THE UNIVERSITY OF IOWA
IOWA INITIATIVE
FOR SUSTAINABLE COMMUNITIES

FINAL DELIVERABLE

Title	Volga Fire Station Expansion Engineering & Design
Completed By	Schuyler Bell, Mitchell Vogt
Date Completed	May 2020
UI Department	Department of Civil & Environmental Engineering
Course Name	CEE:4850:0001 Project Design & Management
Instructor	Christopher Stoakes
Community Partners	City of Volga

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<u>Section I:</u> Executive Summary

The City of Volga, Iowa has requested the services of our team, Vogt and Bell - Engineering and Design, to design a much-needed expansion to their fire station. The fire station not only acts as a facility for firefighting operations, but also for the ambulance crew. The station currently is a 45’ x 85’ building that has three garage doors for their vehicles. The vehicles at the station are stacked behind each other and their gear is tightly packed between and around the vehicles. Limited space has brought the desire for an expansion for room for current equipment and supplies, and the desire to use the facility for additional purposes. The City of Volga would like the facility to house an office for the City Clerk. The city would also like room for the city truck to have a space for the vehicle and the maintenance equipment needed for it. Yet another purpose, this facility also happens to be the flood disaster shelter area for the city. During previous flood events, it has been the only building in the area that remains above water and served as a haven for flood victims to be housed while they were displaced. Additional room is needed to accommodate these people and still act as an effective facility for emergency response. Due to our two-person team, our scope of work for this project has been cut to just the design of the building. Our team has done some sitework design that can be used for consideration.

Vogt and Bell - Engineering and Design team has designed an expansion that is a 58’ x 88’ addition that will be attached to the existing building. The building design of this expansion took this flooding concern into consideration by designing for the flood water and be a base of operations for responding to the flood. The space needed for the firefighters and EMS were taken care of in the design, and the incorporation of the City Clerk and the city truck were both taken care of. A drive through wash bay was included in the design for an easy way to clean all the vehicles in a fast and efficient manner and to serve as a parking space for long term storage. Three additional parking bays were created for fast deployment of any vehicle without the need to move a vehicle in front of it. A separation of the EMS with their own expanded area will help them work in a more efficient manner. A large meeting area has been designed to accommodate extra room for meetings of all types. Above the interior rooms of the expansion is a large second-story storage area. The areas that used to have the stacked vehicles in them can now be used for extra room for storage and room for equipment donning. The north wall of the existing building will now have room for equipment to be hung on the wall. The two buildings can work in a cohesive manner because of the large opening that connect the two building will serve to help as a central area to brief firefighters leaving from both sides of the facility.

The total cost for structural material cost including framing, foundation, and slab with the waste factor is about $119,000. This post-frame building design with a continuous stem-wall foundation design will effectively allow all departments to do their jobs simultaneously without impeding the mission of the other departments in this joint facility.

<u>Section II:</u> Organization Qualifications and Experience

1. <u>Name of Organization</u>
   Vogt and Bell - Engineering and Design

2. <u>Organization Location and Contact Information</u>
   Mitchell Vogt – *Project Manager*
   (712) 541-5399
   mitchell-vogt@uiowa.edu

3. <u>Organization and Design Team Description</u>

-Mitchell Vogt is the project manager with a specialization in management.
-Schuyler Bell is the design lead with a specialization with structural engineering.

4. <u>Description of Experience with Similar Projects</u>

-Schuyler Bell- Completed coursework that is relevant to this project includes: Principles of Structural Engineering, Design of Concrete Structures, Foundations of Structures, Design of Wood Structures, and currently enrolled in Design of Steel Structures and Introduction to Bridge Engineering. Technical knowledge includes a building trades diploma from Indian Hills Community College, years of construction experience, 4 years serving as a builder in the United States Navy Seabees, crew leader on multiple construction projects, and leading construction planning and estimation teams for major projects. Some examples of projects include: pouring concrete for the runway and rebuilding 6 destroyed tension fabric structure aircraft hangers on Camp Bastion, Afghanistan, a total overhaul of all of the buildings on a small combat outpost in the mountains in Afghanistan, construction of buildings on military facilities to support the War on Terror in East Africa, and the construction of an Ebola Treatment Facility in Liberia during the Ebola outbreak.

-Mitchell Vogt- Completed coursework that is relevant to this project includes: Principles of Structural Engineering, Design of Steel Structures, Transportation Design, Hydraulics & Hydrology, and Water Resources Engineering. He currently serves as a Business Analyst for DGR Engineering (Rock Rapids, IA) and will join them full-time in an engineering role upon his Graduation in May 2020. In addition to engineering coursework, Mitch holds a bachelor’s degree in Finance and certificate in Risk Management from the University of Iowa’s Tippie College of Business. He also holds an MBA in Finance from Creighton University’s Heider College of Business. Professional work experience includes several years of Commercial Property & Casualty Insurance Underwriting at two Fortune 500 companies: Berkshire Hathaway, Inc (Omaha,NE) and The Travelers Companies (Hartford, CT). Other relevant work experience includes engineering internships, Plumbing & HVAC contracting, residential and light commercial construction involving site work, building demolition, and structural steel erection.

<u>Section III:</u> Design Services

1. <u>Project Scope</u>

The Volga Fire Station is in need for an expansion to accommodate additional space for multiple reasons. The existing structure is 45' x 85' in size. It is oriented with the long direction in the east/west. There are three garage doors on the east side of the building with two doors that are 10' wide and one that is 10.5' wide. The narrow doors are a very tight fit for some of the wider vehicles that the facility accommodates. The ceiling height in the existing structure are 12'. In the southwest of the building there is a storage/mechanical room that is 12' x 22'. Attached to the east of this room is two restrooms. In the northwest corner of the building there is a kitchen/meeting area. The quantity of firefighting vehicles in the station takes up most of the space inside. The firefighting personal protective equipment stations are positioned in between the vehicles. The vehicles are staged inside the station with the most used vehicles in front and the other vehicles stacked behind them. Different types of emergency vehicles that are used for different situations may be positioned behind vehicles that may be for a different purpose. For example, if there was a brush fire, the EMS vehicle would have to be moved to get to the necessary equipment. This leads to inefficiency that wastes time in responding to an emergency. The station also is the staging area for the EMS vehicle and equipment. Due to the joint operations happening at the station with the limited space, the EMS has a very narrow area next to their truck to hold their essential equipment. The station is also where these teams hold meetings. During flood events this building is the only building in the area that stays above water, so this is the emergency berthing area to flood victims. Due to the number of vehicles in the building, they must be brought outside to accommodate the people during these events and there is no room at the station to house the logistics for these events. The city would also like to have an office space for the city clerk. Also, the garage that houses the city snowplow dump truck has become unfit for storage area due to the serviceability of the concrete floor that has cracked and began to settle. They would like an area for this vehicle with an area for the mechanic equipment for this vehicle. Our project scope was narrowed from designing the whole property design to just the design of the building. Our team was tasked to design an expansion to fulfill all the needs of the station.

2. <u>Work Plan</u>

Task 1- Project Management:
1.1 Progress meeting with team and faculty advisor
1.2 Communicate with client
1.3 Monitor and Report Project Schedule
1.4 Quality Control

Task 2- Preliminary Design:
2.1 Review Details of Current site
2.2 Revit 3D Modeling of current structure and new expansion

2.3 Develop Alternatives
2.4 Conceptual Drawings
2.5 Preliminary Cost Estimate

Task 3- Structural Design Calculations:
3.1 Truss Design using computer aided structural analysis software, Mathcad computer software for calculations, and the appropriate standards for capacity values and reference.
3.2 Wall Framing Design using computer aided structural analysis software, Mathcad computer software for calculations, and the appropriate standards for capacity values and reference.
3.3 Slab Design using computer aided structural analysis software, Mathcad computer software for calculations, and the appropriate standards for capacity values and reference.
3.4 Foundation Design using computer aided structural analysis software, Mathcad computer software for calculations, and the appropriate standards for capacity values and reference.
3.5 Analyze existing room-room loads and determine airflow patterns
3.6 Design and size duct systems
3.7 Building Plan

Task 4- Final Work Products:
4.1 Determine cost of project and budget break down
4.2 Compose Final Report
4.3 Presentations

Methods and Design Guides

The design standards that will be used in the design process of the structure are:

1. NDS 2015
2. NDS supplement 2015
3. SDPWS 2015
4. ACI 318-19
5. ASCE 7-10
6. IBC 2015
7. AASHTO LRFD Bridge Design Specifications 6th Edition
   -For truck live load tire force on concrete floor

Section IV: Constraints, Challenges, and Impacts

1. Constraints

This project was limited to the plot of land that the fire station sits on. The plot of land had room for expansion on the south side of the property, and to the west of the property. There was plenty of room for the expansion, but parking and driveway areas had to be carefully planned with this extra room we had to design with. To the north side of the property line just south of the street is a large ditch which fills with water during periods of rain. This had to be kept in mind when designing where the garage doors would be placed and how they could cross this ditch.

2. Challenges

Our team was given a very challenging task. We were to design a building with extra space for firefighter and EMS that is currently in the existing structure, new space for the city dump truck and maintenance equipment, new space for the City Clerk's office, space for flood disaster relief equipment and supplies, and space for large meetings. All of this must be designed with flood concerns in mind, keeping all the separate departments from disturbing the others, and trying to balance meeting everyone's needs with an efficient and economical design. This facility is a Risk Category IV, which means that it must be designed to be stronger than if it was just a storage warehouse. This caused some of the framing to be difficult to design because of the size and importance of this building. One of the biggest challenges was designing the layout of the floorplan. The challenge was which direction to expand the building, and where everything inside of the building would be positioned. Another challenge was that our design team was cut in half to two people, so we had to double our efforts to overcome this challenge.

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

Historical Populations		
Year	Pop.	±%
1900	444	—
1910	416	−6.3%
1920	415	−0.2%
1930	417	+0.5%
1940	429	+2.9%
1950	423	−1.4%
1960	361	−14.7%
1970	305	−15.5%
1980	310	+1.6%
1990	306	−1.3%
2000	247	−19.3%
2010	208	−15.8%
1880	344	+65.4%
2016	201	−41.6%

Source:"American FactFinder". United States Census Bureau. and Iowa Data Center
Source:
U.S. Decennial Census[7]

Table 1.1- Volga City Historical Population

Volga has been experiencing a gradual decline in its population over the past several decades. As of the 2016 census, there were 201 people, 90 households, and 60 families living in the Volga. At a population density of 266.7 inhabitants per square mile, the city has a much higher population density then the state average of 52.7 people per square mile. Higher population density is typically accompanied by higher fire risk. Improvements in the station's capabilities such as the response time from the new expansion can be a message to prospective residents of the town's continued commitment towards creating a safe and fostering environment for all its residents. Volga's has also been affected by floods in its past and the increased occupancy capacity of the station as well as improved access to disaster relief supplies will provide an additional level of reassurance to residents in the event of future floods. The median income for a household in the city was $24,375, and the median income for a family was $29,821. Males had a median income of $22,813 versus $21,786 for females. The per capita income for the city was $13,440. About 13.7% of families and 18.1% of the population were below the poverty line, including 17.1% of those under the age of 18 and 29.8% of those 65 or over. This project has the potential to stimulate the local economy.

Section V: Design Alternatives

An alternative design that our team considered was to have a separate building that sits like a twin to the existing building on the south side of the building. Reasons for this design was the size of the lot and the worry about the design challenge of connecting the two buildings. Also, this design was considered because of the low depression of the west side of the lot that fills with water during periods of rain. This building would be offset from the existing building according to code and would be connected to the existing building with breezeways. We decided not to go with this design after research was conducted about how connecting the roof, wall, and foundation systems could be achieved. We also decided that this design did not let the two buildings work as one interconnected facility. This design also meant that the addition of the clerk's office and the large meeting space would minimize the space left available for storage and vehicles.

Alternate building materials were considered during the design process. The insulation in the walls that we chose was open-celled spray-foam insulation. The alternative to this would either be a loose fill or batt insulation. The design for these alternatives were difficult because of the odd width size of the wall cavity would make choosing a batt that would fit and installation details difficult to design. Also, an efficient way to hold the loose fill insulation would be difficult to design. The spray-foam insulation was the most expensive choice, but the ease of installation and its high insulation performance and air-infiltration capabilities made this the wall insulation of choice for our design. For a cost saving alternative, we recommend that a less expensive metal cladding that was used on the exterior walls and roof be used on the interior of the building for a ceiling and wall covering. Strength of the metal is not as important on the interior of the structure, but more for looks is what is needed. We believe that the metal would be cheaper than a plywood or drywall wall covering and still serve its purpose of looking nice and covering fixtures and holding in insulation. A couple of options for the exterior wall framing was discussed that the girts could either be 2" x 6" at 4' on center or to be 2" x 4" at 3' on center. Both options would have about the same strength capabilities. The material cost estimate reflects the girts being the 2" x 6" option.

<u>Section VI:</u> Final Design Details

Vogt and Bell - Engineering and Design team has designed a building to meet the needs of the Volga Fire Department along with the EMS and the City of Volga. The joint operations of the facility were kept in mind when this structure was designed so that each entity could operate efficiently without impeding other departments. The building expansion is sized 58' x 88' and will be connected to the existing structure. The expansion is oriented in the north/south direction and will be connected to the west wall of the existing structure. The ceiling height of this structure is 16'. The foundation stem wall has been extended 2' above the ground surface for flood concerns. The expansion has created space for the city truck with a maintenance area, a large meeting room, a bathroom with a shower, and an office for the city clerk. The expansion has also made room for the existing structure to give additional space for the EMS team to have a bay for its truck and an office of their own. There is also enough room for their gear. The expansion has allowed the space that used to have trucks stacked behind each other to be used for a staging area for firefighters to don their gear. The added space has allowed more room for flood victim accommodation with storage space to house the logistics needed for these events.

The building is designed as a post-frame building that uses columns, girts, trusses, purlins, and metal cladding. The trusses will span the entire width of the building without any support in the middle to allow the floorplan to be large and open. For this reason, the trusses are designed using DFL SS framing members. It was decided to change the species of lumber to a higher strength instead of using a wider member to handle the loads from this wide span. The truss design is the triple fink design. The top chords of the trusses are 2" x 8", the bottom chords are 2" x 6", and the web members are 2" x 4". The web members in compression get 2" x 4" lateral bracing to prevent buckling. The trusses are 4' on center. The purlins on top of the trusses are 2" x 4" at 2' on center. The trusses are tied to a double 2" x 12" SPF No. 2 beam with H14 Simpson Strong-Tie anchors. The roofs of the addition and the existing building are tied together by extending the peak of the shorter existing building into the roof of the taller expansion. The girts that run horizontally on the walls are 2" x 6" at 4' on center. These have also been designed to be 2" x 4" at 3' on center. Both designs are DFL SS. The building has 2" x 6" diagonal bracing in the corners and some intermediate areas of the building to resist lateral loads. The columns of this structure have been designed to be Weyerhaeuser 7" x 7" x 14' 1.8E TrusJoist Parallam PSL that are 8' on center. An engineered lumber column was chosen for its strength and because they do not use large trees to be manufactured like solid sawn timbers do. The columns were designed for the compression force of the large roof and for the lateral force from the wind on the large walls which causes bending. The interior walls of the structure are 2" x 4" SPF No. 2 framing members. The ceiling joists of the interior rooms in the expansion are 2" x 12" SPF No. 2. The floor on top of the interior walls in the expansion over the meeting room and city clerk's office is ¾" OSB. The wash bay walls go all the way to the 16' ceiling. The interior framing in the existing structure goes all the way up to the 12' ceiling in that area. The bottom plates for all the interior walls will be pressure treated 2" x 4" lumber because they are in contact with concrete.

These members will be powder-actuated attached to the concrete floor. The roof, ceiling, exterior walls, and most of the interior walls will be covered by metal. The interior rooms will have ½" drywall, and the wash bay will have Glasteel wall coverings. The attic will get 16" of loose-fill, blown-in cellulose insulation. This will give the attic a R53 value. The exterior walls will be filled with open-celled spray foam. The 7" wall thickness will get a value a little larger than R19. The foundation has a continuous stem wall and footing all the way around the structure. It extends 4' below grade and 2' above grade. The footing is sized 8" thick and 24" wide. The stem wall is 8" thick and has a thicker 13" x 14" area where the columns tie into the foundation stem wall with CB 7-1/8 – 7 Simpson Strong-Tie connectors. The foundation of the two buildings are tied together so that there is no differential settlement. The new addition has a 6" concrete slab on grade. Our team incorporated an integral heating system into the slab to give in-floor heating. The floor was designed to withstand the high load of the truck's tire force on the slab.

The new structure will be equipped with three 14'x14' bay doors on the north side. This will allow the facility to place three of their vehicles new parking spaces, so they do not have to stack their vehicles behind each other and free up room. It is recommended by Vogt and Bell - Engineering and Design team that a concrete box culvert be placed in the ditch to the north of the building so that the vehicles exiting the building from the expansion can cross the ditch to reach White Street. There is a walk-in door on the north side to allow access. There are also three windows on the west wall to bring in natural light in the area. The garage doors are designed to have small windows in them to bring in additional light.

The south side of the expansion has a drive through wash bay that has a 14' x 14' garage door on the east and west wall. The bay is also for permanent parking of the city truck. The floor of this wash bay is sloped into a drain in the floor. The bay was oversized to the width of the building to accommodate the longest vehicle that the station has, the number 73 truck, which is around 30 feet long and to also have enough room to start to immediately wash their gear as they return from a fire. This will help to get the harmful fire soot off themselves as soon as possible, and to keep the rest of the station free from the mess. A walk-in door in the middle of the west wall will allow access down a hallway that leads to the wash bay.

To the north of the wash bay there are several interior rooms. A 21' x 30' kitchen/meeting room has been designed to be an area to hold large meetings. An additional restroom has been designed next to the meeting room that will have two additional toilets and a shower for the firefighters. An office has been designed for the Volga City Clerk. This office is designed into the building in a way that it is separate from the rest of the operations being conducted in this building. The office opens to the east with its own door to the outside. There is also a half-bathroom in this office space and a storage area. A window on the east wall will allow natural light into the office.

These interior rooms in the new expansion all have 9' ceilings. This left a 7' space between that will be used for storage. A staircase on the west of these rooms leads up to an area which can hold storage mainly designed for flood disaster items such as cots. This storage area is about 21' x 50' so there is plenty of room for storage from all the different departments that will utilize this facility. The ceiling joists of the interior rooms have been designed to reach the 21' span and to carry the live load of all of the storage items.

The existing structure was modified on the interior. The existing storage/mechanical room was reduced so a walkway to the addition could be made. Another opening was made for an entrance to the new addition. Columns from the addition will need to be intact in this opening for structural integrity, but the existing wall is non-loadbearing. The two bathrooms in the existing structure were left alone. The kitchen was moved into the addition to give room to this area. This area is now to be used for an equipment donning staging area for firefighting operations. The area will remain open to give plenty of room for firefighters to prepare their equipment and don their personal protective equipment. It allows crews that will depart from vehicles from either the existing side or the expansion side to coordinate for final step-off instructions. This open space will also be used in case of a flood event to give flood victims space to sleep.

The EMT area in the existing structure was given more space from the expansion. A 16' x 32' bay was designed for the ambulance to be housed with its own walk-in door from the outside to make their own space. They were also given an 11' x 16' office with access to the rest of the facility to help when they work in conjunction with the fire department. The bay and office each get a window that lets in natural light. This bay and office will let them focus on their job without interference. There is enough room in the bay for their equipment, and more room is available just to the west of their office if they need more storage room. The second-story storage area in the addition can also be utilized if needed.

This building design has given space to move vehicles that were stacked behind others. These vehicles now can be driven out and used more efficiently. The areas that have been freed up can now be used for a more spacious equipment storage area and room for personnel to don gear. EMS has been given more space and separation for them to operate efficiently. A wash bay has been added with an easy drive through design which means that each vehicle does not have to back in each time. Bigger doors in the expansion means that drivers can quickly step-off without the worry of hitting their mirrors. A designated area for the city truck and maintenance equipment has been designed. A city clerk's office with a bathroom and storage has been incorporated into the building as a separate and self-contained area. The taller addition means that a second-story storage area could be designed to keep over 1,000 square feet of supplies needed by all departments. The large meeting area can now be used to hold meetings for all purposes. The sitework from our design was dropped from our scope due to personnel changes. Our team did design site proposals such as gravel expansion in the southeast region of the property for more parking and the drive through bay and a gravel parking and driveway in the west of the property for the drive through wash bay.

Section VII: **Engineer's Cost Estimate**

The cost for structural materials for this project were taken from 2020 market values from material distributors in the area. These values are without taxes or a waste factor. The waste factor usually used in construction is around 10-20%. Due to our client using volunteer labor to construct the building, we have recommended that a factor closer to 20% be used for construction material cost. The total cost for structural material cost including framing, foundation, and slab with the waste factor is about $119,000. Plumbing, Electrical, & Mechanical (materials) will be an additional $35,000.

Material	Quantity	Unit price	Total cost
2x4 DFL Select Structural (ft)	5515	0.6945	$3,830.17
2x6 DFL Select Structural (ft)	2309	0.9945	$2,296.30
2x8 DFL Select Structural (ft)	1445	1.2845	$1,856.10
2x4 Pressure Treated (ft)	225	0.8495	$191.14
2x4 SPF No. 2 (ft)	2884	0.6595	$1,902.00
2x12 SPF No. 2 (ft)	847	2.6495	$2,244.13
7x7x14 PSL (ft)	462	19.02	$8,787.24
4x8x3/4 OSB (ea.)	33	19.69	$649.77
4x8x1-1/8 OSB (ea.)	4	49.99	$199.96
CB 7-1/8-7 connector (ea.)	33	66.86	$2,206.38
H14 anchor (ea.)	46	2.86	$131.56
Cellulose insulation (ea.)	320	13.5	$4,320.00
Spray-foam insulation (ft^3)	1446	8.4	$12,146.40
Rigid foam board (ea.)	160	34.99	$5,598.40
Overhead door (ea.)	5	1638	$8,190.00
Exterior walk-in door (ea.)	3	200	$600.00
Interior door (ea.)	9	109	$981.00
Window (ea.)	7	115.69	$809.83
Metal cladding (ea.)	330	42.55	$14,041.50
Glasteel (ft^2)	928	1.67	$1,549.76
Gypsum board (ea.)	135	10.14	$1,368.90
Concrete (yd^3)	151	97	$14,647.00
Steel reinforcement (ea.)	600	13.79	$8,274.00
Fasteners (tot.)	2000	1	$2,000.00
		Sum =	$98,821.53
		Waste =	1.2
		Total =	$118,585.84

Plumbing, Electrical, & Mechanical

Item	Quantity	Unit	Unit Price	Total Cost
1/2" Pex Tubing	10000	lf	0.2044	$ 2,044.00
1/2" Copper	100	lf	0.68	$ 68.00
3/4" Copper	100	lf	1.1	$ 110.00
1" Copper	100	lf	1.841	$ 184.10
Valves & Fittings	1	L.S.	2500	$ 2,500.00
Radiant 1/25 HP Circulator Pump	6	each	75.64	$ 453.84
Radiant Zone Control	6	each	57.84	$ 347.04
150k BTU Condensing Boiler	2	each	1682.1	$ 3,364.20
Radiant Control Integration & Panel	1	each	2000	$ 2,000.00
Lavatory	3	each	200	$ 600.00
Water Closet	3	each	300	$ 900.00
5' Shower	1	each	400	$ 400.00
2" DWV PVC	75	lf	0.39	$ 29.25
4" DWV PVC	75	lf	0.98	$ 73.50
6" Sewer PVC	200	lf	2	$ 400.00
PCV Fittings	1	LS	500	$ 500.00
Cleanout Structure	1	each	500	$ 500.00
Air Conditioning Condensor	2	each	2750	$ 5,500.00
Condensor Line Set	2	each	150	$ 300.00
AC Air Handler	2	each	750	$ 1,500.00
Light Fixtures	40	each	100	$ 4,000.00
Door openers	5	each	250	$ 1,250.00
12 Guage Romex	3000	lf	0.2	$ 600.00
Channel Drain	50	lf	100	$ 5,000.00
				$ 32,623.93

Appendices

A. Design loads and truss design calculations

See attached Truss Calculations file

B. Framing design calculations

See attached Framing Calculations file

C. Foundation design calculations

See attached Foundation Calculations file

D. Material cost calculations

See attached Material cost calculations file

Design Drawings

Design Renderings and Models

Design Loads

Snow load

Risk category IV

$I_s := 1.2$

$p_g := 30\ psf$

Surface roughness category C

Partially Exposed

$C_e := 1.0$

$C_t := 1.1$ with insulation

$p_f := 0.7 \cdot C_e \cdot C_t \cdot I_s \cdot p_g = 27.72\ psf$

Existing roof slope:

$\frac{8}{22.5} = 0.356 \quad 0.356 \cdot 12 = 4.272 \qquad \frac{4}{12}$

Use for new building $\frac{5}{12}$ Or $\theta := \operatorname{atan}\left(\frac{5}{12}\right) = 22.62\ °$

$C_s := 1$ Snow guards

$p_s := C_s \cdot p_f = 27.72\ psf$ Balanced snow load

Unbalanced snow load:

1/2:12 < 5:12 < 7:12

Simply supported roof framing

$W := \frac{58}{2}\ ft + 16\ in = 30.333\ ft$ > 20 ft with 16 in. eave

∴ Load pattern Unbalanced Other for gable roof

$l_u := W = 30.333\ ft$

$h_d := 0.43 \cdot \sqrt[3]{30.333} \cdot \sqrt[4]{30 + 10} - 1.5 = 1.873$

$h_d := 1.873\ ft$

$S := \frac{12}{5} = 2.4$

$\gamma := 0.13 \cdot 30 + 14 = 17.9$

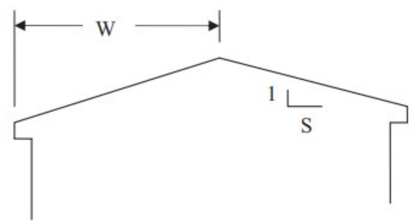
$\gamma := 17.9\ pcf$

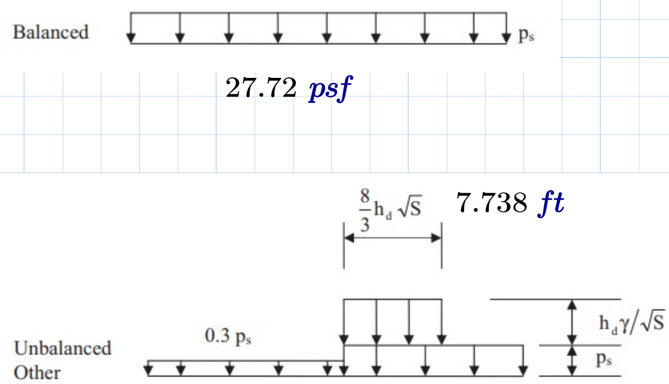
$0.3 \cdot p_s = 8.316\ psf$

$\frac{h_d \cdot \gamma}{\sqrt{S}} + p_s = 49.361\ psf$

$p_s = 27.72\ psf$

$\frac{8}{3} \cdot h_d \cdot \sqrt{S} = 7.738\ ft$





$27.72\ psf$

$7.738\ ft$

$8.316\ psf$ $49.361\ psf$ $27.72\ psf$

To project onto surface for structural analysis software

$W = 30.333\ ft$ Horizontal from facia to peak

$Rise := \frac{5}{12} \cdot W = 12.639\ ft$ Eave to peak vertical

$L := \frac{W}{\cos(\theta)} = 32.861\ ft$ Length of top chord

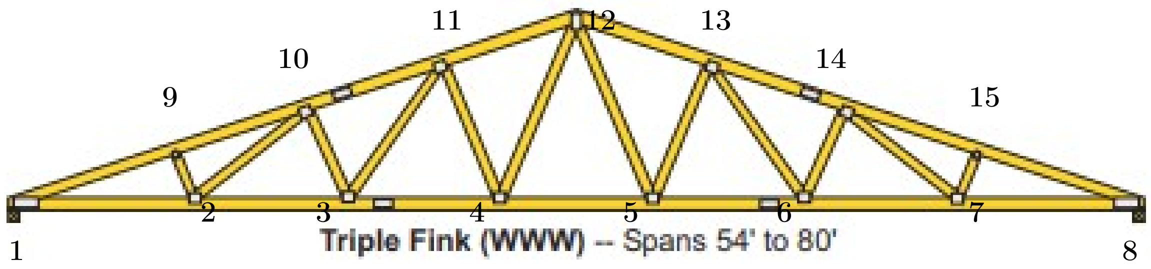
Projected and distributed snow loads

$w_{s1} := 27.72\ psf \cdot \cos(\theta) \cdot 4\ ft = 0.102\ \frac{kip}{ft}$

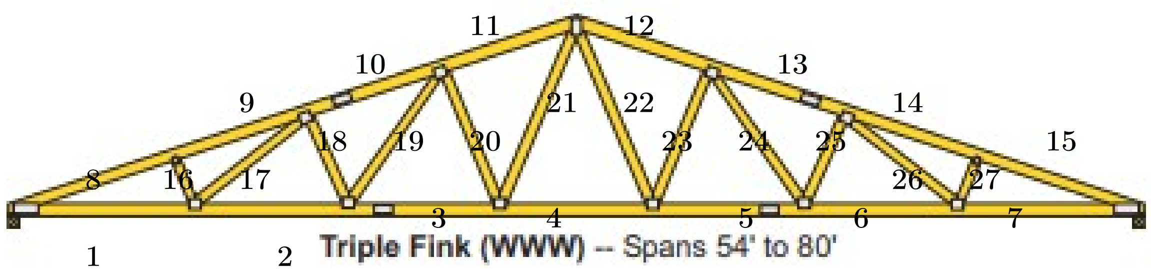
$w_{s2} := 8.316\ psf \cdot \cos(\theta) \cdot 4\ ft = 0.031\ \frac{kip}{ft}$

$w_{s3} := 46.55\ psf \cdot \cos(\theta) \cdot 4\ ft = 0.172\ \frac{kip}{ft}$

Nodes:



Members:



Nodes	x (ft)	y (ft)
1	0	0
2	8.286	0
3	16.571	0
4	24.857	0
5	33.143	0
6	41.429	0
7	49.714	0
8	58	0
9	7.25	3.021
10	14.50	6.042
11	21.75	9.063
12	29.00	12.083
13	36.25	9.063
14	43.50	6.042
15	50.75	3.021

<u>Roof live load</u>

$L_r := 20\ psf$ Upper Chord

<u>Live load</u>

$LL_3 := 50\ psf$ Offices Floor

$LL_4 := 40\ psf$ Ceiling of office with storage above.

<u>Dead load</u>

Upper Chord:

Aluminum roofing

$D_1 := 1\ psf$

2 ft o.c. purlins

$G := 0.5$

$\gamma := G \cdot 62.4\ \frac{lbf}{ft^3} = 31.2\ \frac{lbf}{ft^3}$

Purlins

$D_2 := \frac{\gamma \cdot 1.5\ in \cdot 3.5\ in}{2\ ft} = 0.569\ psf$

Lower Chord:

$D_3 := 0.14\ \frac{psf}{in} \cdot 16\ in = 2.24\ psf$ Insulation - Blown in cellulose

$D_4 := 4\ psf$ Mechanical

$D_5 := \frac{\gamma \cdot 47.05\ ft^2 \cdot 1.5\ in}{58\ ft \cdot 4\ ft} = 0.791\ psf$ Top chord + web member self weights

$D_1 := 1\ psf$ Aluminum ceiling

$D_6 := 1\ psf$ Lighting/electrical

$D_7 := 1\ psf$ Plumbing

Wind load - Envelope method

$V := 120\ mph$

$h_e := 16\ ft$

$h_p := h_e + \frac{58\ ft}{2} \cdot \frac{5}{12} = 28.083\ ft$

$h := \frac{h_e + h_p}{2} = 22.042\ ft$ < $lhd := 58\ ft$ < $60\ ft$

Low-rise building

$K_{zt} := 1.0$

Exposure C

$h = 22.042\ ft$

$y_1 := 1.35$ $x_1 := 25$ $x := 22.042$

$y_0 := 1.29$ $x_0 := 20$

$y := y_0 + (x - x_0) \cdot \frac{y_1 - y_0}{x_1 - x_0} = 1.315$

$\lambda := 1.315$

p_{s30} from linear interpolation of Figure 28.6-1:

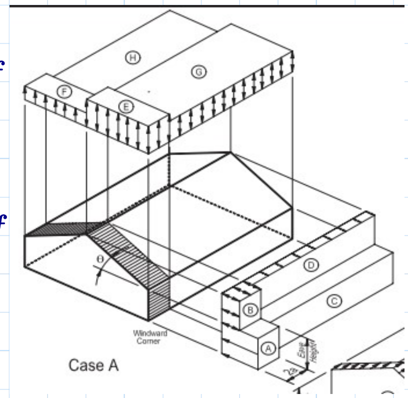
$\theta = 22.62\ °$

$y_1 := 28.6$ $x_1 := 25$ $x := 22.62$

$y_0 := 31.6$ $x_0 := 20$

$y := y_0 + (x - x_0) \cdot \frac{y_1 - y_0}{x_1 - x_0} = 30.028$

Case A: Longitudinal



$A := 30.028\ psf$ $\quad E := -19.697\ psf$ $\quad E_{OH} := -30.697\ psf$

$B := -1.54\ psf$ $\quad F := -18.157\ psf$

$C := 20.89\ psf$ $\quad G := -13.912\ psf$ $\quad G_{OH} := -24.912\ psf$

$D := 0.273\ psf$ $\quad H := -14.186\ psf$

Adjusted wind pressures p_s:

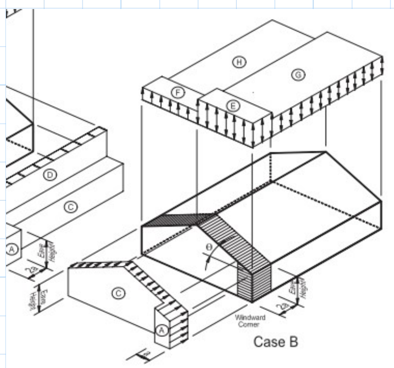
$\lambda \cdot K_{zt} \cdot A = 39.487\ psf$ $\quad \lambda \cdot K_{zt} \cdot E = -25.902\ psf$ $\quad \lambda \cdot K_{zt} \cdot E_{OH} = -40.367\ psf$

$\lambda \cdot K_{zt} \cdot B = -2.025\ psf$ $\quad \lambda \cdot K_{zt} \cdot F = -23.876\ psf$

$\lambda \cdot K_{zt} \cdot C = 27.47\ psf$ $\quad \lambda \cdot K_{zt} \cdot G = -18.294\ psf$ $\quad \lambda \cdot K_{zt} \cdot G_{OH} = -32.759\ psf$

$\lambda \cdot K_{zt} \cdot D = 0.359\ psf$ $\quad \lambda \cdot K_{zt} \cdot H = -18.655\ psf$

Case B: Traverse $\quad \theta := 0\ °$



$A := 22.8\ psf$ $\quad E := -27.4\ psf$ $\quad E_{OH} := -38.4\ psf$

$F := -15.6\ psf$

$C := 15.1\ psf$ $\quad G := -19.1\ psf$ $\quad G_{OH} := -30.1\ psf$

$H := -12.1\ psf$

Adjusted wind pressures p_s:

$\lambda \cdot K_{zt} \cdot A = 29.982\ psf$ $\quad \lambda \cdot K_{zt} \cdot E = -36.031\ psf$ $\quad \lambda \cdot K_{zt} \cdot E_{OH} = -50.496\ psf$

$\lambda \cdot K_{zt} \cdot F = -20.514\ psf$

$\lambda \cdot K_{zt} \cdot C = 19.857\ psf$ $\quad \lambda \cdot K_{zt} \cdot G = -25.117\ psf$ $\quad \lambda \cdot K_{zt} \cdot G_{OH} = -39.582\ psf$

$\lambda \cdot K_{zt} \cdot H = -15.912\ psf$

Total design load

$S := p_s = 27.72\ psf$

$D_{top} := D_1 + D_2 = 1.569\ psf$ $\qquad D_{top} := 2\ psf$

$D_{bottom} := D_1 + D_3 + D_5 + D_6 = 5.031\ psf$ $\qquad D_{bottom} := 5\ psf$

$W := -36.031\ psf$

Top chord:

(1) $D_{top} = 2\ psf$

(3) $D_{top} + S = 29.72\ psf$

(4) $D_{top} + 0.75 \cdot S = 22.79\ psf$

(5) $D_{top} + 0.6 \cdot W = -19.619\ psf$

(6a) $D_{top} + (0.6 \cdot W) + 0.75 \cdot S = 1.171\ psf$

(7) $0.6 \cdot D_{top} + 0.6 \cdot W = -20.419\ psf$

Bottom chord:

(1) $D_{bottom} = 5\ psf$

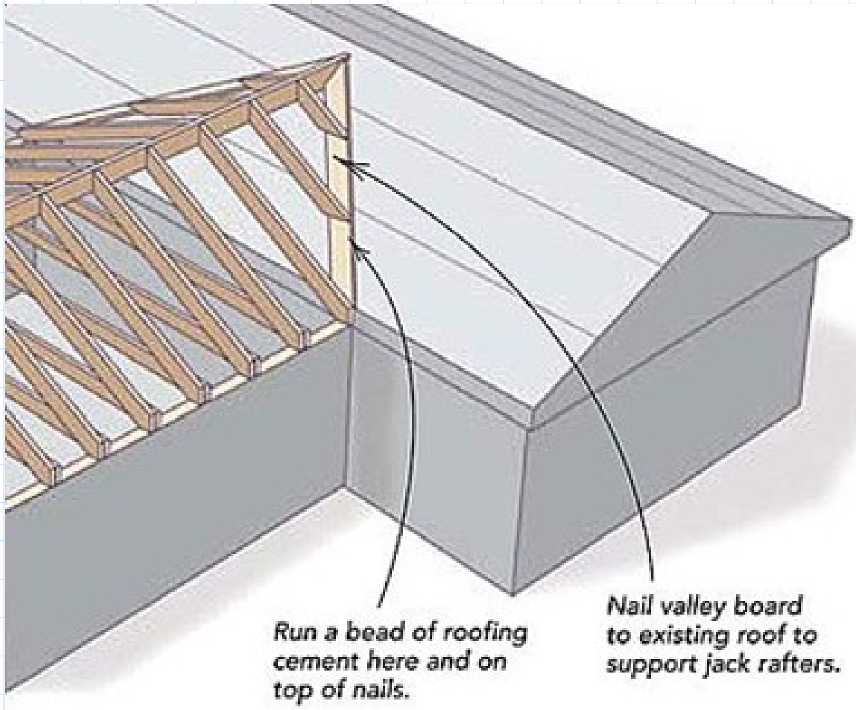
$\theta := \operatorname{atan}\left(\frac{5}{12}\right) = 22.62\ °$

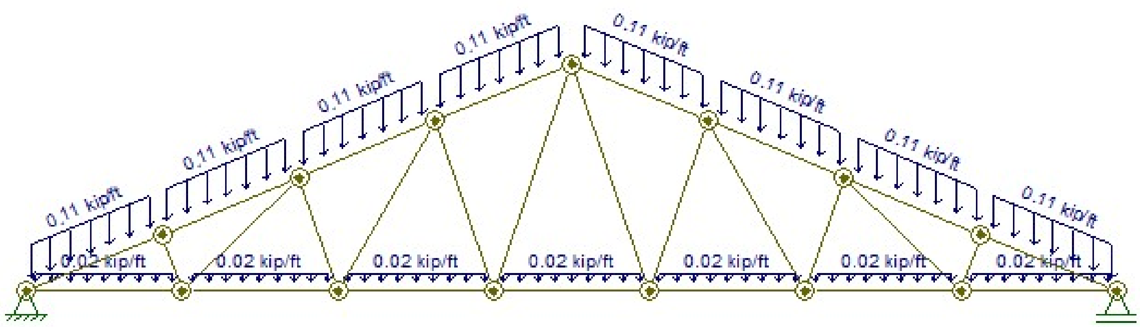
$\cos(\theta) = 0.923$

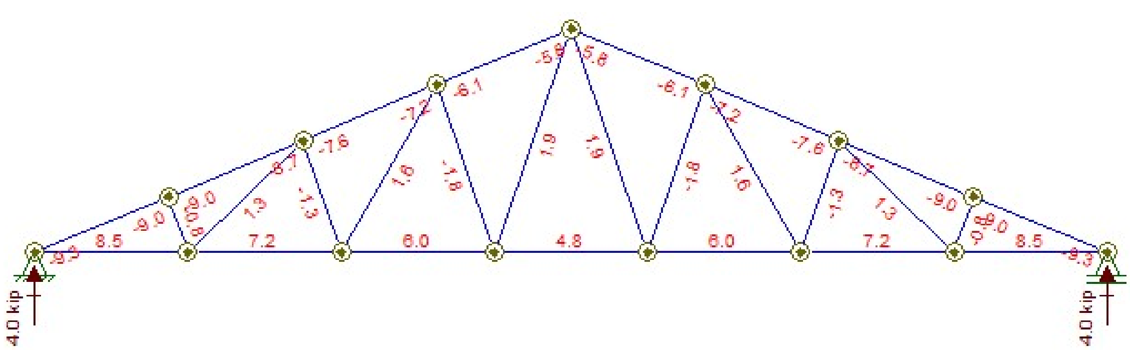
$w_{upper} := 29.72\ psf \cdot \cos(\theta) \cdot 4\ ft = 0.11\ \frac{kip}{ft}$

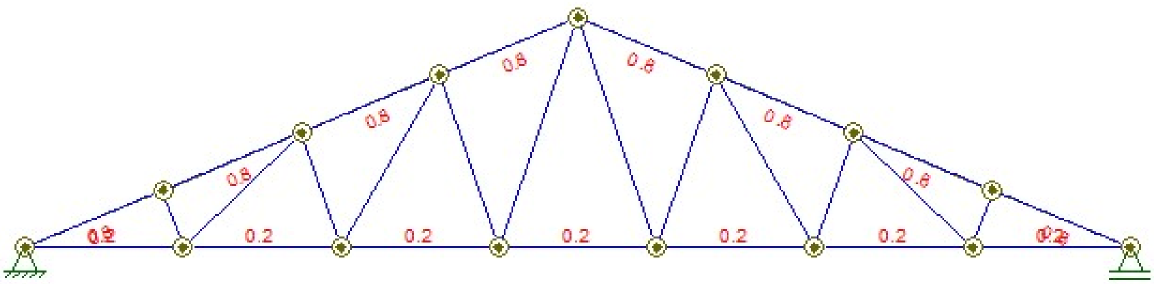
$w_{lower} := 5\ psf \cdot 4\ ft = 0.02\ \frac{kip}{ft}$

$w_{purlin} := (D_1 + S) \cdot \cos(\theta) \cdot 4\ ft = 0.106\ \frac{kip}{ft}$


Run a bead of roofing cement here and on top of nails.
Nail valley board to existing roof to support jack rafters.


0.11 kip/ft
0.02 kip/ft


4.0 kip
4.0 kip



Final structural design calculations demonstrating the roof truss top and bottom chords satisfy the NDS requirements for combined bending and axial force:

Top chord:

2 x 8 DFL Select Structural

$M_{utop} := 0.8\ kip \cdot ft$

$T_{utop} := 9.3\ kip$

$$L := \frac{\sqrt{\left(\frac{58\ ft}{2}\right)^2 + (12.083\ ft)^2}}{4} = 7.854\ ft$$

$b := 1.5\ in$

$d := 7.25\ in$

$S_x := 13.14\ in^3$

$A_g := 10.88\ in^2$

$F_b := 1500\ psi$

$F_t := 1000\ psi$

$F_c := 1700\ psi$

$E_{min} := 690\ ksi$

$C_D := 1.6$ Top chord

$C_M := 1.0$

$C_t := 1.0$

$C_{F1} := 1.2$ For F'_b

$C_{F2} := 1.05$ For F'_c

$C_{fu} := 1.0$

$C_i := 1.0$

$C_r := 1.0$

$C_T := 1.0$

d/b = $\frac{6}{2} = 3$ Case (b), Ends shall be held in position, as by full depth solid blocking, bridging, hangers, nailing, or bolting to other framing members, or other acceptable means.

$C_L := 1.0$ NDS 3.3.3.2: In accordance with NDS 4.4.1

$l_{u2} := 2\ ft$

$d_2 := 1.5\ in$

$K_e := 1$

$l_{e2} := K_e \cdot l_{u2} = 2\ ft$

$\frac{l_{e2}}{d_2} = 16$ < 50 Ok

$l_{u1} := 7.854\ ft$

$d_1 := d = 7.25\ in$

$l_{e1} := K_e \cdot l_{u1} = 7.854\ ft$

$\frac{l_{e1}}{d_1} = 13$ < 50 Ok

$l_e := l_{e1}$

$d := d_1$

$c := 0.8$

$E'_{min} := E_{min} \cdot C_M \cdot C_t \cdot C_i \cdot C_T = \left(6.9 \cdot 10^5\right)\ psi$

$$F_{cE} := \frac{0.822 \cdot E'_{min}}{\left(\frac{l_e}{d}\right)^2} = \left(4.833 \cdot 10^5\right)\ psf$$

$F_{cstar} := F_c \cdot C_D \cdot C_M \cdot C_t \cdot C_{F2} \cdot C_i = \left(4.113 \cdot 10^5\right)\ psf$

$$C_P := \frac{1 + \left(\frac{F_{cE}}{F_{cstar}}\right)}{2 \cdot c} - \sqrt{\left(\frac{1 + \left(\frac{F_{cE}}{F_{cstar}}\right)}{2 \cdot c}\right)^2 - \frac{\frac{F_{cE}}{F_{cstar}}}{c}} = 0.744$$

$F_{bstar} := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_{F1} \cdot C_{fu} \cdot C_i \cdot C_r = \left(4.147 \cdot 10^5\right)\ psf$

$F'_b := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_L \cdot C_{F1} \cdot C_{fu} \cdot C_i \cdot C_r = \left(4.147 \cdot 10^5\right)\ psf$

$F'_c := F_c \cdot C_D \cdot C_M \cdot C_t \cdot C_{F2} \cdot C_i \cdot C_P = \left(3.058 \cdot 10^5\right)\ psf$

Check compression:

$f_c := \frac{T_{utop}}{A_g} = \left(1.231 \cdot 10^5\right)\ psf$ $<$ $F'_c = \left(3.058 \cdot 10^5\right)\ psf$ Ok

Check bending:

$f_b := \frac{M_{utop}}{S_x} = \left(1.052 \cdot 10^5\right)\ psf$ $<$ $F'_b = \left(4.147 \cdot 10^5\right)\ psf$ Ok

Check combined bending and axial compression:

$$F_{cE1} := \frac{0.822 \cdot E'_{min}}{\left(\frac{l_{e1}}{d_1}\right)^2} = \left(4.833 \cdot 10^5\right)\ psf$$

$$B_1 := \left(1 - \left(\frac{f_c}{F_{cE1}}\right)\right)^{-1} = 1.342$$

$$\left(\frac{f_c}{F'_c}\right)^2 + B_1 \cdot \left(\frac{f_b}{F'_b}\right) = 0.502$$ < 1 Ok

Bottom chord:

2x6 DFL Select Structural

$M_{ubottom} := 0.2\ kip \cdot ft$

$T_{ubottom} := 8.5\ kip$

$A_g := 8.25\ in^2$

$S_x := 7.56\ in^3$

$C_D := 0.9$ Bottom chord

$C_F := 1.3$

$F_{bstar} := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_{fu} \cdot C_i \cdot C_r = \left(2.527 \cdot 10^5\right)\ psf$

$F'_b := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_L \cdot C_F \cdot C_{fu} \cdot C_i \cdot C_r = \left(2.527 \cdot 10^5\right)\ psf$

$F'_t := F_t \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i = \left(1.685 \cdot 10^5\right)\ psf$

Check tension:

$f_t := \frac{T_{ubottom}}{A_g} = \left(1.484 \cdot 10^5\right)\ psf$ < $F'_t = \left(1.685 \cdot 10^5\right)\ psf$ Ok

Check bending:

$f_b := \frac{M_{ubottom}}{S_x} = \left(4.571 \cdot 10^4\right)\ psf$ < $F'_b = \left(2.527 \cdot 10^5\right)\ psf$ Ok

Check combined bending and axial tension:

$\frac{f_t}{F'_t} + \frac{f_b}{F_{bstar}} = 1$ <= 1 Ok

$\frac{f_b - f_t}{F'_b} = -0.406$ <= 1 Ok

Check deflection for truss:

$L := 58\ ft$

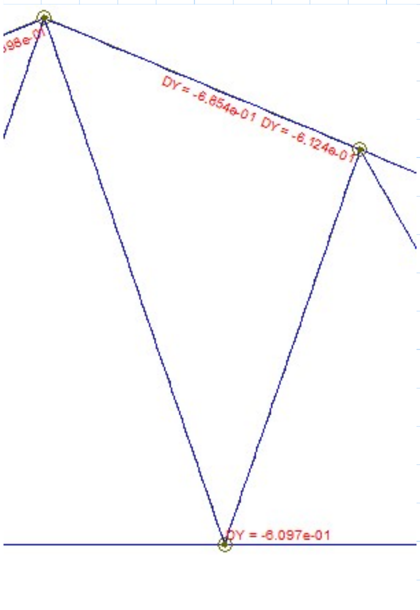
Truss deformed shape, with magnitudes, due to live (or snow) load:

Top chord:

$27.72\ psf \cdot \cos(\theta) \cdot 4\ ft = 0.102\ \frac{kip}{ft}$

Bottom chord:

$0\ \frac{kip}{ft}$



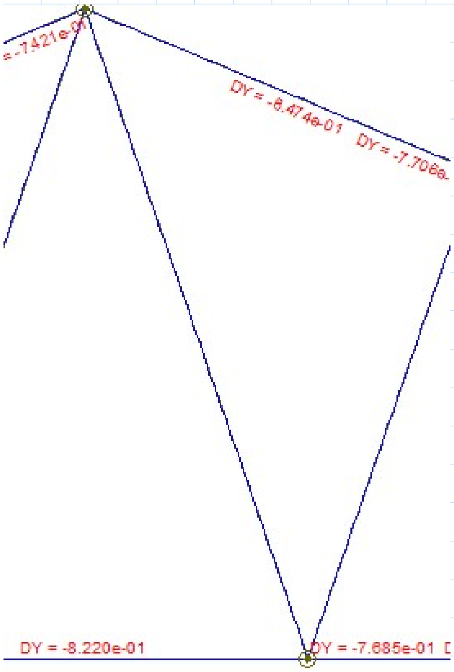
Truss deformed shape, with magnitudes, due to total load:

Top chord:

$$w_{upper} := 29.72\ psf \cdot \cos(\theta) \cdot 4\ ft = 0.11\ \frac{kip}{ft}$$

Bottom chord:

$$w_{lower} := 5\ psf \cdot 4\ ft = 0.02\ \frac{kip}{ft}$$



$\Delta_{2x6} := 0.6097\ in$

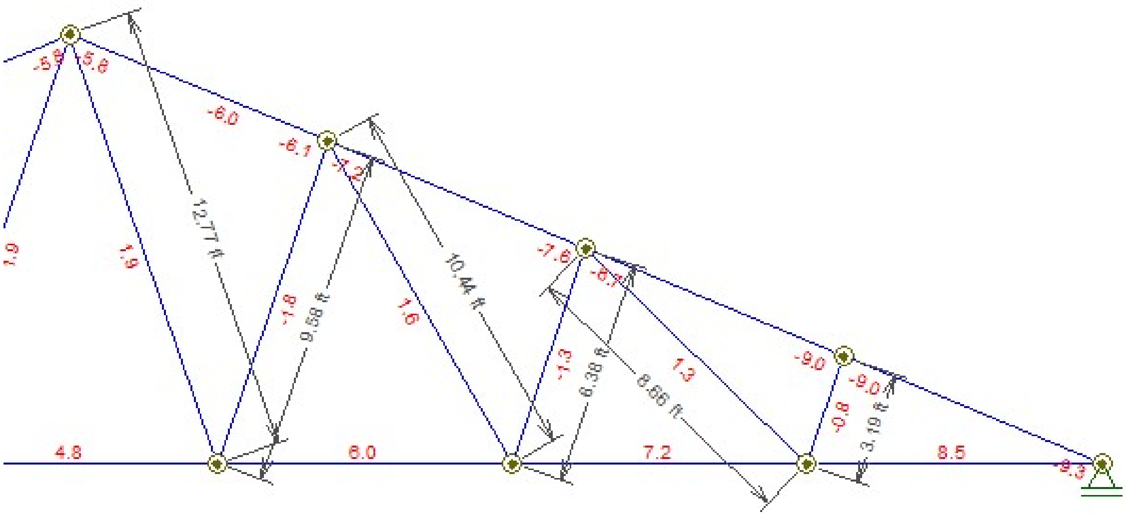
$\Delta_{2x8} := 0.685\ in$

$<$ $\Delta_{st} := \frac{L}{240} = 2.9\ in$ Ok

$\Delta_{max2x6} := 0.822\ in$

$\Delta_{max2x8} := 0.847\ in$

$<$ $\Delta_{tot} := \frac{L}{180} = 3.867\ in$ Ok



Final structural design calculations demonstrating the roof truss web members satisfy the NDS requirements for axial force (tension or compression):

Check each web member:

2 x 4 DFL Select structural

$A_g := 5.25\ in^2$

$d_1 := 3.5\ in$

$d_2 := 1.5\ in$

$l_{e1} := 9.58\ ft$

$l_{e2} := 6.38\ ft$

$l_{e3} := 3.19\ ft$

$\frac{l_{e1}}{d_1} = 32.846$ < 50 Ok

$\frac{l_{e1}}{d_2} = 76.64$ > 50 Bracing required

Brace mid-span: $l_{e1} := \frac{9.58\ ft}{2} = 4.79\ ft$

$\frac{l_{e1}}{d_2} = 38.32$ < 50 Ok

$\frac{l_{e2}}{d_1} = 21.874$ < 50 Ok

$\frac{l_{e2}}{d_2} = 51.04$ < 50 Bracing required

Brace mid-span: $l_{e2} := \frac{6.38\ ft}{2} = 3.19\ ft$

Members 20, 23, 18, 25 recieve lateral bracing about weak axis at halfway point.

$\frac{l_{e2}}{d_2} = 25.52$ < 50 Ok

$\frac{l_{e3}}{d_1} = 10.937$ < 50 Ok

Web members in tension:

$T_{uweb1} := 1.9\ kip$

$T_{uweb2} := 1.6\ kip$

$T_{uweb3} := 1.3\ kip$

$C_D := 1.15$

$C_F := 1.5$

$F'_t := F_t \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i = \left(2.484 \cdot 10^5\right)\ psf$

Check tension for web members:

$f_t := \frac{T_{uweb1}}{A_g} = \left(5.211 \cdot 10^4\right)\ psf$ < $F'_t = \left(2.484 \cdot 10^5\right)\ psf$ Ok

$f_t := \frac{T_{uweb2}}{A_g} = \left(4.389 \cdot 10^4\right)\ psf$ < $F'_t = \left(2.484 \cdot 10^5\right)\ psf$ Ok

$f_t := \frac{T_{uweb3}}{A_g} = \left(3.566 \cdot 10^4\right)\ psf$ < $F'_t = \left(2.484 \cdot 10^5\right)\ psf$ Ok

Web members in compression:

$T_{uweb4} := 1.8\ kip$

$T_{uweb5} := 1.3\ kip$

$T_{uweb6} := 0.8\ kip$

$$F_{cE} := \frac{0.822 \cdot E'_{min}}{\left(\frac{l_{e1}}{d_2}\right)^2} = \left(5.562 \cdot 10^4\right)\ psf$$

$C_F := 1.15$

$$F_{cstar} := F_c \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i = \left(3.237 \cdot 10^5\right)\ psf$$

$$C_P := \frac{1 + \left(\frac{F_{cE}}{F_{cstar}}\right)}{2 \cdot c} - \sqrt{\left(\frac{1 + \left(\frac{F_{cE}}{F_{cstar}}\right)}{2 \cdot c}\right)^2 - \frac{\frac{F_{cE}}{F_{cstar}}}{c}} = 0.165$$

$$F'_{c1} := F_c \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i \cdot C_P = \left(5.35 \cdot 10^4\right)\ psf$$

$$F_{cE} := \frac{0.822 \cdot E'_{min}}{\left(\frac{l_{e2}}{d_2}\right)^2} = \left(1.254 \cdot 10^5\right)\ psf$$

$$C_P := \frac{1 + \left(\frac{F_{cE}}{F_{cstar}}\right)}{2 \cdot c} - \sqrt{\left(\frac{1 + \left(\frac{F_{cE}}{F_{cstar}}\right)}{2 \cdot c}\right)^2 - \frac{\frac{F_{cE}}{F_{cstar}}}{c}} = 0.35$$

$$F'_{c2} := F_c \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i \cdot C_P = \left(1.132 \cdot 10^5\right)\ psf$$

Check compression for web members:

$f_c := \frac{T_{uweb4}}{A_g} = (4.937 \cdot 10^4)\ psf$ < $F'_{c1} = (5.35 \cdot 10^4)\ psf$ Ok

$f_c := \frac{T_{uweb5}}{A_g} = (3.566 \cdot 10^4)\ psf$ < $F'_{c2} = (1.132 \cdot 10^5)\ psf$ Ok

$f_c := \frac{T_{uweb6}}{A_g} = (2.194 \cdot 10^4)\ psf$ < $F'_{c2} = (1.132 \cdot 10^5)\ psf$ Ok

Check for bearing:

$F_{cperp} := 625\ psi$

$l_b := 7.25\ in$

$C_b := 1.0$

$F'_{cperp} := F_{cperp} \cdot C_M \cdot C_t \cdot C_i \cdot C_b = (9 \cdot 10^4)\ psf$

$P := 4\ kip$

$w_b := 1.5\ in$

$A_b := l_b \cdot w_b = 10.875\ in^2$

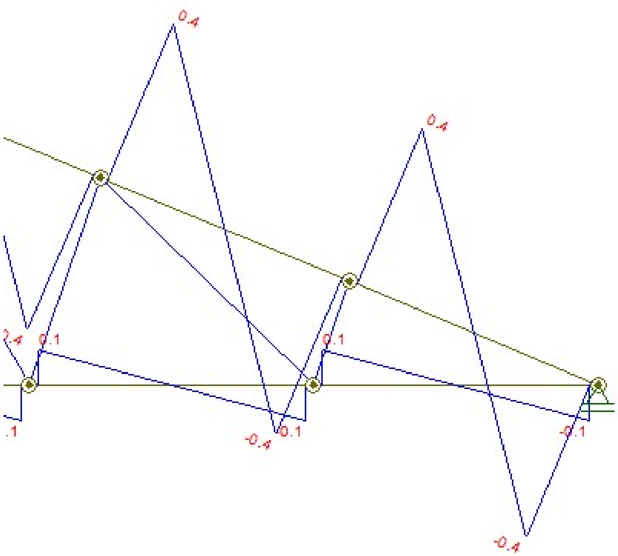
$f_{cperp} := \frac{P}{A_b} = (5.297 \cdot 10^4)\ psf$ < $F'_{cperp} = (9 \cdot 10^4)\ psf$ Ok

Check for shear:

$F_V := 180\ psi$

$C_D := 1.15$

$F'_V := F_V \cdot C_D \cdot C_M \cdot C_t \cdot C_i = (2.981 \cdot 10^4)\ psf$



$V_1 := 0.1\ kip$

$V_2 := 0.4\ kip$

$b := 1.5\ in$

$d_1 := 5.5\ in$

$d_2 := 7.25\ in$

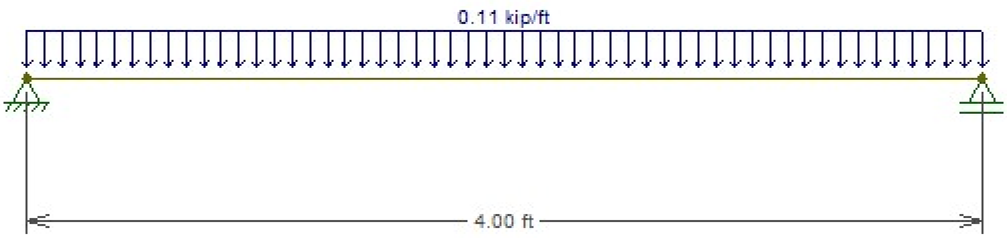
$$f_{Vbot} := \frac{3 \cdot V_1}{2 \cdot b \cdot d_1} = \left(2.618 \cdot 10^3\right)\ psf$$

$$f_{Vtop} := \frac{3 \cdot V_2}{2 \cdot b \cdot d_2} = \left(7.945 \cdot 10^3\right)\ psf$$

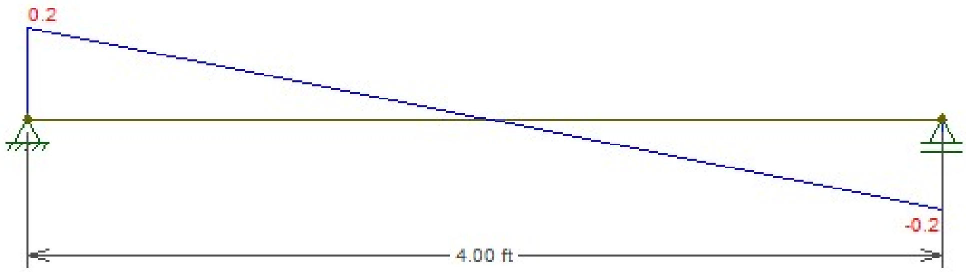
$f_{Vbot} = \left(2.618 \cdot 10^3\right)\ psf$ < $F'_V = \left(2.981 \cdot 10^4\right)\ psf$ Ok

$f_{Vtop} = \left(7.945 \cdot 10^3\right)\ psf$ < $F'_V = \left(2.981 \cdot 10^4\right)\ psf$ Ok

Check purlins:



Check purlins for shear:

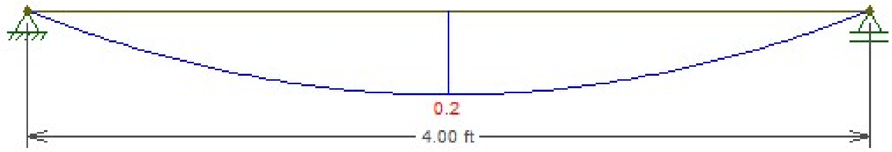


$V_3 := 0.2\ kip$

$d_3 := 3.5\ in$

$f_{Vpurlin} := \frac{3 \cdot V_3}{2 \cdot b \cdot d_3} = \left(8.229 \cdot 10^3\right)\ psf$ < $F'_V = \left(2.981 \cdot 10^4\right)\ psf$ Ok

Check bending:



$M_{upurlin} := 0.2\ kip \cdot ft$

$S_x := 3.06\ in^3$

$C_D := 1.25$

$C_F := 1.5$

$C_r := 1.15$

$F'_b := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_L \cdot C_F \cdot C_{fu} \cdot C_i \cdot C_r = \left(4.658 \cdot 10^5\right)\ psf$

$f_b := \dfrac{M_{utop}}{S_x} = \left(4.518 \cdot 10^5\right)\ psf$ < $F'_b = \left(4.658 \cdot 10^5\right)\ psf$ Ok

Check for uplift:

$WT_{truss} := 11.789\ ft^3 \cdot \gamma = 367.817\ lbf$

$D_{truss} := \dfrac{WT_{truss}}{4\ ft \cdot 58\ ft} = 1.585\ psf$

$D_{tot} := D_{truss} + 2 \cdot D_1 + D_2 + D_3 + D_6 = 7.394\ psf$

$W := -25.117\ psf$

$D_{tot} + 0.6 \cdot W = -7.676\ psf$

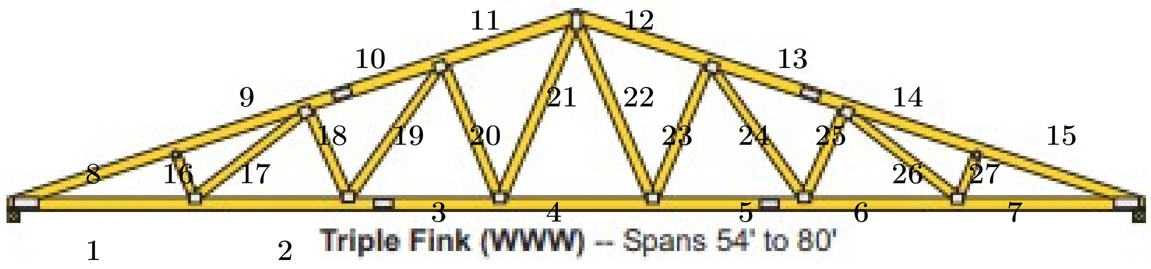
$T_{net} := 7.676\ psf \cdot 4\ ft \cdot 29\ ft = 890.416\ lbf$

$T_{allow} := 1015\ lbf$ Using TSP from Simpson catalogue

$T_{net} = 890.416\ lbf$ < $T_{allow} = \left(1.015 \cdot 10^3\right)\ lbf$ Ok

Truss Summary

Members:



Top chord: 2 x 8 DFL Select Structural

Bottom chord: 2 x 6 DFL Select Structural

Web members: 2 x 4 DFL Select Structural

- Members 20, 23, 18, 25 recieve lateral bracing about weak axis at halfway point.

Lateral bracing: 2 x 4 DFL Select Structural

Purlins: 2 x 4 DFL Select Structural @ 2' spacing

Uplift anchors: TSP - Simpson strong tie

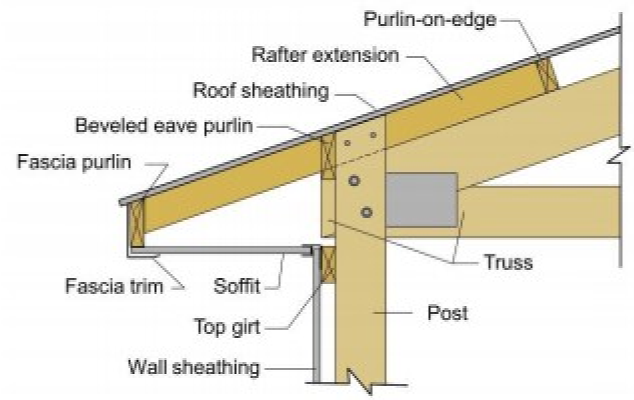


Figure 1-13. Cross-sectional view through an eave overhang that is supported by a rafter extension that runs continuously from the edge purlin/sub-fascia to the first purlin above the post. The rafter extension is fastened to the post, purlin, and top of the truss.

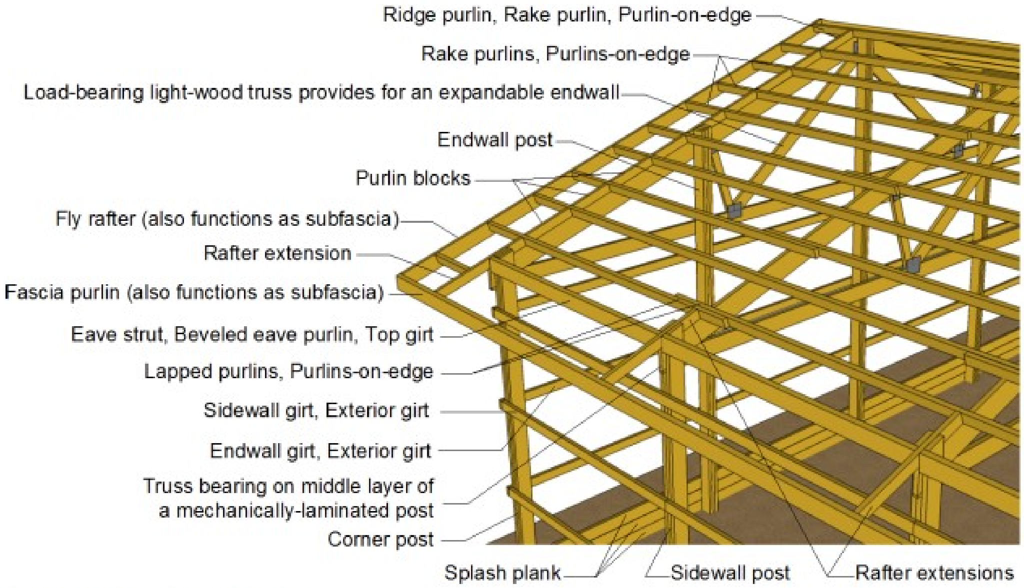


Figure 1-10. Typical corner framing.

Design Framing Members

Columns: 7" x 7" x 14' 1.8E TrusJoist Parallam PSL @ 8' spacing

Manufacturer: Weyerhaeuser

Quality assurance agency: PFS and ICC-ES

See ICC-ES ESR 1387 for specs.

Column base connector: CB 7-1/8 - 7 Simpson Strong-Tie

Post or concrete controlls allowable load for column base.

Truss header: 4" x 8" DFL Select Structural

Girts: 2" x 6" DFL Select Structural @ 4' spacing

Door headers: 2" x 12" LVL

Building dimensions: 55' x 88'

Interior room ceiling joists: 2" x 12"

Plywood sheathing for subfloor of loft: 3/4in

Stringers for stairs to loft: 2" x 12"

$h_e := 16\ ft$

$lhd := 58\ ft$

$L := 88\ ft$

$h_p := h_e + \frac{58\ ft}{2} \cdot \frac{5}{12} = 28.083\ ft$

$h := \frac{h_e + h_p}{2} = 22.042\ ft$

$a_1 := 0.1 \cdot lhd = 5.8\ ft$

$a_2 := 0.4 \cdot h = 8.817\ ft$

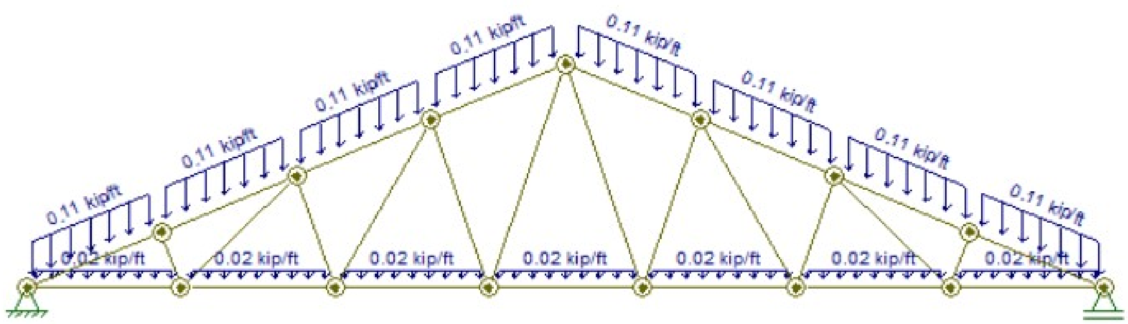
$a := min(a_1, a_2) = 5.8\ ft$

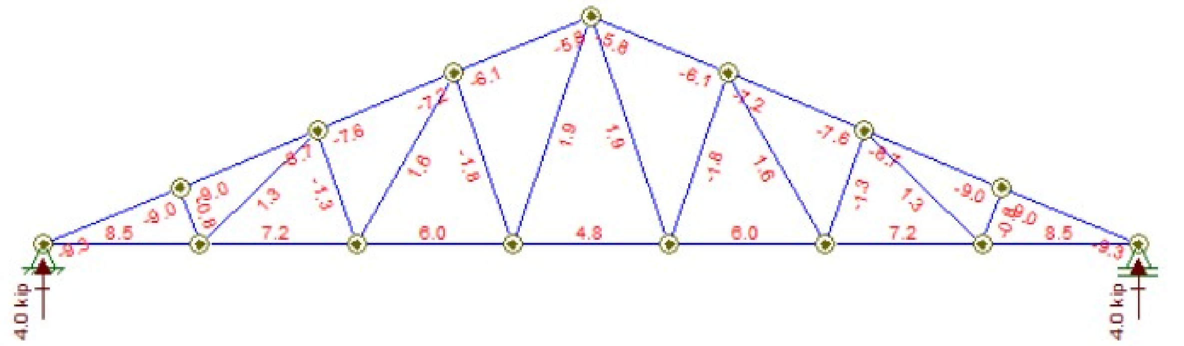
Check 1: $a = 5.8\ ft$ > $0.04 \cdot lhd = 2.32\ ft$ Ok

Check 2: $a = 5.8\ ft$ > $3\ ft$ Ok

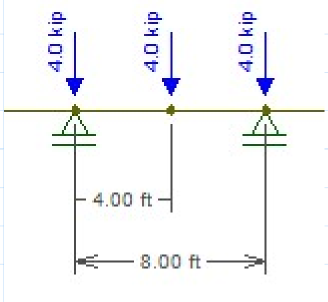
$width_{endzone} := 2 \cdot a = 11.6\ ft$

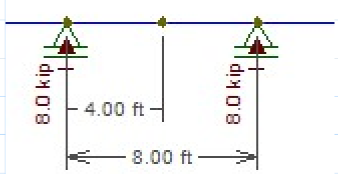
$a = 5.8\ ft$





Reaction force from one side of single truss: $P_s := 4\ kip$



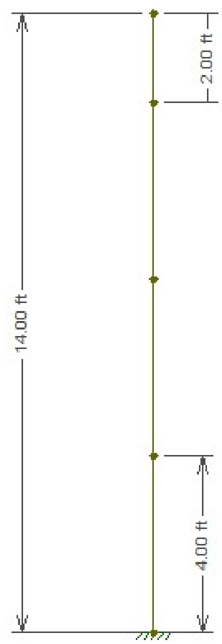


Reaction on column spaced at 8' from trusses spaced every 4': $P := 8\ kip$

Weyerhaeuser recommended allowable axial loads for 1.8E Parallam PSL - 14' x 7" x 7":

$$P_{allow} := 34155\ lbf = 34.155\ kip$$

Design column:



Check middle column of 88' wall:

$w_{col} := 8\ ft \cdot (0.6) \cdot 27.47\ psf = 131.856\ plf$

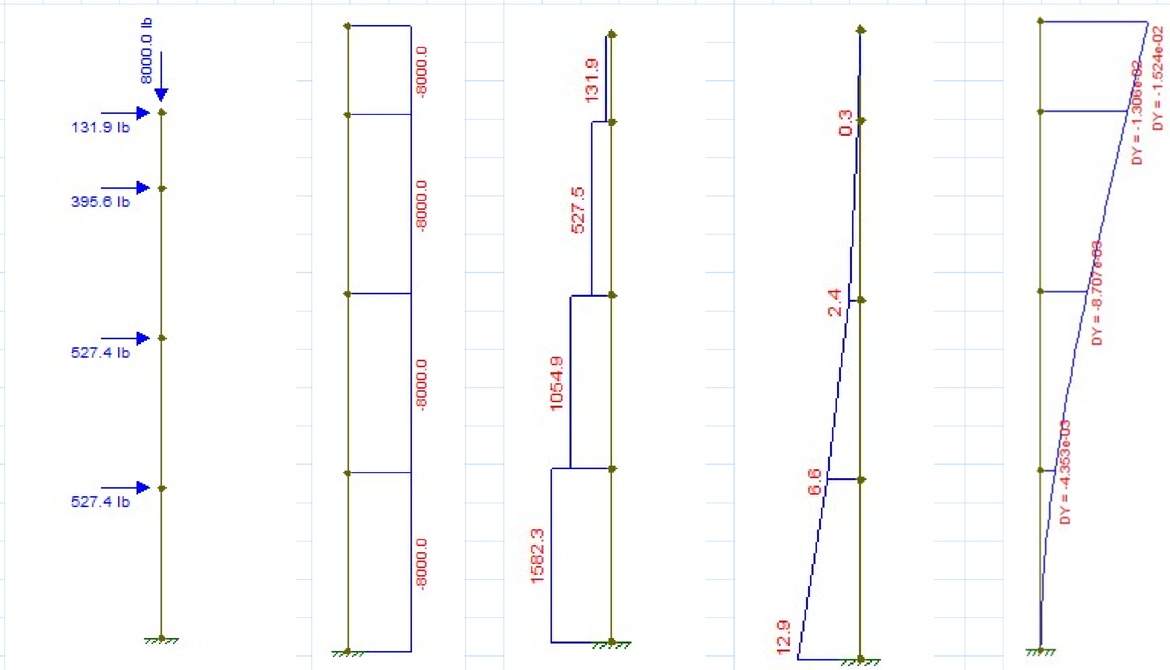
$w_{col} = 131.856\ plf$

$w_{col} \cdot 4\ ft = 527.424\ lbf$

$w_{col} \cdot 3\ ft = 395.568\ lbf$

$w_{col} \cdot 1\ ft = 131.856\ lbf$

Loading: | Axial force (lb): | Shear (lb): | Moment (kip-ft): | Deflection (in):



$T_u := 8000\ lbf$

$M_u := 12.9\ kip \cdot ft$

$E := 1800000\ psi$

$E_{min} := 914880\ psi$

$F_b := 2500\ psi$ Joist/beam orientation: load parallel to wide face of veneer or strands.

$F_c := 2500\ psi$

Check bending with axial compression:

Use structural composite lumber adjustment factors:

$C_D := 1.6$

$C_M := 1.0$

$C_t := 1.0$

$b := 7\ in$

$d := 7\ in$

$C_L := 1.0$ NDS 3.3.3.2: In accordance with NDS 4.4.1

$C_V := \left(\frac{12}{7}\right)^{0.111} = 1.062$ From manufacturer specs.

Interpolate table:

$y_1 := 1.06$ $x_1 := 7.25$ $x := 7$

$y_0 := 1.09$ $x_0 := 5.5$

$y := y_0 + (x - x_0) \cdot \frac{y_1 - y_0}{x_1 - x_0} = 1.064$

$C_V = 1.062$ < 1.064 Ok

$C_r := 1.0$

Calculate Cp:

$l_{u1} := 14\ ft$

$d_1 := 7\ in$

$\frac{l_{u1}}{d_1} = 24$ > 7

$l_{e1} := 1.44 \cdot l_{u1} + 3 \cdot d_1 = 21.91\ ft$

$l_{u2} := 4\ ft$

$d_2 := 7\ in$

$\frac{l_{u2}}{d_2} = 6.857$ < 7

$l_{e2} := 1.87 \cdot l_{u2} = 7.48\ ft$

$\frac{l_{e1}}{d_1} = 37.56$

$\frac{l_{e2}}{d_2} = 12.823$

$l_e := l_{e1} = 21.91\ ft$

$R_B := \sqrt{\dfrac{l_e \cdot d}{b^2}} = 6.129$ < 50 Ok

$c := 0.9$

$E'_{min} := E_{min} \cdot C_M \cdot C_t = \left(9.149 \cdot 10^5\right)\ psi$

$F_{cE} := \dfrac{0.822 \cdot E'_{min}}{\left(\dfrac{l_e}{d}\right)^2} = \left(7.676 \cdot 10^4\right)\ psf$

$F_{cstar} := F_c \cdot C_D \cdot C_M \cdot C_t = \left(5.76 \cdot 10^5\right)\ psf$

$$C_P := \frac{1 + \left(\dfrac{F_{cE}}{F_{cstar}}\right)}{2 \cdot c} - \sqrt{\left(\frac{1 + \left(\dfrac{F_{cE}}{F_{cstar}}\right)}{2 \cdot c}\right)^2 - \frac{\dfrac{F_{cE}}{F_{cstar}}}{c}} = 0.131$$

$F'_c := F_c \cdot C_D \cdot C_M \cdot C_t \cdot C_P = \left(7.562 \cdot 10^4\right)\ psf$

$F'_b := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_L \cdot C_V \cdot C_r = \left(6.115 \cdot 10^5\right)\ psf$

$S_x := \dfrac{b \cdot d^2}{6} = 57.167\ in^3$

$A_g := 49\ in^2$

Check compression:

$f_c := \dfrac{T_u}{A_g} = \left(2.351 \cdot 10^4\right)\ psf$ < $F'_c = \left(7.562 \cdot 10^4\right)\ psf$ Ok

Check bending:

$f_b := \dfrac{M_u}{S_x} = \left(3.899 \cdot 10^5\right)\ psf$ < $F'_b = \left(6.115 \cdot 10^5\right)\ psf$ Ok

Check combined bending and axial compression:

$$F_{cE1} := \frac{0.822 \cdot E'_{min}}{\left(\frac{l_{e1}}{d_1}\right)^2} = \left(7.676 \cdot 10^4\right)\ psf$$

$$B_1 := \left(1 - \left(\frac{f_c}{F_{cE1}}\right)\right)^{-1} = 1.441$$

$$\left(\frac{f_c}{F'_c}\right)^2 + B_1 \cdot \left(\frac{f_b}{F'_b}\right) = 1 \qquad <= \quad 1 \quad \text{Ok}$$

Check deflection for combined bending and shear deflection:

From manufacturer specs:

$$\Delta = \frac{270 \cdot W \cdot L^4}{E \cdot b \cdot d^3} + \frac{28.8 \cdot W \cdot L^2}{E \cdot b \cdot d}$$

$$\Delta := \frac{270 \cdot 131.856 \cdot 14^4}{1800000 \cdot 7 \cdot 7^3}\ in + \frac{28.8 \cdot 131.856 \cdot 14^2}{1800000 \cdot 7 \cdot 7}\ in = 0.325\ in$$

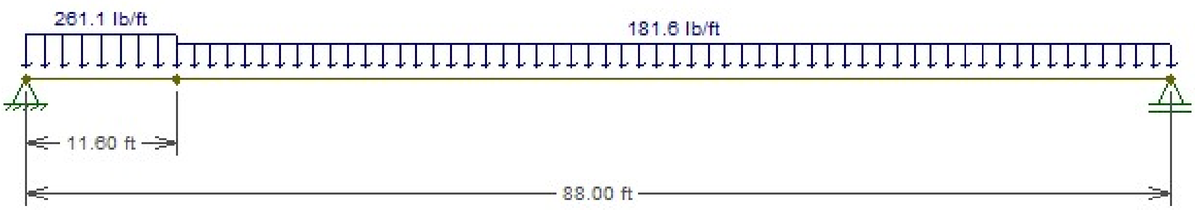
$$\Delta = 0.325\ in \qquad < \qquad \Delta_{tot} := \frac{l_{u1}}{180} = 0.933\ in \qquad \text{Ok}$$

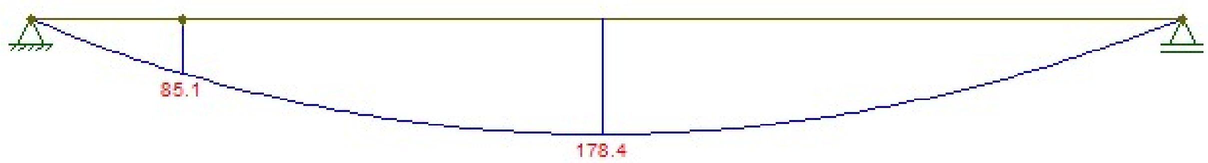
Calculation of chord forces:

$$w_{end} := \frac{h}{2} \cdot (0.6) \cdot 39.487\ psf = 261.108\ plf$$

$$w_{int} := \frac{h}{2} \cdot (0.6) \cdot 27.47\ psf = 181.645\ plf$$

$$2 \cdot a = 11.6\ ft$$





$M_{max} := 178.4\ kip \cdot ft$ @ $x := 43.6\ ft$ from left

$T := \frac{M_{max}}{lhd} = (3.076 \cdot 10^3)\ lbf$

Use 4" x 8" DFL Select Structural

$A_g := 25.38\ in^2$

$f_t := \frac{T}{A_g} = 121.192\ psi$

$F_t := 1000\ psi$

$C_D := 1.6$

$C_M := 1.0$

$C_t := 1.0$

$C_F := 1.2$

$C_i := 1.0$

$F'_t := F_t \cdot C_D \cdot C_M \cdot C_t \cdot C_F \cdot C_i = (1.92 \cdot 10^3)\ psi$

$f_t = 121.192\ psi$ $<$ $F'_t = (1.92 \cdot 10^3)\ psi$ Ok

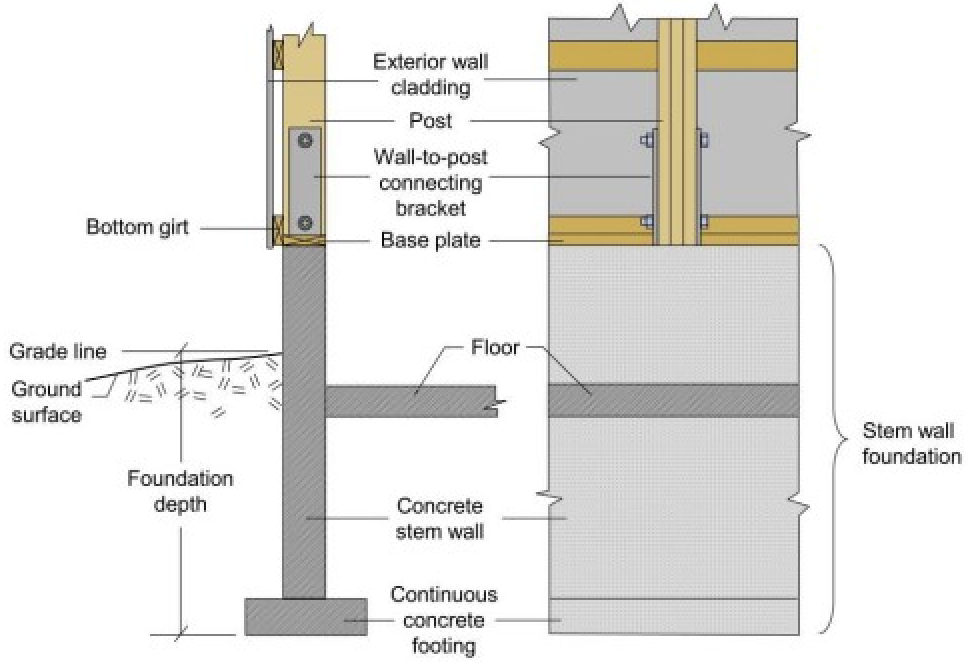


Figure 1-25. Stem wall foundation.

Stem wall depth below grade: 4'

Stem wall height above grade: 2'

$q_{applied}$ < $q_{allow} := 1500\ psf$ already has FS and settlement accounted for

Weight for bearing on foundation stem wall:

$$w_{truss} := \frac{23 \cdot 4\ kip}{88\ ft} = \left(1.045 \cdot 10^3\right)\ plf$$

$$w_{steel} := 1\ psf \cdot 2 \cdot 14\ ft = 28\ plf$$

$$G := 0.5$$

$$\gamma := G \cdot 62.4\ \frac{lbf}{ft^3} = 31.2\ \frac{lbf}{ft^3}$$

$$w_{columns} := \frac{12 \cdot \gamma \cdot 7\ in \cdot 7\ in \cdot 14\ ft}{88\ ft} = 20.268\ plf$$

$$w_{girts} := \gamma \cdot 8 \cdot 8.25\ in^2 = 14.3\ plf$$

$w_{4x8} := \gamma \cdot 25.38\ in^2 = 5.499\ plf$

$w := w_{truss} + w_{steel} + w_{columns} + w_{girts} + w_{4x8} = \left(1.114 \cdot 10^3\right)\ plf$

$f'_c := 4000\ psi$

$W_1 := \left(7 + \frac{1}{8}\right)\ in$

$W_2 := 7\ in$

$cover_{side} := 3\ in$

$t_{stemwall} := W_2 + 2 \cdot cover_{side} = 13\ in$

$\gamma_c := 150\ \frac{lbf}{ft^3}$

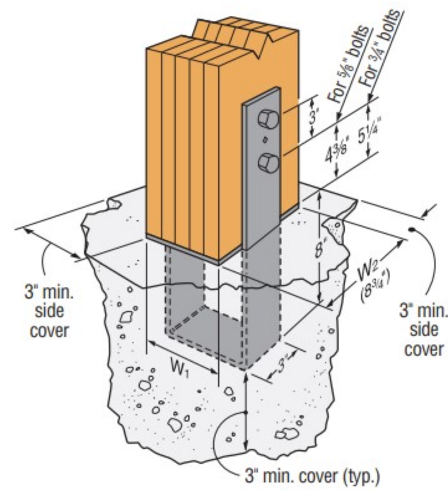
$L := 88\ ft$

$t_f := 8\ in$

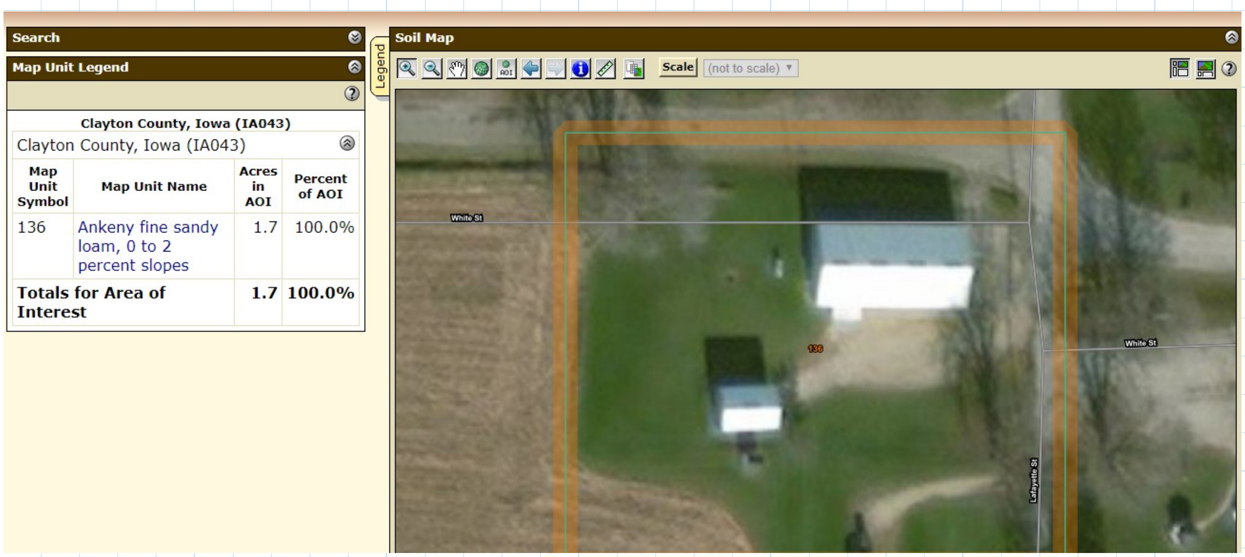
$D_f := 4\ ft$

$B := t_{stemwall} + 2 \cdot 6\ in = 25\ in$ Round to 2'

$B := 24\ in$



CB9
(CB5, CB7 similar)
for Glulam Column



Typical profile

Ap - 0 to 7 inches: fine sandy loam
A1,A2,A3 - 7 to 30 inches: fine sandy loam
BA,Bw - 30 to 44 inches: fine sandy loam
2C1,2C2 - 44 to 60 inches: loamy fine sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to very high (1.42 to 14.17 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: Occasional
Frequency of ponding: None
Available water storage in profile: High (about 9.4 inches)

μ	Soil type
0.4–0.5	Most clay soils
0.45–0.50	Saturated clay soils
0.3–0.4	Cohesionless—medium and dense
0.2–0.35	Cohesionless—loose to medium

Soil	E_s, MPa
Clay	
Very soft	2–15
Soft	5–25
Medium	15–50
Hard	50–100
Sandy	25–250
Glacial till	
Loose	10–150
Dense	150–720
Very dense	500–1440
Loess	15–60
Sand	
Silty	5–20
Loose	10–25
Dense	50–81
Sand and gravel	
Loose	50–150
Dense	100–200
Shale	150–5000
Silt	2–20

*Value range is too large to use an "average" value for design.

$D_w := 80\ in = 6.667\ ft$

$u := 0\ psf$

$\mu_s := 0.35$

$E_s := 75\ MPa = \left(1.088 \cdot 10^4\right)\ psi$

$\phi' := 35\ °$ Estimation

$G_s := 2.67$ Estimation

$\gamma := 1.8\ \dfrac{gm}{cm^3} = 112.37\ \dfrac{lb}{ft^3}$ Estimation

$\gamma := 112.37\ \dfrac{lbf}{ft^3}$

$\dfrac{D_f}{B} = 2$ > 1

$k := \operatorname{atan}\left(\dfrac{D_f}{B}\right) = 1.107$

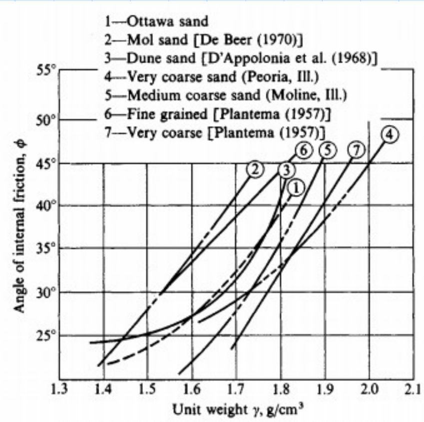
$d_q := 1 + 2 \cdot k \cdot \tan(\phi') \cdot (1 - \sin(\phi'))^2 = 1.282$

$d_\gamma := 1$

$N_q := e^{\pi \cdot \tan(\phi')} \cdot \left(\tan\left(45\ ° + \dfrac{\phi'}{2}\right)\right)^2 = 33.296$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi') = 48.029$

$s_q := 1 + \left(\dfrac{B}{L}\right) \cdot \tan(\phi') = 1.016$



(a) ϕ vs. γ for several soils. [From Bowles (1974a).]

$s_\gamma := 1 - 0.4 \cdot \left(\frac{B}{L}\right) = 0.991$

$q_s := \gamma \cdot D_f = 449.48\ psf$

Ultimate bearing capacity:

$q_n := q_s \cdot N_q \cdot (s_q \cdot d_q) + 0.5 \cdot \gamma \cdot B \cdot N_\gamma \cdot (s_\gamma \cdot d_\gamma) = (2.484 \cdot 10^4)\ psf$

$P_1 := w = (1.114 \cdot 10^3)\ plf$

$w_{footing} := \gamma_c \cdot t_f \cdot B = 200\ plf$

$w_{stemwall} := \gamma_c \cdot t_{stemwall} \cdot (D_f + 2\ ft - t_f) = 866.667\ plf$

$w_{backfill} := \gamma \cdot (D_f - t_f) \cdot (B - t_{stemwall}) = 343.353\ plf$

Account for moment from wind load on structure:

$M := \frac{12.9\ kip \cdot ft}{8\ ft} = 1.613\ \frac{kip \cdot ft}{ft}$ From f-tool shown on framing design.

$e := \frac{B}{6} = 4\ in$

$P_2 := \frac{M}{e} = (4.838 \cdot 10^3)\ plf$

$P := P_1 + P_2 = (5.951 \cdot 10^3)\ plf$

$q := \frac{P}{B} + \frac{w_{footing}}{1\ ft} + \frac{w_{stemwall}}{1\ ft} + \frac{w_{backfill}}{1\ ft} = (4.386 \cdot 10^3)\ psf$

$R_e := 1 - \sqrt{\frac{e}{B}} = 0.592$

$q'_n := q_n \cdot R_e = (1.47 \cdot 10^4)\ psf$

$FS_q := 3$

$q_a := \frac{q'_n}{FS_q} = (4.899 \cdot 10^3)\ psf$

$q = (4.386 \cdot 10^3)\ psf$ $<$ $q_a = (4.899 \cdot 10^3)\ psf$ Ok

Factor of safety: $\frac{q'_n}{q} = 3.352$ $DCR := \frac{q}{q_a} = 0.895$ Ok

Allowable settlement requirements:

$$H := min(35\ ft, 5 \cdot B) = 10\ ft$$

Center settlement:

$$\alpha := 4$$

$$B' := \frac{B}{2} = 1\ ft$$

$$L' := \frac{L}{2} = 44\ ft$$

$$M := \frac{L'}{B'} = 44$$

$$N := \frac{H}{B'} = 10$$

$$I_1 := \frac{1}{\pi} \cdot \left(M \cdot \ln\left(\frac{\left(1+\sqrt{M^2+1}\right) \cdot \sqrt{M^2+N^2}}{M \cdot \left(1+\sqrt{M^2+N^2+1}\right)} \right) + \ln\left(\frac{\left(M+\sqrt{M^2+1}\right) \cdot \sqrt{1+N^2}}{M+\sqrt{M^2+N^2+1}} \right) \right) = 0.738$$

$$I_2 := \frac{N}{2 \cdot \pi} \cdot \operatorname{atan}\left(\frac{M}{N \cdot \sqrt{M^2+N^2+1}} \right) = 0.155$$

$$I_s := I_1 + \left(\frac{1-2 \cdot \mu_s}{1-\mu_s} \right) \cdot I_2 = 0.81$$

$$\frac{L}{B} = 44 \qquad \frac{D_f}{B} = 2 \qquad \mu_s = 0.35$$

$$I_F := 1$$

$$q_{net} := \frac{P}{B} = \left(2.976 \cdot 10^3\right)\ psf$$

$$\delta_{Ef} := \alpha \cdot I_s \cdot I_F \cdot \left(\frac{q_{net} \cdot \left(1-{\mu_s}^2\right)}{E_s} \right) \cdot B' = 0.065\ in$$

$$\delta_{Erigid} := 0.93 \cdot \delta_{Ef} = 0.06\ in$$

$$\delta_z := \delta_{Erigid} = 0.06\ in$$

Total settlement:

$\delta_z = 0.06\ in$ < $\delta_T := 0.5\ in$

Check compression force on concrete from column:

$W_{truss} := 4\ kip$

$W_{column} := \gamma \cdot 7\ in \cdot 7\ in \cdot 14\ ft = 0.535\ kip$

$W_{girts} := \gamma \cdot 8 \cdot 8.25\ in^2 \cdot 8\ ft = 0.412\ kip$

$W_{4x8} := \gamma \cdot 25.38\ in^2 \cdot 8\ ft = 0.158\ kip$

$W_{steel} := 1\ psf \cdot 2 \cdot 14\ ft \cdot 8\ ft = 0.224\ kip$

$F_{column} := W_{truss} + W_{column} + W_{girts} + W_{4x8} + W_{steel} = 5.33\ kip$

$A_c := 7\ in \cdot 7.125\ in = 49.875\ in^2$ Area of column base plate

$F_c := 0.85 \cdot f'_c \cdot A_c = \left(1.696 \cdot 10^5\right)\ lbf$

$F_{column} = \left(5.33 \cdot 10^3\right)\ lbf$ < $F_c = \left(1.696 \cdot 10^5\right)\ lbf$ Ok

Check vehicle point load from tire on concrete:

$t_{slab} := 6\ in$

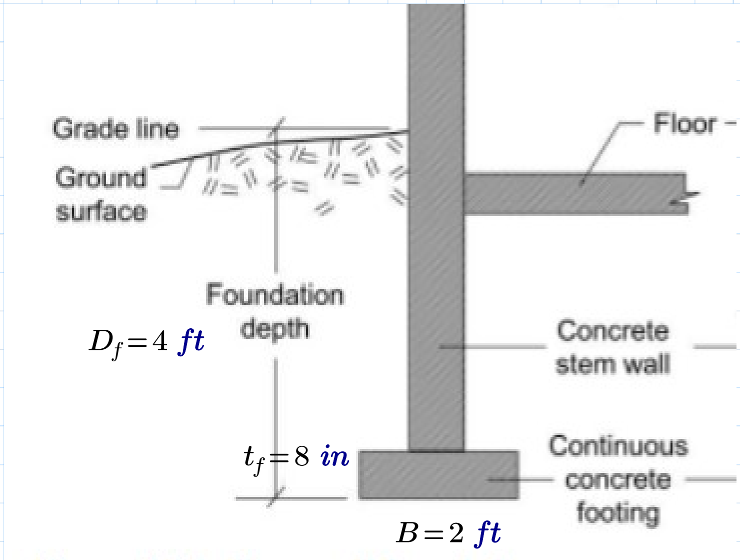
$A_c := 10\ in \cdot 20\ in = 200\ in^2$ AASHTO - 3.6.1.2.5

$F_c := 0.85 \cdot f'_c \cdot A_c = 680\ kip$

$F_{tire} := 16\ kip$ < $F_c = 680\ kip$ Ok

Summary:

$t_{stemwall} = 13\ in$



$D_f = 4\ ft$

$t_f = 8\ in$

$B = 2\ ft$

Material list:

Trusses:

Int. truss - 21

End truss - 2

Top chord: 2 x 8 DFL Select Structural

$23 \cdot 62.833\ ft = (1.445 \cdot 10^3)\ ft$

Bottom chord: 2 x 6 DFL Select Structural

$23 \cdot 58\ ft = (1.334 \cdot 10^3)\ ft$

Web members: 2 x 4 DFL Select Structural

$23 \cdot 102.04\ ft = (2.347 \cdot 10^3)\ ft$

Lateral bracing: 2 x 4 DFL Select Structural

$4 \cdot 88\ ft = 352\ ft$

Purlins: 2 x 4 DFL Select Structural @ 2' spacing

$32 \cdot 88\ ft = (2.816 \cdot 10^3)\ ft$

Uplift anchors:

$23 \cdot 2 = 46$ anchors

Exterior walls:

Columns: 7" x 7" x 14' 1.8E TrusJoist Parallam PSL

$(2 \cdot 12 \cdot 14\ ft) + (6 \cdot 14\ ft) + (3 \cdot 14\ ft) = 462\ ft$

Column base connector: CB 7-1/8 - 7 Simpson Strong-Tie

$24 + 6 + 3 = 33$ connectors

Truss header: 2- 2" x 12" SPF No. 2

$2 \cdot (2 \cdot 58\ ft + 2 \cdot 88\ ft) = 584\ ft$

Girts: 2" x 6" DFL Select Structural

$6 \cdot (88\ ft - 14\ ft) + 3 \cdot (88\ ft - 14\ ft - 45\ ft) + 6 \cdot (58\ ft - 3 \cdot 14\ ft) + 6 \cdot 58\ ft = 975\ ft$

Metal cladding

Roof: $2 \cdot 34.417\ ft \cdot 88\ ft = (6.057 \cdot 10^3)\ ft^2$

Ceiling: $58\ ft \cdot 88\ ft = (5.104 \cdot 10^3)\ ft^2$

North wall: $2 \cdot (58\ ft - 3 \cdot 14\ ft) \cdot 14\ ft = 448\ ft^2$

East: $(2 \cdot (43\ ft - 14\ ft) - 21\ ft) \cdot 14\ ft = 518\ ft^2$

West: $2 \cdot (88\ ft - 14\ ft) \cdot 14\ ft = (2.072 \cdot 10^3)\ ft^2$

South: $2 \cdot 58\ ft \cdot 14\ ft = (1.624 \cdot 10^3)\ ft^2$

$(6.057 \cdot 10^3)\ ft^2 + (5.104 \cdot 10^3)\ ft^2 + 448\ ft^2 + 518\ ft^2 = (1.213 \cdot 10^4)\ ft^2$

$(1.213 \cdot 10^4)\ ft^2 + (2.072 \cdot 10^3)\ ft^2 + (1.624 \cdot 10^3)\ ft^2 = (1.583 \cdot 10^4)\ ft^2$

Summary

2 x 4 DFL Select Structural: $(5.515 \cdot 10^3)\ ft$

Unit cost: $13.89/20ft

$(2.347 \cdot 10^3)\ ft + 352\ ft + (2.816 \cdot 10^3)\ ft = (5.515 \cdot 10^3)\ ft$

2 x 6 DFL Select Structural: $(2.309 \cdot 10^3)\ ft$

Unit cost: $19.89/20ft

$(1.334 \cdot 10^3)\ ft + 975\ ft = (2.309 \cdot 10^3)\ ft$

2 x 8 DFL Select Structural: $(1.445 \cdot 10^3)\ ft$

Unit cost: $25.69/20ft

H14 - Simpson strong tie: 46 anchors

Unit cost: $2.86/anchor

7" x 7" x 14' 1.8E TrusJoist Parallam PSL $462\ ft$

Unit cost: $19.02/ft

2" x 4" pressure treated lumber: $255\ ft$

Unit cost: $16.99/20ft

$$3 \cdot 21\ ft + 50\ ft + 58\ ft + 2 \cdot 10\ ft + 2 \cdot 16\ ft + 32\ ft = 255\ ft$$

2" x 4" SPF No. 2: $(2.884 \cdot 10^3)\ ft$

Unit cost: $13.19/20ft

$$\frac{3 \cdot 21\ ft + 50\ ft + 58\ ft + 2 \cdot 10\ ft}{16\ in} = 143.25 \qquad 144 + 7 = 151 \qquad 151 \cdot 9\ ft = (1.359 \cdot 10^3)\ ft$$

$$\frac{2 \cdot 16\ ft + 32\ ft}{16\ in} = 48 \qquad 48 + 3 = 51 \qquad 51 \cdot 12\ ft = 612\ ft$$

$$\frac{21\ ft + 2 \cdot 50\ ft}{16\ in} = 90.75 \qquad 91 + 3 = 94 \qquad 94 \cdot 7\ ft = 658\ ft$$

$$(1.359 \cdot 10^3)\ ft + 612\ ft + 658\ ft + 255\ ft = (2.884 \cdot 10^3)\ ft$$

2" x 12" SPF No. 2: $847\ ft$

Unit cost: $52.99/20ft

$\frac{50\ ft}{16\ in} = 37.5$ $\qquad 39 \cdot 21\ ft = 819\ ft$

Stringers $\qquad 2 \cdot (13\ ft + 8\ in) = 27.333\ ft$

$819\ ft + 27.333\ ft = 846.333\ ft$

1-1/8in x 4 x 8 OSB Sturd-I-Floor for stair treads: 4 sheets

Unit cost: $49.99/sheet

$13 \cdot 3\ ft = 39\ ft$ $\qquad \frac{48\ in}{11\ in} = 4.364$ $\qquad \frac{13}{4} = 3.25$

16" Cellulose insulation- truss: $(5.104 \cdot 10^3)\ ft^2$ $\quad$ 320 $\quad$ bags

Unit cost: $13.50/bag

$58\ ft \cdot 88\ ft \cdot 16\ in = (1.176 \cdot 10^7)\ in^3$ $\qquad 58\ ft \cdot 88\ ft = (5.104 \cdot 10^3)\ ft^2$

$y_1 := 13.8$ $\qquad x_1 := 60$ $\qquad x := 53$

$y_0 := 17.2$ $\qquad x_0 := 49$

$\frac{(5.104 \cdot 10^3)\ ft^2}{15.964\ ft^2} = 319.719$

$y := y_0 + (x - x_0) \cdot \frac{y_1 - y_0}{x_1 - x_0} = 15.964$

Wall insulation: $(1.446 \cdot 10^3)\ ft^3$

Unit cost: $8.4/cuft

$$7\ in \cdot ((88\ ft - 14\ ft) + 58\ ft + (43\ ft - 14\ ft) + (58\ ft - 3 \cdot 14\ ft)) \cdot 14\ ft = (1.446 \cdot 10^3)\ ft^3$$

4' x 8' x 3/4" OSB: 33 sheets

Unit cost: $19.69/sheet

$50\ ft \cdot 21\ ft = (1.05 \cdot 10^3)\ ft^2$

$$\frac{(1.05 \cdot 10^3)\ ft^2}{4\ ft \cdot 8\ ft} = 32.813$$

CB 7-1/8 - 7 Simpson Strong-Tie: 33 connectors

Unit cost: $66.86/connector

Overhead doors - 14' x 14': 5 doors

Unit cost: $1638/door

Walk-in exterior doors: 3 doors

Unit cost: $200/door

Interior doors: 9 doors

Unit cost: $109/door

Metal cladding: $(1.583 \cdot 10^4)\ ft^2$ 330 sheets

Unit cost: $42.55/sheet

$$\frac{(1.583 \cdot 10^4)\ ft^2}{36\ in \cdot 16\ ft} = 329.792$$

Glasteel: $928\ ft^2$

Unit cost: $1.67/sqft

$$58\ ft \cdot 16\ ft = 928\ ft^2$$

4' x 8' x 1/2" Gypsum board: 135 sheets

Unit cost: $10.14/sheet

$4 \cdot 12\ ft \cdot 16\ ft = 768\ ft^2$

$9\ ft \cdot ((2 \cdot 30\ ft + 2 \cdot 21\ ft) + (2 \cdot 10\ ft + 2 \cdot 21\ ft) + (2 \cdot 15\ ft + 2 \cdot 10\ ft)) = (1.926 \cdot 10^3)\ ft^2$

$9\ ft \cdot ((2 \cdot 6\ ft + 2 \cdot 10\ ft) + (2 \cdot 10\ ft) + (50\ ft) + (22\ ft)) = (1.116 \cdot 10^3)\ ft^2$

$7\ ft \cdot (21\ ft + 50\ ft) = 497\ ft^2$

$768\ ft^2 + (1.926 \cdot 10^3)\ ft^2 + (1.116 \cdot 10^3)\ ft^2 + 497\ ft^2 = (4.307 \cdot 10^3)\ ft^2$

$$\frac{(4.307 \cdot 10^3)\ ft^2}{32\ ft^2} = 134.594$$

Concrete - foundation and slab: $151\ yd^3$

Unit cost: $97/cuyd

Slab: $6\ in \cdot 58\ ft \cdot 88\ ft = 94.519\ yd^3$

Found. wall column bumpout:

$6\ ft - 8\ in = 5.333\ ft$

$14\ in \cdot 33 = 38.5\ ft$

$13\ in \cdot 5.333\ ft \cdot (38.5\ ft) = 8.238\ yd^3$

Found. wall without column bumpout:

$8\ in \cdot 5.333\ ft \cdot (2 \cdot 88\ ft + 2 \cdot 58\ ft - 38.5\ ft) = 33.381\ yd^3$

Footing: $8\ in \cdot 2\ ft \cdot (2 \cdot 88\ ft + 2 \cdot 58\ ft) = 14.42\ yd^3$

$94.519\ yd^3 + 8.238\ yd^3 + 33.381\ yd^3 + 14.42\ yd^3 = 150.558\ yd^3$

$151 \cdot 90 = 1.359 \cdot 10^4$ concrete

$16 \cdot 60 = 960$ Truck cost

$\frac{1.359 \cdot 10^4 + 960}{151} = 96.358$ cost/cuyd

Fasteners:

Framing:

$88 \cdot 58 = 5.104 \cdot 10^3$ $5.104 \cdot 10^3 \cdot 0.15 = 765.6$

Sheet metal:

$3 \cdot \frac{88}{3} \cdot 32 \cdot 2 = 5.632 \cdot 10^3$

$3 \cdot \frac{292}{3} \cdot 6 = 1.752 \cdot 10^3$

$5.632 \cdot 10^3 + 1.752 \cdot 10^3 = 7.384 \cdot 10^3$

$\frac{7.384 \cdot 10^3}{3000} = 2.461$ $3 \cdot 244.75 = 734.25$

Steel reinforcement: 600 bars

Unit cost: $13.79/bar

$2 \cdot 58\ ft + 2 \cdot 88\ ft = 292\ ft$ $292\ ft \cdot 3 = 876\ ft$ Footings

$2553\ ft$ Foundation walls

$8569\ ft$ Slab

$876\ ft + 2553\ ft + 8569\ ft = \left(1.2 \cdot 10^4\right)\ ft$

$\frac{\left(1.2 \cdot 10^4\right)\ ft}{20\ ft} = 600$

2" Under-slab rigid foam board: 160 sheets

Unit cost: $34.99/sheet

$58\ ft \cdot 88\ ft = \left(5.104 \cdot 10^3\right)\ ft^2$ $\frac{\left(5.104 \cdot 10^3\right)\ ft^2}{32\ ft^2} = 159.5$