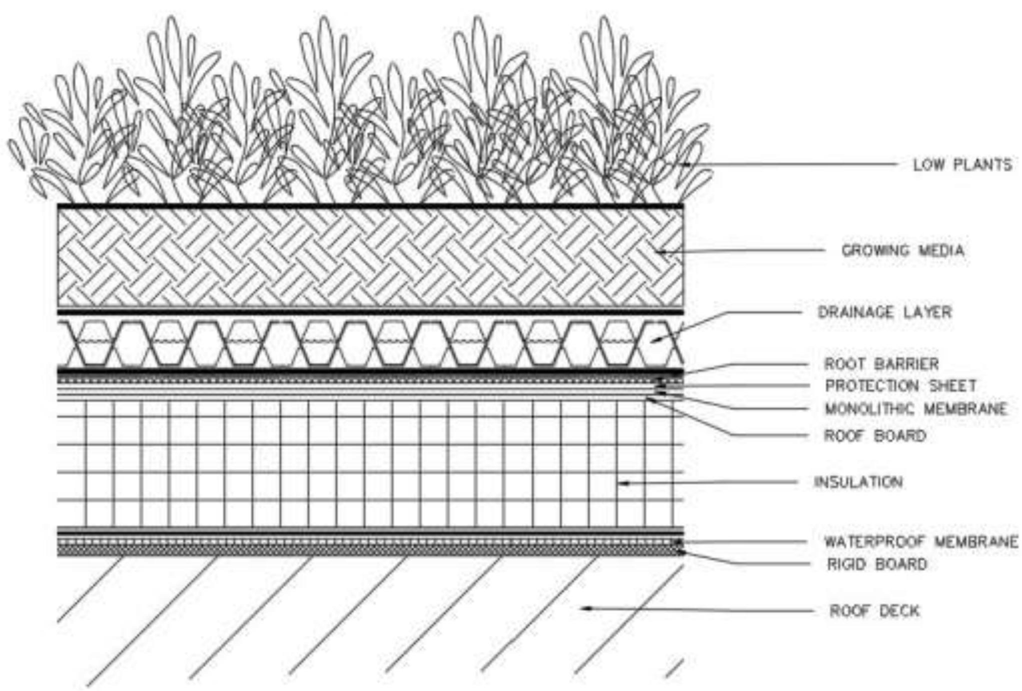


Figure 9. Green Roof Cross Section

Reinforcement details

The material associated with implementing a green and the water retention services they provide add weight to the roof structure that was not accounted for when the Civic Center was first designed. Through detailed structural analysis (documented in Appendix B), it has been found that reinforcement is necessary to add the green roof, although it is not required everywhere. The roof of the arena has three different truss types, shown in Figure 10.

In the areas where the green roof does not span the entire length of the roof (T-2 Series trusses shown in Figure 10), our team redesigned these trusses with 2.25” diameter solid steel rounds on the top chord and 12”x3/4” steel A36 plate on the bottom chord. To be conservative, the trusses that were impacted by deflections are located at two-thirds of the span. This allowed for minimized material usage and increased overall efficiency for the twenty-four T-2 series trusses. The redesigned models, shown in Figures 11 and 12, show the additional steel sections in the existing trusses. These new sections provided increased strength in axial force, moment, and deflection for the top chord and tension on the bottom chord. Planned reinforcement within the details is projected to use electrical arc welding with E60XX carbon-steel alloy weld rods as a cohesive bond to the chords. This method provided both an economical and well-practiced construction method. This allows a potential crew of five Journeyman welders to finish reinforcement at phase completion of three days, with consideration to worker exposure limits to ensure that these Journeyman have occupational safety against arc and flux gases.

Through structural analysis, it was determined that the girders would also need reinforcement. Designing for adequate shear and moment capacity, a 6” x ½” A36 steel plate is recommended to be welded to the bottom of the bottom flange. It is also recommended that square bars are also to be welded on the inside of the top flange (see figure 13). To finalize our load path analysis, the columns were analyzed and fortunately it was determined that no reinforcement or replacement was needed. (See Appendix.)

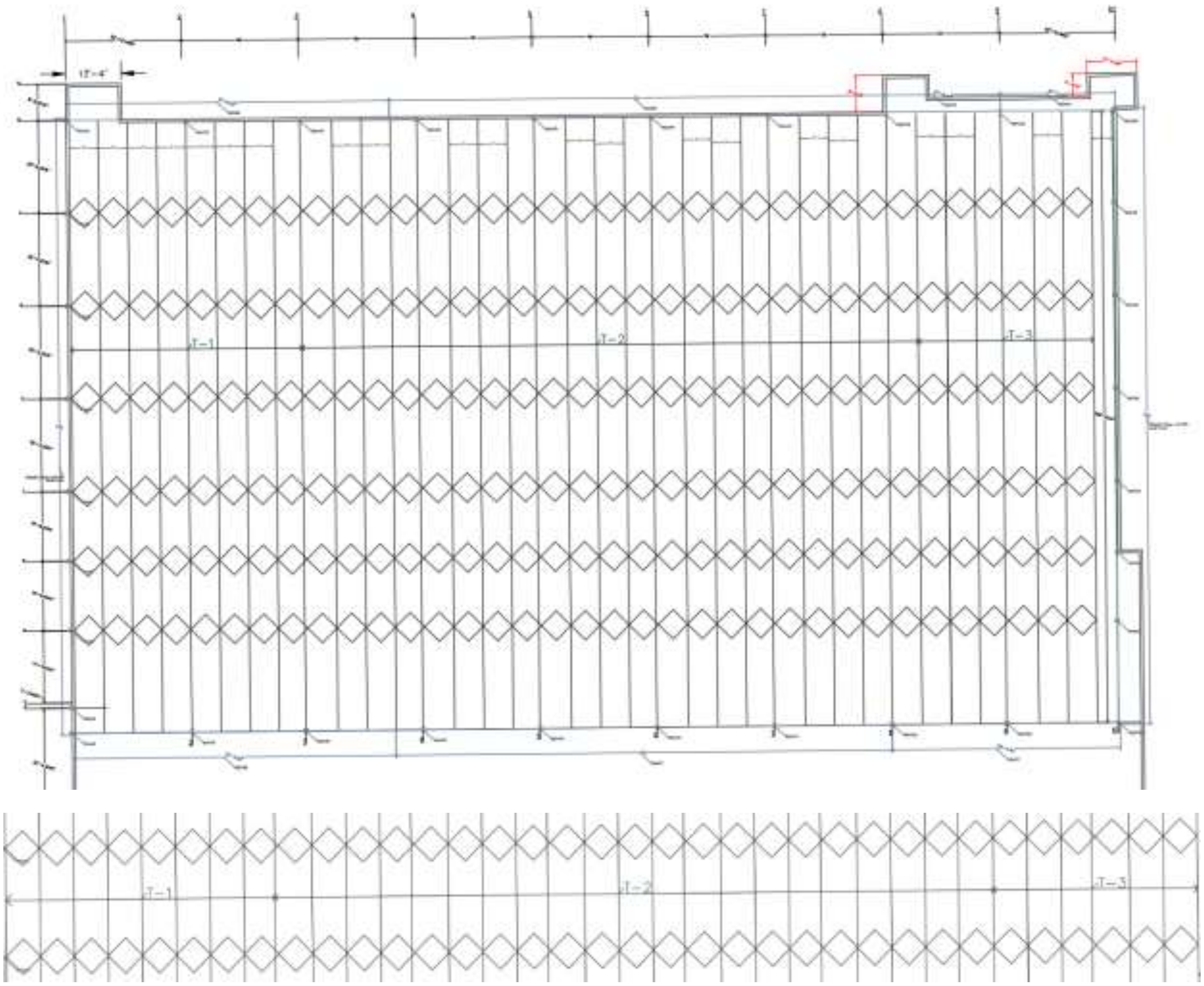


Figure 10. T-Series Framing Plan

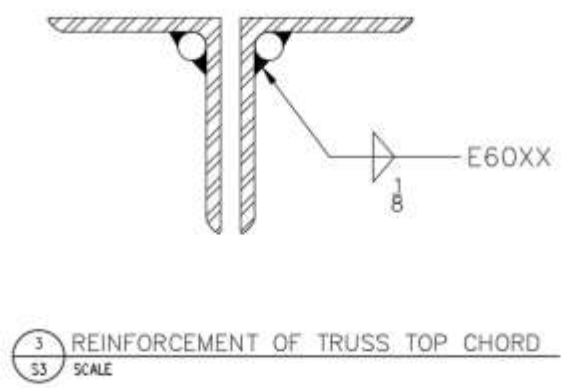


Figure 11. Reinforcement of Truss Top Chord

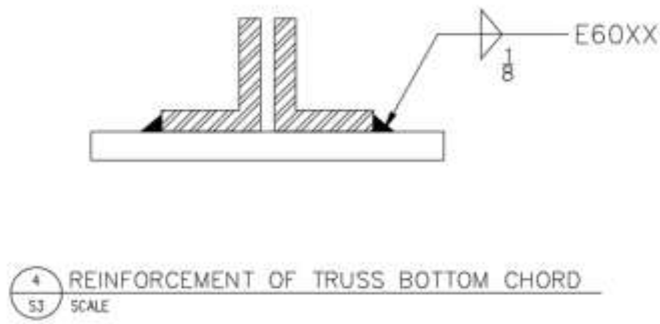


Figure 12. Reinforcement of Truss Bottom Chord

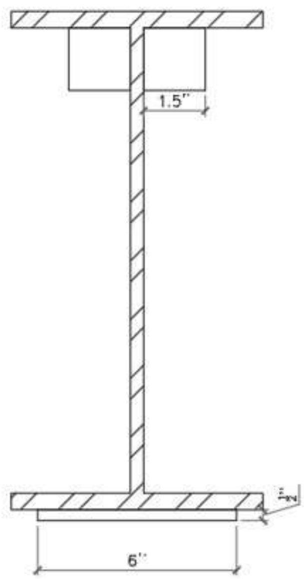


Figure 13. Reinforcement of Girders

Redesign details

Additional loading due to the green roof required replacing the five trusses in the T-3 truss area (see Figure 10). A green roof design of almost 600 plf was made to cover 99% of the truss to maximize the most efficient use of the green roof. Due to these excessive loads, it was discussed if reinforcement could provide enough additional strength against bending and deflection for the top chords, and tension for the bottom chords, without adding too much material where constructability would become an apparent issue. This process had created an infeasibility within our design and thus our group resolved this by remodeling our truss and optimizing dimensions to reduce material usages while adhering to required flexure and deflection limit L/360. In turn, the trusses increased the bottom, top, and middle chords to 2L6"x6"x7/8" DLH for long span considerations. The original 2L 3"x3"x1/2" vertical members remained the same.

Solar Energy

While cool and green roofs are great methods for conserving energy, solar panels add the option to generate electricity as well. In this alternative, Roof Area 3 of the Civic Center roof (the lowest section) has a layer of cool roof material as the base, with solar panels installed on top. Four groupings of 21-30 panels will be installed for a total of 105 panels. The size of the individual array is based on the amount of loading that section of the roof has capacity for. It is recommended to purchase commercial size panels rather than residential due to their energy output and size. The following table shows a comparison of residential solar panels and commercial solar panels.

Table 1. Solar Panel Size Comparison

Panel Type	Size	Solar Cell Amount	Energy Output (Average)	Weight
Residential	5.4 ft x 3.25 ft	60	400 watts	40 lbs.
Commercial	6.5 ft x 3.25 ft	72	525 watts	50 lbs.

Using commercial size solar panels, each of the five panel groupings would occupy 500 ft^2 of Roof Area 3. The solar panel arrangement and spacing allows space for maintenance of the solar panels with six-foot-wide paths between each group and avoids the areas where mechanical equipment and HVAC systems currently sit. The total area of solar paneling is 2,486.25 square feet, with a cool roof underneath them. Figure 14 shows where the solar arrays are located on Roof Area 3.

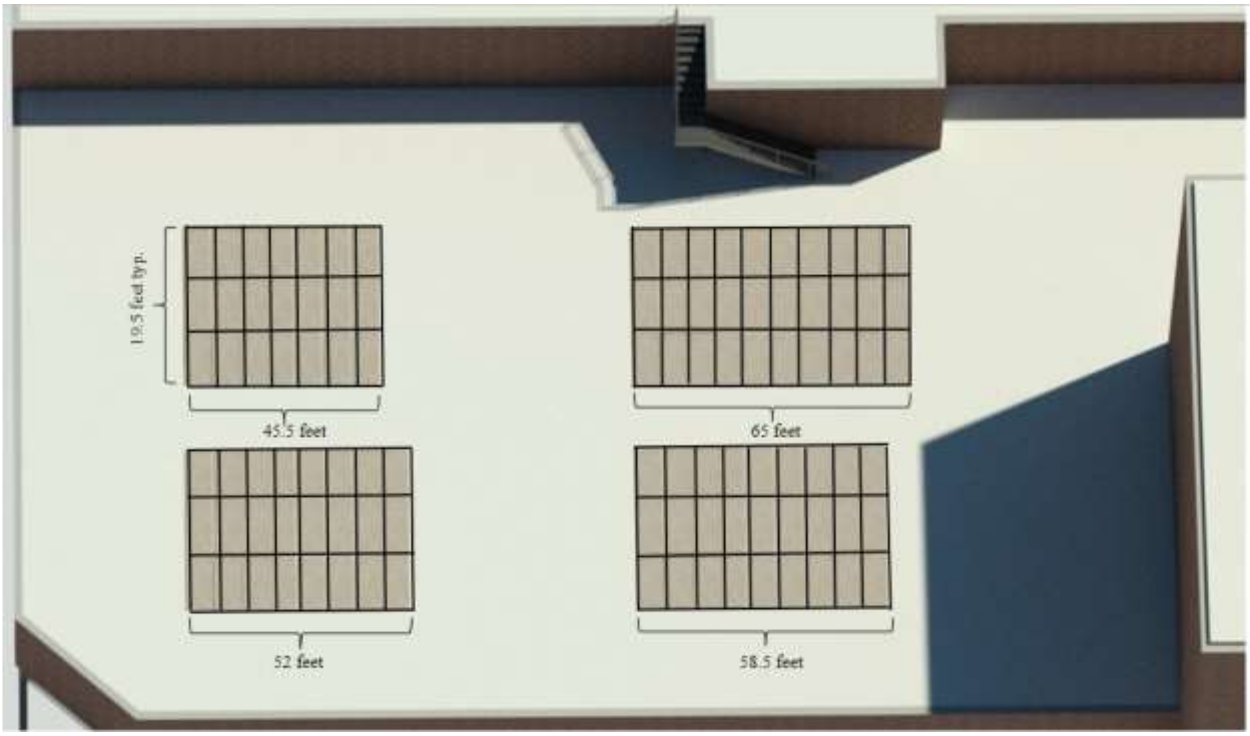


Figure 14. Solar Panel Configuration

Loading:

The lower roof (section three) has the capacity to carry the additional load of 3 psf of replacing insulation, adding a cool roof covering, and adding solar paneling to the selected locations. A commercial solar panel weighs approximately 2 psf, with the roofing replacement underneath, the additional load totals 3 pounds per square foot. The structural portion of the roof in this section is a hollow-core concrete slab. The capacity-demand comparisons were made using the PCI manual load tables for this structure and the provided live and dead loads from the original blueprints from Arnold & O'Sheridan, Inc. Consulting Engineers. See Appendix F for a detailed analysis of each individual array location.

Payback Period:

Solar panels have a shorter payback period and are eligible for federal tax credits. The total cost of the panels comes to $158,208.75 from a rate of $2.87 per watt and 525 watts per panel. The installation of the solar panels is estimated at 5.5% of the cost of the system, which would be $8,702. This brings the total cost to $166,912. This project is eligible for a 30% federal tax credit. This would reduce the total cost to $116,838. Additional costs (not included in the given total) for utilizing solar energy would be maintenance and any extra tracking services that are desired. With 105 panels, this solar panel array is a 55-kW system, meaning it can generate 55 kilowatts of electricity at any given moment when operating at full capacity (100% efficiency). This array size would be considered a small-to-medium array. At 55 kW, the system would output about 96,587.76 kWh annually, estimated based on an average 20% solar energy efficiency rate. In the state of Iowa, one kilowatt-hour of energy costs $0.14, giving these savings a value of $13,522 annually. With these annual savings, the payback period for installing this amount of solar paneling is 8.6 years. These items are organized in Table 2.

Table 2. Solar Panel Energy Savings

System Size	Material Costs	Installation Costs	Total	Total after 30% Tax Credit	Annual Energy Output	Annual Savings	Payback Period
55 kW 105 panels 2,500 sq. ft	$158,210	$8,702	$166,912	$116,838	96,588 kWh	$13,522	8.6 years

Section VII: Engineer's Cost Estimate

The construction cost estimate of the cool roof alternative totals to $1,035,710 and is specified in Table 3. This includes the cost of new insulation, a cool roof covering, removal of the existing roof, installation costs, and associated taxes for all the areas of the roof. With the total roof area being 71,350 square feet, a lot of material and labor hours will be required to renovate the roof to achieve either of the designs specified in this report. It is beneficial to do all renovation work at one time, as costs for materials are more economic in larger quantities.

The estimated annual savings after the replacement of the roof insulation and the addition of the cool roof is $23,550, which gives a payback period of 43 years for the PVC single-ply membrane material choice. Based on research conducted by our team, the annual cost savings associated with the energy efficiency of the roof is estimated from $0.10 per square foot from the cool roof membrane and $0.23 per square foot from the insulation replacement (a total annual savings per square foot of $0.33).

Table 3. Cool Roof Only Construction Cost Estimation

Material	Unit	Coverage	No. Units	Cost Per Unit	Total Cost (Incl. 6% tax)
Cool Roof:					
Polurethane Rigid Board Insulation	ft^2	416	172	$ 1,000.63	$ 182,688.00
PVC Membrane	ft^2	1000	72	$ 1,050.00	$ 80,136.00
Vapor Barrier	ft^2	1000	72	$ 477.00	$ 38,858.00
Spray Foam Insulation	ft^2	92	776	$ 259.00	$ 213,012.00
			Remove Existing		$ 64,200.00
			Material Cost		$ 540,982.00
			Labor Cost		$ 424,500.00
Total Cost Estimation:					
		Cool Roof Cost			$ 1,029,682.48
		Permit, Reviewal, Issuance, and Code fees			$ 6,027.68
					$ 1,035,710.16

In a similar format, the construction cost estimate for the integrated roof alternative totals to $1,694,541. This design has components of cool roof, green roof, and solar panels. The materials are the same for the cool roof and insulation, and in addition to these materials and labor for green roof and solar panel are added to the total cost estimation. The implementation of the green roof also requires additional reinforcements in the trusses, girders, and columns, creating a large extra cost associated with this design. The solar panel cost is based on the cost of the panels themselves and installation, with the advantage of a 30% federal tax credit for utilizing a sustainable energy option. The final addition to the total cost estimation are the costs permits, reviewal fees, issuances, and code fees.

The estimated annual savings of the integrated design with the cool roof, green roof and solar panels is $38,628, which gives a payback period of 46 years. The cost savings associated with the cool roof and insulation replacement is the same as in the cool roof cost estimates, at $0.33 per square foot. The annual cost savings associated with the green roof is estimated to be $0.46 per square foot, which includes its cooling effect and stormwater discharge reduction. As previously described, the 55 kW solar panel array generates $13,522 worth of electricity annually. In finding the total annual energy savings for this alternative, each components savings are weighted to the portion of the roof in square feet that it occupies.

Table 4. Cool Roof, Green Roof, and Solar Panel Construction Cost Estimation

Material	Unit	Coverage	No. Units	Cost Per Unit	Total Cost (Incl. 6% tax)
Cool Roof:					
Polurethane Rigid Board Insulation	ft^2	416	172	$ 1,000.63	$ 182,688.00
PVC Membrane	ft^2	1000	72	$ 1,050.00	$ 80,136.00
Vapor Barrier	ft^2	1000	72	$ 477.00	$ 38,858.00
Spray Foam Insulation	ft^2	92	776	$ 259.00	$ 213,012.00
				Remove Existing	$ 64,200.00
				Material Cost	$ 540,982.00
				Labor Cost	$ 424,500.00
Green Roof:					
Soil Medium	ft^3	10	23	$ 644.03	$ 15,702.10
Drainage Layer Edge	lf	8	88	$ 6.66	$ 624.80
Drainage Layer	ft^2	36	334	$ 2.19	$ 27,912.51
Filter Layer	ft^2	1368.5	9	$ 660.00	$ 6,296.40
Root Barrier	ft^2	1218	10	$ 657.72	$ 6,972.00
Waterproofing Membrane	ft^2	216	56	$ 122.95	$ 7,296.80
Momolithic Membrane	ft^2	40.65	296	$ 42.40	$ 13,290.40
Weather Barrier	ft^2	32	375	$ 25.99	$ 10,312.50
Vapor Barrier	ft^2	1000	12	$ 476.68	$ 6,063.60
Gypsum Board	ft^2	32	375	$ 11.12	$ 4,425.00
Garden Edge Barrier	lf	40	18	$ 831.89	$ 15,872.40
				Material Cost	$ 114,768.51
				Labor Cost	$ 126,000.00
				Reinforcing Cost	$ 298,635.47
Solar Panel:					
				Material Cost	$ 158,208.00
				Installation Cost	$ 8,702.00
Total Cost Estimation:					
				Cool Roof Cost	$ 1,029,682.48
				Green Roof Cost	$ 539,403.99
				Solar Cost	$ 116,837.00
				Permit, Reviewal, Issuance, and Code fees	$ 8,616.82
					$ 1,694,541.00

Appendix A – Green Roof Loadings and General Loading

Green Roof Loading

$A := 12000\ ft^2$

$q_{GrowingMedium} := 30\ psf$ (5 in. growing medium)

https://www.hydrotechusa.com/resources/resources.php?category=Product_Data_Sheets

$q_{FilterFabric} := \frac{3.5\ oz}{yd^2} = 0.024\ \frac{lb}{ft^2}$ $q_{SystemFilter} := 0.024\ psf$

$q_{drainage} := 3.8\ psf$ *(Gardendrain GR30)*

$q_{RootBarrier} := 0.05\ psf$ *(Root Stop)*

$q_{hydroflex30} := 0\ psf$ $(0.085\ in)$

$q_{MM6125} := 0\ psf$

$q_{Waterproofing} := q_{hydroflex30} + q_{MM6125} = 0\ psf$ $(0.27\ in)$

$q := q_{GrowingMedium} + q_{SystemFilter} + q_{drainage} + q_{RootBarrier} + q_{Waterproofing} = 33.874\ psf$

$q_{GR} := 35\ psf = 0.035\ ksf$

clear (q)

Roof Loading

$q_{OSB} := 1.2\ psf$

$q_{insulation} := 0.6\ psf$ *(3.5 in)*

$q_{vapor} := 0.0004\ psf$

$q_{securock} := 3.02\ psf$ *(5/8 in)*

$q_{deck} := 2\ psf$ *(3in-22 gage)*

$q_{HVAC} := 5\ psf$ *(assumed and check with advisor)*

$q_{deck} + q_{securock} + q_{vapor} + q_{insulation} + q_{OSB} + q_{HVAC} = 11.82\ psf$

$q_{DL.roof} := 15\ psf$

Additional snow load

$q_{snow.LRFD} := 58\ psf \quad q_{snow.ASD} := 0.6\ q_{snow.LRFD} = 34.8\ psf \quad q_{snow.old} := 30\ psf$

$q_{snow.additional} := q_{snow.ASD} - q_{snow.old} = 4.8\ psf$

Additional insulation load

$q_{insulation.old} := 0.333\ psf$

$q_{insulation.additional} := q_{insulation} - q_{insulation.old} = 0.267\ psf$

Constant loadings

$q_{existing} := q_{DL.roof} + q_{snow.old} = 45\ psf$

$q_{CR} := 0.773\ psf$

Truss Loading

Truss 1

$W_T := \frac{(27\ ft + 10\ in)}{4} = 6.958\ ft$

$q := (q_{existing} + q_{insulation.additional} + q_{snow.additional}) + q_{CR} = 50.84\ psf$

$w_1 := q \cdot W_T = 0.354\ klf$

clear (W_T, q)

Truss 2

$W_T := \frac{(28\ ft)}{4} = 7\ ft$

$q_1 := (q_{existing} + q_{insulation.additional} + q_{snow.additional}) + q_{CR} = 50.84\ psf$

$q_2 := (q_{existing} + q_{insulation.additional} + q_{snow.additional}) + q_{GR} = 85.067\ psf$

$w_{3.L1} := q_1 \cdot \frac{W_T}{2} = 0.178\ klf$ $w_{3.L2} := q_2 \cdot \frac{W_T}{2} = 0.298\ klf$ $w_{3.L3} := q_1 \cdot \frac{W_T}{2} = 0.178\ klf$

$w_{3.R1} := q_1 \cdot \frac{W_T}{2} = 0.178\ klf$ $w_{3.R2} := q_2 \cdot \frac{W_T}{2} = 0.298\ klf$ $w_{3.R3} := q_1 \cdot \frac{W_T}{2} = 0.178\ klf$

$w_{3.1} := w_{3.L1} + w_{3.R1} = 0.356\ klf$ (from 0' - 39.94')

$w_{3.2} := w_{3.L2} + w_{3.R2} = 0.595\ klf$ (from 39.94' - 89.98')

$w_{4.3} := w_{3.L3} + w_{3.R3} = 0.356\ klf$ (from 89.98' - 146.6')

clear (W_T, q_1, q_2)

Truss 3

$W_T := \frac{(28\ ft)}{4} = 7\ ft$

$q_1 := (q_{existing} + q_{insulation.additional} + q_{snow.additional}) + q_{CR} = 50.84\ psf$

$q_2 := (q_{existing} + q_{insulation.additional} + q_{snow.additional}) + q_{GR} = 85.067\ psf$

$w_{5.L1} := q_1 \cdot \frac{W_T}{2} = 0.178\ klf$ $w_{5.L2} := q_2 \cdot \frac{W_T}{2} = 0.298\ klf$ $w_{5.L3} := q_1 \cdot \frac{W_T}{2} = 0.178\ klf$

$w_{5.R1} := q_1 \cdot \frac{W_T}{2} = 0.178\ klf$ $w_{5.R2} := q_2 \cdot \frac{W_T}{2} = 0.298\ klf$ $w_{5.R3} := q_1 \cdot \frac{W_T}{2} = 0.178\ klf$

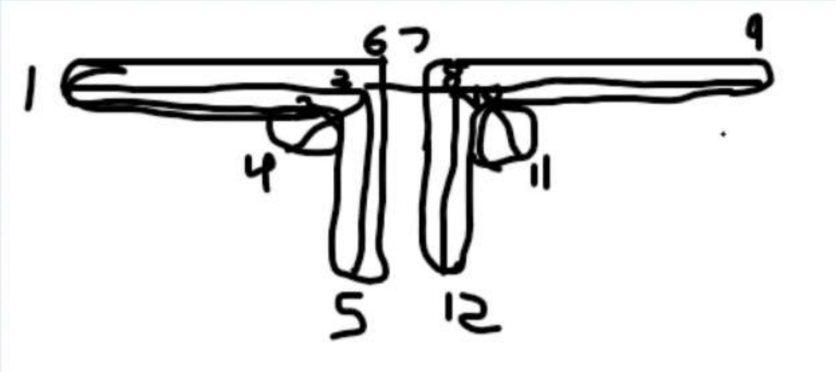
$w_{5.1} := w_{5.L1} + w_{5.R1} = 0.356\ klf$ (from 0' - 6')

$w_{5.2} := w_{5.L2} + w_{5.R2} = 0.595\ klf$ (from 6' - 140.6')

$w_{5.3} := w_{5.L3} + w_{5.R3} = 0.356\ klf$ (from 140.6' - 146.6')

clear (W_T, q_1, q_2)

Appendix B – Truss 2 Re-Design and Reinforcement Calculations



L-Shape Dimension

note: tf and tw are equal

$d := 5 \cdot in$ $b := 5 \cdot in$ $t_f := 0.5 \cdot in$ $t_w := 0.5 \cdot in$

$t_n := 1 \cdot 10^{-6} \cdot in$

Solid Rounds

$d_b := 2.25 \cdot in = 0.188\ ft$ $r := \frac{d_b}{2} = 0.094\ ft$

$t_r := (d_b) = 2.25\ in$

Spacing $s := .5 \cdot in$

Node 1:

$x_{a1} := 0 \cdot in$

$y_{a1} := d - \frac{t_f}{2} = 4.75\ in$

Node 2:

$x_{a2} := b - \frac{t_w}{2} = 4.75\ in$

$y_{a2} := d - \frac{t_f}{2} = 4.75\ in$

Node 3:

$x_{a3} := (b - t_w) = 4.5\ in$

$y_{a3} := (d - t_w) = 4.5\ in$

Node 4:

$x_{a4} := \left(b - t_w - r \cdot \frac{\sqrt[2]{5}}{2}\right) = 3.242\ in$

$y_{a4} := \left(d - t_f - r \cdot \frac{\sqrt[2]{5}}{2}\right) = 3.242\ in$

Node 5:

$x_{a5} := b - \frac{t_w}{2} = 0.396\ ft$

$y_{a5} := 0\ in = 0\ in$

Node 6:

$x_{a6} := b = 5\ in$

$y_{a6} := d - \frac{t_f}{2} = 4.75\ in$

Node 7:

$x_{a7} := b + s = 5.5\ in$

$y_{a7} := d - \frac{t_f}{2} = 4.75\ in$

Node 8:

$x_{a8} := b + s + \frac{t_w}{2} = 5.75\ in$

$y_{a8} := d - \frac{t_f}{2} = 4.75\ in$

Node 9:

$x_{a9} := 2 \cdot b + s = 10.5\ in$

$y_{a9} := d - \frac{t_f}{2} = 4.75\ in$

Node 10:

$x_{a10} := \left(b + s + t_w\right) = 6\ in$

$y_{a10} := \left(d - t_w\right) = 4.5\ in$

Node 11:

$x_{a11} := \left(b + s + t_w + r \cdot \frac{\sqrt[2]{5}}{2}\right) = 7.258\ in$

$y_{a11} := \left(d - t_f - r \cdot \frac{\sqrt[2]{5}}{2}\right) = 3.242\ in$

Node 12:

$x_{a12} := b + s + \frac{t_w}{2} = 5.75\ in$

$y_{a12} := 0 \cdot in = 0\ in$

Element Thickness

Element 1:

$lm := [1\ \ 2] \qquad t_1 := t_f = 0.5\ in$

Element 2:

$lm := [2\ \ 3] \qquad t_2 := t_n = \left(1 \cdot 10^{-6}\right)\ in$

Element 3:

$lm := [3\ \ 4] \qquad t_3 := t_r = 2.25\ in$

Element 4:

$lm := [2\ \ 5] \qquad t_4 := t_w = 0.5\ in$

Element 5:

$lm := [2\ \ 6] \qquad t_5 := t_n = \left(1 \cdot 10^{-6}\right)\ in$

Element 6:

$lm := [6\ \ 7] \qquad t_6 := t_n = \left(1 \cdot 10^{-6}\right)\ in$

Element 7:

$lm := [7\ \ 8] \qquad t_7 := t_n = \left(1 \cdot 10^{-6}\right)\ in$

Element 8:

$lm := [8\ \ 9] \qquad t_8 := t_f = 0.5\ in$

Element 9:

$lm := [8 \ \ 10]$ $t_9 := t_n = (1 \cdot 10^{-6})\ in$

Element 10:

$lm := [10 \ \ 11]$ $t_{10} := t_r$

Element 11:

$lm := [8 \ \ 12]$ $t_{11} := t_w = 0.5\ in$

$$c := \begin{bmatrix} 1 & 2 \\ 2 & 3 \\ 3 & 4 \\ 2 & 5 \\ 2 & 6 \\ 6 & 7 \\ 7 & 8 \\ 8 & 9 \\ 8 & 10 \\ 10 & 11 \\ 8 & 12 \end{bmatrix}$$

(i) Determine the centroid location for this center line model.

Element 1:

$$L_1 := \sqrt[2]{(x_{a1} - x_{a2})^2 + (y_{a1} - y_{a2})^2} = 4.75\ in$$

Element 2:

$$L_2 := \sqrt[2]{(x_{a2} - x_{a3})^2 + (y_{a2} - y_{a3})^2} = 0.354\ in$$

Element 3:

$$L_3 := \sqrt[2]{(x_{a3} - x_{a4})^2 + (y_{a3} - y_{a4})^2} = 1.779\ in$$

Element 4:

$$L_4 := \sqrt[2]{(x_{a2} - x_{a5})^2 + (y_{a2} - y_{a5})^2} = 4.75\ in$$

Element 5:

$$L_5 := \sqrt[2]{(x_{a2} - x_{a6})^2 + (y_{a2} - y_{a6})^2} = 0.25\ in$$

Element 6:

$$L_6 := \sqrt[2]{(x_{a6} - x_{a7})^2 + (y_{a6} - y_{a7})^2} = 0.5\ in$$

Element 7:

$$L_7 := \sqrt[2]{(x_{a7} - x_{a8})^2 + (y_{a7} - y_{a8})^2} = 0.25\ in$$

Element 8:

$$L_8 := \sqrt[2]{(x_{a8} - x_{a9})^2 + (y_{a8} - y_{a9})^2} = 4.75\ in$$

Element 9:

$$L_9 := \sqrt[2]{(x_{a8} - x_{a10})^2 + (y_{a8} - y_{a10})^2} = 0.354\ in$$

Element 10:

$$L_{10} := \sqrt[2]{(x_{a10} - x_{a11})^2 + (y_{a10} - y_{a11})^2} = 1.779\ in$$

Element 11:

$$L_{11} := \sqrt[2]{\left(x_{a8}-x_{a12}\right)^2+\left(y_{a8}-y_{a12}\right)^2} = 4.75\ in$$

$A_1 := L_1 \cdot t_1$ $A_2 := L_2 \cdot t_2$ $A_3 := L_3 \cdot t_3$ $A_4 := L_4 \cdot t_4$ $A_5 := L_5 \cdot t_5$ $A_6 := L_6 \cdot t_6$

$A_7 := L_7 \cdot t_7$ $A_8 := L_8 \cdot t_8$ $A_9 := L_9 \cdot t_9$ $A_{10} := L_{10} \cdot t_{10}$ $A_{11} := L_{11} \cdot t_{11}$

$$A_t := \left(L_1 \cdot t_1 + L_2 \cdot t_2 + L_3 \cdot t_3 + L_4 \cdot t_4 + L_5 \cdot t_5 + L_6 \cdot t_6 + L_7 \cdot t_7 + L_8 \cdot t_8 + L_9 \cdot t_9 + L_{10} \cdot t_{10} + L_{11} \cdot t_{11}\right) = 17.505\ in^2$$

Area Check $2 \cdot \frac{\pi}{4} \cdot \left(d_b\right)^2 + 9.58 \cdot in^2 = 17.532\ in^2$

$$A_{x,j} = \int_{L_j} y\, dA = L_j t_j \int_0^1 y(s)\, ds = \frac{y_m^a + y_n^a}{2} L_j t_j = (y_m^a + y_n^a) A_j / 2$$

$$A_{y,j} = \int_{L_j} x\, dA = L_j t_j \int_0^1 x(s)\, ds = \frac{x_m^a + x_n^a}{2} L_j t_j = (x_m^a + x_n^a) A_j / 2$$

Element 1:

$$A_{x1} := \frac{\left(y_{a1}+y_{a2}\right)}{2} \cdot A_1 = 11.281\ in^3$$

Element 2:

$$A_{x2} := \frac{\left(y_{a2}+y_{a3}\right)}{2} \cdot A_2 = \left(1.635 \cdot 10^{-6}\right)\ in^3$$

Element 3:

$$A_{x3} := \frac{\left(y_{a3}+y_{a4}\right)}{2} \cdot A_3 = 15.493\ in^3$$

Element 4:

$$A_{x4} := \frac{\left(y_{a2}+y_{a5}\right)}{2} \cdot A_4 = 5.641\ in^3$$

Element 5:

$$A_{x5} := \frac{\left(y_{a2}+y_{a6}\right)}{2} \cdot A_5 = \left(1.188 \cdot 10^{-7}\right)\ in^3$$

Element 6:

$$A_{x6} := \frac{\left(y_{a6}+y_{a7}\right)}{2} \cdot A_6 = \left(2.375 \cdot 10^{-6}\right)\ in^3$$

Element 7:

$$A_{x7} := \frac{\left(y_{a7}+y_{a8}\right)}{2} \cdot A_7 = \left(1.188 \cdot 10^{-6}\right)\ in^3$$

Element 8:

$$A_{x8} := \frac{\left(y_{a8}+y_{a9}\right)}{2} \cdot A_8 = 11.281\ in^3$$

Element 9:

$$A_{x9} := \frac{\left(y_{a8}+y_{a10}\right)}{2} \cdot A_9 = \left(1.635 \cdot 10^{-6}\right)\ in^3$$

Element 10:

$$A_{x10} := \frac{\left(y_{a10}+y_{a11}\right)}{2} \cdot A_{10} = 15.493\ in^3$$

Element 11:

$$A_{x11} := \frac{(y_{a8} + y_{a12})}{2} \cdot A_{11} = 5.641\ in^3$$

$$A_{xj} := A_{x1} + A_{x2} + A_{x3} + A_{x4} + A_{x5} + A_{x6} + A_{x7} + A_{x8} + A_{x9} + A_{x10} + A_{x11} = 64.83\ in^3$$

$$y := \frac{A_{xj}}{A_t} = 3.704\ in$$

Element 1:

$$A_{y1} := \frac{(x_{a1} + x_{a2})}{2} \cdot A_1 = 5.641\ in^3$$

Element 2:

$$A_{y2} := \frac{(x_{a2} + x_{a3})}{2} \cdot A_2 = (1.635 \cdot 10^{-6})\ in^3$$

Element 3:

$$A_{y3} := \frac{(x_{a3} + x_{a4})}{2} \cdot A_3 = 15.493\ in^3$$

Element 4:

$$A_{y4} := \frac{(x_{a2} + x_{a5})}{2} \cdot A_4 = 11.281\ in^3$$

Element 5:

$$A_{y5} := \frac{(x_{a2} + x_{a6})}{2} \cdot A_5 = (1.219 \cdot 10^{-6})\ in^3$$

Element 6:

$$A_{y6} := \frac{(x_{a6} + x_{a7})}{2} \cdot A_6 = (2.625 \cdot 10^{-6})\ in^3$$

Element 7:

$$A_{y7} := \frac{(x_{a7} + x_{a8})}{2} \cdot A_7 = (1.406 \cdot 10^{-6})\ in^3$$

Element 8:

$$A_{y8} := \frac{(x_{a8} + x_{a9})}{2} \cdot A_8 = 19.297\ in^3$$

Element 9:

$$A_{y9} := \frac{(x_{a8} + x_{a10})}{2} \cdot A_9 = (2.077 \cdot 10^{-6})\ in^3$$

Element 10:

$$A_{y10} := \frac{(x_{a10} + x_{a11})}{2} \cdot A_{10} = 26.531\ in^3$$

Element 11:

$$A_{y11} := \frac{(x_{a8} + x_{a12})}{2} \cdot A_{11} = 13.656\ in^3$$

$$A_{yj} := A_{y1} + A_{y2} + A_{y3} + A_{y4} + A_{y5} + A_{y6} + A_{y7} + A_{y8} + A_{y9} + A_{y10} + A_{y11} = 91.899\ in^3$$

Centroid Location

$x := \frac{A_{yj}}{A_t} = 5.25\ in$ $y = 3.704\ in$

(ii) Determine the moments of inertias about the coordinates passing through the centroid

Shift Coordinates of Nodes

$x_1 := x_{a1} - x = -5.25\ in$ $y_1 := y_{a1} - y = 1.046\ in$

$x_2 := x_{a2} - x = -0.5\ in$ $y_2 := y_{a2} - y = 1.046\ in$

$x_3 := x_{a3} - x = -0.75\ in$ $y_3 := y_{a3} - y = 0.796\ in$

$x_4 := x_{a4} - x = -2.008\ in$ $y_4 := y_{a4} - y = -0.461\ in$

$x_5 := x_{a5} - x = -0.5\ in$ $y_5 := y_{a5} - y = -3.704\ in$

$x_6 := x_{a6} - x = -0.25\ in$ $y_6 := y_{a6} - y = 1.046\ in$

$x_7 := x_{a7} - x = 0.25\ in$ $y_7 := y_{a7} - y = 1.046\ in$

$x_8 := x_{a8} - x = 0.5\ in$ $y_8 := y_{a8} - y = 1.046\ in$

$x_9 := x_{a9} - x = 5.25\ in$ $y_9 := y_{a9} - y = 1.046\ in$

$x_{10} := x_{a10} - x = 0.75\ in$ $y_{10} := y_{a10} - y = 0.796\ in$

$x_{11} := x_{a11} - x = 2.008\ in$ $y_{11} := y_{a11} - y = -0.461\ in$

$x_{12} := x_{a12} - x = 0.5\ in$ $y_{12} := y_{a12} - y = -3.704\ in$

$I_{x1} := \left(y_1^2 + y_1 \cdot y_2 + y_2^2\right) \cdot \frac{A_1}{3} = 2.6\ in^4$ $I_{x2} := \left(y_2^2 + y_2 \cdot y_3 + y_3^2\right) \cdot \frac{A_2}{3} = \left(3.02 \cdot 10^{-7}\right)\ in^4$

$I_{x3} := \left(y_3^2 + y_3 \cdot y_4 + y_3^2\right) \cdot \frac{A_3}{3} = 1.202\ in^4$ $I_{x4} := \left(y_2^2 + y_2 \cdot y_5 + y_5^2\right) \cdot \frac{A_4}{3} = 8.658\ in^4$

$I_{x5} := \left(y_2^2 + y_2 \cdot y_6 + y_6^2\right) \cdot \frac{A_5}{3} = \left(2.737 \cdot 10^{-7}\right)\ in^4$ $I_{x6} := \left(y_6^2 + y_6 \cdot y_7 + y_7^2\right) \cdot \frac{A_6}{3} = \left(5.475 \cdot 10^{-7}\right)\ in^4$

$$I_{x7} := \left(y_7^{\,2} + y_7 \cdot y_8 + y_9^{\,2}\right) \cdot \frac{A_7}{3} = \left(2.737 \cdot 10^{-7}\right)\ \boldsymbol{in}^4 \quad I_{x8} := \left(y_8^{\,2} + y_8 \cdot y_9 + y_9^{\,2}\right) \cdot \frac{A_8}{3} = 2.6\ \boldsymbol{in}^4$$

$$I_{x9} := \left(y_8^{\,2} + y_8 \cdot y_{10} + y_{10}^{\,2}\right) \cdot \frac{A_9}{3} = \left(3.02 \cdot 10^{-7}\right)\ \boldsymbol{in}^4 \quad I_{x10} := \left(y_{10}^{\,2} + y_{10} \cdot y_{11} + y_{11}^{\,2}\right) \cdot \frac{A_{10}}{3} = 0.64\ \boldsymbol{in}^4$$

$$I_{x11} := \left(y_8^{\,2} + y_8 \cdot y_{12} + y_{12}^{\,2}\right) \cdot \frac{A_{11}}{3} = 8.658\ \boldsymbol{in}^4$$

$$I_{y1} := \left(x_1^{\,2} + x_1 \cdot x_2 + x_2^{\,2}\right) \cdot \frac{A_1}{3} = 24.096\ \boldsymbol{in}^4 \qquad I_{y2} := \left(x_2^{\,2} + x_2 \cdot x_3 + x_3^{\,2}\right) \cdot \frac{A_2}{3} = \left(1.399 \cdot 10^{-7}\right)\ \boldsymbol{in}^4$$

$$I_{y3} := \left(x_3^{\,2} + x_3 \cdot x_4 + x_4^{\,2}\right) \cdot \frac{A_3}{3} = 8.137\ \boldsymbol{in}^4 \qquad I_{y4} := \left(x_2^{\,2} + x_2 \cdot x_5 + x_5^{\,2}\right) \cdot \frac{A_4}{3} = 0.594\ \boldsymbol{in}^4$$

$$I_{y5} := \left(x_2^{\,2} + x_2 \cdot x_6 + x_6^{\,2}\right) \cdot \frac{A_5}{3} = \left(3.646 \cdot 10^{-8}\right)\ \boldsymbol{in}^4 \quad I_{y6} := \left(x_6^{\,2} + x_6 \cdot x_7 + x_7^{\,2}\right) \cdot \frac{A_6}{3} = \left(1.042 \cdot 10^{-8}\right)\ \boldsymbol{in}^4$$

$$I_{y7} := \left(x_7^{\,2} + x_7 \cdot x_8 + x_8^{\,2}\right) \cdot \frac{A_7}{3} = \left(3.646 \cdot 10^{-8}\right)\ \boldsymbol{in}^4 \quad I_{y8} := \left(x_8^{\,2} + x_8 \cdot x_9 + x_9^{\,2}\right) \cdot \frac{A_8}{3} = 24.096\ \boldsymbol{in}^4$$

$$I_{y9} := \left(x_8^{\,2} + x_{10} \cdot x_8 + x_{10}^{\,2}\right) \cdot \frac{A_9}{3} = \left(1.399 \cdot 10^{-7}\right)\ \boldsymbol{in}^4 \quad I_{y10} := \left(x_{10}^{\,2} + x_{10} \cdot x_{11} + x_{11}^{\,2}\right) \cdot \frac{A_{10}}{3} = 8.137\ \boldsymbol{in}^4$$

$$I_{y11} := \left(x_8^{\,2} + x_8 \cdot x_{12} + x_{12}^{\,2}\right) \cdot \frac{A_{11}}{3} = 0.594\ \boldsymbol{in}^4$$

$$I_x := I_{x1} + I_{x2} + I_{x3} + I_{x4} + I_{x5} + I_{x6} + I_{x7} + I_{x8} + I_{x9} + I_{x10} + I_{x11} = 24.359\ \boldsymbol{in}^4$$

$$I_y := I_{y1} + I_{y2} + I_{y3} + I_{y4} + I_{y5} + I_{y6} + I_{y7} + I_{y8} + I_{y9} + I_{y10} + I_{y11} = 65.655\ \boldsymbol{in}^4$$

$$I_{xy,j} = (2\, x_m\, y_m + 2\, x_n\, y_n + x_m\, y_n + x_n\, y_m)_j\, A_j / 6$$

$$I_{xy1} := (2 \cdot x_1 \cdot y_1 + 2 \cdot x_2 \cdot y_2 + x_1 \cdot y_2 + x_2 \cdot y_1) \cdot \frac{A_1}{6} = -7.145\ \boldsymbol{in}^4$$

$$I_{xy2} := (2 \cdot x_2 \cdot y_2 + 2 \cdot x_3 \cdot y_3 + x_2 \cdot y_3 + x_3 \cdot y_2) \cdot \frac{A_2}{6} = -2.018 \cdot 10^{-7}\ \boldsymbol{in}^4$$

$$I_{xy3} := (2 \cdot x_3 \cdot y_3 + 2 \cdot x_4 \cdot y_4 + x_3 \cdot y_4 + x_4 \cdot y_3) \cdot \frac{A_3}{6} = -0.397\ \boldsymbol{in}^4$$

$$I_{xy4} := (2 \cdot x_2 \cdot y_2 + 2 \cdot x_5 \cdot y_5 + x_2 \cdot y_5 + x_5 \cdot y_2) \cdot \frac{A_4}{6} = 1.578\ \boldsymbol{in}^4$$

$$I_{xy5} := (2 \cdot x_2 \cdot y_2 + 2 \cdot x_6 \cdot y_6 + x_2 \cdot y_6 + x_6 \cdot y_2) \cdot \frac{A_5}{6} = -9.81 \cdot 10^{-8}\ in^4$$

$$I_{xy6} := (2 \cdot x_6 \cdot y_6 + 2 \cdot x_7 \cdot y_7 + x_6 \cdot y_7 + x_7 \cdot y_6) \cdot \frac{A_6}{6} = (1.145 \cdot 10^{-21})\ in^4$$

$$I_{xy7} := (2 \cdot x_7 \cdot y_7 + 2 \cdot x_8 \cdot y_8 + x_7 \cdot y_8 + x_8 \cdot y_7) \cdot \frac{A_7}{6} = (9.81 \cdot 10^{-8})\ in^4$$

$$I_{xy8} := (2 \cdot x_8 \cdot y_8 + 2 \cdot x_9 \cdot y_9 + x_8 \cdot y_9 + x_9 \cdot y_8) \cdot \frac{A_8}{6} = 7.145\ in^4$$

$$I_{xy9} := (2 \cdot x_8 \cdot y_8 + 2 \cdot x_{10} \cdot y_{10} + x_8 \cdot y_{10} + x_{10} \cdot y_8) \cdot \frac{A_9}{6} = (2.018 \cdot 10^{-7})\ in^4$$

$$I_{xy10} := (2 \cdot x_{10} \cdot y_{10} + 2 \cdot x_{11} \cdot y_{11} + x_{10} \cdot y_{11} + x_{11} \cdot y_{10}) \cdot \frac{A_{10}}{6} = 0.397\ in^4$$

$$I_{xy11} := (2 \cdot x_8 \cdot y_8 + 2 \cdot x_{12} \cdot y_{12} + x_8 \cdot y_{12} + x_{12} \cdot y_8) \cdot \frac{A_{11}}{6} = -1.578\ in^4$$

$$I_{xy} := I_{xy1} + I_{xy2} + I_{xy3} + I_{xy4} + I_{xy5} + I_{xy6} + I_{xy7} + I_{xy8} + I_{xy9} + I_{xy10} + I_{xy11} = -6.134 \cdot 10^{-20}\ ft^4$$

$$I_{max} := \frac{1}{2}\left(I_x + I_y + \sqrt[2]{(I_x - I_y)^2 + (4 \cdot I_{xy}{}^2)}\right) = 65.655\ in^4$$

$$I_{min} := \frac{1}{2}\left(I_x + I_y - \sqrt[2]{(I_x - I_y)^2 + (4 \cdot I_{xy}{}^2)}\right) = 24.359\ in^4$$

$$\alpha := \frac{1}{2} \cdot \operatorname{atan}\left(\frac{2 \cdot I_{xy}}{I_y - I_x}\right) = -3.08 \cdot 10^{-17}$$

Section Modulus

$$S_x := \frac{I_x}{y} = 6.577\ in^3 \qquad S_y := \frac{I_y}{x} = 12.506\ in^3$$

Plastic Moment

$$t := .5 \cdot in$$

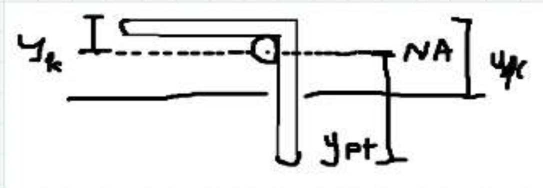
$$y_{pt} := d - y_{pc}$$

$$A_c := b \cdot t + t \cdot (y_{pc} - t) \qquad A_s := y_{pt} \cdot (t) + \frac{\pi}{4} \cdot (d_b{}^2)$$

$$A_c = A_s \xrightarrow{solve,\, y_{pc}} \frac{0.027611654181941542135 \cdot ft^2 + 0.25 \cdot in^2}{in}$$

$$y_{pc} := \frac{0.021816615649929119712 4 \cdot ft^2 + 0.25 \cdot in^2}{in} = 3.392\ in$$

$$y_{pt} := d - y_{pc} = 1.608\ in$$



$$Z_{1x} := t \cdot y_{pt} \cdot \frac{y_{pt}}{2} = 0.647\ in^3 \qquad Z_{2x} := t \cdot y_{pc} \cdot \frac{y_{pc}}{2} = 2.876\ in^3 \qquad Z_{3x} := (b - t) \cdot t \cdot \left(\frac{y_{pc}}{2} - t\right) = 2.691\ in^3$$

$$Z_x := Z_{1x} + Z_{2x} + Z_{3x} = 6.213\ in^3 \qquad Z'_x := 2 \cdot Z_x = 12.426\ in^3$$

$$Z'_x := 15.164\ in^3 \qquad Z_x := Z'_x = 15.164\ in^3 \qquad b - \frac{t}{2} = 4.75\ in$$

$$5.684 + .5625 = 6.247 \qquad 2 \cdot b + s = 10.5\ in$$

$$Z_{y1} := t \cdot (b - t) \cdot \left(\frac{2 \cdot b + s}{2} - \frac{(b - t)}{2}\right) = 6.75\ in^3 \qquad Z_{y2} := d \cdot t \cdot \left(\frac{2 \cdot b + s}{2} - \left(b - \frac{t}{2}\right)\right) = 1.25\ in^3$$

$$Z_{y3} := \frac{\pi}{4} \cdot (d_b)^2 \cdot \left(\frac{2 \cdot b + s}{2} - (s + t + .5 \cdot d_b)\right) = 12.425\ in^3$$

$$Z_y := 2 \cdot (Z_{y1} + Z_{y2} + Z_{y3}) = 40.85\ in^3$$

$$F_y := 36\ ksi \qquad F_u := 58\ ksi$$

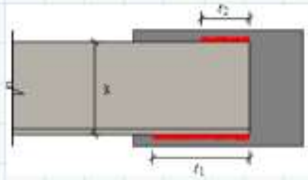
$$M_y := F_y \cdot Z_x = 45.492\ kip \cdot ft \qquad M_x := F_y \cdot Z_y = 122.551\ kip \cdot ft$$

Yielding of Tension Members

P axial stress Ag: Gross Area $A_g := A_t$ $F_y := 36\ ksi$

$\phi_{ty} := .9$ $\phi P_{ny} := \phi_{ty} \cdot F_y \cdot A_g = 567.146\ kip$

Longitudinal welds



w= distance in between welds

$l_1 := 11\ ft$ $l_2 := 11\ ft$

x: distance from the centroid

$l := \frac{l_1 + l_2}{2}$ $w := 2.5 \cdot in$ $U := \frac{3 \cdot l^2}{3 \cdot l^2 + w^2} \cdot \left(1 - \frac{x}{l}\right) = 0.96$

$A_e := U \cdot A_g = 0.117\ ft^2$

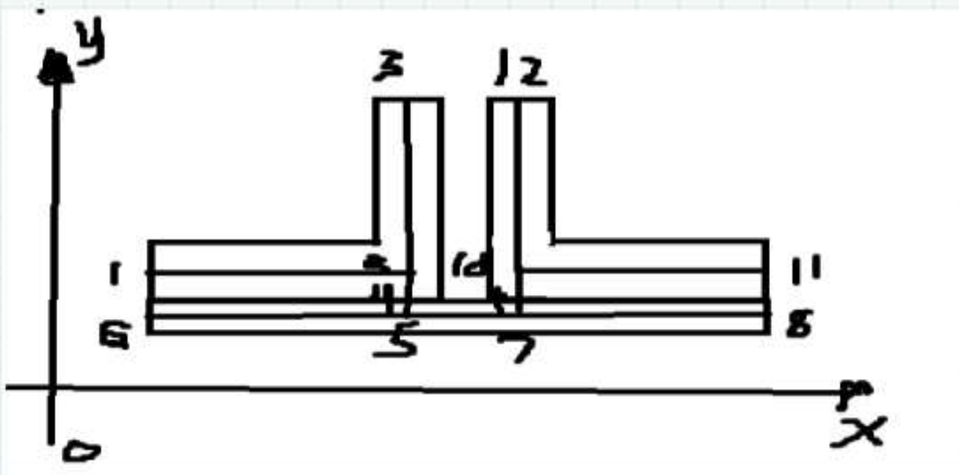
$\phi_{trup} := .75$ $F_u := 58\ ksi$ $\phi P_{nrupt} := \phi_{trup} \cdot F_u \cdot A_e = 731.074\ kip$

$\phi P_n := min\left(\phi P_{ny}, \phi P_{nrupt}\right) = 567.146\ kip$

$\phi_t P_{n.yielding} := \phi P_{ny}$

$\phi_t P_{n.rupture} := \phi P_{nrupt}$

$\phi R_n := min\left(\phi_t P_{n.yielding}, \phi_t P_{n.rupture}\right) = 567.146\ kip$



L-Shape Dimension

note: tf and tw are equal

$d := 5 \cdot in$ $b := 5 \cdot in$ $t_f := 0.5 \cdot in$ $t_w := 0.5 \cdot in$

$t_n := 1 \cdot 10^{-6} \cdot in$

Gauss Plate

$l_p := 12 \cdot in = 1\ ft$ $t_p := \frac{3}{4}\ in$

Spacing $s := .5 \cdot in$

Node 1:

$x_{a1} := 0 \cdot in$

$y_{a1} := t_p + \frac{t_f}{2} = 1\ in$

Node 2:

$x_{a2} := b - \frac{t_w}{2} = 4.75\ in$

$y_{a2} := t_p + \frac{t_f}{2} = 1\ in$

Node 3:

$x_{a3} := b - \frac{t_w}{2} = 4.75\ in$

$y_{a3} := d + t_p = 5.75\ in$

Node 4:

$x_{a4} := b - \frac{t_w}{2} = 4.75\ in$

$y_{a4} := t_p = 0.75\ in$

Node 5:

$x_{a5} := b - \frac{t_w}{2} = 4.75\ in$

$y_{a5} := \frac{t_p}{2} = 0.375\ in$

Node 6:

$x_{a6} := (2 \cdot b + s) - l_p = -1.5\ in$

$y_{a6} := \frac{t_p}{2} = 0.375\ in$

Node 7:

$x_{a7} := b + s + \frac{t_w}{2} = 5.75\ in$

$y_{a7} := \frac{t_p}{2} = 0.375\ in$

Node 8:

$x_{a8} := l_p = 12\ in$

$y_{a8} := \frac{t_p}{2} = 0.375\ in$

Node 9:

$x_{a9} := b + s + \frac{t_w}{2} = 5.75\ in$

$y_{a9} := t_p = 0.75\ in$

Node 10:

$x_{a10} := b + s + \frac{t_f}{2} = 5.75\ in$

$y_{a10} := t_p + \frac{t_f}{2} = 1\ in$

Node 11:

$x_{a11} := 2\ b + s = 10.5\ in$

$y_{a11} := t_p + \frac{t_f}{2} = 1\ in$

Node 12:

$x_{a12} := b + s + \frac{t_f}{2} = 5.75\ in$

$y_{a12} := d + t_p = 5.75\ in$

Element Thickness

Element 1:

$lm := [1\ \ 2]$ $\quad t_1 := t_f = 0.5\ in$

Element 2:

$lm := [2\ \ 3]$ $\quad t_2 := t_f = 0.5\ in$

Element 3:

$lm := [2\ \ 4]$ $\quad t_3 := t_n = (1 \cdot 10^{-6})\ in$

Element 4:

$lm := [4\ \ 5]$ $\quad t_4 := t_n = (1 \cdot 10^{-6})\ in$

Element 5:

$lm := [5\ \ 6]$ $\quad t_5 := t_p = 0.75\ in$

Element 6:

$lm := [5\ \ 7]$ $\quad t_6 := t_p = 0.75\ in$

Element 7:

$lm := [7\ \ 9]$ $\quad t_7 := t_n = (1 \cdot 10^{-6})\ in$

Element 8:

$lm := [7\ \ 8]$ $\quad t_8 := t_p = 0.75\ in$

Element 9:

$lm := [9\ \ 10]$ $\quad t_9 := t_n = (1 \cdot 10^{-6})\ in$

Element 10:

$lm := [10\ \ 11]$ $\quad t_{10} := t_f = 0.042\ ft$

Element 11:

$lm := [10 \;\; 12] \quad t_{11} := t_f = 0.5 \; in$

$$c := \begin{bmatrix} 1 & 2 \\ 2 & 3 \\ 2 & 4 \\ 4 & 5 \\ 5 & 6 \\ 5 & 7 \\ 7 & 9 \\ 7 & 8 \\ 9 & 10 \\ 10 & 11 \\ 10 & 12 \end{bmatrix}$$

(i) Determine the centroid location for this center line model.

Element 1:

$L_1 := \sqrt[2]{(x_{a1} - x_{a2})^2 + (y_{a1} - y_{a2})^2} = 4.75 \; in$

Element 2:

$L_2 := \sqrt[2]{(x_{a2} - x_{a3})^2 + (y_{a2} - y_{a3})^2} = 4.75 \; in$

Element 3:

$L_3 := \sqrt[2]{(x_{a2} - x_{a4})^2 + (y_{a2} - y_{a4})^2} = 0.25 \; in$

Element 4:

$L_4 := \sqrt[2]{(x_{a4} - x_{a5})^2 + (y_{a4} - y_{a5})^2} = 0.375 \; in$

Element 5:

$L_5 := \sqrt[2]{(x_{a5} - x_{a6})^2 + (y_{a5} - y_{a6})^2} = 6.25 \; in$

Element 6:

$L_6 := \sqrt[2]{(x_{a5} - x_{a7})^2 + (y_{a5} - y_{a7})^2} = 1 \; in$

Element 7:

$L_7 := \sqrt[2]{(x_{a7} - x_{a9})^2 + (y_{a7} - y_{a9})^2} = 0.375 \; in$

Element 8:

$L_8 := \sqrt[2]{(x_{a7} - x_{a8})^2 + (y_{a7} - y_{a8})^2} = 6.25 \; in$

Element 9:

$L_9 := \sqrt[2]{(x_{a9} - x_{a10})^2 + (y_{a9} - y_{a10})^2} = 0.25 \; in$

Element 10:

$L_{10} := \sqrt[2]{(x_{a10} - x_{a11})^2 + (y_{a10} - y_{a11})^2} = 4.75 \; in$

Element 11:

$L_{11} := \sqrt[2]{(x_{a10} - x_{a12})^2 + (y_{a10} - y_{a12})^2} = 4.75 \; in$

$A_1 := L_1 \cdot t_1 \quad A_2 := L_2 \cdot t_2 \quad A_3 := L_3 \cdot t_3 \quad A_4 := L_4 \cdot t_4 \quad A_5 := L_5 \cdot t_5 \quad A_6 := L_6 \cdot t_6$

$A_7 := L_7 \cdot t_7 \quad A_8 := L_8 \cdot t_8 \quad A_9 := L_9 \cdot t_9 \quad A_{10} := L_{10} \cdot t_{10} \quad A_{11} := L_{11} \cdot t_{11}$

$A_t := \left(L_1 \cdot t_1 + L_2 \cdot t_2 + L_3 \cdot t_3 + L_4 \cdot t_4 + L_5 \cdot t_5 + L_6 \cdot t_6 + L_7 \cdot t_7 + L_8 \cdot t_8 + L_9 \cdot t_9 + L_{10} \cdot t_{10} + L_{11} \cdot t_{11}\right) = 19.625\ i$

Element 1:

$A_{x1} := \frac{\left(y_{a1} + y_{a2}\right)}{2} \cdot A_1 = 2.375\ in^3$

Element 2:

$A_{x2} := \frac{\left(y_{a2} + y_{a3}\right)}{2} \cdot A_2 = 8.016\ in^3$

Element 3:

$A_{x3} := \frac{\left(y_{a2} + y_{a4}\right)}{2} \cdot A_3 = \left(2.188 \cdot 10^{-7}\right)\ in^3$

Element 4:

$A_{x4} := \frac{\left(y_{a4} + y_{a5}\right)}{2} \cdot A_4 = \left(2.109 \cdot 10^{-7}\right)\ in^3$

Element 5:

$A_{x5} := \frac{\left(y_{a5} + y_{a6}\right)}{2} \cdot A_5 = 1.758\ in^3$

Element 6:

$A_{x6} := \frac{\left(y_{a5} + y_{a7}\right)}{2} \cdot A_6 = 0.281\ in^3$

Element 7:

$A_{x7} := \frac{\left(y_{a7} + y_{a9}\right)}{2} \cdot A_7 = \left(2.109 \cdot 10^{-7}\right)\ in^3$

Element 8:

$A_{x8} := \frac{\left(y_{a7} + y_{a8}\right)}{2} \cdot A_8 = 1.758\ in^3$

Element 9:

$A_{x9} := \frac{\left(y_{a9} + y_{a10}\right)}{2} \cdot A_9 = \left(2.188 \cdot 10^{-7}\right)\ in^3$

Element 10:

$A_{x10} := \frac{\left(y_{a10} + y_{a11}\right)}{2} \cdot A_{10} = 2.375\ in^3$

Element 11:

$A_{x11} := \frac{\left(y_{a10} + y_{a12}\right)}{2} \cdot A_{11} = 8.016\ in^3$

$A_{xj} := A_{x1} + A_{x2} + A_{x3} + A_{x4} + A_{x5} + A_{x6} + A_{x7} + A_{x8} + A_{x9} + A_{x10} + A_{x11} = 24.578\ in^3$

$y := \frac{A_{xj}}{A_t} = 1.252\ in$

Element 1:

$A_{y1} := \frac{\left(x_{a1} + x_{a2}\right)}{2} \cdot A_1 = 5.641\ in^3$

Element 2:

$A_{y2} := \frac{\left(x_{a2} + x_{a3}\right)}{2} \cdot A_2 = 11.281\ in^3$

Element 3:

$A_{y3} := \frac{\left(x_{a2} + x_{a4}\right)}{2} \cdot A_3 = \left(1.188 \cdot 10^{-6}\right)\ in^3$

Element 4:

$A_{y4} := \frac{\left(x_{a4} + x_{a5}\right)}{2} \cdot A_4 = \left(1.781 \cdot 10^{-6}\right)\ in^3$

Element 5:

$$A_{y5} := \frac{(x_{a5}+x_{a6})}{2} \cdot A_5 = 7.617\ in^3$$

Element 6:

$$A_{y6} := \frac{(x_{a5}+x_{a7})}{2} \cdot A_6 = 3.937\ in^3$$

Element 7:

$$A_{y7} := \frac{(x_{a7}+x_{a9})}{2} \cdot A_7 = (2.156 \cdot 10^{-6})\ in^3$$

Element 8:

$$A_{y8} := \frac{(x_{a7}+x_{a8})}{2} \cdot A_8 = 41.602\ in^3$$

Element 9:

$$A_{y9} := \frac{(x_{a9}+x_{a10})}{2} \cdot A_9 = (1.438 \cdot 10^{-6})\ in^3$$

Element 10:

$$A_{y10} := \frac{(x_{a10}+x_{a11})}{2} \cdot A_{10} = 19.297\ in^3$$

Element 11:

$$A_{y11} := \frac{(x_{a10}+x_{a12})}{2} \cdot A_{11} = 13.656\ in^3$$

$$A_{yj} := A_{y1}+A_{y2}+A_{y3}+A_{y4}+A_{y5}+A_{y6}+A_{y7}+A_{y8}+A_{y9}+A_{y10}+A_{y11} = 103.031\ in^3$$

Centroid Location

$$x := \frac{A_{yj}}{A_t} = 5.25\ in \qquad y = 1.252\ in$$

Shift Coordinates of Nodes

$x_1 := x_{a1} - x = -5.25\ in$ $\qquad y_1 := y_{a1} - y = -0.252\ in$

$x_2 := x_{a2} - x = -0.5\ in$ $\qquad y_2 := y_{a2} - y = -0.252\ in$

$x_3 := x_{a3} - x = -0.5\ in$ $\qquad y_3 := y_{a3} - y = 4.498\ in$

$x_4 := x_{a4} - x = -0.5\ in$ $\qquad y_4 := y_{a4} - y = -0.502\ in$

$x_5 := x_{a5} - x = -0.5\ in$ $\qquad y_5 := y_{a5} - y = -0.877\ in$

$x_6 := x_{a6} - x = -6.75\ in$ $\qquad y_6 := y_{a6} - y = -0.877\ in$

$x_7 := x_{a7} - x = 0.5\ in$ $\qquad y_7 := y_{a7} - y = -0.877\ in$

$x_8 := x_{a8} - x = 6.75\ in$ $\qquad y_8 := y_{a8} - y = -0.877\ in$

$x_9 := x_{a9} - x = 0.5\ in$ $\qquad y_9 := y_{a9} - y = -0.502\ in$

$x_{10} := x_{a10} - x = 0.5\ in$ $\qquad y_{10} := y_{a10} - y = -0.252\ in$

$x_{11} := x_{a11} - x = 5.25\ in$ $\qquad y_{11} := y_{a11} - y = -0.252\ in$

$$x_{12} := x_{a12} - x = 0.5\ in \qquad y_{12} := y_{a12} - y = 4.498\ in$$

$$I_{x1} := \left(y_1^2 + y_1 \cdot y_2 + y_2^2\right) \cdot \frac{A_1}{3} = 0.151\ in^4 \qquad I_{x2} := \left(y_2^2 + y_2 \cdot y_3 + y_3^2\right) \cdot \frac{A_2}{3} = 15.166\ in^4$$

$$I_{x3} := \left(y_2^2 + y_2 \cdot y_4 + y_4^2\right) \cdot \frac{A_3}{3} = \left(3.691 \cdot 10^{-8}\right)\ in^4 \quad I_{x4} := \left(y_4^2 + y_4 \cdot y_5 + y_5^2\right) \cdot \frac{A_4}{3} = \left(1.829 \cdot 10^{-7}\right)\ in^4$$

$$I_{x5} := \left(y_5^2 + y_5 \cdot y_6 + y_6^2\right) \cdot \frac{A_5}{3} = 3.608\ in^4 \qquad I_{x6} := \left(y_5^2 + y_5 \cdot y_7 + y_7^2\right) \cdot \frac{A_6}{3} = 0.577\ in^4$$

$$I_{x7} := \left(y_7^2 + y_7 \cdot y_9 + y_9^2\right) \cdot \frac{A_7}{3} = \left(1.829 \cdot 10^{-7}\right)\ in^4 \quad I_{x8} := \left(y_7^2 + y_7 \cdot y_8 + y_8^2\right) \cdot \frac{A_8}{3} = 3.608\ in^4$$

$$I_{x9} := \left(y_9^2 + y_9 \cdot y_{10} + y_{10}^2\right) \cdot \frac{A_9}{3} = \left(3.691 \cdot 10^{-8}\right)\ in^4 \quad I_{x10} := \left(y_{10}^2 + y_{10} \cdot y_{11} + y_{11}^2\right) \cdot \frac{A_{10}}{3} = 0.151\ in^4$$

$$I_{x11} := \left(y_{10}^2 + y_{10} \cdot y_{12} + y_{12}^2\right) \cdot \frac{A_{11}}{3} = 15.166\ in^4$$

$$I_{y1} := \left(x_1^2 + x_1 \cdot x_2 + x_2^2\right) \cdot \frac{A_1}{3} = 24.096\ in^4 \qquad I_{y2} := \left(x_2^2 + x_2 \cdot x_3 + x_3^2\right) \cdot \frac{A_2}{3} = 0.594\ in^4$$

$$I_{y3} := \left(x_2^2 + x_2 \cdot x_4 + x_4^2\right) \cdot \frac{A_3}{3} = \left(6.25 \cdot 10^{-8}\right)\ in^4 \quad I_{y4} := \left(x_4^2 + x_4 \cdot x_5 + x_5^2\right) \cdot \frac{A_4}{3} = \left(9.375 \cdot 10^{-8}\right)\ in^4$$

$$I_{y5} := \left(x_5^2 + x_5 \cdot x_6 + x_6^2\right) \cdot \frac{A_5}{3} = 76.855\ in^4 \qquad I_{y6} := \left(x_5^2 + x_5 \cdot x_7 + x_7^2\right) \cdot \frac{A_6}{3} = 0.062\ in^4$$

$$I_{y7} := \left(x_7^2 + x_7 \cdot x_9 + x_9^2\right) \cdot \frac{A_7}{3} = \left(9.375 \cdot 10^{-8}\right)\ in^4 \quad I_{y8} := \left(x_7^2 + x_7 \cdot x_8 + x_8^2\right) \cdot \frac{A_8}{3} = 76.855\ in^4$$

$$I_{y9} := \left(x_9^2 + x_9 \cdot x_{10} + x_{10}^2\right) \cdot \frac{A_9}{3} = \left(6.25 \cdot 10^{-8}\right)\ in^4 \quad I_{y10} := \left(x_{10}^2 + x_{10} \cdot x_{11} + x_{11}^2\right) \cdot \frac{A_{10}}{3} = 24.096\ in^4$$

$$I_{y11} := \left(x_{10}^2 + x_{10} \cdot x_{12} + x_{12}^2\right) \cdot \frac{A_{11}}{3} = 0.594\ in^4$$

$$I_x := I_{x1} + I_{x2} + I_{x3} + I_{x4} + I_{x5} + I_{x6} + I_{x7} + I_{x8} + I_{x9} + I_{x10} + I_{x11} = 38.429\ in^4$$

$$I_y := I_{y1} + I_{y2} + I_{y3} + I_{y4} + I_{y5} + I_{y6} + I_{y7} + I_{y8} + I_{y9} + I_{y10} + I_{y11} = 203.154\ in^4$$

$$I_{xy1} := \left(2 \cdot x_1 \cdot y_1 + 2 \cdot x_2 \cdot y_2 + x_1 \cdot y_2 + x_2 \cdot y_1\right) \cdot \frac{A_1}{6} = 1.723\ in^4$$

$$I_{xy2} := \left(2 \cdot x_2 \cdot y_2 + 2 \cdot x_3 \cdot y_3 + x_2 \cdot y_3 + x_3 \cdot y_2\right) \cdot \frac{A_2}{6} = -2.521\ in^4$$

$$I_{xy3} := (2 \cdot x_2 \cdot y_2 + 2 \cdot x_4 \cdot y_4 + x_2 \cdot y_4 + x_4 \cdot y_2) \cdot \frac{A_3}{6} = (4.717 \cdot 10^{-8})\ in^4$$

$$I_{xy4} := (2 \cdot x_4 \cdot y_4 + 2 \cdot x_5 \cdot y_5 + x_4 \cdot y_5 + x_5 \cdot y_4) \cdot \frac{A_4}{6} = (1.294 \cdot 10^{-7})\ in^4$$

$$I_{xy5} := (2 \cdot x_5 \cdot y_5 + 2 \cdot x_6 \cdot y_6 + x_5 \cdot y_6 + x_6 \cdot y_5) \cdot \frac{A_5}{6} = 14.909\ in^4$$

$$I_{xy6} := (2 \cdot x_5 \cdot y_5 + 2 \cdot x_7 \cdot y_7 + x_5 \cdot y_7 + x_7 \cdot y_5) \cdot \frac{A_6}{6} = -1.891 \cdot 10^{-16}\ in^4$$

$$I_{xy7} := (2 \cdot x_7 \cdot y_7 + 2 \cdot x_9 \cdot y_9 + x_7 \cdot y_9 + x_9 \cdot y_7) \cdot \frac{A_7}{6} = -1.294 \cdot 10^{-7}\ in^4$$

$$I_{xy8} := (2 \cdot x_7 \cdot y_7 + 2 \cdot x_8 \cdot y_8 + x_7 \cdot y_8 + x_8 \cdot y_7) \cdot \frac{A_8}{6} = -14.909\ in^4$$

$$I_{xy9} := (2 \cdot x_9 \cdot y_9 + 2 \cdot x_{10} \cdot y_{10} + x_9 \cdot y_{10} + x_{10} \cdot y_9) \cdot \frac{A_9}{6} = -4.717 \cdot 10^{-8}\ in^4$$

$$I_{xy10} := (2 \cdot x_{10} \cdot y_{10} + 2 \cdot x_{11} \cdot y_{11} + x_{10} \cdot y_{11} + x_{11} \cdot y_{10}) \cdot \frac{A_{10}}{6} = -1.723\ in^4$$

$$I_{xy11} := (2 \cdot x_{10} \cdot y_{10} + 2 \cdot x_{12} \cdot y_{12} + x_{10} \cdot y_{12} + x_{12} \cdot y_{10}) \cdot \frac{A_{11}}{6} = 2.521\ in^4$$

$$I_{xy} := I_{xy1} + I_{xy2} + I_{xy3} + I_{xy4} + I_{xy5} + I_{xy6} + I_{xy7} + I_{xy8} + I_{xy9} + I_{xy10} + I_{xy11} = (3.68 \cdot 10^{-19})\ ft^4$$

$$I_{max} := \frac{1}{2}\left(I_x + I_y + \sqrt[2]{(I_x - I_y)^2 + (4 \cdot I_{xy}^{\ 2})}\right) = 203.154\ in^4$$

$$I_{min} := \frac{1}{2}\left(I_x + I_y - \sqrt[2]{(I_x - I_y)^2 + (4 \cdot I_{xy}^{\ 2})}\right) = 38.429\ in^4$$

$$\alpha := \frac{1}{2} \cdot \operatorname{atan}\left(\frac{2 \cdot I_{xy}}{I_y - I_x}\right) = 4.633 \cdot 10^{-17}$$

Section Modulus

$$S_x := \frac{I_x}{y} = 30.685\ in^3 \qquad S_y := \frac{I_y}{x} = 38.696\ in^3$$

$$y_{pt} := (d + t_p) - y_{pc} \qquad t_p + \frac{t_f}{2} = 1\ in$$

$$A_s := \left(t_p \cdot \frac{1}{2} \cdot l_p\right) + (b \cdot (y_{pt} - t_p)) \qquad A_c := (t_f \cdot y_{pc}) + (b \cdot y_{pc})$$

$$A_s = A_c \xrightarrow{solve,\ y_{pc}} 0.035714285714285714286 \cdot ft + 2.3809523809523809524 \cdot in$$

$$y_{pc} := 0.035714285714285714286 \cdot ft + 2.3809523809523809524 \cdot in = 2.81\ in$$

$$y_{pt} := (d + t_p) - y_{pc} = 2.94\ in$$

$$Z_{x1} := \frac{l_p}{2} \cdot t_p \cdot \left(y_{pt} - \frac{t_p}{2}\right) = 11.545\ in^3 \qquad Z_{x2} := (b - t_f) \cdot t_f \cdot \left(y_{pt} - \left(t_p + \frac{t_f}{2}\right)\right) = 4.366\ in^3$$

$$Z_{x3} := t_f \cdot (y_{pt} - (t_p + t_f)) \cdot \left(\frac{y_{pt} - (t_p + t_f)}{2}\right) = 0.714\ in^3 \quad Z_{x4} := t_f \cdot (y_{pc}) \cdot \frac{y_{pc}}{2} = 1.973\ in^3$$

$$Z_x := 2 \cdot (Z_{x1} + Z_{x2} + Z_{x3} + Z_{x4}) = 37.197\ in^3$$

$$Z_{y1} := t_p \cdot \frac{l_p}{2} \cdot \left(\frac{l_p}{2} - \frac{l_p}{4}\right) = 13.5\ in^3 \qquad Z_{y2} := t_f \cdot b \cdot \left(\frac{l_p}{2} - \frac{l_p}{4}\right) = 7.5\ in^3$$

$$Z_{y3} := t_f \cdot (b - t_f) \cdot \left(\frac{l_p}{2} - (b + t_f)\right) = 1.125\ in^3 \qquad Z_y := 2 \cdot (Z_{y1} + Z_{y2} + Z_{y3}) = 44.25\ in^3$$

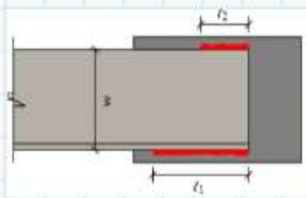
$F_y := 36\ ksi$ $\qquad$ $F_u := 58\ ksi$

$M_y := F_y \cdot Z_x = 111.591\ kip \cdot ft$ $\qquad$ $M_x := F_y \cdot Z_y = 132.75\ kip \cdot ft$

P axial stress $\qquad$ Ag: Gross Area $\qquad$ $A_g := A_t$ $\qquad$ $F_y := 36\ ksi$

$\phi_{ty} := .9$ $\qquad$ $\phi P_{ny} := \phi_{ty} \cdot F_y \cdot A_g = 635.85\ kip$

Longitudinal welds



w= distance in between welds

$l_1 := 11\ ft$ $\quad$ $l_2 := 11\ ft$

x: distance from the centroid

$$l := \frac{l_1 + l_2}{2} \qquad w := 2.5 \cdot in \qquad U := \frac{3 \cdot l^2}{3 \cdot l^2 + w^2} \cdot \left(1 - \frac{x}{l}\right) = 0.96$$

$A_e := U \cdot A_g = 0.131\ ft^2$

$\phi_{trup} := .75$ $\qquad$ $F_u := 58\ ksi$ $\qquad$ $\phi P_{nrupt} := \phi_{trup} \cdot F_u \cdot A_e = 819.636\ kip$

$\phi P_n := min(\phi P_{ny}, \phi P_{nrupt}) = 635.85\ kip$

$\phi_t P_{n.yielding} := \phi P_{ny}$

$\phi_t P_{n.rupture} := \phi P_{nrupt}$

$\phi R_n := min(\phi_t P_{n.yielding}, \phi_t P_{n.rupture}) = 635.85\ kip$

Compression + Bending		***Compression***	***Tension***	
$P_1 := 77.418$ ***kip***	$M_1 := 3.156$ ***kip·ft***	$P_{38} := 3.543$ ***kip***	$P_{25} := 84.126$ ***kip***	$P_{40} := 39.762$ ***kip***
$P_2 := 75.786$ ***kip***	$M_2 := 3.156$ ***kip·ft***	$P_{39} := 43.897$ ***kip***	$P_{26} := 100.731$ ***kip***	$P_{43} := 31.918$ ***kip***
$P_3 := 130.492$ ***kip***	$M_3 := 1.246$ ***kip·ft***	$P_{41} := 1.981$ ***kip***	$P_{27} := 100.731$ ***kip***	$P_{46} := 23.756$ ***kip***
$P_4 := 130.492$ ***kip***	$M_4 := 1.245$ ***kip·ft***	$P_{42} := 35.106$ ***kip***	$P_{28} := 147.212$ ***kip***	$P_{49} := 13.243$ ***kip***
$P_5 := 173.875$ ***kip***	$M_5 := 1.246$ ***kip·ft***	$P_{44} := 1.981$ ***kip***	$P_{29} := 147.212$ ***kip***	$P_{52} := 3.021$ ***kip***
$P_6 := 173.875$ ***kip***	$M_6 := 1.245$ ***kip·ft***	$P_{45} := 27.646$ ***kip***	$P_{30} := 183.416$ ***kip***	$P_{54} := 2.664$ ***kip***
$P_7 := 206.814$ ***kip***	$M_7 := 1.71$ ***kip·ft***	$P_{47} := 3.31$ ***kip***	$P_{31} := 183.416$ ***kip***	$P_{57} := 6.42$ ***kip***
$P_8 := 206.814$ ***kip***	$M_8 := 1.708$ ***kip·ft***	$P_{48} := 17.788$ ***kip***	$P_{32} := 210.001$ ***kip***	$P_{60} := 15.863$ ***kip***
$P_9 := 226.492$ ***kip***	$M_9 := 1.71$ ***kip·ft***	$P_{50} := 3.31$ ***kip***	$P_{33} := 210.001$ ***kip***	$P_{63} := 22.967$ ***kip***
$P_{10} := 226.492$ ***kip***	$M_{10} := 1.708$ ***kip·ft***	$P_{51} := 7.414$ ***kip***	$P_{34} := 226.883$ ***kip***	$P_{66} := 30.226$ ***kip***
$P_{11} := 233.043$ ***kip***	$M_{11} := 1.71$ ***kip·ft***	$P_{53} := 3.268$ ***kip***	$P_{35} := 226.883$ ***kip***	$P_{69} := 38.029$ ***kip***
$P_{12} := 233.043$ ***kip***	$M_{12} := 1.709$ ***kip·ft***	$P_{55} := 0.715$ ***kip***	$P_{36} := 231.357$ ***kip***	
$P_{13} := 230.943$ ***kip***	$M_{13} := 1.71$ ***kip·ft***	$P_{56} := 3.268$ ***kip***	$P_{72} := 231.357$ ***kip***	
$P_{14} := 230.943$ ***kip***	$M_{14} := 1.709$ ***kip·ft***	$P_{58} := 10.872$ ***kip***	$P_{73} := 231.116$ ***kip***	
$P_{15} := 220.089$ ***kip***	$M_{15} := 1.71$ ***kip·ft***	$P_{59} := 2.645$ ***kip***	$P_{74} := 231.116$ ***kip***	
$P_{16} := 220.089$ ***kip***	$M_{16} := 1.245$ ***kip·ft***	$P_{61} := 18.722$ ***kip***	$P_{75} := 218.064$ ***kip***	
$P_{17} := 198.149$ ***kip***	$M_{17} := 1.246$ ***kip·ft***	$P_{62} := 1.98$ ***kip***	$P_{76} := 218.064$ ***kip***	
$P_{18} := 198.149$ ***kip***	$M_{18} := 1.245$ ***kip·ft***	$P_{64} := 25.974$ ***kip***	$P_{77} := 191.566$ ***kip***	
$P_{19} := 166.794$ ***kip***	$M_{19} := 1.246$ ***kip·ft***	$P_{65} := 1.98$ ***kip***	$P_{78} := 191.566$ ***kip***	
$P_{20} := 166.794$ ***kip***	$M_{20} := 1.245$ ***kip·ft***	$P_{67} := 33.39$ ***kip***	$P_{79} := 153.196$ ***kip***	
$P_{21} := 125.616$ ***kip***	$M_{21} := 1.246$ ***kip·ft***	$P_{68} := 1.98$ ***kip***	$P_{80} := 153.196$ ***kip***	
$P_{22} := 125.616$ ***kip***	$M_{22} := 1.245$ ***kip·ft***	$P_{70} := 42.14$ ***kip***	$P_{81} := 104.471$ ***kip***	
$P_{23} := 73.192$ ***kip***	$M_{23} := 3.156$ ***kip·ft***	$P_{71} := 3.542$ ***kip***	$P_{82} := 104.471$ ***kip***	
$P_{24} := 74.824$ ***kip***	$M_{24} := 3.156$ ***kip·ft***		$P_{37} := 87.043$ ***kip***	

$L_1 := 8.85$ ***ft***	$L_{11} := 5.56$ ***ft***	$L_{21} := 5.56$ ***ft***	$L_{31} := 11.13$ ***ft***	$L_{41} := 6.49$ ***ft***	$L_{51} := 8.86$ ***ft***	$L_{61} := 8.77$ ***ft***
$L_2 := 8.85$ ***ft***	$L_{12} := 5.56$ ***ft***	$L_{22} := 5.56$ ***ft***	$L_{32} := 11.13$ ***ft***	$L_{42} := 8.59$ ***ft***	$L_{52} := 8.86$ ***ft***	$L_{62} := 6.73$ ***ft***
$L_3 := 5.56$ ***ft***	$L_{13} := 5.56$ ***ft***	$L_{23} := 8.85$ ***ft***	$L_{33} := 11.13$ ***ft***	$L_{43} := 8.59$ ***ft***	$L_{53} := 6.96$ ***ft***	$L_{63} := 8.68$ ***ft***
$L_4 := 5.56$ ***ft***	$L_{14} := 5.56$ ***ft***	$L_{24} := 8.85$ ***ft***	$L_{34} := 11.13$ ***ft***	$L_{44} := 6.61$ ***ft***	$L_{54} := 8.95$ ***ft***	$L_{64} := 8.68$ ***ft***
$L_5 := 5.56$ ***ft***	$L_{15} := 5.56$ ***ft***	$L_{25} := 13.66$ ***ft***	$L_{35} := 11.13$ ***ft***	$L_{45} := 8.68$ ***ft***	$L_{55} := 8.95$ ***ft***	$L_{65} := 6.61$ ***ft***
$L_6 := 5.56$ ***ft***	$L_{16} := 5.56$ ***ft***	$L_{26} := 11.13$ ***ft***	$L_{36} := 11.13$ ***ft***	$L_{46} := 8.68$ ***ft***	$L_{56} := 6.96$ ***ft***	$L_{66} := 8.59$ ***ft***
$L_7 := 5.56$ ***ft***	$L_{17} := 5.56$ ***ft***	$L_{27} := 11.13$ ***ft***	$L_{37} := 13.66$ ***ft***	$L_{47} := 6.73$ ***ft***	$L_{57} := 8.86$ ***ft***	$L_{67} := 8.59$ ***ft***
$L_8 := 5.56$ ***ft***	$L_{18} := 5.56$ ***ft***	$L_{28} := 11.13$ ***ft***	$L_{38} := 7.14$ ***ft***	$L_{48} := 8.77$ ***ft***	$L_{58} := 8.86$ ***ft***	$L_{68} := 6.49$ ***ft***
$L_9 := 5.56$ ***ft***	$L_{19} := 5.56$ ***ft***	$L_{29} := 11.13$ ***ft***	$L_{39} := 8.51$ ***ft***	$L_{49} := 8.77$ ***ft***	$L_{59} := 6.84$ ***ft***	$L_{69} := 8.51$ ***ft***
$L_{10} := 5.56$ ***ft***	$L_{20} := 5.56$ ***ft***	$L_{30} := 11.13$ ***ft***	$L_{40} := 8.51$ ***ft***	$L_{50} := 6.84$ ***ft***	$L_{60} := 8.77$ ***ft***	$L_{70} := 8.51$ ***ft***
						$L_{71} := 7.15$ ***ft***

Compression + Bending Design Check

(for top chord only = 5" x 5" x 1/2")

$M_{ry} := 0\ kip \cdot ft \quad M_{cx} := F_y \cdot Z_x = 45.492\ kip \cdot ft \quad M_{cy} := F_y \cdot Z_y = 122.551\ kip \cdot ft$

$\phi_c P_{n.4} := 295\ kip$ *(double angle compression value per AISC steel manual under $L_c = 4\ ft$)*

$\phi_c P_{n.6} := 276\ kip$ *(double angle compression value per AISC steel manual under $L_c = 6\ ft$)*

$\phi_c P_{n.8} := 252\ kip$ *(double angle compression value per AISC steel manual under $L_c = 8\ ft$)*

$\phi_c P_{n.10} := 225\ kip$ *(double angle compression value per AISC steel manual under $L_c = 10\ ft$)*

$$\phi_c P_{n.L1} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_1 - 8\ ft) + \phi_c P_{n.8} = 240.525\ kip$$

$$\phi_c P_{n.L2} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_2 - 8\ ft) + \phi_c P_{n.8} = 240.525\ kip$$

$$\phi_c P_{n.L3} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_3 - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L4} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_4 - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L5} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_5 - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L6} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_6 - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L7} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_7 - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L8} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_8 - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L9} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_9 - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L10} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{10} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L11} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{11} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L12} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{12} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L13} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{13} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L14} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{14} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L15} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{15} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L16} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{16} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L17} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{17} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L18} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{18} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L19} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{19} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L20} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{20} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L21} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{21} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L22} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{22} - 4\ ft) + \phi_c P_{n.4} = 280.18\ kip$$

$$\phi_c P_{n.L23} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{23} - 8\ ft) + \phi_c P_{n.8} = 240.525\ kip$$

$$\phi_c P_{n.L24} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{24} - 8\ ft) + \phi_c P_{n.8} = 240.525\ kip$$

$$\phi_c P_{n.L38} := \left(\frac{\phi_c P_{n.8} - \phi_c P_{n.6}}{8\ ft - 6\ ft}\right) \cdot (L_{38} - 6\ ft) + \phi_c P_{n.6} = 262.32\ kip$$

$$\phi_c P_{n.L39} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{39} - 8\ ft) + \phi_c P_{n.8} = 245.115\ kip$$

$$\phi_c P_{n.L42} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{42} - 8\ ft) + \phi_c P_{n.8} = 244.035\ kip$$

$$\phi_c P_{n.L45} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{45} - 8\ ft) + \phi_c P_{n.8} = 242.82\ kip$$

$$\phi_c P_{n.L48} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{48} - 8\ ft) + \phi_c P_{n.8} = 241.605\ kip$$

$$\phi_c P_{n.L51} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{51} - 8\ ft) + \phi_c P_{n.8} = 240.39\ kip$$

$$\phi_c P_{n.L54} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{54} - 8\ ft) + \phi_c P_{n.8} = 239.175\ kip$$

$$\phi_c P_{n.L57} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{57} - 8\ ft) + \phi_c P_{n.8} = 240.39\ kip$$

$$\phi_c P_{n.L58} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{58} - 8\ ft) + \phi_c P_{n.8} = 240.39\ kip$$

$$\phi_c P_{n.L61} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{61} - 8\ ft) + \phi_c P_{n.8} = 241.605\ kip$$

$$\phi_c P_{n.L64} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{64} - 8\ ft) + \phi_c P_{n.8} = 242.82\ kip$$

$$\phi_c P_{n.L67} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{67} - 8\ ft) + \phi_c P_{n.8} = 244.035\ kip$$

$$\phi_c P_{n.L70} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{70} - 8\ ft) + \phi_c P_{n.8} = 245.115\ kip$$

$$\phi_c P_{n.L71} := \left(\frac{\phi_c P_{n.8} - \phi_c P_{n.6}}{8\ ft - 6\ ft}\right) \cdot (L_{71} - 6\ ft) + \phi_c P_{n.6} = 262.2\ kip$$

clear $(\phi_c P_{n.6})$

$$\begin{cases} \text{if } \frac{P_1}{\phi_c P_{n.L1}} \geq 0.2 \\ \quad \frac{P_1}{\phi_c P_{n.L1}} + \frac{8}{9} \cdot \left(\frac{M_1}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \\ \text{else if } \frac{P_1}{\phi_c P_{n.L1}} < 0.2 \\ \quad \frac{P_1}{2\ \phi_c P_{n.L1}} + \left(\frac{M_1}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \end{cases} = 1$$

$$\begin{cases} \text{if } \frac{P_2}{\phi_c P_{n.L2}} \geq 0.2 \\ \quad \frac{P_2}{\phi_c P_{n.L2}} + \frac{8}{9} \cdot \left(\frac{M_2}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \\ \text{else if } \frac{P_2}{\phi_c P_{n.L2}} < 0.2 \\ \quad \frac{P_2}{2\ \phi_c P_{n.L2}} + \left(\frac{M_2}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \end{cases} = 1$$

$$\begin{cases} \text{if } \frac{P_3}{\phi_c P_{n.L3}} \geq 0.2 \\ \quad \frac{P_3}{\phi_c P_{n.L3}} + \frac{8}{9} \cdot \left(\frac{M_3}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \\ \text{else if } \frac{P_3}{\phi_c P_{n.L3}} < 0.2 \\ \quad \frac{P_3}{2\ \phi_c P_{n.L3}} + \left(\frac{M_3}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \end{cases} = 1$$

$$\begin{cases} \text{if } \frac{P_4}{\phi_c P_{n.L4}} \geq 0.2 \\ \quad \frac{P_4}{\phi_c P_{n.L4}} + \frac{8}{9} \cdot \left(\frac{M_4}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \\ \text{else if } \frac{P_4}{\phi_c P_{n.L4}} < 0.2 \\ \quad \frac{P_4}{2\ \phi_c P_{n.L4}} + \left(\frac{M_4}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \end{cases} = 1$$

$$\begin{cases} \text{if } \frac{P_5}{\phi_c P_{n.L5}} \geq 0.2 \\ \quad \frac{P_5}{\phi_c P_{n.L5}} + \frac{8}{9} \cdot \left(\frac{M_5}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \\ \text{else if } \frac{P_5}{\phi_c P_{n.L5}} < 0.2 \\ \quad \frac{P_5}{2\ \phi_c P_{n.L5}} + \left(\frac{M_5}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \end{cases} = 1$$

$$\begin{cases} \text{if } \frac{P_6}{\phi_c P_{n.L6}} \geq 0.2 \\ \quad \frac{P_6}{\phi_c P_{n.L6}} + \frac{8}{9} \cdot \left(\frac{M_6}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \\ \text{else if } \frac{P_6}{\phi_c P_{n.L6}} < 0.2 \\ \quad \frac{P_6}{2\ \phi_c P_{n.L6}} + \left(\frac{M_6}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1 \end{cases} = 1$$

$$\text{if } \frac{P_7}{\phi_c P_{n.L7}} \geq 0.2 \quad \left\| \frac{P_7}{\phi_c P_{n.L7}} + \frac{8}{9} \cdot \left(\frac{M_7}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_7}{\phi_c P_{n.L7}} < 0.2 \quad \left\| \frac{P_7}{2\ \phi_c P_{n.L7}} + \left(\frac{M_7}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_8}{\phi_c P_{n.L8}} \geq 0.2 \quad \left\| \frac{P_8}{\phi_c P_{n.L8}} + \frac{8}{9} \cdot \left(\frac{M_8}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_8}{\phi_c P_{n.L8}} < 0.2 \quad \left\| \frac{P_8}{2\ \phi_c P_{n.L8}} + \left(\frac{M_8}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_9}{\phi_c P_{n.L9}} \geq 0.2 \quad \left\| \frac{P_9}{\phi_c P_{n.L9}} + \frac{8}{9} \cdot \left(\frac{M_9}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_9}{\phi_c P_{n.L9}} < 0.2 \quad \left\| \frac{P_9}{2\ \phi_c P_{n.L9}} + \left(\frac{M_9}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{10}}{\phi_c P_{n.L10}} \geq 0.2 \quad \left\| \frac{P_{10}}{\phi_c P_{n.L10}} + \frac{8}{9} \cdot \left(\frac{M_{10}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{10}}{\phi_c P_{n.L10}} < 0.2 \quad \left\| \frac{P_{10}}{2\ \phi_c P_{n.L10}} + \left(\frac{M_{10}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{11}}{\phi_c P_{n.L1}} \geq 0.2 \quad \left\| \frac{P_{11}}{\phi_c P_{n.L11}} + \frac{8}{9} \cdot \left(\frac{M_{11}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{11}}{\phi_c P_{n.L11}} < 0.2 \quad \left\| \frac{P_{11}}{2\ \phi_c P_{n.L11}} + \left(\frac{M_{11}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{12}}{\phi_c P_{n.L12}} \geq 0.2 \quad \left\| \frac{P_{12}}{\phi_c P_{n.L12}} + \frac{8}{9} \cdot \left(\frac{M_{12}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{12}}{\phi_c P_{n.L12}} < 0.2 \quad \left\| \frac{P_{12}}{2\ \phi_c P_{n.L12}} + \left(\frac{M_{12}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{13}}{\phi_c P_{n.L13}} \geq 0.2 \quad \left\| \frac{P_{13}}{\phi_c P_{n.L13}} + \frac{8}{9} \cdot \left(\frac{M_{13}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{13}}{\phi_c P_{n.L13}} < 0.2 \quad \left\| \frac{P_{13}}{2\ \phi_c P_{n.L13}} + \left(\frac{M_{13}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{14}}{\phi_c P_{n.L14}} \geq 0.2 \quad \left\| \frac{P_{14}}{\phi_c P_{n.L14}} + \frac{8}{9} \cdot \left(\frac{M_{14}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{14}}{\phi_c P_{n.L14}} < 0.2 \quad \left\| \frac{P_{14}}{2\ \phi_c P_{n.L14}} + \left(\frac{M_{14}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } P_{15} \quad > 0.2 \quad = 1$$

$$\text{if } P_{16} \quad > 0.2 \quad = 1$$

$$\phi_c P_{n.L15}$$

$$\frac{P_{15}}{\phi_c P_{n.L15}} + \frac{8}{9} \cdot \left(\frac{M_{15}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1$$

$$\text{else if } \frac{P_{15}}{\phi_c P_{n.L15}} < 0.2$$

$$\frac{P_{15}}{2\ \phi_c P_{n.L15}} + \left(\frac{M_{15}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1$$

$$\phi_c P_{n.L16}$$

$$\frac{P_{16}}{\phi_c P_{n.L16}} + \frac{8}{9} \cdot \left(\frac{M_{16}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1$$

$$\text{else if } \frac{P_{16}}{\phi_c P_{n.L16}} < 0.2$$

$$\frac{P_{16}}{2\ \phi_c P_{n.L16}} + \left(\frac{M_{16}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1$$

$$\begin{aligned} &\text{if } \frac{P_{17}}{\phi_c P_{n.L17}} \ge 0.2 \\ &\quad \frac{P_{17}}{\phi_c P_{n.L17}} + \frac{8}{9} \cdot \left(\frac{M_{17}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \\ &\text{else if } \frac{P_{17}}{\phi_c P_{n.L17}} < 0.2 \\ &\quad \frac{P_{17}}{2\ \phi_c P_{n.L17}} + \left(\frac{M_{17}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \end{aligned} = 1$$

$$\begin{aligned} &\text{if } \frac{P_{18}}{\phi_c P_{n.L18}} \ge 0.2 \\ &\quad \frac{P_{18}}{\phi_c P_{n.L18}} + \frac{8}{9} \cdot \left(\frac{M_{18}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \\ &\text{else if } \frac{P_{18}}{\phi_c P_{n.L18}} < 0.2 \\ &\quad \frac{P_{18}}{2\ \phi_c P_{n.L18}} + \left(\frac{M_{18}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \end{aligned} = 1$$

$$\begin{aligned} &\text{if } \frac{P_{19}}{\phi_c P_{n.L19}} \ge 0.2 \\ &\quad \frac{P_{19}}{\phi_c P_{n.L19}} + \frac{8}{9} \cdot \left(\frac{M_{19}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \\ &\text{else if } \frac{P_{19}}{\phi_c P_{n.L19}} < 0.2 \\ &\quad \frac{P_{19}}{2\ \phi_c P_{n.L19}} + \left(\frac{M_{19}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \end{aligned} = 1$$

$$\begin{aligned} &\text{if } \frac{P_{20}}{\phi_c P_{n.L20}} \ge 0.2 \\ &\quad \frac{P_{20}}{\phi_c P_{n.L20}} + \frac{8}{9} \cdot \left(\frac{M_{20}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \\ &\text{else if } \frac{P_{20}}{\phi_c P_{n.L20}} < 0.2 \\ &\quad \frac{P_{20}}{2\ \phi_c P_{n.L20}} + \left(\frac{M_{20}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \end{aligned} = 1$$

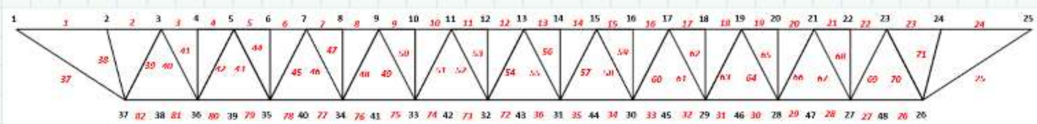
$$\begin{aligned} &\text{if } \frac{P_{21}}{\phi_c P_{n.L21}} \ge 0.2 \\ &\quad \frac{P_{21}}{\phi_c P_{n.L21}} + \frac{8}{9} \cdot \left(\frac{M_{21}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \\ &\text{else if } \frac{P_{21}}{\phi_c P_{n.L21}} < 0.2 \\ &\quad \frac{P_{21}}{2\ \phi_c P_{n.L21}} + \left(\frac{M_{21}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \end{aligned} = 1$$

$$\begin{aligned} &\text{if } \frac{P_{22}}{\phi_c P_{n.L22}} \ge 0.2 \\ &\quad \frac{P_{22}}{\phi_c P_{n.L22}} + \frac{8}{9} \cdot \left(\frac{M_{22}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \\ &\text{else if } \frac{P_{22}}{\phi_c P_{n.L22}} < 0.2 \\ &\quad \frac{P_{22}}{2\ \phi_c P_{n.L22}} + \left(\frac{M_{22}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \end{aligned} = 1$$

$$\begin{aligned} &\text{if } \frac{P_{23}}{\phi_c P_{n.L23}} \ge 0.2 \\ &\quad \frac{P_{23}}{\phi_c P_{n.L23}} + \frac{8}{9} \cdot \left(\frac{M_{23}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \\ &\text{else if } \frac{P_{23}}{\phi_c P_{n.L23}} < 0.2 \\ &\quad \frac{P_{23}}{2\ \phi_c P_{n.L23}} + \left(\frac{M_{23}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \end{aligned} = 1$$

$$\begin{aligned} &\text{if } \frac{P_{24}}{\phi_c P_{n.L24}} \ge 0.2 \\ &\quad \frac{P_{24}}{\phi_c P_{n.L24}} + \frac{8}{9} \cdot \left(\frac{M_{24}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \\ &\text{else if } \frac{P_{24}}{\phi_c P_{n.L24}} < 0.2 \\ &\quad \frac{P_{24}}{2\ \phi_c P_{n.L24}} + \left(\frac{M_{24}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \le 1 \end{aligned} = 1$$

Appendix C – Truss 3 Calculations



$F_y := 36\ ksi$ (yield stress)
$F_u := 58\ ksi$ (ultimate stress)

Structural Analysis (from SkyCiv)

$R_L := 51.636\ kip$ $R_R := 51.636\ kip$

Compression + Bending		***Compression***	***Tension***	
$P_1 := 95.173\ kip$	$M_1 := 3.974\ kip \cdot ft$	$P_{38} := 5.371\ kip$	$P_{25} := 107.008\ kip$	$P_{37} := 107.008\ kip$
$P_2 := 92.708\ kip$	$M_2 := 2.301\ kip \cdot ft$	$P_{39} := 53.759\ kip$	$P_{26} := 127.836\ kip$	$P_{40} := 47.193\ kip$
$P_3 := 158.72\ kip$	$M_3 := 2.302\ kip \cdot ft$	$P_{41} := 3.31\ kip$	$P_{27} := 127.836\ kip$	$P_{43} := 35.785\ kip$
$P_4 := 158.72\ kip$	$M_4 := 2.301\ kip \cdot ft$	$P_{42} := 40.802\ kip$	$P_{28} := 185.106\ kip$	$P_{46} := 24.962\ kip$
$P_5 := 208.294\ kip$	$M_5 := 2.302\ kip \cdot ft$	$P_{44} := 3.31\ kip$	$P_{29} := 185.106\ kip$	$P_{49} := 14.426\ kip$
$P_6 := 208.294\ kip$	$M_6 := 2.301\ kip \cdot ft$	$P_{45} := 29.746\ kip$	$P_{30} := 227.324\ kip$	$P_{52} := 4.171\ kip$
$P_7 := 243.343\ kip$	$M_7 := 2.302\ kip \cdot ft$	$P_{47} := 3.31\ kip$	$P_{31} := 227.324\ kip$	$P_{54} := 1.514\ kip$
$P_8 := 243.343\ kip$	$M_8 := 2.301\ kip \cdot ft$	$P_{48} := 18.99\ kip$	$P_{32} := 255.356\ kip$	$P_{55} := 1.514\ kip$
$P_9 := 264.533\ kip$	$M_9 := 2.302\ kip \cdot ft$	$P_{50} := 3.31\ kip$	$P_{33} := 255.356\ kip$	$P_{57} := 4.17\ kip$
$P_{10} := 264.533\ kip$	$M_{10} := 2.301\ kip \cdot ft$	$P_{51} := 8.592\ kip$	$P_{34} := 269.895\ kip$	$P_{60} := 14.423\ kip$
$P_{11} := 272.545\ kip$	$M_{11} := 2.302\ kip \cdot ft$	$P_{53} := 3.261\ kip$	$P_{35} := 269.895\ kip$	$P_{63} := 24.959\ kip$
$P_{12} := 272.545\ kip$	$M_{12} := 2.301\ kip \cdot ft$	$P_{56} := 3.26\ kip$	$P_{36} := 271.571\ kip$	$P_{66} := 35.781\ kip$
$P_{13} := 272.545\ kip$	$M_{13} := 2.302\ kip \cdot ft$	$P_{58} := 8.593\ kip$	$P_{72} := 271.571\ kip$	$P_{69} := 47.189\ kip$
$P_{14} := 272.545\ kip$	$M_{14} := 2.301\ kip \cdot ft$	$P_{59} := 3.309\ kip$	$P_{73} := 269.894\ kip$	
$P_{15} := 264.533\ kip$	$M_{15} := 2.302\ kip \cdot ft$	$P_{61} := 18.992\ kip$	$P_{74} := 269.894\ kip$	
$P_{16} := 264.533\ kip$	$M_{16} := 2.301\ kip \cdot ft$	$P_{62} := 3.309\ kip$	$P_{75} := 255.354\ kip$	
$P_{17} := 243.323\ kip$	$M_{17} := 2.302\ kip \cdot ft$	$P_{64} := 29.748\ kip$	$P_{76} := 255.354\ kip$	
$P_{18} := 243.323\ kip$	$M_{18} := 2.301\ kip \cdot ft$	$P_{65} := 3.309\ kip$	$P_{77} := 227.32\ kip$	
$P_{19} := 208.293\ kip$	$M_{19} := 2.302\ kip \cdot ft$	$P_{67} := 40.805\ kip$	$P_{78} := 227.32\ kip$	
$P_{20} := 208.293\ kip$	$M_{20} := 2.301\ kip \cdot ft$	$P_{68} := 3.31\ kip$	$P_{79} := 185.102\ kip$	
$P_{21} := 158.72\ kip$	$M_{21} := 2.302\ kip \cdot ft$	$P_{70} := 53.763\ kip$	$P_{80} := 185.102\ kip$	
$P_{22} := 158.72\ kip$	$M_{22} := 2.301\ kip \cdot ft$	$P_{71} := 5.371\ kip$	$P_{81} := 127.83\ kip$	
$P_{23} := 92.708\ kip$	$M_{23} := 5.832\ kip \cdot ft$		$P_{82} := 127.83\ kip$	
$P_{24} := 95.172\ kip$	$M_{24} := 3.974\ kip \cdot ft$			

$L_1 := 8.85\ ft$	$L_{11} := 5.56\ ft$	$L_{21} := 5.56\ ft$	$L_{31} := 11.13\ ft$	$L_{41} := 6.49\ ft$	$L_{51} := 8.86\ ft$	$L_{61} := 8.77\ ft$
$L_2 := 8.85\ ft$	$L_{12} := 5.56\ ft$	$L_{22} := 5.56\ ft$	$L_{32} := 11.13\ ft$	$L_{42} := 8.59\ ft$	$L_{52} := 8.86\ ft$	$L_{62} := 6.73\ ft$
$L_3 := 5.56\ ft$	$L_{13} := 5.56\ ft$	$L_{23} := 8.85\ ft$	$L_{33} := 11.13\ ft$	$L_{43} := 8.59\ ft$	$L_{53} := 6.96\ ft$	$L_{63} := 8.68\ ft$
$L_4 := 5.56\ ft$	$L_{14} := 5.56\ ft$	$L_{24} := 8.85\ ft$	$L_{34} := 11.13\ ft$	$L_{44} := 6.61\ ft$	$L_{54} := 8.95\ ft$	$L_{64} := 8.68\ ft$
$L_5 := 5.56\ ft$	$L_{15} := 5.56\ ft$	$L_{25} := 13.66\ ft$	$L_{35} := 11.13\ ft$	$L_{45} := 8.68\ ft$	$L_{55} := 8.95\ ft$	$L_{65} := 6.61\ ft$
$L_6 := 5.56\ ft$	$L_{16} := 5.56\ ft$	$L_{26} := 11.13\ ft$	$L_{36} := 11.13\ ft$	$L_{46} := 8.68\ ft$	$L_{56} := 6.96\ ft$	$L_{66} := 8.59\ ft$
$L_7 := 5.56\ ft$	$L_{17} := 5.56\ ft$	$L_{27} := 11.13\ ft$	$L_{37} := 13.66\ ft$	$L_{47} := 6.73\ ft$	$L_{57} := 8.86\ ft$	$L_{67} := 8.59\ ft$
$L_8 := 5.56\ ft$	$L_{18} := 5.56\ ft$	$L_{28} := 11.13\ ft$	$L_{38} := 7.14\ ft$	$L_{48} := 8.77\ ft$	$L_{58} := 8.86\ ft$	$L_{68} := 6.49\ ft$
$L_9 := 5.56\ ft$	$L_{19} := 5.56\ ft$	$L_{29} := 11.13\ ft$	$L_{39} := 8.51\ ft$	$L_{49} := 8.77\ ft$	$L_{59} := 6.84\ ft$	$L_{69} := 8.51\ ft$
$L_{10} := 5.56\ ft$	$L_{20} := 5.56\ ft$	$L_{30} := 11.13\ ft$	$L_{40} := 8.51\ ft$	$L_{50} := 6.84\ ft$	$L_{60} := 8.77\ ft$	$L_{70} := 8.51\ ft$
						$L_{71} := 7.15\ ft$

Existing Double Angle Members - 6" x 6" x 7/8"

$\phi_t P_{n.yielding} := 632\ kip$ *(double angle tension value per AISC steel manual under yielding)*

$\phi_t P_{n.rupture} := 635\ kip$ *(double angle tension value per AISC steel manual under rupture)*

$\phi R_n := min\left(\phi_t P_{n.yielding}, \phi_t P_{n.rupture}\right) = 632\ kip$

$\phi_c P_{n.4} := 609\ kip$ *(double angle compression value per AISC steel manual under $L_c = 4\ ft$)*

$\phi_c P_{n.6} := 581\ kip$ *(double angle compression value per AISC steel manual under $L_c = 6\ ft$)*

$\phi_c P_{n.8} := 545\ kip$ *(double angle compression value per AISC steel manual under $L_c = 8\ ft$)*

$\phi_c P_{n.10} := 501\ kip$ *(double angle compression value per AISC steel manual under $L_c = 10\ ft$)*

$$\phi_c P_{n.L1} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot \left(L_1 - 8\ ft\right) + \phi_c P_{n.8} = 526.3\ kip$$

$$\phi_c P_{n.L2} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot \left(L_2 - 8\ ft\right) + \phi_c P_{n.8} = 526.3\ kip$$

$$\phi_c P_{n.L3} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_3 - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L4} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_4 - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L5} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_5 - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L6} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_6 - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L7} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_7 - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L8} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_8 - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L9} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_9 - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L10} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_{10} - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L11} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_{11} - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L12} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_{12} - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L13} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_{13} - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L14} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_{14} - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L15} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_{15} - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L16} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot \left(L_{16} - 4\ ft\right) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L17} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{17} - 4\ ft) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L18} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{18} - 4\ ft) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L19} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{19} - 4\ ft) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L20} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{20} - 4\ ft) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L21} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{21} - 4\ ft) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L22} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.4}}{6\ ft - 4\ ft}\right) \cdot (L_{22} - 4\ ft) + \phi_c P_{n.4} = 587.16\ kip$$

$$\phi_c P_{n.L23} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{23} - 8\ ft) + \phi_c P_{n.8} = 526.3\ kip$$

$$\phi_c P_{n.L24} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{24} - 8\ ft) + \phi_c P_{n.8} = 526.3\ kip$$

$$\phi_c P_{n.L38} := \left(\frac{\phi_c P_{n.8} - \phi_c P_{n.6}}{8\ ft - 6\ ft}\right) \cdot (L_{38} - 6\ ft) + \phi_c P_{n.6} = 560.48\ kip$$

$$\phi_c P_{n.L39} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{39} - 8\ ft) + \phi_c P_{n.8} = 533.78\ kip$$

$$\phi_c P_{n.L42} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{42} - 8\ ft) + \phi_c P_{n.8} = 532.02\ kip$$

$$\phi_c P_{n.L45} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{45} - 8\ ft) + \phi_c P_{n.8} = 530.04\ kip$$

$$\phi_c P_{n.L48} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{48} - 8\ ft) + \phi_c P_{n.8} = 528.06\ kip$$

$$\phi_c P_{n.L51} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{51} - 8\ ft) + \phi_c P_{n.8} = 526.08\ kip$$

$$\phi_c P_{n.L58} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{58} - 8\ ft) + \phi_c P_{n.8} = 526.08\ kip$$

$$\phi_c P_{n.L61} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{61} - 8\ ft) + \phi_c P_{n.8} = 528.06\ kip$$

$$\phi_c P_{n.L64} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{64} - 8\ ft) + \phi_c P_{n.8} = 530.04\ kip$$

$$\phi_c P_{n.L67} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{67} - 8\ ft) + \phi_c P_{n.8} = 532.02\ kip$$

$$\phi_c P_{n.L70} := \left(\frac{\phi_c P_{n.10} - \phi_c P_{n.8}}{10\ ft - 8\ ft}\right) \cdot (L_{70} - 8\ ft) + \phi_c P_{n.8} = 533.78\ kip$$

$$\phi_c P_{n.L71} := \left(\frac{\phi_c P_{n.8} - \phi_c P_{n.6}}{8\ ft - 6\ ft}\right) \cdot (L_{71} - 6\ ft) + \phi_c P_{n.6} = 560.3\ kip$$

clear $(\phi_c P_{n.6})$

Existing Double Angle Members - 3" x 3" x 1/4"

$\phi_t P_{n.yielding1} := 93.3\ \textbf{kip}$ *(double angle tension value per AISC steel manual under yielding)*

$\phi_t P_{n.rupture1} := 94\ \textbf{kip}$ *(double angle tension value per AISC steel manual under rupture)*

$\phi R_{n1} := min\left(\phi_t P_{n.yielding1}, \phi_t P_{n.rupture1}\right) = 93.3\ \textbf{kip}$

$\phi_c P_{n.6} := 67.9\ \textbf{kip}$ *(double angle compression value per AISC steel manual under $L_c = 6\ ft$)*

$\phi_c P_{n.7} := 60.5\ \textbf{kip}$ *(double angle compression value per AISC steel manual under $L_c = 7\ ft$)*

$$\phi_c P_{n.L41} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{41} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 64.274\ \textbf{kip}$$

$$\phi_c P_{n.L44} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{44} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 63.386\ \textbf{kip}$$

$$\phi_c P_{n.L47} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{47} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 62.498\ \textbf{kip}$$

$$\phi_c P_{n.L50} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{50} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 61.684\ \textbf{kip}$$

$$\phi_c P_{n.L53} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{53} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 60.796\ \textbf{kip}$$

$$\phi_c P_{n.L56} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{56} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 60.796\ \textbf{kip}$$

$$\phi_c P_{n.L59} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{59} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 61.684\ \textbf{kip}$$

$$\phi_c P_{n.L62} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{62} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 62.498\ \textbf{kip}$$

$$\phi_c P_{n.L65} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{65} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 63.386\ \textbf{kip}$$

$$\phi_c P_{n.L68} := \left(\frac{\phi_c P_{n.7} - \phi_c P_{n.6}}{7\ \textbf{ft} - 6\ \textbf{ft}}\right) \cdot \left(L_{68} - 6\ \textbf{ft}\right) + \phi_c P_{n.6} = 64.274\ \textbf{kip}$$

Tension Design Check

$\phi R_n \geq P_{25} = 1$ $\phi R_n \geq P_{37} = 1$
$\phi R_n \geq P_{26} = 1$ $\phi R_n \geq P_{40} = 1$
$\phi R_n \geq P_{27} = 1$ $\phi R_n \geq P_{43} = 1$
$\phi R_n \geq P_{28} = 1$ $\phi R_n \geq P_{46} = 1$
$\phi R_n \geq P_{29} = 1$ $\phi R_n \geq P_{49} = 1$
$\phi R_n \geq P_{30} = 1$ $\phi R_n \geq P_{52} = 1$
$\phi R_n \geq P_{31} = 1$ $\phi R_n \geq P_{54} = 1$
$\phi R_n \geq P_{32} = 1$ $\phi R_n \geq P_{55} = 1$
$\phi R_n \geq P_{33} = 1$ $\phi R_n \geq P_{57} = 1$
$\phi R_n \geq P_{34} = 1$ $\phi R_n \geq P_{60} = 1$
$\phi R_n \geq P_{35} = 1$ $\phi R_n \geq P_{63} = 1$
$\phi R_n \geq P_{36} = 1$ $\phi R_n \geq P_{66} = 1$
$\phi R_n \geq P_{72} = 1$ $\phi R_n \geq P_{69} = 1$
$\phi R_n \geq P_{73} = 1$
$\phi R_n \geq P_{74} = 1$
$\phi R_n \geq P_{75} = 1$
$\phi R_n \geq P_{76} = 1$
$\phi R_n \geq P_{77} = 1$
$\phi R_n \geq P_{78} = 1$
$\phi R_n \geq P_{79} = 1$
$\phi R_n \geq P_{80} = 1$
$\phi R_n \geq P_{81} = 1$
$\phi R_n \geq P_{82} = 1$

Compression Design Check

$\phi_c P_{n.L38} \geq P_{38} = 1$
$\phi_c P_{n.L39} \geq P_{39} = 1$
$\phi_c P_{n.L41} \geq P_{41} = 1$
$\phi_c P_{n.L42} \geq P_{42} = 1$
$\phi_c P_{n.L44} \geq P_{44} = 1$
$\phi_c P_{n.L45} \geq P_{45} = 1$
$\phi_c P_{n.L47} \geq P_{47} = 1$
$\phi_c P_{n.L48} \geq P_{48} = 1$
$\phi_c P_{n.L50} \geq P_{50} = 1$
$\phi_c P_{n.L51} \geq P_{51} = 1$
$\phi_c P_{n.L53} \geq P_{53} = 1$
$\phi_c P_{n.L56} \geq P_{56} = 1$
$\phi_c P_{n.L58} \geq P_{58} = 1$
$\phi_c P_{n.L59} \geq P_{59} = 1$
$\phi_c P_{n.L61} \geq P_{61} = 1$
$\phi_c P_{n.L62} \geq P_{62} = 1$
$\phi_c P_{n.L64} \geq P_{64} = 1$
$\phi_c P_{n.L65} \geq P_{65} = 1$
$\phi_c P_{n.L67} \geq P_{67} = 1$
$\phi_c P_{n.L68} \geq P_{68} = 1$
$\phi_c P_{n.L70} \geq P_{70} = 1$
$\phi_c P_{n.L71} \geq P_{71} = 1$

Compression + Bending Design Check

$Z_x := 27.4\ in^3$ $Z_y := 35.3\ in^3$ (for top chord only = 6" x 6" x 7/8")

$M_{ry} := 0\ kip \cdot ft$ $M_{cx} := F_y \cdot Z_x = 82.2\ kip \cdot ft$ $M_{cy} := F_y \cdot Z_y = 105.9\ kip \cdot ft$

$$\begin{array}{l} \text{if } \dfrac{P_1}{\phi_c P_{n.L1}} \geq 0.2 \\ \quad \left\| \dfrac{P_1}{\phi_c P_{n.L1}} + \dfrac{8}{9} \cdot \left(\dfrac{M_1}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_1}{\phi_c P_{n.L1}} < 0.2 \\ \quad \left\| \dfrac{P_1}{2\ \phi_c P_{n.L1}} + \left(\dfrac{M_1}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array} = 1$$

$$\begin{array}{l} \text{if } \dfrac{P_2}{\phi_c P_{n.L2}} \geq 0.2 \\ \quad \left\| \dfrac{P_2}{\phi_c P_{n.L2}} + \dfrac{8}{9} \cdot \left(\dfrac{M_2}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_2}{\phi_c P_{n.L2}} < 0.2 \\ \quad \left\| \dfrac{P_2}{2\ \phi_c P_{n.L2}} + \left(\dfrac{M_2}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array} = 1$$

$$\left|\begin{array}{l} \text{if } \dfrac{P_3}{\phi_c P_{n.L3}} \geq 0.2 \\ \quad \left\| \dfrac{P_3}{\phi_c P_{n.L3}} + \dfrac{8}{9} \cdot \left(\dfrac{M_3}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_3}{\phi_c P_{n.L3}} < 0.2 \\ \quad \left\| \dfrac{P_3}{2\ \phi_c P_{n.L3}} + \left(\dfrac{M_3}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array}\right. = 1$$

$$\left|\begin{array}{l} \text{if } \dfrac{P_4}{\phi_c P_{n.L4}} \geq 0.2 \\ \quad \left\| \dfrac{P_4}{\phi_c P_{n.L4}} + \dfrac{8}{9} \cdot \left(\dfrac{M_4}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_4}{\phi_c P_{n.L4}} < 0.2 \\ \quad \left\| \dfrac{P_4}{2\ \phi_c P_{n.L4}} + \left(\dfrac{M_4}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array}\right. = 1$$

$$\left|\begin{array}{l} \text{if } \dfrac{P_5}{\phi_c P_{n.L5}} \geq 0.2 \\ \quad \left\| \dfrac{P_5}{\phi_c P_{n.L5}} + \dfrac{8}{9} \cdot \left(\dfrac{M_5}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_5}{\phi_c P_{n.L5}} < 0.2 \\ \quad \left\| \dfrac{P_5}{2\ \phi_c P_{n.L5}} + \left(\dfrac{M_5}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array}\right. = 1$$

$$\left|\begin{array}{l} \text{if } \dfrac{P_6}{\phi_c P_{n.L6}} \geq 0.2 \\ \quad \left\| \dfrac{P_6}{\phi_c P_{n.L6}} + \dfrac{8}{9} \cdot \left(\dfrac{M_6}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_6}{\phi_c P_{n.L6}} < 0.2 \\ \quad \left\| \dfrac{P_6}{2\ \phi_c P_{n.L6}} + \left(\dfrac{M_6}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array}\right. = 1$$

$$\left|\begin{array}{l} \text{if } \dfrac{P_7}{\phi_c P_{n.L7}} \geq 0.2 \\ \quad \left\| \dfrac{P_7}{\phi_c P_{n.L7}} + \dfrac{8}{9} \cdot \left(\dfrac{M_7}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_7}{\phi_c P_{n.L7}} < 0.2 \\ \quad \left\| \dfrac{P_7}{2\ \phi_c P_{n.L7}} + \left(\dfrac{M_7}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array}\right. = 1$$

$$\left|\begin{array}{l} \text{if } \dfrac{P_8}{\phi_c P_{n.L8}} \geq 0.2 \\ \quad \left\| \dfrac{P_8}{\phi_c P_{n.L8}} + \dfrac{8}{9} \cdot \left(\dfrac{M_8}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_8}{\phi_c P_{n.L8}} < 0.2 \\ \quad \left\| \dfrac{P_8}{2\ \phi_c P_{n.L8}} + \left(\dfrac{M_8}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array}\right. = 1$$

$$\left|\begin{array}{l} \text{if } \dfrac{P_9}{\phi_c P_{n.L9}} \geq 0.2 \\ \quad \left\| \dfrac{P_9}{\phi_c P_{n.L9}} + \dfrac{8}{9} \cdot \left(\dfrac{M_9}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_9}{\phi_c P_{n.L9}} < 0.2 \\ \quad \left\| \dfrac{P_9}{2\ \phi_c P_{n.L9}} + \left(\dfrac{M_9}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array}\right. = 1$$

$$\left|\begin{array}{l} \text{if } \dfrac{P_{10}}{\phi_c P_{n.L10}} \geq 0.2 \\ \quad \left\| \dfrac{P_{10}}{\phi_c P_{n.L10}} + \dfrac{8}{9} \cdot \left(\dfrac{M_{10}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \\ \text{else if } \dfrac{P_{10}}{\phi_c P_{n.L10}} < 0.2 \\ \quad \left\| \dfrac{P_{10}}{2\ \phi_c P_{n.L10}} + \left(\dfrac{M_{10}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \end{array}\right. = 1$$

$$\text{if } \frac{P_{11}}{\phi_c P_{n.L11}} \geq 0.2 \quad \left\| \frac{P_{11}}{\phi_c P_{n.L11}} + \frac{8}{9} \cdot \left(\frac{M_{11}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{11}}{\phi_c P_{n.L11}} < 0.2 \quad \left\| \frac{P_{11}}{2\ \phi_c P_{n.L11}} + \left(\frac{M_{11}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{12}}{\phi_c P_{n.L12}} \geq 0.2 \quad \left\| \frac{P_{12}}{\phi_c P_{n.L12}} + \frac{8}{9} \cdot \left(\frac{M_{12}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{12}}{\phi_c P_{n.L12}} < 0.2 \quad \left\| \frac{P_{12}}{2\ \phi_c P_{n.L12}} + \left(\frac{M_{12}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{13}}{\phi_c P_{n.L13}} \geq 0.2 \quad \left\| \frac{P_{13}}{\phi_c P_{n.L13}} + \frac{8}{9} \cdot \left(\frac{M_{13}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{13}}{\phi_c P_{n.L13}} < 0.2 \quad \left\| \frac{P_{13}}{2\ \phi_c P_{n.L13}} + \left(\frac{M_{13}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{14}}{\phi_c P_{n.L14}} \geq 0.2 \quad \left\| \frac{P_{14}}{\phi_c P_{n.L14}} + \frac{8}{9} \cdot \left(\frac{M_{14}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{14}}{\phi_c P_{n.L14}} < 0.2 \quad \left\| \frac{P_{14}}{2\ \phi_c P_{n.L14}} + \left(\frac{M_{14}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{15}}{\phi_c P_{n.L15}} \geq 0.2 \quad \left\| \frac{P_{15}}{\phi_c P_{n.L15}} + \frac{8}{9} \cdot \left(\frac{M_{15}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{15}}{\phi_c P_{n.L15}} < 0.2 \quad \left\| \frac{P_{15}}{2\ \phi_c P_{n.L15}} + \left(\frac{M_{15}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{16}}{\phi_c P_{n.L16}} \geq 0.2 \quad \left\| \frac{P_{16}}{\phi_c P_{n.L16}} + \frac{8}{9} \cdot \left(\frac{M_{16}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{16}}{\phi_c P_{n.L16}} < 0.2 \quad \left\| \frac{P_{16}}{2\ \phi_c P_{n.L16}} + \left(\frac{M_{16}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{17}}{\phi_c P_{n.L17}} \geq 0.2 \quad \left\| \frac{P_{17}}{\phi_c P_{n.L17}} + \frac{8}{9} \cdot \left(\frac{M_{17}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{17}}{\phi_c P_{n.L17}} < 0.2 \quad \left\| \frac{P_{17}}{2\ \phi_c P_{n.L17}} + \left(\frac{M_{17}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\text{if } \frac{P_{18}}{\phi_c P_{n.L18}} \geq 0.2 \quad \left\| \frac{P_{18}}{\phi_c P_{n.L18}} + \frac{8}{9} \cdot \left(\frac{M_{18}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad \text{else if } \frac{P_{18}}{\phi_c P_{n.L18}} < 0.2 \quad \left\| \frac{P_{18}}{2\ \phi_c P_{n.L18}} + \left(\frac{M_{18}}{M_{cx}} + \frac{M_{ry}}{M_{cy}} \right) \leq 1 \right. \quad = 1$$

$$\left|\begin{array}{l}\text{if } \dfrac{P_{19}}{\phi_c P_{n.L19}} \geq 0.2 \\ \left\| \dfrac{P_{19}}{\phi_c P_{n.L19}} + \dfrac{8}{9} \cdot \left(\dfrac{M_{19}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \\ \text{else if } \dfrac{P_{19}}{\phi_c P_{n.L19}} < 0.2 \\ \left\| \dfrac{P_{19}}{2\ \phi_c P_{n.L19}} + \left(\dfrac{M_{19}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \end{array}\right| = 1$$

$$\left|\begin{array}{l}\text{if } \dfrac{P_{20}}{\phi_c P_{n.L20}} \geq 0.2 \\ \left\| \dfrac{P_{20}}{\phi_c P_{n.L20}} + \dfrac{8}{9} \cdot \left(\dfrac{M_{20}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \\ \text{else if } \dfrac{P_{20}}{\phi_c P_{n.L20}} < 0.2 \\ \left\| \dfrac{P_{20}}{2\ \phi_c P_{n.L20}} + \left(\dfrac{M_{20}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \end{array}\right| = 1$$

$$\left|\begin{array}{l}\text{if } \dfrac{P_{21}}{\phi_c P_{n.L21}} \geq 0.2 \\ \left\| \dfrac{P_{21}}{\phi_c P_{n.L21}} + \dfrac{8}{9} \cdot \left(\dfrac{M_{21}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \\ \text{else if } \dfrac{P_{21}}{\phi_c P_{n.L21}} < 0.2 \\ \left\| \dfrac{P_{21}}{2\ \phi_c P_{n.L21}} + \left(\dfrac{M_{21}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \end{array}\right| = 1$$

$$\left|\begin{array}{l}\text{if } \dfrac{P_{22}}{\phi_c P_{n.L22}} \geq 0.2 \\ \left\| \dfrac{P_{22}}{\phi_c P_{n.L22}} + \dfrac{8}{9} \cdot \left(\dfrac{M_{22}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \\ \text{else if } \dfrac{P_{22}}{\phi_c P_{n.L22}} < 0.2 \\ \left\| \dfrac{P_{22}}{2\ \phi_c P_{n.L22}} + \left(\dfrac{M_{22}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \end{array}\right| = 1$$

$$\left|\begin{array}{l}\text{if } \dfrac{P_{23}}{\phi_c P_{n.L23}} \geq 0.2 \\ \left\| \dfrac{P_{23}}{\phi_c P_{n.L23}} + \dfrac{8}{9} \cdot \left(\dfrac{M_{23}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \\ \text{else if } \dfrac{P_{23}}{\phi_c P_{n.L23}} < 0.2 \\ \left\| \dfrac{P_{23}}{2\ \phi_c P_{n.L23}} + \left(\dfrac{M_{23}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \end{array}\right| = 1$$

$$\left|\begin{array}{l}\text{if } \dfrac{P_{24}}{\phi_c P_{n.L24}} \geq 0.2 \\ \left\| \dfrac{P_{24}}{\phi_c P_{n.L24}} + \dfrac{8}{9} \cdot \left(\dfrac{M_{24}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \\ \text{else if } \dfrac{P_{24}}{\phi_c P_{n.L24}} < 0.2 \\ \left\| \dfrac{P_{24}}{2\ \phi_c P_{n.L24}} + \left(\dfrac{M_{24}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1 \right. \end{array}\right| = 1$$

$$DCR_{25} := \frac{P_{25}}{\phi R_n} = 0.169$$
$$DCR_{26} := \frac{P_{26}}{\phi R_n} = 0.202$$
$$DCR_{27} := \frac{P_{27}}{\phi R_n} = 0.202$$
$$DCR_{28} := \frac{P_{28}}{\phi R_n} = 0.293$$
$$DCR_{29} := \frac{P_{29}}{\phi R_n} = 0.293$$
$$DCR_{30} := \frac{P_{30}}{\phi R_n} = 0.36$$
$$DCR_{31} := \frac{P_{31}}{\phi R_n} = 0.36$$
$$DCR_{32} := \frac{P_{32}}{\phi R_n} = 0.404$$
$$DCR_{33} := \frac{P_{33}}{\phi R_n} = 0.404$$
$$DCR_{34} := \frac{P_{34}}{\phi R_n} = 0.427$$
$$DCR_{35} := \frac{P_{35}}{\phi R_n} = 0.427$$
$$DCR_{36} := \frac{P_{36}}{\phi R_n} = 0.43$$
$$DCR_{72} := \frac{P_{72}}{\phi R_n} = 0.43$$
$$DCR_{73} := \frac{P_{73}}{\phi R_n} = 0.427$$
$$DCR_{74} := \frac{P_{74}}{\phi R_n} = 0.427$$

$$DCR_{75} := \frac{P_{75}}{\phi R_n} = 0.404$$
$$DCR_{76} := \frac{P_{76}}{\phi R_n} = 0.404$$
$$DCR_{77} := \frac{P_{75}}{\phi R_n} = 0.404$$
$$DCR_{78} := \frac{P_{76}}{\phi R_n} = 0.404$$
$$DCR_{79} := \frac{P_{72}}{\phi R_n} = 0.43$$
$$DCR_{80} := \frac{P_{80}}{\phi R_n} = 0.293$$
$$DCR_{81} := \frac{P_{81}}{\phi R_n} = 0.202$$
$$DCR_{82} := \frac{P_{82}}{\phi R_n} = 0.202$$
$$DCR_{37} := \frac{P_{37}}{\phi R_n} = 0.169$$
$$DCR_{38} := \frac{P_{38}}{\phi_c P_{n.L38}} = 0.01$$
$$DCR_{39} := \frac{P_{39}}{\phi_c P_{n.L39}} = 0.101$$
$$DCR_{40} := \frac{P_{40}}{\phi R_n} = 0.075$$
$$DCR_{41} := \frac{P_{41}}{\phi_c P_{n.L41}} = 0.051$$
$$DCR_{42} := \frac{P_{42}}{\phi_c P_{n.L42}} = 0.077$$
$$DCR_{43} := \frac{P_{43}}{\phi R_n} = 0.057$$

$$DCR_{44} := \frac{P_{44}}{\phi_c P_{n.L44}} = 0.052$$
$$DCR_{45} := \frac{P_{45}}{\phi_c P_{n.L45}} = 0.056$$
$$DCR_{46} := \frac{P_{46}}{\phi R_n} = 0.039$$
$$DCR_{47} := \frac{P_{47}}{\phi_c P_{n.L47}} = 0.053$$
$$DCR_{48} := \frac{P_{48}}{\phi_c P_{n.L48}} = 0.036$$
$$DCR_{49} := \frac{P_{49}}{\phi R_n} = 0.023$$
$$DCR_{50} := \frac{P_{50}}{\phi_c P_{n.L50}} = 0.054$$
$$DCR_{51} := \frac{P_{51}}{\phi_c P_{n.L51}} = 0.016$$
$$DCR_{52} := \frac{P_{52}}{\phi R_n} = 0.007$$
$$DCR_{53} := \frac{P_{53}}{\phi_c P_{n.L53}} = 0.054$$
$$DCR_{54} := \frac{P_{54}}{\phi R_n} = 0.002$$
$$DCR_{55} := \frac{P_{55}}{\phi R_n} = 0.002$$
$$DCR_{56} := \frac{P_{56}}{\phi_c P_{n.L56}} = 0.054$$
$$DCR_{57} := \frac{P_{57}}{\phi R_n} = 0.007$$
$$DCR_{58} := \frac{P_{58}}{\phi_c P_{n.L58}} = 0.016$$

$$DCR_{59} := \frac{P_{59}}{\phi_c P_{n.L59}} = 0.054$$
$$DCR_{60} := \frac{P_{60}}{\phi R_n} = 0.023$$
$$DCR_{61} := \frac{P_{61}}{\phi_c P_{n.L61}} = 0.036$$
$$DCR_{62} := \frac{P_{62}}{\phi_c P_{n.L62}} = 0.053$$
$$DCR_{63} := \frac{P_{63}}{\phi R_n} = 0.039$$
$$DCR_{64} := \frac{P_{64}}{\phi_c P_{n.L64}} = 0.056$$
$$DCR_{65} := \frac{P_{65}}{\phi_c P_{n.L65}} = 0.052$$
$$DCR_{66} := \frac{P_{66}}{\phi R_n} = 0.057$$
$$DCR_{67} := \frac{P_{67}}{\phi_c P_{n.L67}} = 0.077$$
$$DCR_{68} := \frac{P_{68}}{\phi_c P_{n.L68}} = 0.051$$
$$DCR_{69} := \frac{P_{69}}{\phi R_n} = 0.075$$
$$DCR_{70} := \frac{P_{70}}{\phi_c P_{n.L70}} = 0.101$$
$$DCR_{71} := \frac{P_{71}}{\phi_c P_{n.L71}} = 0.01$$

Deflection Check

$L := 146\ \mathbf{ft} + 8\ \mathbf{in}$

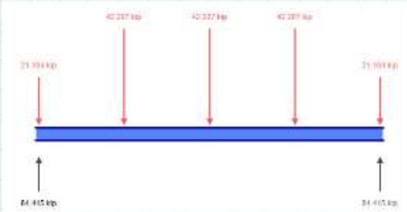
$\Delta_{max} := \frac{L}{360} = 4.889\ \mathbf{in}$

$\Delta_{mid} := 3.413\ \mathbf{in}$ *(from skyciv)*

$\Delta_{max} > \Delta_{mid} = 1$

Appendix D – Girder Re-Design Calculations

W24 x 62 (girder 3 - girder 7)



$R_L := 84.415\ \textbf{kip}$ $R_R := 84.415\ \textbf{kip}$ *(From SkyCiv)*

Unbraced length (b/w each truss)

$L_b := 7\ \textbf{ft}$

Moment Check:

$M_{max} := 590.898\ \textbf{kip} \cdot \textbf{ft}$ *(From SkyCiv)*

$\phi_b M_n := 655\ \textbf{kip} \cdot \textbf{ft}$ *(W24 x 68)*

if $\phi_b M_n \geq M_{max}$
  ‖ return "Adequate"
else if $\phi_b M_n < M_{max}$
  ‖ return "Inadequate"

= "Adequate"

$$DCR_M := \frac{M_{max}}{\phi_b M_n} = 0.902$$

Shear Check:

$V_{max} := 63.63\ \textbf{kip}$ *(From SkyCiv)*

$\phi_b V_n := 295\ \textbf{kip}$ *(W24 x 68)*

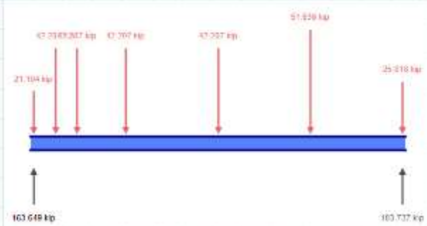
if $\phi_b V_n \geq V_{max}$
  ‖ return "Adequate"
else if $\phi_b V_n < V_{max}$
  ‖ return "Inadequate"

= "Adequate"

$$DCR_V := \frac{V_{max}}{\phi_b V_n} = 0.216$$

clear $\left(R_L, R_R, L_b, M_{max}, \phi_b M_n, V_{max}, \phi_b V_n, DCR_M, DCR_V\right)$

W24 x 62 (girder 8)



$R_L := 163.679$ ***kip*** $\quad R_R := 103.737$ ***kip*** $\quad$ *(From SkyCiv)*

Unbraced length (b/w each truss)

$L_b := 7$ ***ft***

Moment Check:

$M_{max} := 729.417$ ***kip·ft*** $\quad$ *(From SkyCiv)*

$\phi_b M_n := 745$ ***kip·ft*** $\quad$ *(W24 x 76)*

$$\begin{array}{l|l} \text{if } \phi_b M_n \geq M_{max} & = \text{“Adequate”} \\ \quad \| \text{return “Adequate”} & \\ \text{else if } \phi_b M_n < M_{max} & \\ \quad \| \text{return “Inadequate”} & \end{array}$$

$$DCR_M := \frac{M_{max}}{\phi_b M_n} = 0.979$$

Shear Check:

$V_{max} := 142.545$ ***kip*** $\quad$ *(From SkyCiv)*

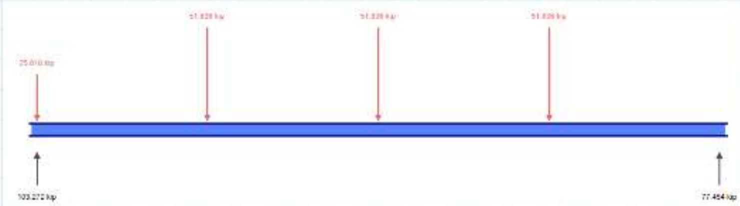
$\phi_b V_n := 315$ ***kip*** $\quad$ *(W24 x 76)*

$$\begin{array}{l|l} \text{if } \phi_b V_n \geq V_{max} & = \text{“Adequate”} \\ \quad \| \text{return “Adequate”} & \\ \text{else if } \phi_b V_n < V_{max} & \\ \quad \| \text{return “Inadequate”} & \end{array}$$

$$DCR_V := \frac{V_{max}}{\phi_b V_n} = 0.453$$

clear $\left(R_L, R_R, L_b, M_{max}, \phi_b M_n, V_{max}, \phi_b V_n, DCR_M, DCR_V\right)$

W24 x 62 (girder 9)



$R_L := 103.212\ \textbf{kip}$ $\quad R_R := 77.454\ \textbf{kip}$ $\quad$ *(From SkyCiv)*

<u>Unbraced length (b/w each truss)</u>

$L_b := 7\ \textbf{ft}$

<u>Moment Check:</u>

$M_{max} := 722.904\ \textbf{kip} \cdot \textbf{ft}$ $\quad$ *(From SkyCiv)*

$\phi_b M_n := 837\ \textbf{kip} \cdot \textbf{ft}$ $\quad$ *(W24 x 84)*

```
if φbMn ≥ Mmax
   ‖ return "Adequate"
else if φbMn < Mmax
   ‖ return "Inadequate"
```
= "Adequate"

$$DCR_M := \frac{M_{max}}{\phi_b M_n} = 0.864$$

<u>Shear Check:</u>

$V_{max} := 77.454\ \textbf{kip}$ $\quad$ *(From SkyCiv)*

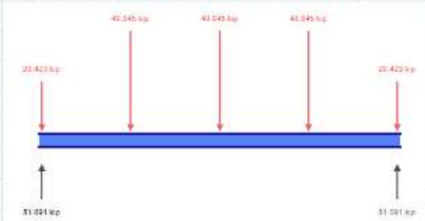
$\phi_b V_n := 340\ \textbf{kip}$ $\quad$ *(W24 x 84)*

```
if φbVn ≥ Vmax
   ‖ return "Adequate"
else if φbVn < Vmax
   ‖ return "Inadequate"
```
= "Adequate"

$$DCR_V := \frac{V_{max}}{\phi_b V_n} = 0.228$$

clear $\left(R_L, R_R, L_b, M_{max}, \phi_b M_n, V_{max}, \phi_b V_n, DCR_M, DCR_V\right)$

W21 x 68 (girder 12 - girder 16)



$R_L := 81.691\ \textbf{kip}$ $\quad R_R := 81.691\ \textbf{kip}$ $\quad$ *(From SkyCiv)*

Unbraced length (b/w each truss)

$L_b := 7\ \textbf{ft}$

Moment Check:

$M_{max} := 590.898\ \textbf{kip} \cdot \textbf{ft}$ $\quad$ *(From SkyCiv)*

$\phi_b M_n := 633\ \textbf{kip} \cdot \textbf{ft}$ $\quad$ *(W21 x 73)*

```
if ϕbMn ≥ Mmax                  = "Adequate"
  ‖ return "Adequate"
else if ϕbMn < Mmax
  ‖ return "Inadequate"
```

$$DCR_M := \frac{M_{max}}{\phi_b M_n} = 0.933$$

Shear Check:

$V_{max} := 61.267\ \textbf{kip}$ $\quad$ *(From SkyCiv)*

$\phi_b V_n := 272\ \textbf{kip}$ $\quad$ *(W21 x 73)*

```
if ϕbVn ≥ Vmax                  = "Adequate"
  ‖ return "Adequate"
else if ϕbVn < Vmax
  ‖ return "Inadequate"
```

$$DCR_V := \frac{V_{max}}{\phi_b V_n} = 0.225$$

clear $\left(R_L, R_R, L_b, M_{max}, \phi_b M_n, V_{max}, \phi_b V_n, DCR_M, DCR_V\right)$

Appendix D – Column Re-Design

Column 3-7

$R_{G1} := 84.415\ kip \qquad R_{G2} := 84.415\ kip$

$P_r := R_{G1} + R_{G2} = 168.83\ kip$

$\phi_c P_n := 216\ kip \qquad$ *(W21 x 101)*

$$\left.\begin{array}{l} \text{if } \phi_c P_n \geq P_r \\ \quad \| \text{return "Adequate"} \\ \text{else if } \phi_c P_n < P_r \\ \quad \| \text{return "Inadequate"} \end{array}\right| = \text{"Adequate"}$$

$$DCR := \frac{P_r}{\phi_c P_n} = 0.782$$

clear $(R_{G1}, R_{G2}, P_r, \phi_c P_n, DCR)$

Column 8

$R_{G1} := 84.415\ kip \qquad R_{G2} := 163.674\ kip$

$P_r := R_{G1} + R_{G2} = 248.089\ kip$

$\phi_c P_n := 270\ kip \qquad$ *(W21 x 132)*

$$\left.\begin{array}{l} \text{if } \phi_c P_n \geq P_r \\ \quad \| \text{return "Adequate"} \\ \text{else if } \phi_c P_n < P_r \\ \quad \| \text{return "Inadequate"} \end{array}\right| = \text{"Adequate"}$$

$$DCR := \frac{P_r}{\phi_c P_n} = 0.919$$

clear $(R_{G1}, R_{G2}, P_r, \phi_c P_n, DCR)$

Column 9-10

$R_{G1} := 103.737\ kip \qquad R_{G2} := 103.212\ kip$

$P_r := R_{G1} + R_{G2} = 206.949\ kip$

$\phi_c P_n := 270\ kip \qquad$ *(W21 x 132)*

```
if φcPn ≥ Pr                  = "Adequate"
  ‖ return "Adequate"
else if φcPn < Pr
  ‖ return "Inadequate"
```

$DCR := \frac{P_r}{\phi_c P_n} = 0.766$

clear $(R_{G1}, R_{G2}, P_r, \phi_c P_n, DCR)$

Column 13-17

$R_{G1} := 81.691\ kip \qquad R_{G2} := 81.691\ kip$

$P_r := R_{G1} + R_{G2} = 163.382\ kip$

$\phi_c P_n := 216\ kip \qquad$ *(W21 x 101)*

```
if φcPn ≥ Pr                  = "Adequate"
  ‖ return "Adequate"
else if φcPn < Pr
  ‖ return "Inadequate"
```

$DCR := \frac{P_r}{\phi_c P_n} = 0.756$

clear $(R_{G1}, R_{G2}, P_r, \phi_c P_n, DCR)$

Column 18

$R_{G1} := 81.691$ ***kip*** $R_{G2} := 158.785$ ***kip***

$P_r := R_{G1} + R_{G2} = 240.476$ ***kip***

$\phi_c P_n := 270$ ***kip*** *(W21 x 132)*

if $\phi_c P_n \geq P_r$
  return "Adequate"
else if $\phi_c P_n < P_r$
  return "Inadequate"
= "Adequate"

$DCR := \frac{P_r}{\phi_c P_n} = 0.891$

clear $(R_{G1}, R_{G2}, P_r, \phi_c P_n, DCR)$

Column 19-20

$R_{G1} := 158.785$ ***kip*** $R_{G2} := 103.212$ ***kip***

$P_r := R_{G1} + R_{G2} = 261.997$ ***kip***

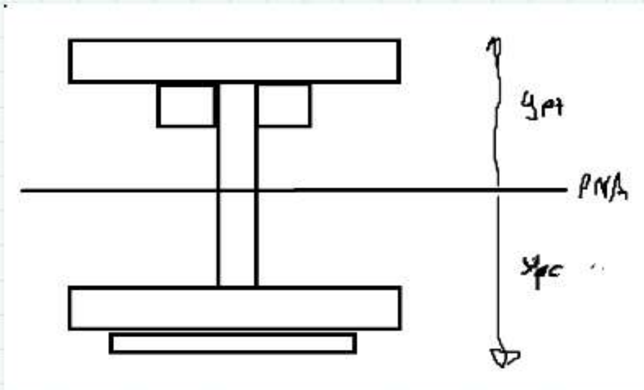
$\phi_c P_n := 270$ ***kip*** *(W21 x 132)*

if $\phi_c P_n \geq P_r$
  return "Adequate"
else if $\phi_c P_n < P_r$
  return "Inadequate"
= "Adequate"

$DCR := \frac{P_r}{\phi_c P_n} = 0.97$

clear $(R_{G1}, R_{G2}, P_r, \phi_c P_n, DCR)$

RHS Side



W-shape: 24x84

$A := 24.7 \cdot in^2$ $d := 24.1 \cdot in$ $b_f := 9.02 \cdot in$ $t_w := .470 \cdot in$ $t_f := .77 \cdot in$

Assumed 6"x1/2" plate Solid square bar: 1.0"x1.0"

$b_{pf} := 6 \cdot in$ $t_{pf} := .5 \cdot in$ $t_{sb} := 1.0 \cdot in$

$y_{pc} := ((d + t_{pf}) - y_{pt}) \rightarrow 24.6 \cdot in - 1.0 \cdot y_{pt}$

$A_c := b_{pf} \cdot t_{pf} + t_f \cdot b_f + t_w \cdot y_{pc}$ $A_t := b_f \cdot t_f + 2 \cdot t_{sb}^2 + t_w \cdot (y_{pt} - t_f)$

$$A_c = A_t \xrightarrow{solve, y_{pt}} 13.748829787234042553 \cdot in$$

$y_{pt} := 13.748829787234042553 \cdot in$ $y_{pc} := ((d + t_{pf}) - y_{pt}) = 10.851\ in$

$y_{pc} + y_{pt} = 24.6\ in$

Zx moment area

$Z_{x1} := b_{pf} \cdot t_{pf} \cdot \left(y_{pc} - \frac{t_{pf}}{2}\right) = 31.804\ in^3$ $Z_{x2} := b_f \cdot t_f \cdot \left(y_{pc} - \left(t_{pf} + \frac{t_f}{2}\right)\right) = 69.219\ in^3$

$$Z_{x3} := t_w \cdot (y_{pc} - (t_{pf} + t_f)) \cdot \left(\frac{y_{pc} - (t_{pf} + t_f)}{2} \right) = 21.573 \ in^3$$ $$y_{pt} - (t_f + .5 \cdot t_{sb}) = 12.479 \ in$$

$$Z_{x4} := t_w \cdot (y_{pt} - t_f) \cdot \left(\frac{(y_{pt} - t_f)}{2} \right) = 39.586 \ in^3$$ $$Z_{x5} := 2 \cdot t_{sb}^2 \cdot (y_{pt} - (t_f + .5 \cdot t_{sb})) = 24.958 \ in^3$$

$$Z_{x6} := t_f \cdot b_f \cdot \left(y_{pt} - \frac{t_f}{2} \right) = 92.817 \ in^3$$

$$Z_x := Z_{x1} + Z_{x2} + Z_{x3} + Z_{x4} + Z_{x5} + Z_{x6} = 279.956 \ in^3$$ $$F_y := 36 \ ksi$$

$$F_y \cdot Z_x = 839.867 \ kip \cdot ft$$

$$M_{ps} := .9 \cdot F_y \cdot Z_x = 755.881 \ kip \cdot ft$$ $$M_{pr} := 722.9 \ kip \cdot ft$$

$$DRC := \frac{M_{pr}}{M_{ps}} = 0.956$$

Moment Check
$M_{pr} \le M_{ps} = 1$

1.12
W24x84

Chapter G- Design of members for shear
For columns:

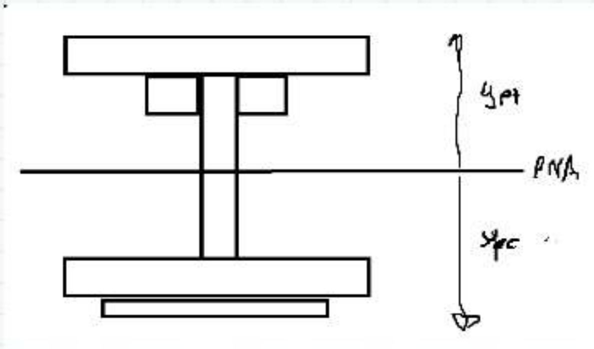
Doubly symmetric and singly symmetric members to minor-axis shear

$$\phi_{ty} := .9$$ $$A_g := A + (b_{pf} \cdot t_{pf}) + 2 \cdot t_{sb}^2$$ $$\phi P_{ny} := \phi_{ty} \cdot F_y \cdot A_g = 962.28 \ kip$$

$$A_w := d \cdot t_w = 9.836 \ in^2$$ $$C_{v1} := 1$$ $$V_{max} := 61.267 \ kip$$

$$V_n := .6 \cdot F_y \cdot A_w \cdot C_{v1} = 212.447 \ kip$$

Shear Check
$V_{max} \le V_n = 1$



$\mathbf{clear}\left(y_{pc}, y_{pt}\right)$

W-shape: 21x73

$A := 21.5 \cdot in^2$ $\quad d := 21.2 \cdot in$ $\quad b_f := 8.3 \cdot in$ $\quad t_w := .455 \cdot in$ $\quad t_f := .74 \cdot in$

Assumed 6"x1/2" plate   Solid square bar: 1.0"x1.0"

$b_{pf} := 6 \cdot in$ $\quad t_{pf} := .5 \cdot in$ $\quad t_{sb} := 1.0 \cdot in$

$y_{pc} := \left(\left(d + t_{pf}\right) - y_{pt}\right) \rightarrow 21.7 \cdot in - 1.0 \cdot y_{pt}$

$A_c := b_{pf} \cdot t_{pf} + t_f \cdot b_f + t_w \cdot y_{pc}$ $\qquad A_t := b_f \cdot t_f + 2 \cdot t_{sb}^{\ 2} + t_w \cdot \left(y_{pt} - t_f\right)$

$A_c = A_t \xrightarrow{solve, y_{pt}} 12.318901098901098901 \cdot in$

$y_{pt} := 12.318901098901098901 \cdot in$ $\qquad y_{pc} := \left(\left(d + t_{pf}\right) - y_{pt}\right) = 9.381\ in$

$y_{pc} + y_{pt} = 21.7\ in$

Zx moment area

$Z_{x1} := b_{pf} \cdot t_{pf} \cdot \left(y_{pc} - \frac{t_{pf}}{2}\right) = 27.393\ in^3$ $\qquad Z_{x2} := b_f \cdot t_f \cdot \left(y_{pc} - \left(t_{pf} + \frac{t_f}{2}\right)\right) = 52.275\ in^3$

$Z_{x3} := t_w \cdot (y_{pc} - (t_{pf} + t_f)) \cdot \left(\frac{y_{pc} - (t_{pf} + t_f)}{2} \right) = 15.078 \ in^3$ $y_{pt} - (t_f + .5 \cdot t_{sb}) = 11.079 \ in$

$Z_{x4} := t_w \cdot (y_{pt} - t_f) \cdot \left(\frac{(y_{pt} - t_f)}{2} \right) = 30.501 \ in^3$ $Z_{x5} := 2 \cdot t_{sb}^{\ 2} \cdot (y_{pt} - (t_f + .5 \cdot t_{sb})) = 22.158 \ in^3$

$Z_{x6} := t_f \cdot b_f \cdot \left(y_{pt} - \frac{t_f}{2} \right) = 73.39 \ in^3$

$Z_x := Z_{x1} + Z_{x2} + Z_{x3} + Z_{x4} + Z_{x5} + Z_{x6} = 220.796 \ in^3$ $F_y := 36 \ ksi$

$F_y \cdot Z_x = 662.387 \ kip \cdot ft$

$M_{ps} := .9 \cdot F_y \cdot Z_x = 596.148 \ kip \cdot ft$ $M_{pr} := 571.83 \ kip \cdot ft$

$DRC := \frac{M_{pr}}{M_{ps}} = 0.959$

Moment Check
$M_{pr} \le M_{ps} = 1$

1.12
W21x73
Chapter G- Design of members for shear
For columns:

Doubly symmetric and singly symmetric members to minor-axis shear

$\phi_{ty} := .9$ $A_g := A + (b_{pf} \cdot t_{pf}) + 2 \cdot t_{sb}^{\ 2}$ $\phi P_{ny} := \phi_{ty} \cdot F_y \cdot A_g = 858.6 \ kip$

$A_w := d \cdot t_w = 9.646 \ in^2$ $C_{v1} := 1$ $V_{max} := 61.267 \ kip$

$V_n := .6 \cdot F_y \cdot A_w \cdot C_{v1} = 208.354 \ kip$

Shear Check
$V_{max} \le V_n = 1$

$\mathbf{clear}\left(y_{pc}, y_{pt}\right)$

W-shape: 21x73

$A := 21.5 \cdot in^2$ $\quad d := 21.2 \cdot in$ $\quad b_f := 8.3 \cdot in$ $\quad t_w := .455 \cdot in$ $\quad t_f := .74 \cdot in$

Assumed 6"x1/2" plate

Solid square bar:
1.75"x1.75"

$b_{pf} := 6 \cdot in$ $\quad t_{pf} := .5 \cdot in$ $\quad t_{sb} := 1.75 \cdot in$

$y_{pc} := \left(\left(d + t_{pf}\right) - y_{pt}\right) \rightarrow 21.7 \cdot in - 1.0 \cdot y_{pt}$

$A_c := b_{pf} \cdot t_{pf} + t_f \cdot b_f + t_w \cdot y_{pc}$ $\quad A_t := b_f \cdot t_f + 2 \cdot t_{sb}{}^2 + t_w \cdot \left(y_{pt} - t_f\right)$

$A_c = A_t \xrightarrow{solve,\, y_{pt}} 7.7859340659340659341 \cdot in$

$y_{pt} := 7.7859340659340659341 \cdot in$ $\quad y_{pc} := \left(\left(d + t_{pf}\right) - y_{pt}\right) = 13.914\ in$

$y_{pc} + y_{pt} = 21.7\ in$

Zx moment area

$Z_{x1} := b_{pf} \cdot t_{pf} \cdot \left(y_{pc} - \dfrac{t_{pf}}{2}\right) = 40.992\ in^3$ $\quad Z_{x2} := b_f \cdot t_f \cdot \left(y_{pc} - \left(t_{pf} + \dfrac{t_f}{2}\right)\right) = 80.117\ in^3$

$Z_{x3} := t_w \cdot \left(y_{pc} - \left(t_{pf} + t_f\right)\right) \cdot \left(\dfrac{y_{pc} - \left(t_{pf} + t_f\right)}{2}\right) = 36.544\ in^3$ $\quad y_{pt} - \left(t_f + .5 \cdot t_{sb}\right) = 6.171\ in$

$Z_{x4} := t_w \cdot \left(y_{pt} - t_f\right) \cdot \left(\dfrac{\left(y_{pt} - t_f\right)}{2}\right) = 11.294\ in^3$ $\quad Z_{x5} := 2 \cdot t_{sb}{}^2 \cdot \left(y_{pt} - \left(t_f + .5 \cdot t_{sb}\right)\right) = 37.797\ in^3$

$Z_{x6} := t_f \cdot b_f \cdot \left(y_{pt} - \dfrac{t_f}{2}\right) = 45.549\ in^3$

$Z_x := Z_{x1} + Z_{x2} + Z_{x3} + Z_{x4} + Z_{x5} + Z_{x6} = 252.293\ in^3$ $F_y := 36\ ksi$

$F_y \cdot Z_x = 756.878\ kip \cdot ft$

$M_{ps} := .9 \cdot F_y \cdot Z_x = 681.19\ kip \cdot ft$ $M_{pr} := 677.67\ kip \cdot ft$

$DRC := \frac{M_{pr}}{M_{ps}} = 0.995$

Moment Check
$M_{pr} \le M_{ps} = 1$

1.12
W21x73
Chapter G- Design of members for shear
For columns:

Doubly symmetric and singly symmetric members to minor-axis shear

$\phi_{ty} := .9$ $A_g := A + (b_{pf} \cdot t_{pf}) + 2 \cdot t_{sb}^2$ $\phi P_{ny} := \phi_{ty} \cdot F_y \cdot A_g = 992.25\ kip$

$A_w := d \cdot t_w = 9.646\ in^2$ $C_{v1} := 1$ $V_{max} := 99.948\ kip$

$V_n := .6 \cdot F_y \cdot A_w \cdot C_{v1} = 208.354\ kip$

Shear Check
$V_{max} \le V_n = 1$

clear (y_{pc}, y_{pt})

W-shape: 21x68

$A := 20.0 \cdot in^2$ $d := 21.1 \cdot in$ $b_f := 8.27 \cdot in$ $t_w := .43 \cdot in$ $t_f := .685 \cdot in$

Assumed 6"x1/2" plate

Solid square bar:
1.25"x1.25"

$b_{pf} := 6 \cdot in$ $t_{pf} := .5 \cdot in$ $t_{sb} := 1.25 \cdot in$

$y_{pc} := ((d + t_{pf}) - y_{pt}) \rightarrow 21.6 \cdot in - 1.0 \cdot y_{pt}$

$A_c := b_{pf} \cdot t_{pf} + t_f \cdot b_f + t_w \cdot y_{pc}$ $A_t := b_f \cdot t_f + 2 \cdot t_{sb}^2 + t_w \cdot (y_{pt} - t_f)$

$$A_c = A_t \xrightarrow{solve, y_{pt}} 10.997151162790697674 \cdot in$$

$y_{pt} := 10.997151162790697674 \cdot in$ $\qquad$ $y_{pc} := ((d + t_{pf}) - y_{pt}) = 10.603\ in$

$y_{pc} + y_{pt} = 21.6\ in$

Zx moment area

$Z_{x1} := b_{pf} \cdot t_{pf} \cdot \left(y_{pc} - \dfrac{t_{pf}}{2}\right) = 31.059\ in^3$ $\qquad$ $Z_{x2} := b_f \cdot t_f \cdot \left(y_{pc} - \left(t_{pf} + \dfrac{t_f}{2}\right)\right) = 55.292\ in^3$

$Z_{x3} := t_w \cdot (y_{pc} - (t_{pf} + t_f)) \cdot \left(\dfrac{y_{pc} - (t_{pf} + t_f)}{2}\right) = 19.07\ in^3$ $\qquad$ $y_{pt} - (t_f + .5 \cdot t_{sb}) = 9.687\ in$

$Z_{x4} := t_w \cdot (y_{pt} - t_f) \cdot \left(\dfrac{(y_{pt} - t_f)}{2}\right) = 22.863\ in^3$ $\qquad$ $Z_{x5} := 2 \cdot {t_{sb}}^2 \cdot (y_{pt} - (t_f + .5 \cdot t_{sb})) = 30.272\ in^3$

$Z_{x6} := t_f \cdot b_f \cdot \left(y_{pt} - \dfrac{t_f}{2}\right) = 60.358\ in^3$

$Z_x := Z_{x1} + Z_{x2} + Z_{x3} + Z_{x4} + Z_{x5} + Z_{x6} = 218.914\ in^3$ $\qquad$ $F_y := 36\ ksi$

$F_y \cdot Z_x = 656.741\ kip \cdot ft$

$M_{ps} := .9 \cdot F_y \cdot Z_x = 591.067\ kip \cdot ft$ $\qquad$ $M_{pr} := 571.83\ kip \cdot ft$

$DRC := \dfrac{M_{pr}}{M_{ps}} = 0.967$ $\qquad$ Moment Check

$M_{pr} \le M_{ps} = 1$

1.12

W21x68

Chapter G- Design of members for shear

Doubly symmetric and singly symmetric members to minor-axis shear

For columns:

$\phi_{ty} := .9$ $\quad A_g := A + (b_{pf} \cdot t_{pf}) + 2 \cdot t_{sb}^2$ $\quad \phi P_{ny} := \phi_{ty} \cdot F_y \cdot A_g = 846.45\ \boldsymbol{kip}$

$A_w := d \cdot t_w = 9.073\ \boldsymbol{in}^2$ $\quad C_{v1} := 1$ $\quad V_{max} := 61.267\ \boldsymbol{kip}$

Shear Check

$V_n := .6 \cdot F_y \cdot A_w \cdot C_{v1} = 195.977\ \boldsymbol{kip}$ $\quad V_{max} \le V_n = 1$

LHS:

clear (y_{pc}, y_{pt})

W-shape: 24x62

$A := 18.2 \cdot \boldsymbol{in}^2$ $\quad d := 23.7 \cdot \boldsymbol{in}$ $\quad b_f := 7.04 \cdot \boldsymbol{in}$ $\quad t_w := .43 \cdot \boldsymbol{in}$ $\quad t_f := .590 \cdot \boldsymbol{in}$

Assumed 6"x1/2" plate

Solid square bar: 1.25"x1.25"

$b_{pf} := 6 \cdot \boldsymbol{in}$ $\quad t_{pf} := .5 \cdot \boldsymbol{in}$ $\quad t_{sb} := 1.25 \cdot \boldsymbol{in}$

$y_{pc} := ((d + t_{pf}) - y_{pt}) \rightarrow 24.2 \cdot in - 1.0 \cdot y_{pt}$

$A_c := b_{pf} \cdot t_{pf} + t_f \cdot b_f + t_w \cdot y_{pc}$ $\quad A_t := b_f \cdot t_f + 2 \cdot t_{sb}^2 + t_w \cdot (y_{pt} - t_f)$

$$A_c = A_t \xrightarrow{solve,\, y_{pt}} 12.249651162790697674 \cdot in$$

$y_{pt} := 12.249651162790697674 \cdot \boldsymbol{in}$ $\quad y_{pc} := ((d + t_{pf}) - y_{pt}) = 11.95\ \boldsymbol{in}$

$y_{pc} + y_{pt} = 24.2\ \boldsymbol{in}$

Zx moment area

$Z_{x1} := b_{pf} \cdot t_{pf} \cdot \left(y_{pc} - \frac{t_{pf}}{2}\right) = 35.101\ \boldsymbol{in}^3$ $\quad Z_{x2} := b_f \cdot t_f \cdot \left(y_{pc} - \left(t_{pf} + \frac{t_f}{2}\right)\right) = 46.335\ \boldsymbol{in}^3$

$Z_{x3} := t_w \cdot (y_{pc} - (t_{pf} + t_f)) \cdot \left(\frac{y_{pc} - (t_{pf} + t_f)}{2}\right) = 25.359\ \boldsymbol{in}^3$ $\quad y_{pt} - (t_f + .5 \cdot t_{sb}) = 11.035\ \boldsymbol{in}$

$Z_{x4} := t_w \cdot (y_{pt} - t_f) \cdot \left(\frac{(y_{pt} - t_f)}{2} \right) = 29.229\ in^3$ $Z_{x5} := 2 \cdot t_{sb}^2 \cdot (y_{pt} - (t_f + .5 \cdot t_{sb})) = 34.483\ in^3$

$Z_{x6} := t_f \cdot b_f \cdot \left(y_{pt} - \frac{t_f}{2} \right) = 49.655\ in^3$

$Z_x := Z_{x1} + Z_{x2} + Z_{x3} + Z_{x4} + Z_{x5} + Z_{x6} = 220.161\ in^3$ $F_y := 36\ ksi$

$F_y \cdot Z_x = 660.484\ kip \cdot ft$

$M_{ps} := .9 \cdot F_y \cdot Z_x = 594.436\ kip \cdot ft$ $M_{pr} := 590.898\ kip \cdot ft$

$DRC := \frac{M_{pr}}{M_{ps}} = 0.994$

Moment Check
$M_{pr} \le M_{ps} = 1$

1.12
W24x62
Chapter G- Design of members for shear
For columns:

Doubly symmetric and singly symmetric members to minor-axis shear

$\phi_{ty} := .9$ $A_g := A + (b_{pf} \cdot t_{pf}) + 2 \cdot t_{sb}^2$ $\phi P_{ny} := \phi_{ty} \cdot F_y \cdot A_g = 788.13\ kip$

$A_w := d \cdot t_w = 10.191\ in^2$ $C_{v1} := 1$ $V_{max} := 61.267\ kip$

$V_n := .6 \cdot F_y \cdot A_w \cdot C_{v1} = 220.126\ kip$

Shear Check
$V_{max} \le V_n = 1$

clear (y_{pc}, y_{pt})

W-shape: 24x62

$A := 18.2 \cdot in^2$ $d := 23.7 \cdot in$ $b_f := 7.04 \cdot in$ $t_w := .43 \cdot in$ $t_f := .590 \cdot in$

Assumed 6"x1/2" plate   Solid square bar: 2.0"x2.0"

$b_{pf} := 6 \cdot in$ $t_{pf} := .5 \cdot in$ $t_{sb} := 2 \cdot in$

$y_{pc} := ((d + t_{pf}) - y_{pt}) \rightarrow 24.2 \cdot in - 1.0 \cdot y_{pt}$

$A_c := b_{pf} \cdot t_{pf} + t_f \cdot b_f + t_w \cdot y_{pc}$ $A_t := b_f \cdot t_f + 2 \cdot t_{sb}^2 + t_w \cdot (y_{pt} - t_f)$

$A_c = A_t \xrightarrow{solve, y_{pt}} 6.5810465116279069767 \cdot in$

$y_{pt} := 8.7612790697674418605 \cdot in$ $y_{pc} := ((d + t_{pf}) - y_{pt}) = 15.439\ in$

$y_{pc} + y_{pt} = 24.2\ in$

Zx moment area

$Z_{x1} := b_{pf} \cdot t_{pf} \cdot \left(y_{pc} - \frac{t_{pf}}{2}\right) = 45.566\ in^3$ $Z_{x2} := b_f \cdot t_f \cdot \left(y_{pc} - \left(t_{pf} + \frac{t_f}{2}\right)\right) = 60.824\ in^3$

$Z_{x3} := t_w \cdot (y_{pc} - (t_{pf} + t_f)) \cdot \left(\frac{y_{pc} - (t_{pf} + t_f)}{2}\right) = 44.265\ in^3$ $y_{pt} - (t_f + .5 \cdot t_{sb}) = 7.171\ in$

$Z_{x4} := t_w \cdot (y_{pt} - t_f) \cdot \left(\frac{(y_{pt} - t_f)}{2}\right) = 14.356\ in^3$ $Z_{x5} := 2 \cdot t_{sb}^2 \cdot (y_{pt} - (t_f + .5 \cdot t_{sb})) = 57.37\ in^3$

$Z_{x6} := t_f \cdot b_f \cdot \left(y_{pt} - \frac{t_f}{2}\right) = 35.166\ in^3$

$Z_x := Z_{x1} + Z_{x2} + Z_{x3} + Z_{x4} + Z_{x5} + Z_{x6} = 257.547\ in^3$ $F_y := 36\ ksi$

$F_y \cdot Z_x = 772.641\ kip \cdot ft$

$M_{ps} := .9 \cdot F_y \cdot Z_x = 695.377\ kip \cdot ft$ $M_{pr} := 694.237\ kip \cdot ft$

$DRC := \frac{M_{pr}}{M_{ps}} = 0.998$

Moment Check

$M_{pr} \le M_{ps} = 1$

1.12

W24x62

Chapter G- Design of members for shear

For columns:

Doubly symmetric and singly symmetric members to minor-axis shear

$\phi_{ty} := .9$ $\quad A_g := A + (b_{pf} \cdot t_{pf}) + 2 \cdot t_{sb}^2$ $\quad \phi P_{ny} := \phi_{ty} \cdot F_y \cdot A_g = 946.08\ kip$

$A_w := d \cdot t_w = 10.191\ in^2$ $\quad C_{v1} := 1$ $\quad V_{max} := 102.851\ kip$

$V_n := .6 \cdot F_y \cdot A_w \cdot C_{v1} = 220.126\ kip$

Shear Check

$V_{max} \le V_n = 1$

clear (y_{pc}, y_{pt})

W-shape: 24x62

Plastic NA, assumption falls apart if solid bar exceeds 2.5" w/o changing thickness of plate

$A := 18.2 \cdot in^2$ $\quad d := 23.7 \cdot in$ $\quad b_f := 7.04 \cdot in$ $\quad t_w := .43 \cdot in$ $\quad t_f := .590 \cdot in$

Assumed 6"x5/8" plate

Solid square bar: 2"x2"

$b_{pf} := 6 \cdot in$ $\quad t_{pf} := .625 \cdot in$ $\quad t_{sb} := 2 \cdot in$

$y_{pc} := ((d + t_{pf}) - y_{pt}) \rightarrow 24.325 \cdot in - 1.0 \cdot y_{pt}$

$A_c := b_{pf} \cdot t_{pf} + t_f \cdot b_f + t_w \cdot y_{pc}$ $\quad A_t := b_f \cdot t_f + 2 \cdot t_{sb}^2 + t_w \cdot (y_{pt} - t_f)$

$A_c = A_t \xrightarrow{solve,\, y_{pt}} 7.5156395348837209302 \cdot in$

$y_{pt} := 8.4502325581395348837 \cdot in$ $\quad y_{pc} := ((d + t_{pf}) - y_{pt}) = 15.875\ in$

$y_{pc}+y_{pt}=24.325\ in$

Zx moment area

$Z_{x1}:=b_{pf}\cdot t_{pf}\cdot\left(y_{pc}-\frac{t_{pf}}{2}\right)=58.359\ in^3$

$Z_{x2}:=b_f\cdot t_f\cdot\left(y_{pc}-\left(t_{pf}+\frac{t_f}{2}\right)\right)=62.116\ in^3$

$Z_{x3}:=t_w\cdot\left(y_{pc}-\left(t_{pf}+t_f\right)\right)\cdot\left(\frac{y_{pc}-\left(t_{pf}+t_f\right)}{2}\right)=46.205\ in^3$

$y_{pt}-\left(t_f+.5\cdot t_{sb}\right)=6.86\ in$

$Z_{x4}:=t_w\cdot\left(y_{pt}-t_f\right)\cdot\left(\frac{\left(y_{pt}-t_f\right)}{2}\right)=13.283\ in^3$

$Z_{x5}:=2\cdot t_{sb}^{\ 2}\cdot\left(y_{pt}-\left(t_f+.5\cdot t_{sb}\right)\right)=54.882\ in^3$

$Z_{x6}:=t_f\cdot b_f\cdot\left(y_{pt}-\frac{t_f}{2}\right)=33.874\ in^3$

$Z_x:=Z_{x1}+Z_{x2}+Z_{x3}+Z_{x4}+Z_{x5}+Z_{x6}=268.719\ in^3$

$F_y:=36\ ksi$

$F_y\cdot Z_x=806.157\ kip\cdot ft$

$M_{ps}:=.9\cdot F_y\cdot Z_x=725.541\ kip\cdot ft$

$M_{pr}:=722.904\ kip\cdot ft$

$DRC:=\frac{M_{pr}}{M_{ps}}=0.996$

Moment Check

$M_{pr}\le M_{ps}=1$

1.12

W24x62

Chapter G- Design of members for shear

For columns:

Doubly symmetric and singly symmetric members to minor-axis shear

$\phi_{ty} := .9$

$A_g := A + (b_{pf} \cdot t_{pf}) + 2 \cdot t_{sb}^2$

$\phi P_{ny} := \phi_{ty} \cdot F_y \cdot A_g = 970.38\ \mathbf{kip}$

$A_w := d \cdot t_w = 10.191\ \mathbf{in^2}$

$C_{v1} := 1$

$V_{max} := 77.454\ \mathbf{kip}$

$V_n := .6 \cdot F_y \cdot A_w \cdot C_{v1} = 220.126\ \mathbf{kip}$

Shear Check

$V_{max} \le V_n = 1$

Columns L3-L7 (W21x83)

$R_{G1} := 84.415\ \textbf{kip}$ $R_{G2} := 84.415\ \textbf{kip}$

$P_r := R_{G1} + R_{G2} = 168.83\ \textbf{kip}$

$L_{c.xx} := 40\ \textbf{ft}$ *(unbraced length for strong axis buckling)*

$L_{c.yy} := 0\ \textbf{ft}$ *(unbraced length for weak axis buckling)*

$L_c := \frac{L_{c.xx}}{4.74} = 8.439\ \textbf{ft}$ *(transition of strong axis buckling to weak axis buckling L_c)*

$\phi_c P_{n.8} := 597\ \textbf{kip}$

$\phi_c P_{n.9} := 566\ \textbf{kip}$

$\phi_c P_n := \left(\frac{\phi_c P_{n.9} - \phi_c P_{n.8}}{9\ \textbf{ft} - 8\ \textbf{ft}}\right) \cdot (L_c - 8\ \textbf{ft}) + \phi_c P_{n.8} = 583.397\ \textbf{kip}$

```
if ϕcPn ≥ Pr                                            = "Adequate - no reinforcement needed"
  ‖ return "Adequate - no reinforcement needed"
else if ϕcPn < Pr
  ‖ return "Inadequate - reinforcement needed"
```

$DCR := \frac{P_r}{\phi_c P_n} = 0.289$

clear $(R_{G1}, R_{G2}, \phi_c P_{n.8}, \phi_c P_{n.9}, P_r, L_{c.xx}, L_{c.yy}, L_c, \phi_c P_n, DCR)$

Column L8 (W21x83)

$R_{G1} := 84.415\ \textbf{kip}$ $R_{G2} := 123.955\ \textbf{kip}$

$P_r := R_{G1} + R_{G2} = 208.37\ \textbf{kip}$

$L_{c.xx} := 40\ \textbf{ft}$ *(unbraced length for strong axis buckling)*

$L_{c.yy} := 0\ \textbf{ft}$ *(unbraced length for weak axis buckling)*

$L_c := \frac{L_{c.xx}}{4.74} = 8.439\ \textbf{ft}$ *(transition of strong axis buckling to weak axis buckling L_c)*

$\phi_c P_{n.8} := 597\ \textbf{kip}$

$\phi_c P_{n.9} := 566\ \textbf{kip}$

$\phi_c P_n := \left(\frac{\phi_c P_{n.9} - \phi_c P_{n.8}}{9\ \textbf{ft} - 8\ \textbf{ft}}\right) \cdot (L_c - 8\ \textbf{ft}) + \phi_c P_{n.8} = 583.397\ \textbf{kip}$

$$\begin{aligned}&\text{if } \phi_c P_n \geq P_r \\ &\quad \| \textbf{return} \text{ "Adequate - no reinforcement needed"} \\ &\text{else if } \phi_c P_n < P_r \\ &\quad \| \textbf{return} \text{ "Inadequate - reinforcement needed"}\end{aligned} \quad = \text{"Adequate - no reinforcement needed"}$$

$$DCR := \frac{P_r}{\phi_c P_n} = 0.357$$

clear $(R_{G1}, R_{G2}, \phi_c P_{n.8}, \phi_c P_{n.9}, P_r, L_{c.xx}, L_{c.yy}, L_c, \phi_c P_n, DCR)$

Column L9 (W21x83)

$R_{G1} := 101.224$ ***kip*** $\quad R_{G2} := 103.272$ ***kip***

$P_r := R_{G1} + R_{G2} = 204.496$ ***kip***

$L_{c.xx} := 40$ ***ft*** *(unbraced length for strong axis buckling)*

$L_{c.yy} := 0$ ***ft*** *(unbraced length for weak axis buckling)*

$L_c := \frac{L_{c.xx}}{4.74} = 8.439$ ***ft*** *(transition of strong axis buckling to weak axis buckling L_c)*

$\phi_c P_{n.8} := 597$ ***kip***

$\phi_c P_{n.9} := 566$ ***kip***

$$\phi_c P_n := \left(\frac{\phi_c P_{n.9} - \phi_c P_{n.8}}{9\ ft - 8\ ft}\right) \cdot (L_c - 8\ ft) + \phi_c P_{n.8} = 583.397\ kip$$

$$\begin{aligned}&\text{if } \phi_c P_n \geq P_r \\ &\quad \| \textbf{return} \text{ "Adequate - no reinforcement needed"} \\ &\text{else if } \phi_c P_n < P_r \\ &\quad \| \textbf{return} \text{ "Inadequate - reinforcement needed"}\end{aligned} \quad = \text{"Adequate - no reinforcement needed"}$$

$$DCR := \frac{P_r}{\phi_c P_n} = 0.351$$

clear $(R_{G1}, R_{G2}, \phi_c P_{n.8}, \phi_c P_{n.9}, P_r, L_{c.xx}, L_{c.yy}, L_c, \phi_c P_n, DCR)$

Column L10 (W27x84)

$R_{G1} := 77.454$ ***kip*** $\quad R_{G2} := 3.938$ ***kip***

$P_r := R_{G1} + R_{G2} = 81.392$ ***kip***

$L_{c.xx} := 0$ ***ft*** *(unbraced length for strong axis buckling)*

$L_{c.yy} := 10\ ft$ *(unbraced length for weak axis buckling)*

$L_c := L_{c.yy} = 10\ ft$

$\phi_c P_n := 533\ kip$

```
if φcPn ≥ Pr                                        = "Adequate - no reinforcement needed"
  ‖ return "Adequate - no reinforcement needed"
else if φcPn < Pr
  ‖ return "Inadequate - reinforcement needed"
```

$DCR := \frac{P_r}{\phi_c P_n} = 0.153$

clear $(R_{G1}, R_{G2}, \phi_c P_{n.8}, \phi_c P_{n.9}, P_r, L_{c.xx}, L_{c.yy}, L_c, \phi_c P_n, DCR)$

Columns D3-D7 (W16x77)

$R_{G1} := 81.691\ kip$ $R_{G2} := 81.691\ kip$

$P_r := R_{G1} + R_{G2} = 163.382\ kip$

$L_{c.xx} := 30.5\ ft$ *(unbraced length for strong axis buckling)*

$L_{c.XX} := \frac{L_{c.xx}}{2.83} = 10.777\ ft$ *(transition of strong axis buckling to weak axis buckling L_c)*

$\phi_c P_{n.10} := 569\ kip$

$\phi_c P_{n.11} := 549\ kip$

$\phi_c P_{n.xx} := \left(\frac{\phi_c P_{n.11} - \phi_c P_{n.10}}{11\ ft - 10\ ft}\right) \cdot (L_{c.XX} - 10\ ft) + \phi_c P_{n.10} = 553.452\ kip$

```
if φcPn.xx ≥ Pr                                     = "Adequate - no reinforcement needed"
  ‖ return "Adequate - no reinforcement needed"
else if φcPn.xx < Pr
  ‖ return "Inadequate - reinforcement needed"
```

$DCR_{xx} := \frac{P_r}{\phi_c P_{n.xx}} = 0.295$

$L_{c.yy} := 17\ ft$ *(unbraced length for weak axis buckling)*

$\phi_c P_{n.yy} := 411\ kip$

if $\phi_c P_{n.xx} \geq P_r$
  return "Adequate - no reinforcement needed"
else if $\phi_c P_{n.xx} < P_r$
  return "Inadequate - reinforcement needed"

= "Adequate - no reinforcement needed"

$$DCR_{yy} := \frac{P_r}{\phi_c P_{n.xx}} = 0.295$$

clear $(R_{G1}, R_{G2}, \phi_c P_{n.10}, \phi_c P_{n.11}, P_r, L_{c.xx}, L_{c.XX}, L_{c.yy}, L_c, \phi_c P_{n.xx}, \phi_c P_{n.yy}, DCR_{xx}, DCR_{yy})$

Column D8 (W16x77)

$R_{G1} := 81.691\ kip$ $R_{G2} := 120.371\ kip$

$P_r := R_{G1} + R_{G2} = 202.062\ kip$

$L_{c.xx} := 30.5\ ft$ *(unbraced length for strong axis buckling)*

$L_{c.XX} := \frac{L_{c.xx}}{2.83} = 10.777\ ft$ *(transition of strong axis buckling to weak axis buckling L_c)*

$\phi_c P_{n.10} := 569\ kip$

$\phi_c P_{n.11} := 549\ kip$

$$\phi_c P_{n.xx} := \left(\frac{\phi_c P_{n.11} - \phi_c P_{n.10}}{11\ ft - 10\ ft}\right) \cdot (L_{c.XX} - 10\ ft) + \phi_c P_{n.10} = 553.452\ kip$$

if $\phi_c P_{n.xx} \geq P_r$
  return "Adequate - no reinforcement needed"
else if $\phi_c P_{n.xx} < P_r$
  return "Inadequate - reinforcement needed"

= "Adequate - no reinforcement needed"

$$DCR_{xx} := \frac{P_r}{\phi_c P_{n.xx}} = 0.365$$

$L_{c.yy} := 17\ ft$ *(unbraced length for weak axis buckling)*

$\phi_c P_{n.yy} := 411\ kip$

if $\phi_c P_{n.xx} \geq P_r$
  return "Adequate - no reinforcement needed"
else if $\phi_c P_{n.xx} < P_r$
  return "Inadequate - reinforcement needed"

= "Adequate - no reinforcement needed"

$$DCR_{yy} := \frac{P_r}{\phi_c P_{n.xx}} = 0.365$$

clear $(R_{G1}, R_{G2}, \phi_c P_{n.10}, \phi_c P_{n.11}, P_r, L_{c.xx}, L_{c.XX}, L_{c.yy}, L_c, \phi_c P_{n.xx}, \phi_c P_{n.yy}, DCR_{xx}, DCR_{yy})$

<u>Column D9 (W16x77)</u>

$R_{G1} := 100.041\ kip$ $R_{G2} := 103.272\ kip$

$P_r := R_{G1} + R_{G2} = 203.313\ kip$

$L_{c.xx} := 30.5\ ft$ *(unbraced length for strong axis buckling)*

$L_{c.XX} := \frac{L_{c.xx}}{2.83} = 10.777\ ft$ *(transition of strong axis buckling to weak axis buckling L_c)*

$\phi_c P_{n.10} := 569\ kip$

$\phi_c P_{n.11} := 549\ kip$

$$\phi_c P_{n.xx} := \left(\frac{\phi_c P_{n.11} - \phi_c P_{n.10}}{11\ ft - 10\ ft}\right) \cdot (L_{c.XX} - 10\ ft) + \phi_c P_{n.10} = 553.452\ kip$$

if $\phi_c P_{n.xx} \geq P_r$
  return "Adequate - no reinforcement needed"
else if $\phi_c P_{n.xx} < P_r$
  return "Inadequate - reinforcement needed"

= "Adequate - no reinforcement needed"

$$DCR_{xx} := \frac{P_r}{\phi_c P_{n.xx}} = 0.367$$

$L_{c.yy} := 17\ ft$ *(unbraced length for weak axis buckling)*

$\phi_c P_{n.yy} := 411\ kip$

if $\phi_c P_{n.xx} \geq P_r$
  return "Adequate - no reinforcement needed"
else if $\phi_c P_{n.xx} < P_r$
  return "Inadequate - reinforcement needed"

= "Adequate - no reinforcement needed"

$$DCR_{yy} := \frac{P_r}{\phi_c P_{n.xx}} = 0.367$$

clear $(R_{G1}, R_{G2}, \phi_c P_{n.10}, \phi_c P_{n.11}, P_r, L_{c.xx}, L_{c.XX}, L_{c.yy}, L_c, \phi_c P_{n.xx}, \phi_c P_{n.yy}, DCR_{xx}, DCR_{yy})$

Column D10 (W18x46)

$R_{G1} := 77.454\ kip$ $R_{G2} := 3.142\ kip$

$P_r := R_{G1} + R_{G2} = 80.596\ kip$

$L_{c.xx} := 30.5\ ft$ *(unbraced length for strong axis buckling)*

$L_{c.XX} := \frac{L_{c.xx}}{5.62} = 5.427\ ft$ *(transition of strong axis buckling to weak axis buckling L_c)*

$\phi_c P_{n.0} := 379\ kip$

$\phi_c P_{n.6} := 312\ kip$

$$\phi_c P_{n.xx} := \left(\frac{\phi_c P_{n.6} - \phi_c P_{n.0}}{6\ ft - 0\ ft}\right) \cdot (L_{c.XX} - 0\ ft) + \phi_c P_{n.0} = 318.398\ kip$$

if $\phi_c P_{n.xx} \geq P_r$
  return "Adequate - no reinforcement needed"
else if $\phi_c P_{n.xx} < P_r$
  return "Inadequate - reinforcement needed"

= "Adequate - no reinforcement needed"

$$DCR_{xx} := \frac{P_r}{\phi_c P_{n.xx}} = 0.253$$

$L_{c.yy} := 17\ ft$ *(unbraced length for weak axis buckling)*

$\phi_c P_{n.yy} := 411\ kip$

```
if φcPn.xx ≥ Pr
  ‖ return "Adequate - no reinforcement needed"
else if φcPn.xx < Pr
  ‖ return "Inadequate - reinforcement needed"
```
= "Adequate - no reinforcement needed"

$$DCR_{yy} := \frac{P_r}{\phi_c P_{n.xx}} = 0.253$$

$L_{c.xx} := 0\ ft$ *(unbraced length for strong axis buckling)*

$L_{c.yy} := 10\ ft$ *(unbraced length for weak axis buckling)*

$L_c := L_{c.yy} = 10\ ft$

$\phi_c P_n := 533\ kip$

```
if φcPn ≥ Pr
  ‖ return "Adequate - no reinforcement needed"
else if φcPn < Pr
  ‖ return "Inadequate - reinforcement needed"
```
= "Adequate - no reinforcement needed"

$$DCR := \frac{P_r}{\phi_c P_n} = 0.151$$

Appendix F – Loading Capacity Analysis for Solar

Concrete Plank: Normal-weight concrete, 8" with 2" topper (+25 psf)

Additional loading from cool roof and solar panels = 3 psf

Assuming the strand configuration is the same for the concrete planks of the same span, and loading capacity was designed for the mechanical loads on their designated span section, the additional capacity of each individual concrete plank was found:

Array 1: (bottom left)

- Span = 31 feet
- Strand = 78-S
- Capacity = 80 psf +25 psf = 105 psf
- PCI rating = 124 psf
- Has Capacity (19 psf extra)

Array 2: (top left)

- Span = 24.5 feet
- Strand = 66-S
- Capacity = 45 psf + 25 psf = 70 psf
- PCI Rating = 95.4 psf
- Has Capacity (25.4 psf extra)

Array 3: (top middle)

- Span = 24.5 feet
- Strand = 66-S
- Capacity = 68 psf + 25 psf = 93 psf
- PCI Rating = 95.4 psf
- Not met (2.4 extra)
- This array was moved to areas of the roof that have the extra capacity, making four arrays instead of five and not exceeding capacity

Array 4: (top right)

- Span = 24.5 feet
- Strand = 66-S
- Capacity = 45 psf + 25 psf = 70 psf
- PCI Rating = 95.4 psf
- Has Capacity (25.4 psf extra)

Array 5: (bottom right)

- Span = 31 feet
- Strand = 78-S
- Capacity = 80 psf + 25 psf = 105 psf
- PCI Rating = 124 psf
- Has Capacity (19 psf extra)