THE UNIVERSITY OF IOWA
IOWA INITIATIVE
FOR SUSTAINABLE COMMUNITIES

FINAL DELIVERABLE

Title	Volga Old School and Gymnasium Retrofit Engineering & Design
Completed By	Dallas Smith, John Bermele, Parker Rasmussen, Jason Taylor
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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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School and Gymnasium Retrofit

Submitted to: Christopher Stoakes

Community of Volga, IA

May 15, 2020

RFP: 09-spring20

IOWA
CIVIL & ENVIRONMENTAL ENGINEERING

SBRT Consultants

Prepared by: Dallas Smith, John Bermele, Parker Rasmussen, Jason Taylor

Section I: Executive Summary

The city of Volga, Iowa, requested designs for a project that would refit and repurpose the old Volga Central Community School building on Cass Street in the eastern part of town. The original three story concrete and brick school building was built in the early 1900's with the gymnasium being added on in the 1970's. The gymnasium connects to the original building on the first floor. However, the door connecting the two is currently sealed off. The building and gymnasium feature approximately 20,000 square feet of space, the majority of which has been left unoccupied since the school closed in 2005. The community of Volga is looking to update the building with amenities that would benefit the residents of the town and the visitors coming for recreation, celebrations, or other town events. The primary goals of the project were to create a place in the community to serve as a coworking space where people could work to start and grow their own businesses, a bed and breakfast for visitors coming for events, and a general community gathering space for the city of Volga.

The building has a number of necessary repairs that must be completed before any other work can be completed. These repairs include (1) removing hazardous materials, (2) repairing the roof, and (3) fixing water damage caused by the leaky roof. The building contains features like asbestos floor tiles that must be safely removed. Other materials like the old boilers and boiler fuel tanks located on the first floor of the school building and underneath the stage of the gymnasium will need to be cleaned, dismantled, and removed. There may also be lead paint throughout the school building that must be removed. Where the roof of the gymnasium addition meets the original school building is leaking and will need repairs. The roof of the school building itself will also need to be checked as there was some water damage on the third floor.

Our design features four distinct areas: a revamped gymnasium, vibrant first floor community area, modern second floor office space, and third floor bed and breakfast. Additionally, the design features a new outdoor pavilion on the east side of the building overlooking the river.

In the gymnasium the existing bathrooms on the gym floor will be removed and two new bathrooms will be added to the area behind the stage. The area behind the stage will also feature new storage units for members of the community to use. The locker rooms beneath the stage will be completely refurbished, with all new lockers, showers, and fixtures. These locker rooms will be available to users of the gym and guests at the neighboring campground. The gymnasium will also feature a refinished hardwood floor, new basketball hoops, and the previously sealed off entrance to the school building will be reopened, providing direct access to the first floor of the school.

The first floor of the school building will be updated with the new main entrance and lobby relocated to the existing garage area. The main entrance had to be relocated in order to provide ADA accessibility. The new main entrance will include three paved handicap parking spaces, all new sidewalks, and a canopy covering the entrance to the building. The renovated first floor will also feature a large new kitchen/dining area and laundry facilities for both guests of the bed and breakfast and people throughout the Volga community. The existing kitchen will be removed with two new handicap accessible bathrooms taking its place. Another key element is the new community library as well as two new office and conference room spaces.

The office space continues into the second floor of the school. The space will contain both individual offices and conference rooms. The office space is separated into two areas. One area is to serve as a city hall for the town of Volga with office space for the mayor, city clerk, and conference space for city council and town hall meetings. The second area will be designated as a coworking space where people from Volga and neighboring communities can come to work and grow their own startup businesses.

The third floor is dedicated solely to the bed and breakfast. The bed and breakfast will have six rooms, four single rooms with queen beds and two double rooms with two beds, enabling it to host up to fourteen guests at a time. It will also have a dedicated lounge area with couches, televisions, pool table, and other amenities for guests to enjoy. The bed and breakfast will include two unisex pod style bathrooms each containing a shower, vanity and toilet. To make all floors of the building ADA accessible and in order to comply with fire safety code a new fire escape and elevator shaft will be added to the southwest face of the building. While the third floor will not have a kitchen itself, guests will be able to use the new kitchen and dining area on the first floor of the building.

Proposed project phasing will help to break up the total cost of the project into more manageable pieces. Phase 1 will include just the necessary repairs to the building. Early estimates for just the necessary repair costs are $200,000 and could increase depending on the extent of the damage throughout the building. Phase 2 of the project includes the construction of the new main entrance, ADA parking, sidewalk, and the stairwell and elevator addition. Phase 2 is estimated to cost $198,500. Phases 3 includes the renovation of the second floor into office spaces. Phase 3 is estimated to cost $154,500. Phase 4 sees the completion of the third floor bed and breakfast and the first floor finished. Phase 4 is estimated to cost $275,000. Phase 5 is saved for features that were deemed optional to the project such as the outdoor patio, new gym floor, and kitchen relocation. Phase 5 is estimated at $217,500. Together with an additional 10% for contingencies and 20% for engineering and administration costs, this yields a total project cost of $1,360,000.

Section II: Organization Qualifications and Experience

SBRT Consultants

Dallas Smith - *Project Manager*

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Parker Rasmussen - *Technology Support*

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Section III: Design Services

Project Scope

The objective of this project was to rehabilitate the existing Volga Central Community School building. Adding amenities that benefit residents of the community and visitors coming for recreation, celebrations, or other town events would give the building a second life as an integral part of the Volga community. The project's main design elements were updating the gymnasium and locker rooms, a new entrance and community gathering space on the first floor, providing office space for the city of Volga and other start-ups on the second floor, and a bed and breakfast on the third floor.

SBRT Consultants provided professional engineering services for this project in architectural design, structural design, civil site design, and M/E/P design. A new architectural layout for each of the floors was designed, creating new rooms and repurposing others. For this project we also successfully designed and incorporated new ADA accessible parking, a new main entrance, fire escape, elevator, outdoor patio, and bathrooms throughout the building. Additionally, a complete drawing set of our design was created along with a 3D model, design poster highlighting the key features, and a complete cost estimate for the project.

Originally we had proposed completing two separate designs for the project with one design being a cost effective option and the other an elaborate expensive option. However, as we progressed through the design process we determined that it would be more efficient to just have one overall design. Within this design we selected a number of features that could be considered optional. The optional aspects of the design include resurfacing the gym floor, relocating the kitchen on the first floor, and adding the outdoor patio. These elements were selected because they provided an opportunity to save on the cost of the project while still being able to accomplish the overall goals of the project.

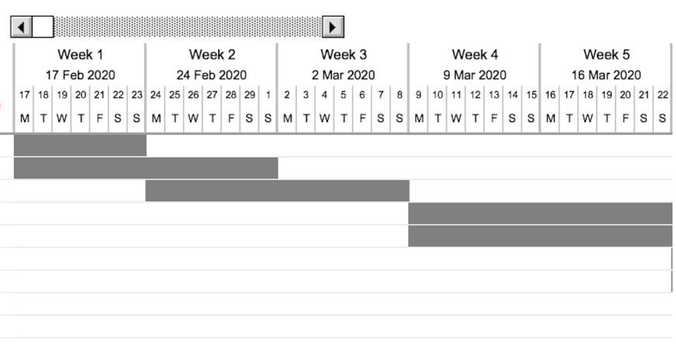
Work Plan

Volga School and Gynmasium Retrofit Project Schedule

Project Start Date: 2/17/2020 (Monday)   Display Week: 1

Project Lead: Dallas Smith

WBS	TASK	START	END	DAYS	% DONE	WORK DAYS
1	Code Research	Mon 2/17/20	Sun 2/23/20	7	100%	7
1.1	Make Model (Opt. 1)	Mon 2/17/20	Sun 3/01/20	14	100%	14
1.2	Make Model (Opt. 2)	Mon 2/24/20	Sun 3/08/20	14	100%	14
1.3	Analyze Model (Opt. 1)	Mon 3/09/20	Sun 3/22/20	14	100%	14
1.4	Analyze Model (Opt. 2)	Mon 3/09/20	Sun 3/22/20	14	100%	14
1.5	Room Assignments	Mon 3/23/20	Sun 3/29/20	7	100%	7
1.6	Electric/Plumbing/ADA	Mon 3/23/20	Sun 3/29/20	7	100%	7
1.7	Architectural (Opt. 1)	Mon 3/30/20	Sun 4/12/20	14	100%	14
1.8	Architectural (Opt. 2)	Mon 3/30/20	Sun 4/12/20	14	100%	14
1.9	Write Reports	Mon 4/13/20	Sun 4/19/20	7	100%	7

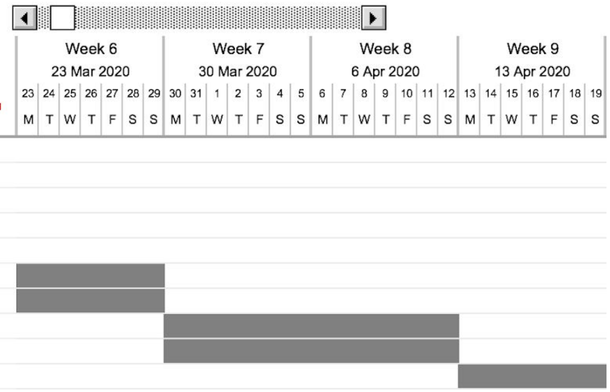


Volga School and Gynmasium Retrofit Project Schedule

Project Start Date: 2/17/2020 (Monday) Display Week: 6

Project Lead: Dallas Smith

WBS	TASK	START	END	DAYS	% DONE	WORK DAYS
1	Code Research	Mon 2/17/20	Sun 2/23/20	7	100%	7
1.1	Make Model (Opt. 1)	Mon 2/17/20	Sun 3/01/20	14	100%	14
1.2	Make Model (Opt. 2)	Mon 2/24/20	Sun 3/08/20	14	100%	14
1.3	Analyze Model (Opt. 1)	Mon 3/09/20	Sun 3/22/20	14	100%	14
1.4	Analyze Model (Opt. 2)	Mon 3/09/20	Sun 3/22/20	14	100%	14
1.5	Room Assignments	Mon 3/23/20	Sun 3/29/20	7	100%	7
1.6	Electric/Plumbing/ADA	Mon 3/23/20	Sun 3/29/20	7	100%	7
1.7	Architectural (Opt. 1)	Mon 3/30/20	Sun 4/12/20	14	100%	14
1.8	Architectural (Opt. 2)	Mon 3/30/20	Sun 4/12/20	14	100%	14
1.9	Write Reports	Mon 4/13/20	Sun 4/19/20	7	100%	7



The work plan above was generated by estimating how long certain tasks would likely take to complete and by identifying what tasks could be done simultaneously. For instance, the room assignments probably won't take as long as the structural analysis so it is only given a week. The room assignment task is also done at the same time as the electric/plumbing layout because both are related.

Section IV: Constraints, Challenges, Impacts

Constraints

There were two primary constraints on this project. The first of these constraints was the overall budget of this project. The second was the current condition of the existing building. These two constraints worked together. With the current state of the building a significant amount of money is required to complete necessary repairs and remove hazardous materials to make the building safe for construction and occupancy. These costly repairs could consume a large portion of the budget and leave little money for incorporating other features of the design.

Challenges

The largest challenges within this project are safely disposing of the asbestos throughout the building and other hazardous materials. Another challenge was meeting ADA compliance throughout the building. With the current front entrance that leads to a split-level and an unpaved parking lot, an alternative solution was needed to meet these standards. Fire and safety exits were also a challenge. Currently the building only has one main staircase that flows from the first to third floor and an outdated fire escape that is attached to the exterior of the building. Modern fire code does not allow open exterior fire escapes so an additional emergency exit was needed which was added on to the exterior of the building. We chose to add the fire escape to the exterior of the building rather than the interior for two reasons. First to avoid having to punch holes in the floor and affect the structural integrity of the building and to avoid having to sacrifice internal floor space.

Societal Impact

This project has the potential to have a substantial impact on the community of Volga. On a daily basis the updated building could impact the community recreationally, economically, and culturally. With its close proximity to the camp grounds the site is able to provide a location for showers and laundry to the users of the campgrounds. Users of the gymnasium would have new locker rooms to use and safely store their possessions in. The coworking and office spaces will provide opportunities for residents of Volga to start and grow their own businesses. The space would provide a place for people in the community to meet and work outside of their homes without having to pay for office space themselves and allows them to share resources like printers, copiers, and other expensive items they could not otherwise afford themselves. Additionally, the bed and breakfast portion would allow people from out of town to stay within the city of Volga. The project would also provide the community with another gathering place and a venue to host outdoor events. The outdoor pavilion could provide a place to host outdoor weddings, live music, and other events and celebrations.

Section V: Alternative Solutions That Were Considered

At the beginning of this project our design team had thought to create two separate designs to present. As we progressed through the design of the project however, it became clear that several of the options we had originally considered as just part of the elaborate design were actually essential in both designs. This led to us curtailing the cost effective design and instead opting to focus solely on the elaborate design.

Throughout the main floor and gymnasium level several alternatives were considered. One option had the current bathrooms on the gymnasium floor remaining where they are. This option was rejected for a number of reasons. First by removing the bathrooms more space would be opened up on the gymnasium floor for use. Additionally, by reopening the school building there would be accessible bathrooms available for use. Another consideration was renovating the old locker rooms underneath the stage. This was originally considered so that they would be available for use to the neighboring campground users. We ultimately decided against this because the showers that would be available in the bathrooms of the bed and breakfast area.

Section VI: Final Design Details

In order to make the second and third floors ADA accessible and to provide an additional fire escape for said floors, a stair with an elevator attached was designed. The elevator and stair go to all three floors. To reduce cost, the elevator is hydraulic, which is all that is needed for a short structure. In order to make room for people walking on the stairs and people going to the elevator the landing on the elevator side was made wider than that for the treads. The same was also done for the other sets of landings because there is a door going to the outside. This made the stair shaft take up more space along the wall than initially anticipated but still not that much. This is good because the goal of making this stair was to limit how much space it took up so as little of the wall it connects to needed to be altered. However all the old foundation below where the new footings for the CMU shaft will need to be excavated and removed. The new footings do not need to connect to the old foundation however because of how high above the new footings will be so as to put little surcharge loading. As far as the stair itself, it is designed in very standard fashion. Dead load and live load on the stair walking surface are 30 psf and 100 psf respectively, and the guardrails are designed for 50 plf along the top rail. The framing members and the guardrail members are analyzed for bending based on these loads. The stringers frame into headers which bear in pockets in the walls of the shaft, as is typical for CMU shaft stair framing. For economy, the roof deck is used for the landings. The guardrail posts use high strength steel in order for them to be as small as possible so that they can be welded on top of the smallest possible stringers.

In order to provide aesthetic appeal to the new entrance an aluminum canopy is provided. It uses the cheapest available aluminum for economy. Most of the members are the smallest possible except for the top members which need to be bigger to account for bending. Assuming there are brick ties in the brick facade that the canopy attaches to, the canopy can simply be attached to the facade, which makes the erection phase quicker. The canopy does need a post in the front middle as well as the ends to accomodate for strength, but there is still plenty of room to walk through.

The design of the paved handicap parking spaces satisfies the ADA Standards for quantity and dimensions. The addition of these spaces allow for easier access for handicap persons to the main entrance and the elevator shaft. The spaces are designed to fit a large size vehicle, such as a van, and allow 3 feet of space on each side in between parking spots. The ramps up to sidewalk level are appropriate slopes with detectable warnings for increased safety. The north side of the parking lot will be lined with a 4-foot wide sidewalk and curb, and the rest of it remaining gravel. The outdoor patio was a simple design, a 2000 square-foot patch of permeable pavers that provides ample space for receptions, ceremonies, and community get-togethers.

Section VII: Engineer’s Cost Estimate

Table 1: Cost estimate of proposed project phasing and overall cost.

Phase	Amount	Units	Column1	Total Price
Phase 1				$ 200,000.00
Phase 2				$ 198,500.00
Phase 3				$ 154,500.00
Phase 4				$ 275,000.00
Phase 5				$ 217,500.00
Construction Subtotal				$ 1,045,500.00
Contingencies	10%	%		$ 105,000.00
Engineering and Administation	20%	%		$ 209,500.00
Total Project Cost				$ 1,360,000.00

Appendix A

References

ICC. (2014). *2015 Ibc international building code*. Country Club Hills, IL.

Dept. of Justice. (2010). *Guidance on the 2010 Ada standards for accessible design*. Washington, D.C.

International Code Council. (2014). *International existing building code 2015: Iebc*. Country Club Hills, IL.

International Code Council. (2015). *International fire code, 2015*. Falls Church, VA.

Stair Framing Calculations

Define Variables

$l := 9.5\ ft$ $b := 3\ ft + 4\ in$ $b_2 := 7\ ft + 10.5\ in$ $g := 13\ in$ $e := 1.5\ in$ $h := 42\ in$

$\gamma_s := 490\ pcf$ $\gamma_c := 150\ pcf$ $LL := 100\ psf$ $F_y := 36\ ksi$ $\Omega := 1.67$ $f_m' := 1500\ psi$

Design Calculations

Dead Load

$t := 2.25\ in$ Average landing slab thickness

$DL := \gamma_c \cdot t = 28.125\ psf$ $DL := 30\ psf$

Guardrail Dead Load

$w_{HSS} := 2.27\ plf$ $t := 1.66\ in$

$d := 0.375\ in$ $s_{picket} := 3.5\ in$ $rise := 7$ $run := 11$ $c := \sqrt{rise^2 + run^2} = 13.038$

$A_{picket} := \frac{\pi}{4}\ d^2 = 0.11\ in^2$ $L_{picket} := h - 2\ t - 3\ in - 2\ in = 33.68\ in$

$DL_{rail} := 4\ w_{HSS} + \frac{\gamma_s \cdot A_{picket} \cdot L_{picket}}{s_{picket}} = 12.697\ plf$ so $DL_{rail} := 15\ plf$

Stringer

$w_S := 10.6\ plf$ $Z_{xMC} := 11.6\ in^3$

$w := \frac{1}{2}\ b \cdot DL + \frac{1}{2}\ b \cdot LL + w_S + DL_{rail} = 242.267\ plf$

$R_S := \frac{1}{2}\ w \cdot l = \left(1.151 \cdot 10^3\right)\ lbf$

$M := \frac{1}{8}\ w \cdot l^2 = 2.733\ kip \cdot ft$

$M_n := F_y \cdot Z_{xMC} = 34.8\ kip \cdot ft$ $\frac{M_n}{\Omega} = 20.838\ kip \cdot ft$

Use MC12x10.6 (A36)

Front Header

$W := 2\ b + g + 2\ e = 8\ ft$

$w_{FH} := 9.8\ plf \qquad Z_{xC} := 7.19\ in^3$

$w := \frac{1}{4}\ b_2 \cdot DL + \frac{1}{4}\ b_2 \cdot LL + w_{FH} = 265.738\ plf$

$R_{FH} := \frac{1}{2}\ w \cdot W + 2\ R_S = \left(3.364 \cdot 10^3\right)\ lbf$

$M := R_{FH} \cdot \left(\frac{1}{2}\ W\right) - R_S \cdot \left(\frac{1}{2}\ W - e\right) - R_S \cdot \left(\frac{1}{2}\ g\right) - w \cdot \frac{1}{2}\ W \cdot \frac{1}{4}\ W = 6.249\ kip \cdot ft$

$M_n := F_y \cdot Z_{xC} = 21.57\ kip \cdot ft \qquad \frac{M_n}{\Omega} = 12.916\ kip \cdot ft$

Use C7x9.8 (A36)

Intermediate Header

$w_{IH} := 8.2\ plf \qquad Z_{xC} := 5.16\ in^3$

$w := \frac{1}{2}\ b_2 \cdot DL + \frac{1}{2}\ b_2 \cdot LL + w_{IH} = 520.075\ plf$

$R_{IH} := \frac{1}{2}\ w \cdot W = \left(2.08 \cdot 10^3\right)\ lbf$

$M := \frac{1}{8}\ w \cdot W^2 = 4.161\ kip \cdot ft$

$M_n := F_y \cdot Z_{xC} = 15.48\ kip \cdot ft \qquad \frac{M_n}{\Omega} = 9.269\ kip \cdot ft$

Use C6x8.2 (A36)

Rear Header

$w_{RH} := 8.2\ plf \qquad Z_{xC} := 5.16\ in^3$

$w := \frac{1}{4}\ b_2 \cdot DL + \frac{1}{4}\ b_2 \cdot LL + w_{RH} = 264.138\ plf$

$R_{RH} := \frac{1}{2}\ w \cdot W = \left(1.057 \cdot 10^3\right)\ lbf$

$M := \frac{1}{8}\ w \cdot W^2 = 2.113\ kip \cdot ft$

$M_n := F_y \cdot Z_{xC} = 15.48\ kip \cdot ft \qquad \frac{M_n}{\Omega} = 9.269\ kip \cdot ft$

Use C6x8.2 (A36)

Front Header Bearing Check and Bearing Plate Design

$b_p := 4\ in$ $l_p := 4\ in$ $t_p := \frac{3}{8}\ in$ $R_{all} := 0.25\ f_m' \cdot b_p \cdot l_p = 6\ kip$ $R_{FH} = 3.364\ kip$

Use 4" x 4" x 3/8" Plate (A36) w/ (1) 1/2" dia. x 4" long Headed Stud

Guardrail Calculations

Define Variables

$s := 3\ ft + 7\ in$ $E := 29000\ ksi$

Design Calculations

Guardrail Post and Top, Bottom, and Handrails By Extension

$F_y := 50\ ksi$ $Z_{xHSS} := 0.305\ in^3$

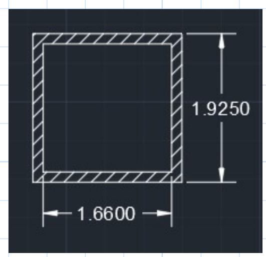
$S := \frac{rise}{run} = 0.636$ $c := \sqrt{rise^2 + run^2} = 13.038$

$P := \max\left(50\ plf \cdot s, 200\ lbf\right) = 200\ lbf$

$M := P \cdot \left(h - \frac{1}{2}\ t - 2\ in\right) = 0.653\ kip \cdot ft$

$M_n := F_y \cdot Z_{xHSS} = 1.271\ kip \cdot ft$ $\frac{M_n}{\Omega} = 0.761\ kip \cdot ft$

Use HSS1.660x0.140 (A500-HSLA-50)



assumed weld dimensions

Guardrail Post Weld

$t := \frac{3}{16}\ in$ $d_{HSS} := 1.66\ in$ $F_y := 70\ ksi$

$Z_x := \frac{1}{6}\left(\left(d_{HSS} + 2\ 0.707\ t\right)^3 - \left(d_{HSS}\right)^3\right) = 0.427\ in^3$

$M_n := \frac{0.6}{2}\ F_y \cdot Z_x = 0.747\ kip \cdot ft$ $M = 0.653\ kip \cdot ft$

Use 3/16" Weld (E70XX)

Stringer Web Weak Axis Bending

Assuming 40" of Web Resist Bending $b_w := 40\ in$ $F_y := 36\ ksi$

$t_w := 0.19\ in$ $Z_w := \frac{1}{4}\ b_w \cdot t_w^2 = 0.361\ in^3$

$M_n := F_y \cdot Z_w = 1.083\ kip \cdot ft$ $\qquad \dfrac{M_n}{\Omega} = 0.649\ kip \cdot ft$ $\qquad M = 0.653\ kip \cdot ft$

Picket

$F_y := 36\ ksi$ $\qquad Z := \dfrac{1}{6}\ d^3 = 0.009\ in^3$ $\qquad I := \dfrac{\pi}{64}\ d^4 = \left(9.707 \cdot 10^{-4}\right)\ in^4$

$P := 50\ lbf \cdot \dfrac{s_{picket}}{12\ in} = 14.583\ lbf$

$M := \dfrac{1}{4}\ P \cdot L_{picket} = 0.01\ kip \cdot ft$ $\qquad M_n := F_y \cdot Z = 0.026\ kip \cdot ft$ $\qquad \dfrac{M_n}{\Omega} = 0.016\ kip \cdot ft$

$\Delta := \dfrac{P \cdot L_{picket}{}^3}{48 \cdot E \cdot I} = 0.412\ in$ $\qquad d_{opening} := s_{picket} - d + 2\ \Delta = 3.95\ in$ $\qquad$ < 4 in

Use 3/8" Dia. Round Bars (A36)

Handrail Bracket

$d := \dfrac{5}{8}\ in$ $\qquad c := 2.5\ in$ $\qquad M := 200\ lbf \cdot c = 0.042\ kip \cdot ft$

$M_n := F_y \cdot \left(\dfrac{1}{6}\ d^3\right) = 0.122\ kip \cdot ft$ $\qquad \dfrac{M_n}{\Omega} = 0.073\ kip \cdot ft$

Use 5/8" Dia. Round Bars (A36)

Handrail Bracket Weld

$t := \dfrac{3}{16}\ in$ $\qquad F_y := 70\ ksi$

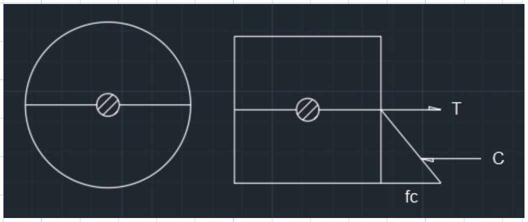
$Z_x := \dfrac{1}{6}\left(\left(d + 2\ 0.707\ t\right)^3 - \left(d\right)^3\right) = 0.077\ in^3$

$M_n := \dfrac{0.6}{2}\ F_y \cdot Z_x = 0.134\ kip \cdot ft$ $\qquad M = 0.042\ kip \cdot ft$

Use 3/16" Weld (E70XX)

Wall Rail Attachment

stress analysis
using area
transformation



$d_{bp} := 2.75\ in$ $\qquad s_{eq} := \sqrt{\dfrac{\pi}{4}\ d_{bp}{}^2} = 2.437\ in$

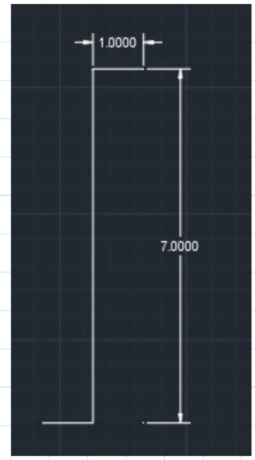
$c := \dfrac{s_{eq}}{3} = 0.812\ in$ $\qquad C := \dfrac{M}{c} = 615.48\ lbf$ $\qquad f_c := \dfrac{4\ C}{s_{eq}{}^2} = 414.494\ psi$ $\qquad F_c := 0.7\ f_m' = 1050\ psi$

$T := C = 615.48\ lbf$ $\qquad T_{n\_\Omega} := 780\ lbf$

Use 2-3/4" dia. Bracket Plate (A36) w/ (1) 3/8" dia. HILTI KB3

Tread and Riser Plate Calculations

The tread and riser plate is analyzed for one foot of load but to avoid slenderness the flanges are kept to 1 inch



Define Variables

$F_y := 36\ ksi \quad t := 0.0598\ in \quad turn := 1\ in \quad P_{LL} := 300\ lbf$

Design Calculations

$w := 1\ ft \cdot DL + 1\ ft \cdot LL = 130\ plf$

$M := \frac{1}{8} w \cdot b^2 = 0.181\ kip \cdot ft \qquad M := \frac{1}{4} P_{LL} \cdot b + \frac{1}{8} (1\ ft \cdot DL) \cdot b^2 = 0.292\ kip \cdot ft$

$I_x := \frac{1}{12} t \cdot (rise \cdot in + t)^3 + \frac{1}{12} (turn - t) \cdot t^3 + 2\ (turn - t) \cdot t \cdot \left(\frac{rise \cdot in}{2}\right)^2 = 3.131\ in^4$

$S_x := \frac{2\ I_x}{rise \cdot in + t} = 0.887\ in^3$

$M_n := F_y \cdot S_x = 2.661\ kip \cdot ft \qquad \frac{M_n}{\Omega} = 1.593\ kip \cdot ft$

$\Delta_{LL} := \frac{5\ (LL \cdot 1\ ft) \cdot b^4}{384 \cdot E \cdot I_x} = 0.003059\ in \qquad \frac{b}{1000} = 0.04\ in$

Use 16-Gauge Steel Plate (A36)

Landing Deck Design

$TL := DL + LL = 130\ psf \qquad b = 3.333\ ft$ Vulcraft: span: 4' 10" TL=131.6 psf

Use 1.5B20 Deck with 1.5" Concrete Topping

Elevator Hoist Beam Design

Define Variables

$W := 4650\ lbf \quad A := 7\ ft + 4\ in \quad B := 6\ ft + 0\ in \quad F_y := 50\ ksi$

Design Calculations

$V := \frac{1}{2} W = 2.325\ kip \qquad M := \frac{1}{4} W \cdot B = 6.975\ kip \cdot ft \qquad Z_x := 5.73\ in^3$

$M_n := F_y \cdot Z_x = 23.875\ kip \cdot ft \qquad \frac{M_n}{\Omega} = 14.296\ kip \cdot ft$

Use W6x8.5 (A992)

Elevator Pit Slab Strength

Define Variables

$B := 8\ ft + 8\ in$ $L := 10\ ft$ $H := 40\ ft + 2\ in$ $w_{CMU} := 58\ psf$

$\gamma_c := 145\ pcf$ $t := 1\ ft$ $A_b := 0.2\ in^2$ $d_b := 0.5\ in$ $f_c' := 4\ ksi$ $f_y := 60\ ksi$

Design Calculations

$$P_{wall\_slab} := w_{CMU} \cdot H \cdot (2\ (B - 2\ ft) + 2\ (L - 2\ ft)) + \gamma_c \cdot t \cdot B \cdot L = 80.904\ kip$$

$$p_{slab} := \frac{P_{wall\_slab}}{B \cdot L} = 0.934\ ksf$$

$$M_u := \frac{1}{8}\ (1.2\ 0.50\ p_{slab})\ (L - 2\ ft)^2 = 4.481\ kip$$

$$A_s := 2 \cdot A_b = 0.4\ in^2$$

$$d := t - 2\ in - 1.5\ d_b = 9.25\ in \qquad \frac{A_s}{1\ ft \cdot d} = 0.0036 > \rho_{min} := 0.0018$$

$$A_{s\_tensioncontrolled} := \frac{0.85 \cdot f_c' \cdot 0.85 \cdot 1\ ft}{f_y} \left(\frac{3\ d}{8}\right) = 2.005\ in^2$$

$$a := \frac{A_s \cdot f_y}{0.85\ f_c' \cdot 1\ ft} = 0.588\ in$$

$$\phi M_n := 0.9 \cdot A_s \cdot f_y \cdot \left(d - \frac{a}{2}\right) = 16.1\ kip \cdot ft$$

Elevator Pit Slab Bearing Capacity

Define Variables

$c' := 0\ psf$ $\phi' := 30\ °$ $\gamma := 120\ pcf$ $FS_q := 3$ $D_f := 12\ ft$

Design Calculations

$$N_q := \exp(\pi\ \tan(\phi')) \cdot \left(\tan\left(45\ ° + \frac{\phi'}{2}\right)\right)^2 = 18.401$$

$$N_c := \frac{(N_q - 1)}{\tan(\phi')} = 30.14$$

$$N_\gamma := 2\ (N_q + 1)\ \tan(\phi') = 22.402$$

$$s_c := 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right) = 1.529$$

$$s_q := 1 + \left(\frac{B}{L}\right)\tan(\phi') = 1.5$$

$$s_\gamma := 1 - 0.4\left(\frac{B}{L}\right) = 0.653$$

$$d_c := 1 + 0.4\left(\frac{D_f}{B}\right) = 1.554$$

$$d_q := 1 + 2\left(\frac{D_f}{B}\right)\tan(\phi')\left(1 - \sin(\phi')\right)^2 = 1.4$$

$$d_\gamma := 1$$

$$q_s := \gamma \cdot D_f = 1440\ psf$$

$$q_n' := c' \cdot N_c \cdot (s_c \cdot d_c) + q_s \cdot N_q \cdot (s_q \cdot d_q) + 0.5\ \gamma \cdot B \cdot N_\gamma \cdot (s_\gamma \cdot d_\gamma) = 63258\ psf$$

$$P_n := q_n' \cdot B \cdot L = 5482.346\ kip$$

$$P_a := \frac{P_n}{FS_q} = 1827.449\ kip \qquad P_{wall\_slab} = 80.904\ kip$$

Dead Load Calculation

Calculated later

Live Load Calculation

$p_{lfloor} := 50\ psf$ $p_{lroof} := 20\ psf$

Snow Load Calculation

Define Variables

$p_g := 30\ psf$ Ground snow load for Volga, IA

$C_e := 0.9$ Exposure factor for surface roughness category B, fully exposed

$C_t := 1.0$ Thermal factor

$I_s := 1.0$ Importance factor for risk category II

Design Calculations

Balanced Load

$p_f := 0.7 \cdot C_e \cdot C_t \cdot I_s \cdot p_g = 18.9\ psf$

Wind Load Calculations

Define Variables

$V := 110\ mph$ (b/c Cat. II)

$K_d := 0.85$ $K_{zt} := 1.0$

$z_g := 900\ ft$ $\alpha := 9.5$ (Exposure Class C, Surface Roughness B)

$z_{15} := 15\ ft$ $z_{16} := 16\ ft$ $z_{27} := 27\ ft$ $z_h := 27\ ft$

$B := 61\ ft$ $L := 68\ ft$ $H := 27\ ft$

$b_w := 3\ ft$ $l_w := 7.5\ ft$

Design Calculations

$$K_e := e^{-0.0000362 \cdot \frac{z_g}{ft}} = 0.968$$

$$K_{15} := 2.01 \cdot \left(\frac{z_{15}}{z_g}\right)^{\frac{2}{\alpha}} = 0.849 \qquad K_{16} := 2.01 \cdot \left(\frac{z_{16}}{z_g}\right)^{\frac{2}{\alpha}} = 0.86$$

$$K_{27} := 2.01 \cdot \left(\frac{z_{27}}{z_g}\right)^{\frac{2}{\alpha}} = 0.961 \qquad K_h := 2.01 \cdot \left(\frac{z_h}{z_g}\right)^{\frac{2}{\alpha}} = 0.961$$

$$q_{15} := 0.00256\ \frac{psf}{mph^2} \cdot K_{15} \cdot K_{zt} \cdot K_d \cdot K_e \cdot V^2 = 21.634\ psf$$

$$q_{16} := 0.00256\ \frac{psf}{mph^2} \cdot K_{16} \cdot K_{zt} \cdot K_d \cdot K_e \cdot V^2 = 21.93\ psf$$

$$q_{27} := 0.00256\ \frac{psf}{mph^2} \cdot K_{27} \cdot K_{zt} \cdot K_d \cdot K_e \cdot V^2 = 24.484\ psf$$

$$q_h := 0.00256\ \frac{psf}{mph^2} \cdot K_h \cdot K_{zt} \cdot K_d \cdot K_e \cdot V^2 = 24.484\ psf$$

$G := 0.85$

Check North wall for partial enclosure classification:

$A_o := 31 \cdot b_w \cdot l_w = 697.5\ ft^2$ $\quad A_g := L \cdot H = 1836\ ft^2$

$A_{oi} := 45\ b_w \cdot l_w = 1012.5\ ft^2$ $\quad A_{gi} := (2\ B + L)\ H = 5130\ ft^2$

$A_o > 0.8\ A_g = 0$ $\quad A_o > 1.1 \cdot A_{oi} = 0$ $\quad A_o > min\left(4\ ft^2, 0.01\ A_g\right) = 1$ $\quad \dfrac{A_{oi}}{A_{gi}} < 0.20 = 1$

Therefore, building is partially open $\quad GC_{pi} := 0.18$

East-West Wind Pressures

$\dfrac{L}{B} = 1.115$ $\quad C_{p\_windward} := 0.8$ $\quad C_{p\_leeward\_EastWest} := -0.5$

$p_{15\_windward\_EastWest} := q_{15} \cdot G \cdot C_{p\_windward} - q_h \cdot GC_{pi} = 10.304\ psf$

$p_{16\_windward\_EastWest} := q_{16} \cdot G \cdot C_{p\_windward} - q_h \cdot GC_{pi} = 10.505\ psf$

$p_{27\_windward\_EastWest} := q_{27} \cdot G \cdot C_{p\_windward} - q_h \cdot GC_{pi} = 12.242\ psf$

$p_{leeward\_EastWest} := q_h \cdot G \cdot C_{p\_leeward\_EastWest} - q_h \cdot GC_{pi} = -14.813\ psf$

$p_{15\_net\_EastWest} := p_{15\_windward\_EastWest} - p_{leeward\_EastWest} = 25.117\ psf$

$p_{16\_net\_EastWest} := p_{16\_windward\_EastWest} - p_{leeward\_EastWest} = 25.318\ psf$

$p_{27\_net\_EastWest} := p_{27\_windward\_EastWest} - p_{leeward\_EastWest} = 27.055\ psf$

North-South Wind Pressures

$\dfrac{B}{L} = 0.897$ $\quad C_{p\_leeward\_NorthSouth} := -0.5$

$p_{leeward\_NorthSouth} := q_h \cdot G \cdot C_{p\_leeward\_NorthSouth} - q_h \cdot GC_{pi} = -14.813\ psf$

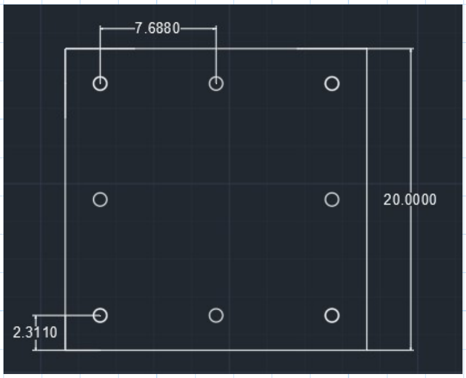
Windward East-West pressures are same as
windward North-South pressures.

$p_{15\_net\_NorthSouth} := p_{15\_windward\_EastWest} - p_{leeward\_NorthSouth} = 25.117\ psf$

$p_{16\_net\_NorthSouth} := p_{16\_windward\_EastWest} - p_{leeward\_NorthSouth} = 25.318\ psf$

$p_{27\_net\_NorthSouth} := p_{27\_windward\_EastWest} - p_{leeward\_NorthSouth} = 27.055\ psf$

Column Axial Strength Calculations



Define Variables

$b := 20\ in$ $A_7 := 0.6\ in^2$ $f_c' := 3000\ psi$ $f_y := 40\ ksi$ $P_c := 178\ kip$ $M_c := 16\ kip \cdot ft$

Design Calculations

$A_g := b^2 = 400\ in^2$ $A_{st} := 8\ A_7 = 4.8\ in^2$ $A_c := A_g - A_{st} = 395.2\ in^2$

$\phi P_n := 0.8 \cdot 0.65\ \left(0.85\ f_c' \cdot A_c + f_y \cdot A_{st}\right) = 624\ kip$ $P_{r1} := \phi P_n = 623.9\ kip$ $M_{r1} := 0\ kip \cdot ft$

Column Bending and Axial Interaction Calculations

Define Variables

$f_c' := 3000\ psi$ $f_y := 40000\ psi$ $E_s := 29000\ ksi$ $\varepsilon_{cu} := 0.003$

$h := 20\ in$ $c_c := 1.5\ in$ $d_s := \frac{3}{8}\ in$ $d_7 := 0.875\ in$ $A_7 := 0.6\ in^2$

Design Calculations

$F_{c1} := 0.85\ f_c' \cdot h^2 = 1020\ kip$ $y_{c1} := \frac{h}{2} = 10\ in$

$d' := c_c + d_s + \frac{d_7}{2} = 2.313\ in$ $s := \frac{h - 2\ d'}{2} = 7.688\ in$

$F_{s1} := \left(f_y - 0.85\ f_c'\right) \cdot 3\ A_7 = 67\ kip$ $y_{s1} := d' = 2.313\ in$

$F_{s2} := \left(f_y - 0.85\ f_c'\right) \cdot 2\ A_7 = 45\ kip$ $y_{s2} := d' + s = 10\ in$

$F_{s3} := \left(f_y - 0.85\ f_c'\right) \cdot 3\ A_7 = 67\ kip$ $y_{s3} := d' + 2\ s = 17.69\ in$

$$y_p := \frac{F_{c1} \cdot y_{c1} + F_{s1} \cdot y_{s1} + F_{s2} \cdot y_{s2} + F_{s3} \cdot y_{s3}}{F_{c1} + F_{s1} + F_{s2} + F_{s3}} = 10\ in$$

$\varepsilon_{s1} := 0$ $\quad \varepsilon_0 := \dfrac{\varepsilon_{s1} \cdot h - \varepsilon_{cu} \cdot y_{s1}}{h - y_{s1}} = -3.922 \cdot 10^{-4}$

$c := \dfrac{\varepsilon_{cu} \cdot h}{\varepsilon_{cu} - \varepsilon_0} = 17.688\ in \quad a := 0.85\ c = 15.034\ in$

$\Sigma F_c := 0.85\ f_c' \cdot a \cdot h = 766.8\ kip \quad M_{c1} := \Sigma F_c \cdot \left(h - \dfrac{a}{2} - y_p\right) = 158.6\ kip \cdot ft$

$\varepsilon_{ty} := \dfrac{f_y}{E_s} = 0.001379 \quad \varepsilon_0 := -\varepsilon_{cu} \cdot \dfrac{(h - c)}{c} = -3.922 \cdot 10^{-4}$

$\varepsilon_{s1} := \varepsilon_0 \cdot \dfrac{h - y_{s1}}{h} + \varepsilon_{cu} \cdot \dfrac{y_{s1}}{h} = -5.421 \cdot 10^{-20} \quad \varepsilon_{s2} := \varepsilon_0 \cdot \dfrac{h - y_{s2}}{h} + \varepsilon_{cu} \cdot \dfrac{y_{s2}}{h} = 0.001$

$\varepsilon_{s3} := \varepsilon_0 \cdot \dfrac{h - y_{s3}}{h} + \varepsilon_{cu} \cdot \dfrac{y_{s3}}{h} = 0.002608$

$f_{s1} := \varepsilon_{s1} \cdot E_s = 0\ psi \quad f_{s2} := \varepsilon_{s2} \cdot E_s - 0.85\ f_c' = 35263\ psi$

$f_{s3} := f_y - 0.85\ f_c' = 37450\ psi \quad f_{s4} := f_y - 0.85\ f_c' = 37450\ psi$

$F_{s1} := f_{s1} \cdot 3\ A_7 = -2.83 \cdot 10^{-15}\ kip \quad F_{s2} := f_{s2} \cdot 2\ A_7 = 42.315\ kip$

$F_{s3} := f_{s3} \cdot 3\ A_7 = 67.41\ kip$

$\Sigma F_s := F_{s1} + F_{s2} + F_{s3} = 109.725\ kip$

$P_n := \Sigma F_c + \Sigma F_s = 876.5\ kip$

$M_n := F_{s1} \cdot (y_{s1} - y_p) + F_{s2} \cdot (y_{s2} - y_p) + F_{s3} \cdot (y_{s3} - y_p) + M_{c1} = 201.8\ kip \cdot ft$

$\phi := 0.65 = 0.65$

$P_{r2} := \phi \cdot P_n = 569.7\ kip \quad M_{r2} := \phi \cdot M_n = 131.2\ kip \cdot ft$

$\varepsilon_{s1} := \dfrac{-f_y}{E_s} = -0.001 \quad \varepsilon_0 := \dfrac{\varepsilon_{s1} \cdot h - \varepsilon_{cu} \cdot y_{s1}}{h - y_{s1}} = -0.002$

$c := \dfrac{\varepsilon_{cu} \cdot h}{\varepsilon_{cu} - \varepsilon_0} = 12.117\ in \quad a := 0.85\ c = 10.299\ in$

$\Sigma F_c := 0.85\ f_c{}' \cdot a \cdot h = 525.3\ kip$ $\quad M_{c1} := \Sigma F_c \cdot \left(h - \frac{a}{2} - y_p\right) = 212.3\ kip \cdot ft$

$\varepsilon_{ty} := \frac{f_y}{E_s} = 0.001379$ $\quad \varepsilon_0 := -\varepsilon_{cu} \cdot \frac{(h-c)}{c} = -0.002$

$\varepsilon_{s1} := \varepsilon_0 \cdot \frac{h - y_{s1}}{h} + \varepsilon_{cu} \cdot \frac{y_{s1}}{h} = -0.001$ $\quad \varepsilon_{s2} := \varepsilon_0 \cdot \frac{h - y_{s2}}{h} + \varepsilon_{cu} \cdot \frac{y_{s2}}{h} = 5.241 \cdot 10^{-4}$

$\varepsilon_{s3} := \varepsilon_0 \cdot \frac{h - y_{s3}}{h} + \varepsilon_{cu} \cdot \frac{y_{s3}}{h} = 0.002427$

$f_{s1} := \varepsilon_{s1} \cdot E_s = -40000\ psi$ $\quad f_{s2} := \varepsilon_{s2} \cdot E_s = 15198\ psi$

$f_{s3} := f_y - 0.85\ f_c{}' = 37450\ psi$

$F_{s1} := f_{s1} \cdot 3\ A_7 = -72\ kip$ $\quad F_{s2} := f_{s2} \cdot 2\ A_7 = 18.237\ kip$

$F_{s3} := f_{s3} \cdot 3\ A_7 = 67.41\ kip$

$\Sigma F_s := F_{s1} + F_{s2} + F_{s3} = 13.647\ kip$

$P_n := \Sigma F_c + \Sigma F_s = 538.9\ kip$

$M_n := F_{s1} \cdot (y_{s1} - y_p) + F_{s2} \cdot (y_{s2} - y_p) + F_{s3} \cdot (y_{s3} - y_p) + M_{c1} = 301.6\ kip \cdot ft$

$\phi := 0.65 + 0.25 \left(\frac{\text{abs}(\varepsilon_{s1}) - \varepsilon_{ty}}{0.003}\right) = 0.65$

$P_{r3} := \phi \cdot P_n = 350.3\ kip$ $\quad M_{r3} := \phi \cdot M_n = 196.1\ kip \cdot ft$

$\varepsilon_{s1} := -0.005$ $\quad \varepsilon_0 := \frac{\varepsilon_{s1} \cdot h - \varepsilon_{cu} \cdot y_{s1}}{h - y_{s1}} = -0.006$

$c := \frac{\varepsilon_{cu} \cdot h}{\varepsilon_{cu} - \varepsilon_0} = 6.633\ in$ $\quad a := 0.85\ c = 5.638\ in$

$\Sigma F_c := 0.85\ f_c{}' \cdot a \cdot h = 287.5\ kip$ $\quad M_{c1} := \Sigma F_c \cdot \left(h - \frac{a}{2} - y_p\right) = 172.1\ kip \cdot ft$

$\varepsilon_{ty} := \frac{f_y}{E_s} = 0.001379$ $\quad \varepsilon_0 := -\varepsilon_{cu} \cdot \frac{(h-c)}{c} = -0.006$

$\varepsilon_{s1} := \varepsilon_0 \cdot \frac{h - y_{s1}}{h} + \varepsilon_{cu} \cdot \frac{y_{s1}}{h} = -0.005$ $\quad \varepsilon_{s2} := \varepsilon_0 \cdot \frac{h - y_{s2}}{h} + \varepsilon_{cu} \cdot \frac{y_{s2}}{h} = -0.002$

$$\varepsilon_{s3} := \varepsilon_0 \cdot \frac{h - y_{s3}}{h} + \varepsilon_{cu} \cdot \frac{y_{s3}}{h} = 0.001954$$

$f_{s1} := -f_y = -40000\ psi$ $\quad$ $f_{s2} := -f_y = -40000\ psi$

$f_{s3} := f_y - 0.85\ f_c{}' = 37450\ psi$

$F_{s1} := f_{s1} \cdot 3\ A_7 = -72\ kip$ $\quad$ $F_{s2} := f_{s2} \cdot 2\ A_7 = -48\ kip$

$F_{s3} := f_{s3} \cdot 3\ A_7 = 67.41\ kip$

$\Sigma F_s := F_{s1} + F_{s2} + F_{s3} = -52.59\ kip$

$P_n := \Sigma F_c + \Sigma F_s = 234.9\ kip$

$M_n := F_{s1} \cdot (y_{s1} - y_p) + F_{s2} \cdot (y_{s2} - y_p) + F_{s3} \cdot (y_{s3} - y_p) + M_{c1} = 261.4\ kip \cdot ft$

$\phi := 0.90 = 0.9$

$P_{r4} := \phi \cdot P_n = 211.4\ kip$ $\quad$ $M_{r4} := \phi \cdot M_n = 235.2\ kip \cdot ft$

$\varepsilon_{s1} := -0.02$ $\quad$ $\varepsilon_0 := \dfrac{\varepsilon_{s1} \cdot h - \varepsilon_{cu} \cdot y_{s1}}{h - y_{s1}} = -0.023$

$c := \dfrac{\varepsilon_{cu} \cdot h}{\varepsilon_{cu} - \varepsilon_0} = 2.307\ in$ $\quad$ $a := 0.85\ c = 1.961\ in$

$\Sigma F_c := 0.85\ f_c{}' \cdot a \cdot h = 100\ kip$ $\quad$ $M_{c1} := \Sigma F_c \cdot \left(h - \dfrac{a}{2} - y_p\right) = 75.2\ kip \cdot ft$

$\varepsilon_{ty} := \dfrac{f_y}{E_s} = 0.001379$ $\quad$ $\varepsilon_0 := -\varepsilon_{cu} \cdot \dfrac{(h - c)}{c} = -0.023$

$\varepsilon_{s1} := \varepsilon_0 \cdot \dfrac{h - y_{s1}}{h} + \varepsilon_{cu} \cdot \dfrac{y_{s1}}{h} = -0.02$ $\quad$ $\varepsilon_{s2} := \varepsilon_0 \cdot \dfrac{h - y_{s2}}{h} + \varepsilon_{cu} \cdot \dfrac{y_{s2}}{h} = -0.01$

$$\varepsilon_{s3} := \varepsilon_0 \cdot \frac{h - y_{s3}}{h} + \varepsilon_{cu} \cdot \frac{y_{s3}}{h} = -0.000007$$

$f_{s1} := -f_y = -40000\ psi$ $\quad$ $f_{s2} := -f_y = -40000\ psi$

$f_{s3} := \varepsilon_{s3} \cdot E_s = -205\ psi$

$F_{s1} := f_{s1} \cdot 3\ A_7 = -72\ kip$ $F_{s2} := f_{s2} \cdot 2\ A_7 = -48\ kip$

$F_{s3} := f_{s3} \cdot 3\ A_7 = -0.369\ kip$

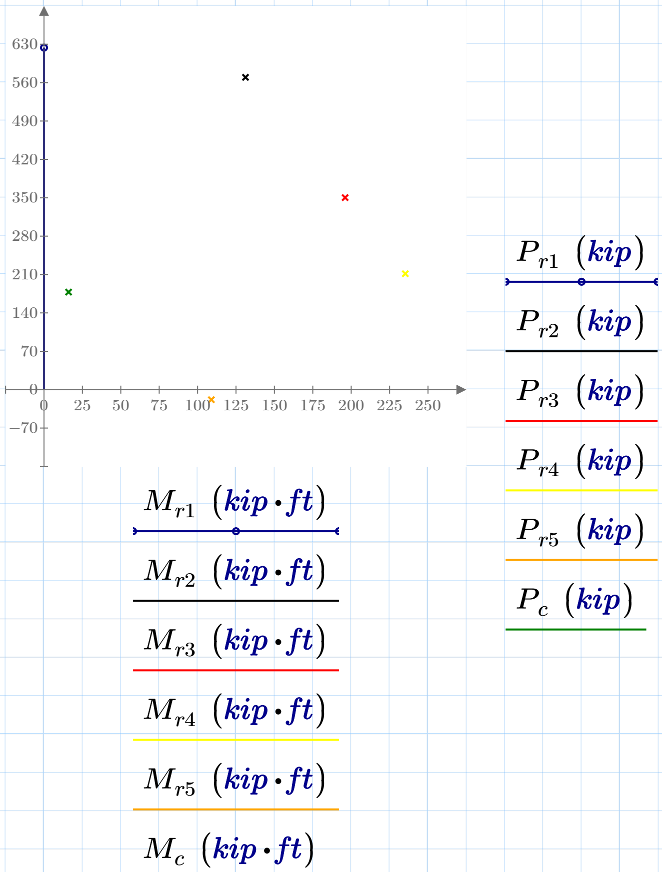
$\Sigma F_s := F_{s1} + F_{s2} + F_{s3} = -120.369\ kip$

$P_n := \Sigma F_c + \Sigma F_s = -20.4\ kip$

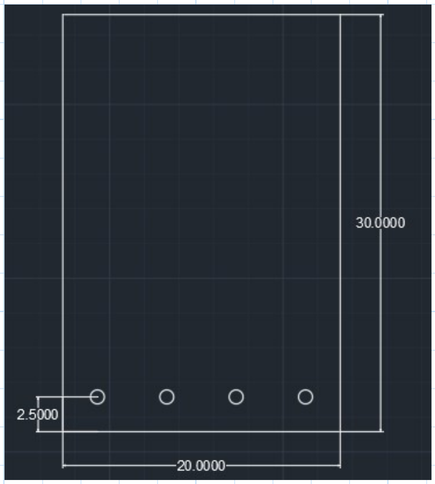
$M_n := F_{s1} \cdot (y_{s1} - y_p) + F_{s2} \cdot (y_{s2} - y_p) + F_{s3} \cdot (y_{s3} - y_p) + M_{c1} = 121.1\ kip \cdot ft$

$\phi := 0.9 = 0.9$

$P_{r5} := \phi \cdot P_n = -18.3\ kip$ $M_{r5} := \phi \cdot M_n = 109\ kip \cdot ft$



Beam Shear Design



Define Variables

$b_w := 20\ in$ $h := 30\ in$ $c := 2.5\ in$ $h_s := 6\ in$ $N_u := 4\ kip$ $V_u := 61\ kip$

$A_b := 0.79\ in^2$ $f_c' := 3000\ psi$ $\lambda := 1$ $A_s := 0.2\ in^2$

Design Calculations

$d := h - c = 27.5\ in$

$\rho_w := \frac{4\ A_b}{b_w \cdot d} = 0.006$

$A_g := b_w \cdot h = 600\ in^2$

$$\phi V_c := 0.75\ min\left(5\ \lambda \cdot \sqrt{f_c'} \cdot \frac{\sqrt{lbf}}{in}, 8 \cdot \lambda \cdot (\rho_w)^{\frac{1}{3}} \cdot \sqrt{f_c'} \cdot \frac{\sqrt{lbf}}{in} + min\left(0.05 \cdot f_c', \frac{N_u}{6\ A_g}\right)\right) b_w \cdot d = 32.8\ kip$$

$\phi := 0.75$ $A_v := 2\ A_s = 0.4\ in^2$ $f_{yt} := f_y = 40\ ksi$

$V_{srequired} := \frac{V_u - \phi V_c}{\phi} = 37.558\ kip$

$s_{max} := A_v \cdot f_{yt} \cdot \frac{d}{V_{srequired}} = 11.715\ in$

Beam Moment Design

Define Variables

$b_w := 20\ in$ $h := 30\ in$ $y_s := 2.5\ in$ $h_s := 6\ in$ $M_u := 252\ kip \cdot ft$

$A_b := 0.79\ in^2$ $f_c' := 3000\ psi$ $\lambda := 1$ $A_s := 0.2\ in^2$

Design Calculations

$A_s := 4 \cdot A_b = 3.16\ in^2$

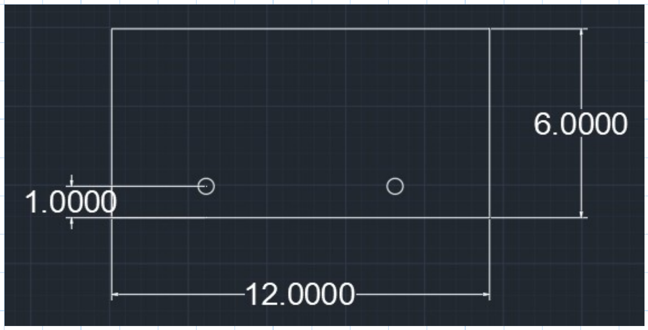
$d := h - y_s = 27.5\ in$ $\frac{A_s}{b_w \cdot d} = 0.00575 > \rho_{min} := 0.0018$

$$A_{s\_tensioncontrolled} := \frac{0.85 \cdot f_c' \cdot 0.85 \cdot b_w}{f_y} \left(\frac{3\ d}{8}\right) = 11.176\ in^2$$

$$a := \frac{A_s \cdot f_y}{0.85\ f_c' \cdot b_w} = 2.478\ in$$

$$\phi M_n := 0.9 \cdot A_s \cdot f_y \cdot \left(d - \frac{a}{2}\right) = 249\ kip \cdot ft$$

Slab Shear Design



Foot worth of slab

Define Variables

$b_w := 20\ in$ $h := 30\ in$ $c := 1\ in$ $h_s := 6\ in$ $N_u := 0\ kip$ $V_u := 1.563\ kip$

$A_b := 0.2\ in^2$ $f_c' := 3000\ psi$ $\lambda := 1$ $A_s := 0.2\ in^2$

Design Calculations

$d := h_s - c = 5\ in$

$\rho_w := \frac{2\ A_b}{1\ ft \cdot d} = 0.007$

$A_g := 1\ ft \cdot h_s = 72\ in^2$

$$\phi V_c := 0.75\ min\left(5\ \lambda \cdot \sqrt{f_c'} \cdot \frac{\sqrt{lbf}}{in}, 8 \cdot \lambda \cdot (\rho_w)^{\frac{1}{3}} \cdot \sqrt{f_c'} \cdot \frac{\sqrt{lbf}}{in} + min\left(0.05 \cdot f_c', \frac{N_u}{6\ A_g}\right)\right) 1\ ft \cdot d = 3.7\ kip$$

Slab Moment Design

Define Variables

$b_w := 20\ in$ $h := 30\ in$ $y_s := 1\ in$ $h_s := 6\ in$ $M_u := 4.345\ kip \cdot ft$

$A_b := 0.2\ in^2$ $f_c' := 3000\ psi$ $\lambda := 1$ $A_s := 0.2\ in^2$

Design Calculations

$A_s := 2 \cdot A_b = 0.4\ in^2$

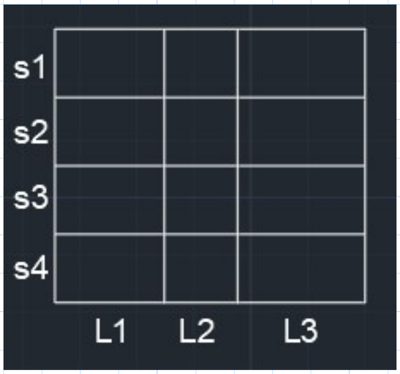
$d := h_s - y_s = 5\ in$ $\frac{A_s}{1\ ft \cdot d} = 0.00667 > \rho_{min} := 0.0018$

$$A_{s\_tensioncontrolled} := \frac{0.85 \cdot f_c{}' \cdot 0.85 \cdot 1\ ft}{f_y} \left(\frac{3\ d}{8}\right) = 1.219\ in^2$$

$$a := \frac{A_s \cdot f_y}{0.85\ f_c{}' \cdot 1\ ft} = 0.523\ in$$

$$\phi M_n := 0.9 \cdot A_s \cdot f_y \cdot \left(d - \frac{a}{2}\right) = 5.7\ kip \cdot ft$$

Wind Load Shear, Axial Force, and Moments Calculated Using Portal Method



Define Variables

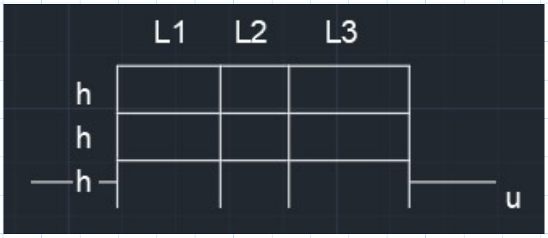
$p_1 := 25.117\ psf$ $p_2 := 27.055\ psf$ $h := 11\ ft$ $u := 6\ ft$

$s_1 := 15\ ft$ $s_2 := 15\ ft$ $s_3 := 15\ ft$ $s_4 := 15\ ft$

$L_1 := 24\ ft$ $L_2 := 16\ ft$ $L_3 := 28\ ft$

Design Calculations

East-West Wind



$w_1 := p_1 \cdot (h - u + 0.5\ h) = 263.729\ plf$ $w_2 := p_2 \cdot (0.5\ h) + p_1 \cdot (0.5\ h) = 286.946\ plf$

$w_3 := p_2 \cdot (0.5\ h) = 148.803\ plf$ $\Sigma s := s_1 + s_2 + s_3 + s_4 = 60\ ft$

$P_1 := w_1 \cdot \frac{\Sigma s}{5} = 3.165\ kip$ $P_2 := w_2 \cdot \frac{\Sigma s}{5} = 3.443\ kip$ $P_3 := w_3 \cdot \frac{\Sigma s}{5} = 1.786\ kip$

Guess Values

$V_{c1} := 1\ kip \quad V_{c2} := 1\ kip \quad V_{c3} := 1\ kip \quad V_{c4} := 1\ kip$

Constraints

$0\ kip = P_3 + V_{c1} + V_{c2} + V_{c3} + V_{c4} \quad V_{c2} = 2\ V_{c1} \quad V_{c3} = 2\ V_{c4} \quad V_{c4} = V_{c1}$

Solver

$$\begin{bmatrix} V_{c1} \\ V_{c2} \\ V_{c3} \\ V_{c4} \end{bmatrix} := \text{find}\left(V_{c1}, V_{c2}, V_{c3}, V_{c4}\right) = \begin{bmatrix} -0.298 \\ -0.595 \\ -0.595 \\ -0.298 \end{bmatrix} kip$$

Guess Values

$V_{b1} := 1\ kip \quad F_{c1} := 1\ kip \quad F_{b1} := 1\ kip \quad M_{c1} := 1\ kip \cdot ft \quad M_{b1} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c1} + F_{b1} + P_3 \quad 0\ kip = F_{c1} + V_{b1} \quad 0\ kip \cdot ft = M_{b1} + M_{c1}$

$M_{c1} = 0.5\ h\ V_{c1} \quad M_{b1} = 0.5\ L_1\ V_{b1}$

Solver

$$\begin{bmatrix} V_{b1} \\ F_{c1} \\ F_{b1} \\ M_{c1} \\ M_{b1} \end{bmatrix} := \text{find}\left(V_{b1}, F_{c1}, F_{b1}, M_{c1}, \mathrm{M_{b1}}\right) = \begin{bmatrix} 0.136 \\ -0.136 \\ -1.488 \\ -1.637\ ft \\ 1.637\ ft \end{bmatrix} kip$$

Guess Values

$V_{b2} := 1\ kip \quad F_{c2} := 1\ kip \quad F_{b2} := 1\ kip \quad M_{c2} := 1\ kip \cdot ft \quad M_{b2} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c2} + F_{b2} - F_{b1} \quad 0\ kip = F_{c2} + V_{b2} - V_{b1} \quad 0\ kip \cdot ft = M_{b2} + M_{c2} + M_{b1}$

$M_{c2} = 0.5\ h\ V_{c2} \quad M_{b2} = 0.5\ L_2\ V_{b2}$

Solver

$$\begin{bmatrix} V_{b2} \\ F_{c2} \\ F_{b2} \\ M_{c2} \\ M_{b2} \end{bmatrix} := \text{find}\left(V_{b2}, F_{c2}, F_{b2}, M_{c2}, \mathrm{M_{b2}}\right) = \begin{bmatrix} 0.205 \\ -0.068 \\ -0.893 \\ -3.274\ ft \\ 1.637\ ft \end{bmatrix} kip$$

Guess Values

$V_{b3} := 1\ kip \quad F_{c3} := 1\ kip \quad F_{b3} := 1\ kip \quad M_{c3} := 1\ kip \cdot ft \quad M_{b3} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c3} + F_{b3} - F_{b2} \quad 0\ kip = F_{c3} + V_{b3} - V_{b2} \quad 0\ kip \cdot ft = M_{b3} + M_{c3} + M_{b2}$

$M_{c3} = 0.5\ h\ V_{c3} \quad M_{b3} = 0.5\ L_3\ V_{b3}$

Solver

$$\begin{bmatrix} V_{b3} \\ F_{c3} \\ F_{b3} \\ M_{c3} \\ M_{b3} \end{bmatrix} := \text{find}\left(V_{b3}, F_{c3}, F_{b3}, M_{c3}, M_{b3}\right) = \begin{bmatrix} 0.117 \\ 0.088 \\ -0.298 \\ -3.274\ ft \\ 1.637\ ft \end{bmatrix} kip$$

Guess Values

$F_{c4} := 1\ kip \qquad M_{c4} := 1\ kip \cdot ft$

Constraints

$0\ kip = F_{c4} - V_{b3} \qquad M_{c4} = 0.5\ h\ V_{c4}$

Solver

$$\begin{bmatrix} F_{c4} \\ M_{c4} \end{bmatrix} := \text{find}\left(F_{c4}, M_{c4}\right) = \begin{bmatrix} 0.117 \\ -1.637\ ft \end{bmatrix} kip$$

Guess Values

$V_{c5} := 1\ kip \qquad V_{c6} := 1\ kip \qquad V_{c7} := 1\ kip \qquad V_{c8} := 1\ kip$

Constraints

$0\ kip = P_2 + P_3 + V_{c5} + V_{c6} + V_{c7} + V_{c8} \qquad V_{c6} = 2\ V_{c5} \qquad V_{c7} = 2\ V_{c8} \qquad V_{c8} = V_{c5}$

Solver

$$\begin{bmatrix} V_{c5} \\ V_{c6} \\ V_{c7} \\ V_{c8} \end{bmatrix} := \text{find}\left(V_{c5}, V_{c6}, V_{c7}, V_{c8}\right) = \begin{bmatrix} -0.871 \\ -1.743 \\ -1.743 \\ -0.871 \end{bmatrix} kip$$

Guess Values

$V_{b4} := 1\ kip \qquad F_{c5} := 1\ kip \qquad F_{b4} := 1\ kip \qquad M_{c5} := 1\ kip \cdot ft \qquad M_{b4} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c5} + F_{b4} + P_2 - V_{c1} \qquad 0\ kip = F_{c5} + V_{b4} - F_{c1} \qquad 0\ kip \cdot ft = M_{b4} + M_{c5} + M_{c1}$

$M_{c5} = 0.5\ h\ V_{c5} \qquad M_{b4} = 0.5\ L_1\ V_{b4}$

Solver

$$\begin{bmatrix} V_{b4} \\ F_{c5} \\ F_{b4} \\ M_{c5} \\ M_{b4} \end{bmatrix} := \text{find}\left(V_{b4}, F_{c5}, F_{b4}, M_{c5}, \mathrm{M_{b4}}\right) = \begin{bmatrix} 0.536 \\ -0.672 \\ -2.869 \\ -4.793\ ft \\ 6.43\ ft \end{bmatrix} kip$$

Guess Values

$V_{b5} := 1\ kip \qquad F_{c6} := 1\ kip \qquad F_{b5} := 1\ kip \qquad M_{c6} := 1\ kip \cdot ft \qquad M_{b5} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c6} + F_{b5} - F_{b4} - V_{c2} \qquad 0\ kip = F_{c6} + V_{b5} - V_{b4} - F_{c2}$

$M_{c6} = 0.5\ h\ V_{c6} \qquad M_{b5} = 0.5\ L_2\ V_{b5} \qquad 0\ kip \cdot ft = M_{b5} + M_{c6} + M_{b4}$

Solver

$$\begin{bmatrix} V_{b5} \\ F_{c6} \\ F_{b5} \\ M_{c6} \\ M_{b5} \end{bmatrix} := \text{find}\left(V_{b5}, F_{c6}, F_{b5}, M_{c6}, M_{b5}\right) = \begin{bmatrix} 0.395 \\ 0.073 \\ -1.722 \\ -9.586\ ft \\ 3.156\ ft \end{bmatrix} kip$$

Guess Values

$V_{b6} := 1\ kip \quad F_{c7} := 1\ kip \quad F_{b6} := 1\ kip \quad M_{c7} := 1\ kip \cdot ft \quad M_{b6} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c7} + F_{b6} - F_{b5} - V_{c3} \quad 0\ kip = F_{c7} + V_{b6} - V_{b5} - F_{c3}$

$M_{c7} = 0.5\ h\ V_{c7} \quad M_{b6} = 0.5\ L_3\ V_{b6} \quad 0\ kip \cdot ft = M_{b6} + M_{c7} + M_{b5}$

Solver

$$\begin{bmatrix} V_{b6} \\ F_{c7} \\ F_{b6} \\ M_{c7} \\ M_{b6} \end{bmatrix} := \text{find}\left(V_{b6}, F_{c7}, F_{b6}, M_{c7}, M_{b6}\right) = \begin{bmatrix} 0.459 \\ 0.023 \\ -0.574 \\ -9.586\ ft \\ 6.43\ ft \end{bmatrix} kip$$

Guess Values

$F_{c8} := 1\ kip \quad M_{c8} := 1\ kip \cdot ft$

Constraints

$0\ kip = F_{c8} - V_{b6} - F_{c4} \quad M_{c8} = 0.5\ h\ V_{c8}$

Solver

$$\begin{bmatrix} F_{c8} \\ M_{c8} \end{bmatrix} := \text{find}\left(F_{c8}, M_{c8}\right) = \begin{bmatrix} 0.576 \\ -4.793\ ft \end{bmatrix} kip$$

Guess Values

$V_{c9} := 1\ kip \quad V_{c10} := 1\ kip \quad V_{c11} := 1\ kip \quad V_{c12} := 1\ kip$

Constraints

$0\ kip = P_1 + P_2 + P_3 + V_{c9} + V_{c10} + V_{c11} + V_{c12} \quad V_{c10} = 2\ V_{c9} \quad V_{c11} = 2\ V_{c12} \quad V_{c12} = V_{c9}$

Solver

$$\begin{bmatrix} V_{c9} \\ V_{c10} \\ V_{c11} \\ V_{c12} \end{bmatrix} := \text{find}\left(V_{c9}, V_{c10}, V_{c11}, V_{c12}\right) = \begin{bmatrix} -1.399 \\ -2.798 \\ -2.798 \\ -1.399 \end{bmatrix} kip$$

Guess Values

$V_{b7} := 1\ kip \quad F_{c9} := 1\ kip \quad F_{b7} := 1\ kip \quad M_{c9} := 1\ kip \cdot ft \quad M_{b7} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c9} + F_{b7} + P_1 - V_{c5} \quad 0\ kip = F_{c9} + V_{b7} - F_{c5} \quad 0\ kip \cdot ft = M_{b7} + M_{c9} + M_{c5}$

$M_{c9} = 0.5\ h\ V_{c9} \quad M_{b7} = 0.5\ L_1\ V_{b7}$

Solver

$$\begin{bmatrix} V_{b7} \\ F_{c9} \\ F_{b7} \\ M_{c9} \\ M_{b7} \end{bmatrix} := \text{find}\left(V_{b7}, F_{c9}, F_{b7}, M_{c9}, M_{b7}\right) = \begin{bmatrix} 1.041 \\ -1.713 \\ -2.637 \\ -7.694\ ft \\ 12.487\ ft \end{bmatrix} kip$$

Guess Values

$V_{b8} := 1\ kip \quad F_{c10} := 1\ kip \quad F_{b8} := 1\ kip \quad M_{c10} := 1\ kip \cdot ft \quad M_{b8} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c10} + F_{b8} - F_{b7} - V_{c6} \quad 0\ kip = F_{c10} + V_{b8} - V_{b7} - F_{c6}$

$M_{c10} = 0.5\ h\ V_{c10} \quad M_{b8} = 0.5\ L_2\ V_{b8} \quad 0\ kip \cdot ft = M_{b8} + M_{c10} + M_{b7}$

Solver

$$\begin{bmatrix} V_{b8} \\ F_{c10} \\ F_{b8} \\ M_{c10} \\ M_{b8} \end{bmatrix} := \text{find}\left(V_{b8}, F_{c10}, F_{b8}, M_{c10}, M_{b8}\right) = \begin{bmatrix} 0.363 \\ 0.751 \\ -1.582 \\ -15.388\ ft \\ 2.901\ ft \end{bmatrix} kip$$

Guess Values

$V_{b9} := 1\ kip \quad F_{c11} := 1\ kip \quad F_{b9} := 1\ kip \quad M_{c11} := 1\ kip \cdot ft \quad M_{b9} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c11} + F_{b9} - F_{b8} - V_{c7} \quad 0\ kip = F_{c11} + V_{b9} - V_{b8} - F_{c7}$

$M_{c11} = 0.5\ h\ V_{c11} \quad M_{b9} = 0.5\ L_3\ V_{b9} \quad 0\ kip \cdot ft = M_{b9} + M_{c11} + M_{b8}$

Solver

$$\begin{bmatrix} V_{b9} \\ F_{c11} \\ F_{b9} \\ M_{c11} \\ M_{b9} \end{bmatrix} := \text{find}\left(V_{b9}, F_{c11}, F_{b9}, M_{c11}, M_{b9}\right) = \begin{bmatrix} 0.892 \\ -0.506 \\ -0.527 \\ -15.388\ ft \\ 12.487\ ft \end{bmatrix} kip$$

Guess Values

$F_{c12} := 1\ kip \quad M_{c12} := 1\ kip \cdot ft$

Constraints

$0\ kip = F_{c12} - V_{b9} - F_{c8} \quad M_{c12} = 0.5\ h\ V_{c12}$

Solver

$$\begin{bmatrix} F_{c12} \\ M_{c12} \end{bmatrix} := \text{find}\left(F_{c12}, M_{c12}\right) = \begin{bmatrix} 1.468 \\ -7.694\ ft \end{bmatrix} kip$$

$V_{c1} = -0.298\ kip \quad V_{c2} = -0.595\ kip \quad V_{c3} = -0.595\ kip \quad V_{c4} = -0.298\ kip$

$V_{c5} = -0.871\ kip \quad V_{c6} = -1.743\ kip \quad V_{c7} = -1.743\ kip \quad V_{c8} = -0.871\ kip$

$V_{c9} = -1.399\ kip \quad V_{c10} = -2.798\ kip \quad V_{c11} = -2.798\ kip \quad V_{c12} = -1.399\ kip$

$V_{b1} = 0.136\ kip \quad V_{b2} = 0.205\ kip \quad V_{b3} = 0.117\ kip$

$V_{b4} = 0.536\ kip \quad V_{b5} = 0.395\ kip \quad V_{b6} = 0.459\ kip$

$V_{b7} = 1.041\ kip \quad V_{b8} = 0.363\ kip \quad V_{b9} = 0.892\ kip$

$F_{c1} = -0.136\ kip \quad F_{c2} = -0.068\ kip \quad F_{c3} = 0.088\ kip \quad F_{c4} = 0.117\ kip$

$F_{c5} = -0.672\ kip$ $F_{c6} = 0.073\ kip$ $F_{c7} = 0.023\ kip$ $F_{c8} = 0.576\ kip$

$F_{c9} = -1.713\ kip$ $F_{c10} = 0.751\ kip$ $F_{c11} = -0.506\ kip$ $F_{c12} = 1.468\ kip$

$F_{b1} = -1.488\ kip$ $F_{b2} = -0.893\ kip$ $F_{b3} = -0.298\ kip$

$F_{b4} = -2.869\ kip$ $F_{b5} = -1.722\ kip$ $F_{b6} = -0.574\ kip$

$F_{b7} = -2.637\ kip$ $F_{b8} = -1.582\ kip$ $F_{b9} = -0.527\ kip$

$M_{c1} = -1.637\ kip \cdot ft$ $M_{c2} = -3.274\ kip \cdot ft$ $M_{c3} = -3.274\ kip \cdot ft$ $M_{c4} = -1.637\ kip \cdot ft$

$M_{c5} = -4.793\ kip \cdot ft$ $M_{c6} = -9.586\ kip \cdot ft$ $M_{c7} = -9.586\ kip \cdot ft$ $M_{c8} = -4.793\ kip \cdot ft$

$M_{c9} = -7.694\ kip \cdot ft$ $M_{c10} = -15.388\ kip \cdot ft$ $M_{c11} = -15.388\ kip \cdot ft$ $M_{c12} = -7.694\ kip \cdot ft$

$M_{b1} = 1.637\ kip \cdot ft$ $M_{b2} = 1.637\ kip \cdot ft$ $M_{b3} = 1.637\ kip \cdot ft$

$M_{b4} = 6.43\ kip \cdot ft$ $M_{b5} = 3.156\ kip \cdot ft$ $M_{b6} = 6.43\ kip \cdot ft$

$M_{b7} = 12.487\ kip \cdot ft$ $M_{b8} = 2.901\ kip \cdot ft$ $M_{b9} = 12.487\ kip \cdot ft$

$P_c := \max\left(\text{abs}\left(F_{c1}\right), \text{abs}\left(F_{c2}\right), \text{abs}\left(F_{c3}\right), \text{abs}\left(F_{c4}\right), \text{abs}\left(F_{c5}\right), \text{abs}\left(F_{c6}\right), \text{abs}\left(F_{c7}\right), \text{abs}\left(F_{c8}\right), \text{abs}\left(F_{c9}\right)\right.$

$V_c := -min\left(V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_{c5}, V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}, V_{c11}, V_{c12}\right) = 2.798\ kip$

$M_c := -min\left(M_{c1}, M_{c2}, M_{c3}, M_{c4}, M_{c5}, M_{c6}, M_{c7}, M_{c8}, M_{c9}, M_{c10}, M_{c11}, M_{c12}\right) = 15.388\ kip \cdot ft$

$P_b := \max\left(\text{abs}\left(F_{b1}\right), \text{abs}\left(F_{b2}\right), \text{abs}\left(F_{b3}\right), \text{abs}\left(F_{b4}\right), \text{abs}\left(F_{b5}\right), \text{abs}\left(F_{b6}\right), \text{abs}\left(F_{b7}\right), \text{abs}\left(F_{b8}\right), \text{abs}\left(F_{b9}\right)\right.$

$V_b := \max\left(\text{abs}\left(V_{b1}\right), \text{abs}\left(V_{b2}\right), \text{abs}\left(V_{b3}\right), \text{abs}\left(V_{b4}\right), \text{abs}\left(V_{b5}\right), \text{abs}\left(V_{b6}\right), \text{abs}\left(V_{b7}\right), \text{abs}\left(V_{b8}\right), \text{abs}\left(V_{b\right.\right.$

$M_b := \max\left(\text{abs}\left(M_{b1}\right), \text{abs}\left(M_{b2}\right), \text{abs}\left(M_{b3}\right), \text{abs}\left(M_{b4}\right), \text{abs}\left(M_{b5}\right), \text{abs}\left(M_{b6}\right), \text{abs}\left(M_{b7}\right), \text{abs}\left(M_{b8}\right), \text{ab}\right.$

North-South Wind

$w_1 := p_1 \cdot (h - u + 0.5\ h) = 263.729\ plf$ $w_2 := p_2 \cdot (0.5\ h) + p_1 \cdot (0.5\ h) = 286.946\ plf$

$w_3 := p_2 \cdot (0.5\ h) = 148.803\ plf$ $\Sigma L := L_1 + L_2 + L_3 = 68\ ft$

$P_1 := w_1 \cdot \frac{\Sigma L}{4} = 4.483\ kip$ $P_2 := w_2 \cdot \frac{\Sigma L}{4} = 4.878\ kip$ $P_3 := w_3 \cdot \frac{\Sigma L}{4} = 2.53\ kip$

Guess Values

$V_{c1} := 1\ kip$ $V_{c2} := 1\ kip$ $V_{c3} := 1\ kip$ $V_{c4} := 1\ kip$ $V_{c5} := 1\ kip$

Constraints

$0\ kip = P_3 + V_{c1} + V_{c2} + V_{c3} + V_{c4} + V_{c5}$ $V_{c2} = 2\ V_{c1}$ $V_{c3} = 2\ V_{c1}$ $V_{c4} = 2\ V_{c1}$ $V_{c5} = V_{c1}$

Solver

$$\begin{bmatrix} V_{c1} \\ V_{c2} \\ V_{c3} \\ V_{c4} \\ V_{c5} \end{bmatrix} := \text{find}\left(V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_{c5}\right) = \begin{bmatrix} -0.316 \\ -0.632 \\ -0.632 \\ -0.632 \\ -0.316 \end{bmatrix} kip$$

Guess Values

$V_{b1} := 1\ kip$ $F_{c1} := 1\ kip$ $F_{b1} := 1\ kip$ $M_{c1} := 1\ kip \cdot ft$ $M_{b1} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c1} + F_{b1} + P_3$ $0\ kip = F_{c1} + V_{b1}$ $0\ kip \cdot ft = M_{b1} + M_{c1}$

$M_{c1} = 0.5\ h\ V_{c1}$ $M_{b1} = 0.5\ s_1\ V_{b1}$

Solver

$$\begin{bmatrix} V_{b1} \\ F_{c1} \\ F_{b1} \\ M_{c1} \\ M_{b1} \end{bmatrix} := \text{find}\left(V_{b1}, F_{c1}, F_{b1}, M_{c1}, M_{b1}\right) = \begin{bmatrix} 0.232 \\ -0.232 \\ -2.213 \\ -1.739\ ft \\ 1.739\ ft \end{bmatrix} kip$$

Guess Values

$V_{b2} := 1\ kip \quad F_{c2} := 1\ kip \quad F_{b2} := 1\ kip \quad M_{c2} := 1\ kip \cdot ft \quad M_{b2} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c2} + F_{b2} - F_{b1} \quad 0\ kip = F_{c2} + V_{b2} - V_{b1} \quad 0\ kip \cdot ft = M_{b2} + M_{c2} + M_{b1}$

$M_{c2} = 0.5\ h\ V_{c2} \quad M_{b2} = 0.5\ s_2\ V_{b2}$

Solver

$$\begin{bmatrix} V_{b2} \\ F_{c2} \\ F_{b2} \\ M_{c2} \\ M_{b2} \end{bmatrix} := \text{find}\left(V_{b2}, F_{c2}, F_{b2}, M_{c2}, \mathrm{M_{b2}}\right) = \begin{bmatrix} 0.232 \\ 3.695 \cdot 10^{-10} \\ -1.581 \\ -3.478\ ft \\ 1.739\ ft \end{bmatrix} kip$$

Guess Values

$V_{b3} := 1\ kip \quad F_{c3} := 1\ kip \quad F_{b3} := 1\ kip \quad M_{c3} := 1\ kip \cdot ft \quad M_{b3} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c3} + F_{b3} - F_{b2} \quad 0\ kip = F_{c3} + V_{b3} - V_{b2} \quad 0\ kip \cdot ft = M_{b3} + M_{c3} + M_{b2}$

$M_{c3} = 0.5\ h\ V_{c3} \quad M_{b3} = 0.5\ s_3\ V_{b3}$

Solver

$$\begin{bmatrix} V_{b3} \\ F_{c3} \\ F_{b3} \\ M_{c3} \\ M_{b3} \end{bmatrix} := \text{find}\left(V_{b3}, F_{c3}, F_{b3}, M_{c3}, M_{b3}\right) = \begin{bmatrix} 0.232 \\ 3.767 \cdot 10^{-10} \\ -0.949 \\ -3.478\ ft \\ 1.739\ ft \end{bmatrix} kip$$

Guess Values

$V_{b4} := 1\ kip \quad F_{c4} := 1\ kip \quad F_{b4} := 1\ kip \quad M_{c4} := 1\ kip \cdot ft \quad M_{b4} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c4} + F_{b4} - F_{b3} \quad 0\ kip = F_{c4} + V_{b4} - V_{b3} \quad 0\ kip \cdot ft = M_{b4} + M_{c4} + M_{b3}$

$M_{c4} = 0.5\ h\ V_{c4} \quad M_{b4} = 0.5\ s_4\ V_{b4}$

Solver

$$\begin{bmatrix} V_{b4} \\ F_{c4} \\ F_{b4} \\ M_{c4} \\ M_{b4} \end{bmatrix} := \text{find}\left(V_{b4}, F_{c4}, F_{b4}, M_{c4}, \mathrm{M_{b4}}\right) = \begin{bmatrix} 0.232 \\ 3.754 \cdot 10^{-10} \\ -0.316 \\ -3.478\ ft \\ 1.739\ ft \end{bmatrix} kip$$

Guess Values

$F_{c5} := 1\ kip \quad M_{c5} := 1\ kip \cdot ft$

Constraints

$0\ kip = F_{c5} - V_{b4} \quad M_{c5} = 0.5\ h\ V_{c5}$

Solver

$$\begin{bmatrix} F_{c5} \\ M_{c5} \end{bmatrix} := \text{find}\left(F_{c5}, \mathrm{M_{c5}}\right) = \begin{bmatrix} 0.232 \\ -1.739\ ft \end{bmatrix} kip$$

Guess Values

$V_{c6} := 1\ kip \quad V_{c7} := 1\ kip \quad V_{c8} := 1\ kip \quad V_{c9} := 1\ kip \quad V_{c10} := 1\ kip$

Constraints

$0\ kip = P_2 + P_3 + V_{c6} + V_{c7} + V_{c8} + V_{c9} + V_{c10} \quad V_{c7} = 2\ V_{c6} \quad V_{c8} = 2\ V_{c6} \quad V_{c9} = 2\ V_{c6} \quad V_{c10} = V_{c6}$

Solver

$$\begin{bmatrix} V_{c6} \\ V_{c7} \\ V_{c8} \\ V_{c9} \\ V_{c10} \end{bmatrix} := \text{find}\left(V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}\right) = \begin{bmatrix} -0.926 \\ -1.852 \\ -1.852 \\ -1.852 \\ -0.926 \end{bmatrix} kip$$

Guess Values

$V_{b5} := 1\ kip \quad F_{c6} := 1\ kip \quad F_{b5} := 1\ kip \quad M_{c6} := 1\ kip \cdot ft \quad M_{b5} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c6} + F_{b5} + P_2 - V_{c1} \quad 0\ kip = F_{c6} + V_{b5} - F_{c1} \quad 0\ kip \cdot ft = M_{b5} + M_{c6} + M_{c1}$

$M_{c6} = 0.5\ h\ V_{c6} \quad M_{b5} = 0.5\ s_1\ V_{b5}$

Solver

$$\begin{bmatrix} V_{b5} \\ F_{c6} \\ F_{b5} \\ M_{c6} \\ M_{b5} \end{bmatrix} := \text{find}\left(V_{b5}, F_{c6}, F_{b5}, M_{c6}, M_{b5}\right) = \begin{bmatrix} 0.911 \\ -1.143 \\ -4.268 \\ -5.093\ ft \\ 6.832\ ft \end{bmatrix} kip$$

Guess Values

$V_{b6} := 1\ kip \quad F_{c7} := 1\ kip \quad F_{b6} := 1\ kip \quad M_{c7} := 1\ kip \cdot ft \quad M_{b6} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c7} + F_{b6} - F_{b5} - V_{c2} \quad 0\ kip = F_{c7} + V_{b6} - V_{b5} - F_{c2}$

$M_{c7} = 0.5\ h\ V_{c7} \quad M_{b6} = 0.5\ s_2\ V_{b6} \quad 0\ kip \cdot ft = M_{b6} + M_{c7} + M_{b5}$

Solver

$$\begin{bmatrix} V_{b6} \\ F_{c7} \\ F_{b6} \\ M_{c7} \\ M_{b6} \end{bmatrix} := \text{find}\left(V_{b6}, F_{c7}, F_{b6}, M_{c7}, M_{b6}\right) = \begin{bmatrix} 0.447 \\ 0.464 \\ -3.049 \\ -10.186\ ft \\ 3.354\ ft \end{bmatrix} kip$$

Guess Values

$V_{b7} := 1\ kip \quad F_{c8} := 1\ kip \quad F_{b7} := 1\ kip \quad M_{c8} := 1\ kip \cdot ft \quad M_{b7} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c8} + F_{b7} - F_{b6} - V_{c3} \quad 0\ kip = F_{c8} + V_{b7} - V_{b6} - F_{c3}$

$M_{c8} = 0.5\ h\ V_{c8} \quad M_{b7} = 0.5\ s_3\ V_{b7} \quad 0\ kip \cdot ft = M_{b7} + M_{c8} + M_{b6}$

Solver

$$\begin{bmatrix} V_{b7} \\ F_{c8} \\ F_{b7} \\ M_{c8} \\ M_{b7} \end{bmatrix} := \text{find}\left(V_{b7}, F_{c8}, F_{b7}, M_{c8}, M_{b7}\right) = \begin{bmatrix} 0.911 \\ -0.464 \\ -1.829 \\ -10.186\ ft \\ 6.832\ ft \end{bmatrix} kip$$

Guess Values

$V_{b8} := 1\ kip \quad F_{c9} := 1\ kip \quad F_{b8} := 1\ kip \quad M_{c9} := 1\ kip \cdot ft \quad M_{b8} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c9} + F_{b8} - F_{b7} - V_{c4} \quad 0\ kip = F_{c9} + V_{b8} - V_{b7} - F_{c4}$

$M_{c9} = 0.5\ h\ V_{c9} \quad M_{b8} = 0.5\ s_4\ V_{b8} \quad 0\ kip \cdot ft = M_{b8} + M_{c9} + M_{b7}$

Solver

$$\begin{bmatrix} V_{b8} \\ F_{c9} \\ F_{b8} \\ M_{c9} \\ M_{b8} \end{bmatrix} := \text{find}\left(V_{b8}, F_{c9}, F_{b8}, M_{c9}, M_{b8}\right) = \begin{bmatrix} 0.447 \\ 0.464 \\ -0.61 \\ -10.186\ ft \\ 3.354\ ft \end{bmatrix} kip$$

Guess Values

$F_{c10} := 1\ kip \quad M_{c10} := 1\ kip \cdot ft$

Constraints

$0\ kip = F_{c10} - V_{b8} - F_{c5} \quad M_{c10} = 0.5\ h\ V_{c10}$

Solver

$$\begin{bmatrix} F_{c10} \\ M_{c10} \end{bmatrix} := \text{find}\left(F_{c10}, M_{c10}\right) = \begin{bmatrix} 0.679 \\ -5.093\ ft \end{bmatrix} kip$$

Guess Values

$V_{c11} := 1\ kip \quad V_{c12} := 1\ kip \quad V_{c13} := 1\ kip \quad V_{c14} := 1\ kip \quad V_{c15} := 1\ kip$

Constraints

$0\ kip = P_1 + P_2 + P_3 + V_{c11} + V_{c12} + V_{c13} + V_{c14} + V_{c15} \quad V_{c12} = 2\ V_{c11} \quad V_{c13} = 2\ V_{c11} \quad V_{c14} = 2\ V_{c11} \quad V_{c15} = V_{c11}$

Solver

$$\begin{bmatrix} V_{c11} \\ V_{c12} \\ V_{c13} \\ V_{c14} \\ V_{c15} \end{bmatrix} := \text{find}\left(V_{c11}, V_{c12}, V_{c13}, V_{c14}, V_{c15}\right) = \begin{bmatrix} -1.486 \\ -2.973 \\ -2.973 \\ -2.973 \\ -1.486 \end{bmatrix} kip$$

Guess Values

$V_{b9} := 1\ kip \quad F_{c11} := 1\ kip \quad F_{b9} := 1\ kip \quad M_{c11} := 1\ kip \cdot ft \quad M_{b9} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c11} + F_{b9} + P_3 - V_{c6} \quad 0\ kip = F_{c11} + V_{b9} - F_{c6} \quad 0\ kip \cdot ft = M_{b9} + M_{c11} + M_{c6}$

$M_{c11} = 0.5\ h\ V_{c11} \quad M_{b9} = 0.5\ s_1\ V_{b9}$

Solver

$$\begin{bmatrix} V_{b9} \\ F_{c11} \\ F_{b9} \\ M_{c11} \\ M_{b9} \end{bmatrix} := \text{find}\left(V_{b9}, F_{c11}, F_{b9}, M_{c11}, M_{b9}\right) = \begin{bmatrix} 1.769 \\ -2.912 \\ -1.969 \\ -8.175\ ft \\ 13.268\ ft \end{bmatrix} kip$$

Guess Values

$V_{b10} := 1\ kip \quad F_{c12} := 1\ kip \quad F_{b10} := 1\ kip \quad M_{c12} := 1\ kip \cdot ft \quad M_{b10} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c12} + F_{b10} - F_{b9} - V_{c7} \quad 0\ kip = F_{c12} + V_{b10} - V_{b9} - F_{c7}$

$M_{c12} = 0.5\ h\ V_{c12} \quad M_{b10} = 0.5\ s_2\ V_{b10} \quad 0\ kip \cdot ft = M_{b10} + M_{c12} + M_{b9}$

Solver

$$\begin{bmatrix} V_{b10} \\ F_{c12} \\ F_{b10} \\ M_{c12} \\ M_{b10} \end{bmatrix} := \text{find}\left(V_{b10}, F_{c12}, F_{b10}, M_{c12}, M_{b10}\right) = \begin{bmatrix} 0.411 \\ 1.822 \\ -0.848 \\ -16.35\ ft \\ 3.082\ ft \end{bmatrix} kip$$

Guess Values

$V_{b11} := 1\ kip \quad F_{c13} := 1\ kip \quad F_{b11} := 1\ kip \quad M_{c13} := 1\ kip \cdot ft \quad M_{b11} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c13} + F_{b11} - F_{b10} - V_{c8} \quad 0\ kip = F_{c13} + V_{b11} - V_{b10} - F_{c8}$

$M_{c13} = 0.5\ h\ V_{c13} \quad M_{b11} = 0.5\ s_3\ V_{b11} \quad 0\ kip \cdot ft = M_{b11} + M_{c13} + M_{b10}$

Solver

$$\begin{bmatrix} V_{b11} \\ F_{c13} \\ F_{b11} \\ M_{c13} \\ M_{b11} \end{bmatrix} := \text{find}\left(V_{b11}, F_{c13}, F_{b11}, M_{c13}, M_{b11}\right) = \begin{bmatrix} 1.769 \\ -1.822 \\ 0.272 \\ -16.35\ ft \\ 13.268\ ft \end{bmatrix} kip$$

Guess Values

$V_{b12} := 1\ kip \quad F_{c14} := 1\ kip \quad F_{b12} := 1\ kip \quad M_{c14} := 1\ kip \cdot ft \quad M_{b12} := 1\ kip \cdot ft$

Constraints

$0\ kip = V_{c14} + F_{b12} - F_{b11} - V_{c9} \quad 0\ kip = F_{c14} + V_{b12} - V_{b11} - F_{c9}$

$M_{c14} = 0.5\ h\ V_{c14} \quad M_{b12} = 0.5\ s_4\ V_{b12} \quad 0\ kip \cdot ft = M_{b12} + M_{c14} + M_{b11}$

Solver

$$\begin{bmatrix} V_{b12} \\ F_{c14} \\ F_{b12} \\ M_{c14} \\ M_{b12} \end{bmatrix} := \text{find}\left(V_{b12}, F_{c14}, F_{b12}, M_{c14}, \mathrm{M_{b12}}\right) = \begin{bmatrix} 0.411 \\ 1.822 \\ 1.393 \\ -16.35\ ft \\ 3.082\ ft \end{bmatrix} kip$$

Guess Values

$F_{c15} := 1\ kip \quad M_{c15} := 1\ kip \cdot ft$

Constraints

$0\ kip = F_{c15} - V_{b12} - F_{c10} \quad M_{c15} = 0.5\ h\ V_{c15}$

Solver

$$\begin{bmatrix} F_{c15} \\ M_{c15} \end{bmatrix} := \text{find}\left(F_{c15}, \mathrm{M_{c15}}\right) = \begin{bmatrix} 1.09 \\ -8.175\ ft \end{bmatrix} kip$$

$V_{c1} = -0.316\ kip \quad V_{c2} = -0.632\ kip \quad V_{c3} = -0.632\ kip \quad V_{c4} = -0.632\ kip \quad V_{c5} = -0.316\ kip$

$V_{c6}=-0.926\ kip$ $V_{c7}=-1.852\ kip$ $V_{c8}=-1.852\ kip$ $V_{c9}=-1.852\ kip$ $V_{c10}=-0.926\ kip$

$V_{c11}=-1.486\ kip$ $V_{c12}=-2.973\ kip$ $V_{c13}=-2.973\ kip$ $V_{c14}=-2.973\ kip$ $V_{c15}=-1.486\ kip$

$V_{b1}=0.232\ kip$ $V_{b2}=0.232\ kip$ $V_{b3}=0.232\ kip$ $V_{b4}=0.232\ kip$

$V_{b5}=0.911\ kip$ $V_{b6}=0.447\ kip$ $V_{b7}=0.911\ kip$ $V_{b8}=0.447\ kip$

$V_{b9}=1.769\ kip$ $V_{b10}=0.411\ kip$ $V_{b11}=1.769\ kip$ $V_{b12}=0.411\ kip$

$F_{c1}=-0.232\ kip$ $F_{c2}=0\ kip$ $F_{c3}=0\ kip$ $F_{c4}=0\ kip$ $F_{c5}=0.232\ kip$

$F_{c6}=-1.143\ kip$ $F_{c7}=0.464\ kip$ $F_{c8}=-0.464\ kip$ $F_{c9}=0.464\ kip$ $F_{c10}=0.679\ kip$

$F_{c11}=-2.912\ kip$ $F_{c12}=1.822\ kip$ $F_{c13}=-1.822\ kip$ $F_{c14}=1.822\ kip$ $F_{c15}=1.09\ kip$

$F_{b1}=-2.213\ kip$ $F_{b2}=-1.581\ kip$ $F_{b3}=-0.949\ kip$ $F_{b4}=-0.316\ kip$

$F_{b5}=-4.268\ kip$ $F_{b6}=-3.049\ kip$ $F_{b7}=-1.829\ kip$ $F_{b8}=-0.61\ kip$

$F_{b9}=-1.969\ kip$ $F_{b10}=-0.848\ kip$ $F_{b11}=0.272\ kip$ $F_{b12}=1.393\ kip$

$M_{c1}=-1.739\ kip\cdot ft$ $M_{c2}=-3.478\ kip\cdot ft$ $M_{c3}=-3.478\ kip\cdot ft$ $M_{c4}=-3.478\ kip\cdot ft$ $M_{c5}=-1.739\ k$

$M_{c6}=-5.093\ kip\cdot ft$ $M_{c7}=-10.186\ kip\cdot ft$ $M_{c8}=-10.186\ kip\cdot ft$ $M_{c9}=-10.186\ kip\cdot ft$ $M_{c10}=-5.093\ k$

$M_{c11}=-8.175\ kip\cdot ft$ $M_{c12}=-16.35\ kip\cdot ft$ $M_{c13}=-16.35\ kip\cdot ft$ $M_{c14}=-16.35\ kip\cdot ft$ $M_{c15}=-8.175\ k$

$M_{b1}=1.739\ kip\cdot ft$ $M_{b2}=1.739\ kip\cdot ft$ $M_{b3}=1.739\ kip\cdot ft$ $M_{b4}=1.739\ kip\cdot ft$

$M_{b5}=6.832\ kip\cdot ft$ $M_{b6}=3.354\ kip\cdot ft$ $M_{b7}=6.832\ kip\cdot ft$ $M_{b8}=3.354\ kip\cdot ft$

$M_{b9}=13.268\ kip\cdot ft$ $M_{b10}=3.082\ kip\cdot ft$ $M_{b11}=13.268\ kip\cdot ft$ $M_{b12}=3.082\ kip\cdot ft$

$P_{c2}:=\max\left(\text{abs}\left(F_{c1}\right),\text{abs}\left(F_{c2}\right),\text{abs}\left(F_{c3}\right),\text{abs}\left(F_{c4}\right),\text{abs}\left(F_{c5}\right),\text{abs}\left(F_{c6}\right),\text{abs}\left(F_{c7}\right),\text{abs}\left(F_{c8}\right),\text{abs}\left(F_{c9}\right)\right.$

$V_{c2}:=-min\left(V_{c1},V_{c2},V_{c3},V_{c4},V_{c5},V_{c6},V_{c7},V_{c8},V_{c9},V_{c10},V_{c11},V_{c12},V_{c13},V_{c14},V_{c15}\right)=2.973\ kip$

$M_{c2}:=-min\left(M_{c1},M_{c2},M_{c3},M_{c4},M_{c5},M_{c6},M_{c7},M_{c8},M_{c9},M_{c10},M_{c11},M_{c12},M_{c13},M_{c14},M_{c15}\right)=16.$

$P_{b2}:=\max\left(\text{abs}\left(F_{b1}\right),\text{abs}\left(F_{b2}\right),\text{abs}\left(F_{b3}\right),\text{abs}\left(F_{b4}\right),\text{abs}\left(F_{b5}\right),\text{abs}\left(F_{b6}\right),\text{abs}\left(F_{b7}\right),\text{abs}\left(F_{b8}\right),\text{abs}\left(F_{b9}\right.\right.$

$V_{b2}:=\max\left(\text{abs}\left(V_{b1}\right),\text{abs}\left(V_{b2}\right),\text{abs}\left(V_{b3}\right),\text{abs}\left(V_{b4}\right),\text{abs}\left(V_{b5}\right),\text{abs}\left(V_{b6}\right),\text{abs}\left(V_{b7}\right),\text{abs}\left(V_{b8}\right),\text{abs}\left(V\right.\right.$

$M_{b2} := \max\left(\text{abs}\left(M_{b1}\right), \text{abs}\left(M_{b2}\right), \text{abs}\left(M_{b3}\right), \text{abs}\left(M_{b4}\right), \text{abs}\left(M_{b5}\right), \text{abs}\left(M_{b6}\right), \text{abs}\left(M_{b7}\right), \text{abs}\left(M_{b8}\right), \text{a}\right.$

$P_c := \max\left(P_c, P_{c2}\right) = 2.912\ \boldsymbol{kip}$

$V_c := \max\left(V_c, V_{c2}\right) = 2.973\ \boldsymbol{kip}$

$M_c := \max\left(M_c, M_{c2}\right) = 16.35\ \boldsymbol{ft \cdot kip}$

$P_b := \max\left(P_b, P_{b2}\right) = 4.268\ \boldsymbol{kip}$

$V_b := \max\left(V_b, V_{b2}\right) = 1.769\ \boldsymbol{kip}$

$M_b := \max\left(M_b, M_{b2}\right) = 13.268\ \boldsymbol{ft \cdot kip}$

Column Factored Loading

Define Variables

$p_{lfloor} := 50\ psf \quad p_{lroof} := 20\ psf \quad p_f := 18.9\ psf \quad w_c := 150\ pcf$

$b_w := 20\ in \quad d := 30\ in \quad c := 20\ in \quad h_s := 6\ in$

Design Calculations

$p_{slab} := w_c \cdot h_s = 75\ psf \qquad p_{beam} := \dfrac{w_c \cdot b_w \cdot (d - h_s)\ (4\ (s_1 + s_2 + s_3 + s_4) + 5\ (L_1 + L_2 + L_3))}{(s_1 + s_2 + s_3 + s_4)\ (L_1 + L_2 + L_3)} = 71.078\ ps$

$P_{column} := w_c \cdot c^2 \cdot h = 4.583\ kip$

$A_I := s_1 \cdot L_2 + s_1 \cdot L_3 + s_2 \cdot L_2 + s_2 \cdot L_3 = 1320\ ft^2$

$P_d := (2\ p_{slab} + 2\ p_{beam}) \cdot (0.5\ s_1 + 0.5\ s_2) \cdot (0.5\ L_2 + 0.5\ L_3) + 3\ P_{column} = 110.162\ kip$

$p_{lfloor2} := p_{lfloor} \cdot \max\left(0.4, 0.25 + \dfrac{15\ ft}{\sqrt{1\ A_I}}\right) = 33.143\ psf$

$p_{lfloor1} := p_{lfloor} \cdot \max\left(0.4, 0.25 + \dfrac{15\ ft}{\sqrt{2\ A_I}}\right) = 27.097\ psf$

$P_l := (p_{lfloor1} + p_{lfloor2} + p_{lroof}) \cdot (0.5\ s_1 + 0.5\ s_2) \cdot (0.5\ L_2 + 0.5\ L_3) = 26\ kip$

$P_{lr} := p_{lroof} \cdot (0.5\ s_1 + 0.5\ s_2) \cdot (0.5\ L_2 + 0.5\ L_3) = 7\ kip$

$P_s := p_f \cdot (0.5\ s_1 + 0.5\ s_2) \cdot (0.5\ L_2 + 0.5\ L_3) = 6.237\ kip$

$P_w := P_c = 2.912\ kip$

$P_{u1} := \max(1.4\ P_d, 1.2\ P_d + 1.6\ P_l + 0.5\ \max(P_{lr}, P_s)) = 178\ kip$

$P_{u2} := \max(1.2\ P_d + 1.6\ \max(P_{lr}, P_s) + \max(P_l, 0.5\ P_w)) = 169\ kip$

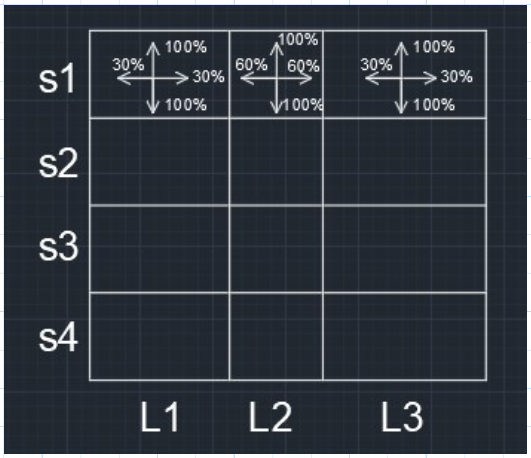
$P_{u3} := \max(1.2\ P_d + 1.0\ P_w + P_l + 0.5\ \max(P_{lr}, P_s), 0.9\ P_d + 1.0\ P_w) = 165\ kip$

$P_{column} := \max(P_{u1}, P_{u2}, P_{u3}) = 178\ kip$

$M_{column} := M_c = 16\ kip \cdot ft$

$V_{column} := V_c = 3\ kip$

Assumed floor load distribution for slab and beam analysis



Slab Factored Loading

Define Variables

$p_{lfloor} := 50\ psf$ $p_{lroof} := 20\ psf$ $p_f := 18.9\ psf$ $w_c := 150\ pcf$

$b_w := 20\ in$ $d := 30\ in$ $c := 20\ in$ $h_s := 6\ in$

Design Calculations

Case 1

$DL := p_{slab} = 75\ psf$ $LL := p_{lfloor} = 50\ psf$ $B := s_1 = 15\ ft$

$w_{1AL} := 0.446\ LL \cdot B = 334.5\ plf$ $w_{1BL} := 1.22\ LL \cdot B = 915\ plf$

$w_{1CL} := 0.464\ LL \cdot B = 348\ plf$ $w_{1DL} := 0.598\ LL \cdot B = 448.5\ plf$

$w_{1EL} := 0.442\ LL \cdot B = 331.5\ plf$ $w_{1L} := w_{1BL} = 915\ plf$

$V_{1L} := 0.620\ LL \cdot B = 465\ plf$

$M_{1Lneg} := 0.121\ LL \cdot B^2 = 1361.25\ lbf$ $M_{1Lpos} := 0.0996\ LL \cdot B^2 = 1120.5\ lbf$

$w_{1AD} := 0.393\ DL \cdot B = 442.125\ plf$ $w_{1BD} := 1.14\ DL \cdot B = 1282.5\ plf$

$w_{1CD} := 0.928\ DL \cdot B = 1044\ plf$ $w_{1DD} := 1.14\ DL \cdot B = 1282.5\ plf$

$w_{1ED} := 0.393\ DL \cdot B = 442.125\ plf$ $w_{1D} := w_{1BD} = \left(1.283 \cdot 10^3\right)\ plf$

$V_{1D} := 0.607\ DL \cdot B = 682.875\ plf$

$M_{1Dneg} := 0.107\ DL \cdot B^2 = 1805.625\ lbf$ $M_{1Dpos} := 0.0772\ DL \cdot B^2 = 1302.75\ lbf$

Case 2

$DL := 0.6\ p_{slab} = 45\ psf$ $LL := 0.6\ p_{lfloor} = 30\ psf$ $B = 15\ ft$

$w_{2AL} := 0.446\ LL \cdot B = 200.7\ plf$ $w_{2BL} := 1.22\ LL \cdot B = 549\ plf$

$w_{2CL} := 0.464\ LL \cdot B = 208.8\ plf$ $w_{2DL} := 0.598\ LL \cdot B = 269.1\ plf$

$w_{2EL} := 0.442\ LL \cdot B = 198.9\ plf$ $w_{2L} := w_{2BL} = 549\ plf$

$V_{2L} := 0.620\ LL \cdot B = 279\ plf$

$M_{2Lneg} := 0.121\ LL \cdot B^2 = 816.75\ lbf$ $M_{2Lpos} := 0.0996\ LL \cdot B^2 = 672.3\ lbf$

$w_{2AD} := 0.393\ DL \cdot B = 265.275\ plf$ $w_{2BD} := 1.14\ DL \cdot B = 769.5\ plf$

$w_{2CD} := 0.928\ DL \cdot B = 626.4\ plf$ $w_{2DD} := 1.14\ DL \cdot B = 769.5\ plf$

$w_{2ED} := 0.393\ DL \cdot B = 265.275\ plf$ $w_{2D} := w_{2BD} = 769.5\ plf$

$V_{2D} := 0.607\ DL \cdot B = 409.725\ plf$

$M_{2Dneg} := 0.107\ DL \cdot B^2 = 1083.375\ lbf$ $M_{2Dpos} := 0.0772\ DL \cdot B^2 = 781.65\ lbf$

Case 3

$E := 1\ ksi$ $I := 1\ \frac{in^4}{ft}$ $P := 1$

$$R_{r\_1} := -\frac{q_1 \cdot L_1 \cdot \left(\frac{1}{2}\ L_1 + L_2 + L_3\right) + q_2 \cdot L_2 \cdot \left(\frac{1}{2}\ L_2 + L_3\right) + q_3 \cdot L_3 \cdot \left(\frac{1}{2}\ L_3\right)}{L_1 + L_2 + L_3} \rightarrow \frac{\left(-\left(98 \cdot q_3\right) - \left(144 \cdot q_2 + 336 \cdot\right.\right.}{17}$$

$$M_1(x) := R_{r\_1} \cdot x + \frac{1}{2}\ q_1 \cdot x^2 \rightarrow \frac{ft \cdot x \cdot \left(-\left(98 \cdot q_3\right) - \left(144 \cdot q_2 + 336 \cdot q_1\right)\right)}{17} + \frac{q_1 \cdot x^2}{2}$$

$$M_2(x) := R_{r\_1} \cdot x + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2}\ L_1\right) + \frac{1}{2}\ q_2 \cdot \left(x - L_1\right)^2 \rightarrow \frac{q_2 \cdot (x - 24 \cdot ft)^2}{2} + \left(24 \cdot q_1 \cdot ft \cdot (x - 12 \cdot ft) -\right.$$

$$M_3(x) := R_{r\_1} \cdot x + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2}\ L_1\right) + q_2 \cdot L_2 \cdot \left(x - L_1 - \frac{1}{2}\ L_2\right) + \frac{1}{2}\ q_3 \cdot \left(x - L_1 - L_2\right)^2 \rightarrow \frac{q_3 \cdot (x - 40 \cdot ft)}{2}$$

$$R_{v1\_1} := -\frac{P \cdot (L_2 + L_3)}{L_1 + L_2 + L_3} = -0.647$$

$$M_{v1\_1}(x) := R_{v1\_1} \cdot x \rightarrow -0.64705882352941191 \cdot x$$

$$M_{v1\_2}(x) := R_{v1\_1} \cdot x + P \cdot (x - L_1) \rightarrow 0.35294117647058809 \cdot x - 24.0 \cdot ft$$

$$M_{v1\_3}(x) := R_{v1\_1} \cdot x + P \cdot (x - L_1) \rightarrow 0.35294117647058809 \cdot x - 24.0 \cdot ft$$

$$R_{v2\_1} := -\frac{P \cdot L_3}{L_1 + L_2 + L_3} = -0.412$$

$$M_{v2\_1}(x) := R_{v2\_1} \cdot x \rightarrow -0.411764705882353 \cdot x$$

$$M_{v2\_2}(x) := R_{v2\_1} \cdot x \rightarrow -0.411764705882353 \cdot x$$

$$M_{v2\_3}(x) := R_{v2\_1} \cdot x + P \cdot (x - L_1 - L_2) \rightarrow 0.588235294117647 \cdot x - 40.0 \cdot ft$$

$$d_1(q_1, q_2, q_3) := \int_{0\,ft}^{L_1} \frac{M_1(x) \cdot M_{v1\_1}(x)}{E \cdot I} \, dx + \int_{L_1}^{L_1+L_2} \frac{M_2(x) \cdot M_{v1\_2}(x)}{E \cdot I} \, dx + \int_{L_1+L_2}^{L_1+L_2+L_3} \frac{M_3(x) \cdot M_{v1\_3}(x)}{E \cdot I} \, dx \rightarrow \frac{(84}{}$$

$$d_2(q_1, q_2, q_3) := \int_{0\,ft}^{L_1} \frac{M_1(x) \cdot M_{v2\_1}(x)}{E \cdot I} \, dx + \int_{L_1}^{L_1+L_2} \frac{M_2(x) \cdot M_{v2\_2}(x)}{E \cdot I} \, dx + \int_{L_1+L_2}^{L_1+L_2+L_3} \frac{M_3(x) \cdot M_{v2\_3}(x)}{E \cdot I} \, dx \rightarrow \frac{(10}{}$$

$$f_{11} := \int_{0\,ft}^{L_1} \frac{M_{v1\_1}(x) \cdot M_{v1\_1}(x)}{E \cdot I} \, dx + \int_{L_1}^{L_1+L_2+L_3} \frac{M_{v1\_2}(x) \cdot M_{v1\_2}(x)}{E \cdot I} \, dx \rightarrow \frac{5466.3529411764752934 \cdot ft^4}{in^4 \cdot ksi}$$

$$f_{12} := \int_{0\,ft}^{L_1} \frac{M_{v1\_1}(x) \cdot M_{v2\_1}(x)}{E \cdot I} \, dx + \int_{L_1}^{L_1+L_2} \frac{M_{v1\_2}(x) \cdot M_{v2\_2}(x)}{E \cdot I} \, dx + \int_{L_1+L_2}^{L_1+L_2+L_3} \frac{M_{v1\_3}(x) \cdot M_{v2\_3}(x)}{E \cdot I} \, dx \rightarrow \frac{5376.0}{}$$

$$f_{22} := \int_{0\,ft}^{L_1+L_2} \frac{M_{v2\_1}(x) \cdot M_{v2\_1}(x)}{E \cdot I} \, dx + \int_{L_1+L_2}^{L_1+L_2+L_3} \frac{M_{v2\_3}(x) \cdot M_{v2\_3}(x)}{E \cdot I} \, dx \rightarrow \frac{6149.0196078431396267 \cdot ft^4}{in^4 \cdot ksi}$$

Dead Load

$q_1 := -0.3\ p_{slab}$ $q_2 := -0.6\ p_{slab}$ $q_3 := -0.3\ p_{slab}$

Guess Values

$R_1 := 1\ plf$ $R_2 := 1\ plf$ $R_3 := 1\ plf$ $R_4 := 1\ plf$

Constraints

$$0\ lbf = R_2 \cdot L_1 + R_3 \cdot (L_1 + L_2) + R_4 \cdot (L_1 + L_2 + L_3) + q_1 \cdot L_1 \cdot \left(\frac{1}{2} L_1\right) + q_2 \cdot L_2 \cdot \left(L_1 + \frac{1}{2} L_2\right) + q_3 \cdot L_3 \cdot \left(L_1 + L_2 + \frac{1}{2} L_3\right)$$

$$0\ plf = q_1 \cdot L_1 + q_2 \cdot L_2 + q_3 \cdot L_3 + R_1 + R_2 + R_3 + R_4$$

$$d_1(q_1, q_2, q_3) + f_{11} \cdot R_2 + f_{12} \cdot R_3 = 0\ ft$$

$$d_2(q_1, q_2, q_3) + f_{12} \cdot R_2 + f_{22} \cdot R_3 = 0\ ft$$

Solver

$$\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix} := \text{find}(R_1, R_2, R_3, R_4) = \begin{bmatrix} 219.729 \\ 648.962 \\ 767.289 \\ 254.02 \end{bmatrix} plf$$

$w_{3AD} := R_1 = 219.729\ plf$ $w_{3BD} := R_2 = 648.962\ plf$

$w_{3CD} := R_3 = 767.289\ plf$ $w_{3DD} := R_4 = 254.02\ plf$ $w_{3D} := R_3 = 767.289\ plf$

$w_1 := R_1 = 219.729\ plf$ $w_2 := R_2 = 648.962\ plf$ $w_3 := R_3 = 767.289\ plf$

$$M_1(x) := w_1 \cdot x + \frac{1}{2} q_1 \cdot x^2 \rightarrow -11.2499999999999979 \cdot psf \cdot x^2 + 219.72877358490581 \cdot plf \cdot x$$

$$M_2(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + \frac{1}{2} q_2 \cdot (x - L_1)^2 \rightarrow -539.9999999999998992 \cdot ft \cdot p$$

$$M_3(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + w_3 \cdot (x - L_1 - L_2) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + q_2 \cdot L_2 \cdot \left(x - L_1 - \frac{1}{2} L_2\right) + \frac{1}{2} q_3 \cdot ($$

$$V_1(x) := \frac{d}{dx} M_1(x) \rightarrow -22.4999999999999958 \cdot psf \cdot x + 219.72877358490581 \cdot plf$$

$$V_2(x) := \frac{d}{dx} M_2(x) \rightarrow -44.9999999999999916 \cdot psf \cdot x + 539.9999999999998992 \cdot ft \cdot psf + 868...$$

$V_3(x) := \frac{d}{dx} M_3(x) \rightarrow -22.4999999999999958 \cdot psf \cdot x + (1635.98045822102376 \cdot plf - 359.99...$

Solver		
Guess Values: $x := 1\ ft$	Guess Values: $x := 1\ ft$	Guess Values: $x := 1\ ft$
Constraints: $V_1(x) = 0\ plf$	Constraints: $V_2(x) = 0\ plf$	Constraints: $V_3(x) = 0\ plf$
Solver: $x_1 := find(x) = 9.766\ ft$	Solver: $x_2 := find(x) = 31.304\ ft$	Solver: $x_3 := find(x) = 56.71\ ft$
$L_1 = 24\ ft$	$L_1 + L_2 = 40\ ft$	$L_1 + L_2 + L_3 = 68\ ft$

$V_1(0\ ft) = 219.729\ plf$

$V_1(L_1) = -320.271\ plf$ $\quad V_2(L_1) = 328.691\ plf$

$V_2(L_1 + L_2) = -391.309\ plf$ $\quad V_3(L_1 + L_2) = 375.98\ plf$

$V_3(L_1 + L_2 + L_3) = -254.02\ plf$ $\quad V_{3D} := V_2(L_1 + L_2) = -391.309\ plf$

$M_1(0\ ft) = 0\ lbf$

$M_1(L_1) = -1206.509\ lbf$ $\quad M_2(L_1) = -1206.509\ lbf$

$M_2(L_1 + L_2) = -1707.453\ lbf$ $\quad M_3(L_1 + L_2) = -1707.453\ lbf$

$M_3(L_1 + L_2 + L_3) = 0\ lbf$ $\quad M_{3Dneg} := M_2(L_1 + L_2) = -1.707 \cdot 10^3\ lbf$

$M_1(x_1) = 1072.905\ lbf$

$M_2(x_2) = -6.089\ lbf$

$M_3(x_3) = 1433.91\ lbf$ $\quad M_{3Dpos} := M_3(x_3) = 1433.91\ lbf$

Live Load Max Positive Moment

$q_1 := -0.3\ LL$ $\quad q_2 := -0\ LL$ $\quad q_3 := -0.3\ LL$

Guess Values

$R_1 := 1\ plf$ $\quad R_2 := 1\ plf$ $\quad R_3 := 1\ plf$ $\quad R_4 := 1\ plf$

Constraints

$$0\ lbf = R_2 \cdot L_1 + R_3 \cdot (L_1 + L_2) + R_4 \cdot (L_1 + L_2 + L_3) + q_1 \cdot L_1 \cdot \left(\frac{1}{2} L_1\right) + q_2 \cdot L_2 \cdot \left(L_1 + \frac{1}{2} L_2\right) + q_3 \cdot L_3 \cdot \left(L_1 + L_2 + \frac{1}{2} L_3\right)$$

Constraints

$0\ plf = q_1 \cdot L_1 + q_2 \cdot L_2 + q_3 \cdot L_3 + R_1 + R_2 + R_3 + R_4$

$d_1(q_1, q_2, q_3) + f_{11} \cdot R_2 + f_{12} \cdot R_3 = 0\ ft$

$d_2(q_1, q_2, q_3) + f_{12} \cdot R_2 + f_{22} \cdot R_3 = 0\ ft$

Solver

$$\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix} := \text{find}(R_1, R_2, R_3, R_4) = \begin{bmatrix} 96.042 \\ 106.075 \\ 158.064 \\ 107.818 \end{bmatrix} plf$$

$w_{3AL} := R_1 = 96.042\ plf$ $w_{3BL} := R_2 = 106.075\ plf$

$w_{3CL} := R_3 = 158.064\ plf$ $w_{3DL} := R_4 = 107.818\ plf$

$w_1 := R_1 = 96.042\ plf$ $w_2 := R_2 = 106.075\ plf$ $w_3 := R_3 = 158.064\ plf$

$$M_1(x) := w_1 \cdot x + \frac{1}{2} q_1 \cdot x^2 \rightarrow -4.5 \cdot psf \cdot x^2 + 96.042452830188779 \cdot plf \cdot x$$

$$M_2(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + \frac{1}{2} q_2 \cdot (x - L_1)^2 \rightarrow -216.0 \cdot ft \cdot psf \cdot (x - 12.0 \cdot ft) +$$

$$M_3(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + w_3 \cdot (x - L_1 - L_2) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + q_2 \cdot L_2 \cdot \left(x - L_1 - \frac{1}{2} L_2\right) + \frac{1}{2} q_3 \cdot ($$

$$V_1(x) := \frac{d}{dx} M_1(x) \rightarrow -9.0 \cdot psf \cdot x + 96.042452830188779 \cdot plf$$

$$V_2(x) := \frac{d}{dx} M_2(x) \rightarrow -216.0 \cdot ft \cdot psf + 202.117924528301859 \cdot plf$$

$$V_3(x) := \frac{d}{dx} M_3(x) \rightarrow -9.0 \cdot psf \cdot x + 144.0 \cdot ft \cdot psf + 360.181940700808689 \cdot plf$$

Guess Values / Constraints / Solver

$x := 1\ ft$

$V_1(x) = 0\ plf$

$x_1 := \text{find}(x) = 10.671\ ft$

Guess Values / Constraints / Solver

$x := 1\ ft$

$V_2(x) = 0\ plf$

$x_2 := \text{find}(x) = ?$

Guess Values / Constraints / Solver

$x := 1\ ft$

$V_3(x) = 0\ plf$

$x_3 := \text{find}(x) = 56.02\ ft$

$L_1 = 24\ ft$ $L_1 + L_2 = 40\ ft$ $L_1 + L_2 + L_3 = 68\ ft$

$V_1(0\ ft) = 96.042\ plf$

$V_1(L_1) = -119.958\ plf$ $\quad V_2(L_1) = -13.882\ plf$

$V_2(L_1+L_2) = -13.882\ plf$ $\quad V_3(L_1+L_2) = 144.182\ plf$

$V_3(L_1+L_2+L_3) = -107.818\ plf$

$M_1(0\ ft) = 0\ lbf$

$M_1(L_1) = -286.981\ lbf$ $\quad M_2(L_1) = -286.981\ lbf$

$M_2(L_1+L_2) = -509.094\ lbf$ $\quad M_3(L_1+L_2) = -509.094\ lbf$

$M_3(L_1+L_2+L_3) = 0\ lbf$

$M_1(x_1) = 512.453\ lbf$

$M_2(x_2) = ?\ lbf$

$M_3(x_3) = 645.819\ lbf$ $\quad M_{3Lpos} := M_3(x_3) = 645.819\ lbf$

Live Load Max Negative Moment, Shear, and Reaction

$q_1 := -0\ LL$ $\quad q_2 := -0.6\ LL$ $\quad q_3 := -0.3\ LL$

Guess Values

$R_1 := 1\ plf$ $\quad R_2 := 1\ plf$ $\quad R_3 := 1\ plf$ $\quad R_4 := 1\ plf$

Constraints

$$0\ lbf = R_2 \cdot L_1 + R_3 \cdot (L_1+L_2) + R_4 \cdot (L_1+L_2+L_3) + q_1 \cdot L_1 \cdot \left(\frac{1}{2}\ L_1\right) + q_2 \cdot L_2 \cdot \left(L_1 + \frac{1}{2}\ L_2\right) + q_3 \cdot L_3 \cdot \left(L_1 + L_2 + \frac{1}{2}\ L_3\right)$$

$$0\ plf = q_1 \cdot L_1 + q_2 \cdot L_2 + q_3 \cdot L_3 + R_1 + R_2 + R_3 + R_4$$

$$d_1(q_1, q_2, q_3) + f_{11} \cdot R_2 + f_{12} \cdot R_3 = 0\ ft$$

$$d_2(q_1, q_2, q_3) + f_{12} \cdot R_2 + f_{22} \cdot R_3 = 0\ ft$$

Solver

$$\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix} := \text{find}(R_1, R_2, R_3, R_4) = \begin{bmatrix} -3.297 \\ 104.972 \\ 339.338 \\ 98.988 \end{bmatrix} plf$$

$w_{3AL} := R_1 = -3.297\ plf$ $w_{3BL} := R_2 = 104.972\ plf$

$w_{3CL} := R_3 = 339.338\ plf$ $w_{3DL} := R_4 = 98.988\ plf$ $w_{3L} := R_3 = 339.338\ plf$

$w_1 := R_1 = -3.297\ plf$ $w_2 := R_2 = 104.972\ plf$ $w_3 := R_3 = 339.338\ plf$

$$M_1(x) := w_1 \cdot x + \frac{1}{2} q_1 \cdot x^2 \rightarrow -3.297169811320698 \cdot plf \cdot x$$

$$M_2(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + \frac{1}{2} q_2 \cdot (x - L_1)^2 \rightarrow -9.0 \cdot psf \cdot (x - 24.0 \cdot ft)^2 + 104.$$

$$M_3(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + w_3 \cdot (x - L_1 - L_2) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + q_2 \cdot L_2 \cdot \left(x - L_1 - \frac{1}{2} L_2\right) + \frac{1}{2} q_3 \cdot ($$

$$V_1(x) := \frac{d}{dx} M_1(x) \rightarrow -3.297169811320698 \cdot plf$$

$$V_2(x) := \frac{d}{dx} M_2(x) \rightarrow -18.0 \cdot psf \cdot x + 432.0 \cdot ft \cdot psf + 101.674528301886972 \cdot plf$$

$$V_3(x) := \frac{d}{dx} M_3(x) \rightarrow -9.0 \cdot psf \cdot x + 72.0 \cdot ft \cdot psf + 441.012129380053972 \cdot plf$$

Guess Values: $x := 1\ ft$	Guess Values: $x := 1\ ft$	Guess Values: $x := 1\ ft$
Constraints: $V_1(x) = 0\ plf$	Constraints: $V_2(x) = 0\ plf$	Constraints: $V_3(x) = 0\ plf$
Solver: $x_1 := \text{find}(x) = ?$	Solver: $x_2 := \text{find}(x) = 29.649\ ft$	Solver: $x_3 := \text{find}(x) = 57.001\ ft$

$L_1 = 24\ ft$ $L_1 + L_2 = 40\ ft$ $L_1 + L_2 + L_3 = 68\ ft$

$V_1(0\ ft) = -3.297\ plf$

$V_1(L_1) = -3.297\ plf$ $V_2(L_1) = 101.675\ plf$

$V_2(L_1 + L_2) = -186.325\ plf$ $V_3(L_1 + L_2) = 153.012\ plf$

$V_3(L_1 + L_2 + L_3) = -98.988\ plf$ $V_{3L} := V_2(L_1 + L_2) = -186.325\ plf$

$M_1(0\ ft) = 0\ lbf$

$M_1(L_1) = -79.132\ lbf$ $M_2(L_1) = -79.132\ lbf$

$M_2(L_1+L_2)=-756.34\ lbf$ $\quad M_3(L_1+L_2)=-756.34\ lbf$

$M_3(L_1+L_2+L_3)=0\ lbf$ $\quad M_{3Lneg}:=M_2(L_1+L_2)=-756.34\ lbf$

$M_1(x_1)=?\ lbf$

$M_2(x_2)=208.027\ lbf$

$M_3(x_3)=544.367\ lbf$

Summary

$w_{1D}=1282.5\ plf$ $\quad V_{1D}=682.875\ plf$ $\quad M_{1Dneg}=1805.625\ lbf$ $\quad M_{1Dpos}=1302.75\ lbf$

$w_{1L}=915\ plf$ $\quad V_{1L}=465\ plf$ $\quad M_{1Lneg}=1361.25\ lbf$ $\quad M_{1Lpos}=1120.5\ lbf$

$w_{2D}=769.5\ plf$ $\quad V_{2D}=409.725\ plf$ $\quad M_{2Dneg}=1083.375\ lbf$ $\quad M_{2Dpos}=781.65\ lbf$

$w_{2L}=549\ plf$ $\quad V_{2L}=279\ plf$ $\quad M_{2Lneg}=816.75\ lbf$ $\quad M_{2Lpos}=672.3\ lbf$

$w_{3D}=767.289\ plf$ $\quad V_{3D}=-391.309\ plf$ $\quad M_{3Dneg}=-1707.453\ lbf$ $\quad M_{3Dpos}=1433.91\ lbf$

$w_{3L}=339.338\ plf$ $\quad V_{3L}=-186.325\ plf$ $\quad M_{3Lneg}=-756.34\ lbf$ $\quad M_{3Lpos}=645.819\ lbf$

$V_{Dslab}:=\max(\text{abs}(V_{1D}),\text{abs}(V_{2D}),\text{abs}(V_{3D}))=682.875\ plf$

$V_{Lslab}:=\max(\text{abs}(V_{1L}),\text{abs}(V_{2L}),\text{abs}(V_{3L}))=465\ plf$

$M_{Dnegslab}:=\max(\text{abs}(M_{1Dneg}),\text{abs}(M_{2Dneg}),\text{abs}(M_{3Dneg}))=1805.625\ lbf$

$M_{Lnegslab}:=\max(\text{abs}(M_{1Lneg}),\text{abs}(M_{2Lneg}),\text{abs}(M_{3Lneg}))=1361.25\ lbf$

$M_{Dposslab}:=\max(\text{abs}(M_{1Dpos}),\text{abs}(M_{2Dpos}),\text{abs}(M_{3Dpos}))=1433.91\ lbf$

$M_{Lposslab}:=\max(\text{abs}(M_{1Lpos}),\text{abs}(M_{2Lpos}),\text{abs}(M_{3Lpos}))=1120.5\ lbf$

$V_{slab}:=1.2\ V_{Dslab}+1.6\ V_{Lslab}=1.563\ klf$

$M_{neg\_slab}:=1.2\ M_{Dnegslab}+1.6\ M_{Lnegslab}=4.345\ kip$

$M_{pos\_slab}:=1.2\ M_{Dposslab}+1.6\ M_{Lposslab}=3.513\ kip$

Beam Factored Loading

Define Variables

$p_{lfloor} := 50\ psf$ $p_{lroof} := 20\ psf$ $p_f := 18.9\ psf$ $w_c := 150\ pcf$

$b_w := 20\ in$ $d := 30\ in$ $c := 20\ in$ $h_s := 6\ in$

Design Calculations

Case 1

$w_{beam} := w_c \cdot (d - h_s)\ b_w = 500\ plf$

$DL := w_{3D} + w_{beam} = (1.267 \cdot 10^3)\ plf$ $LL := w_{3L} = 339.338\ plf$ $B = 15\ ft$

$w_{1AL} := 0.446\ LL \cdot B = (2.27 \cdot 10^3)\ ft \cdot plf$ $w_{1BL} := 1.22\ LL \cdot B = (6.21 \cdot 10^3)\ ft \cdot plf$

$w_{1CL} := 0.464\ LL \cdot B = (2.362 \cdot 10^3)\ ft \cdot plf$ $w_{1DL} := 0.598\ LL \cdot B = (3.044 \cdot 10^3)\ ft \cdot plf$

$w_{1EL} := 0.442\ LL \cdot B = (2.25 \cdot 10^3)\ ft \cdot plf$

$V_{1L} := 0.620\ LL \cdot B = (3.156 \cdot 10^3)\ ft \cdot plf$

$M_{1Lneg} := 0.121\ LL \cdot B^2 = 9238.466\ ft \cdot lbf$ $M_{1Lpos} := 0.0996\ LL \cdot B^2 = 7604.556\ ft \cdot lbf$

$w_{1AD} := 0.393\ DL \cdot B = 7470.671\ ft \cdot plf$ $w_{1BD} := 1.14\ DL \cdot B = 21670.649\ ft \cdot plf$

$w_{1CD} := 0.928\ DL \cdot B = 17640.669\ ft \cdot plf$ $w_{1DD} := 1.14\ DL \cdot B = 21670.649\ ft \cdot plf$

$w_{1ED} := 0.393\ DL \cdot B = (7.471 \cdot 10^3)\ ft \cdot plf$

$V_{1D} := 0.607\ DL \cdot B = (1.154 \cdot 10^4)\ ft \cdot plf$

$M_{1Dneg} := 0.107\ DL \cdot B^2 = 30509.993\ ft \cdot lbf$ $M_{1Dpos} := 0.0772\ DL \cdot B^2 = 22012.817\ ft \cdot lbf$

Case 2

$E := 1\ ksi$ $I := 1\ in^4$ $P := 1$

clear (q_1, q_2, q_3)

$$R_{r\_1} := -\frac{q_1 \cdot L_1 \cdot \left(\frac{1}{2}\ L_1 + L_2 + L_3\right) + q_2 \cdot L_2 \cdot \left(\frac{1}{2}\ L_2 + L_3\right) + q_3 \cdot L_3 \cdot \left(\frac{1}{2}\ L_3\right)}{L_1 + L_2 + L_3} \rightarrow \frac{(-(98 \cdot q_3) - (144 \cdot q_2 + 336 \cdot}{17}$$

$$M_1(x) := R_{r\_1} \cdot x + \frac{1}{2} q_1 \cdot x^2 \rightarrow \frac{ft \cdot x \cdot \left(-\left(98 \cdot q_3\right) - \left(144 \cdot q_2 + 336 \cdot q_1\right)\right)}{17} + \frac{q_1 \cdot x^2}{2}$$

$$M_2(x) := R_{r\_1} \cdot x + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + \frac{1}{2} q_2 \cdot \left(x - L_1\right)^2 \rightarrow \frac{q_2 \cdot \left(x - 24 \cdot ft\right)^2}{2} + \left(24 \cdot q_1 \cdot ft \cdot \left(x - 12 \cdot ft\right) - \right.$$

$$M_3(x) := R_{r\_1} \cdot x + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + q_2 \cdot L_2 \cdot \left(x - L_1 - \frac{1}{2} L_2\right) + \frac{1}{2} q_3 \cdot \left(x - L_1 - L_2\right)^2 \rightarrow \frac{q_3 \cdot \left(x - 40 \cdot ft\right)}{2}$$

$$R_{v1\_1} := -\frac{P \cdot \left(L_2 + L_3\right)}{L_1 + L_2 + L_3} = -0.647$$

$$M_{v1\_1}(x) := R_{v1\_1} \cdot x \rightarrow -0.64705882352941191 \cdot x$$

$$M_{v1\_2}(x) := R_{v1\_1} \cdot x + P \cdot \left(x - L_1\right) \rightarrow 0.35294117647058809 \cdot x - 24.0 \cdot ft$$

$$M_{v1\_3}(x) := R_{v1\_1} \cdot x + P \cdot \left(x - L_1\right) \rightarrow 0.35294117647058809 \cdot x - 24.0 \cdot ft$$

$$R_{v2\_1} := -\frac{P \cdot L_3}{L_1 + L_2 + L_3} = -0.412$$

$$M_{v2\_1}(x) := R_{v2\_1} \cdot x \rightarrow -0.411764705882353 \cdot x$$

$$M_{v2\_2}(x) := R_{v2\_1} \cdot x \rightarrow -0.411764705882353 \cdot x$$

$$M_{v2\_3}(x) := R_{v2\_1} \cdot x + P \cdot \left(x - L_1 - L_2\right) \rightarrow 0.588235294117647 \cdot x - 40.0 \cdot ft$$

$$d_1\left(q_1, q_2, q_3\right) := \int_{0\,ft}^{L_1} \frac{M_1(x) \cdot M_{v1\_1}(x)}{E \cdot I} \, dx + \int_{L_1}^{L_1 + L_2} \frac{M_2(x) \cdot M_{v1\_2}(x)}{E \cdot I} \, dx + \int_{L_1 + L_2}^{L_1 + L_2 + L_3} \frac{M_3(x) \cdot M_{v1\_3}(x)}{E \cdot I} \, dx \rightarrow \frac{(84}{}$$

$$d_2\left(q_1, q_2, q_3\right) := \int_{0\,ft}^{L_1} \frac{M_1(x) \cdot M_{v2\_1}(x)}{E \cdot I} \, dx + \int_{L_1}^{L_1 + L_2} \frac{M_2(x) \cdot M_{v2\_2}(x)}{E \cdot I} \, dx + \int_{L_1 + L_2}^{L_1 + L_2 + L_3} \frac{M_3(x) \cdot M_{v2\_3}(x)}{E \cdot I} \, dx \rightarrow \frac{(10}{}$$

$$f_{11} := \int_{0\,ft}^{L_1} \frac{M_{v1\_1}(x) \cdot M_{v1\_1}(x)}{E \cdot I} \, dx + \int_{L_1}^{L_1 + L_2 + L_3} \frac{M_{v1\_2}(x) \cdot M_{v1\_2}(x)}{E \cdot I} \, dx \rightarrow \frac{5466.3529411764752934 \cdot ft^3}{in^4 \cdot ksi}$$

$$f_{12} := \int_{0\,ft}^{L_1} \frac{M_{v1\_1}(x) \cdot M_{v2\_1}(x)}{E \cdot I}\,dx + \int_{L_1}^{L_1+L_2} \frac{M_{v1\_2}(x) \cdot M_{v2\_2}(x)}{E \cdot I}\,dx + \int_{L_1+L_2}^{L_1+L_2+L_3} \frac{M_{v1\_3}(x) \cdot M_{v2\_3}(x)}{E \cdot I}\,dx \rightarrow \frac{5376.0}{}$$

$$f_{22} := \int_{0\,ft}^{L_1+L_2} \frac{M_{v2\_1}(x) \cdot M_{v2\_1}(x)}{E \cdot I}\,dx + \int_{L_1+L_2}^{L_1+L_2+L_3} \frac{M_{v2\_3}(x) \cdot M_{v2\_3}(x)}{E \cdot I}\,dx \rightarrow \frac{6149.0196078431396267 \cdot ft^3}{in^4 \cdot ksi}$$

<u>Dead Load</u>

$q_1 := -w_{1D} - w_{beam}$ $q_2 := -w_{2D} - w_{beam}$ $q_3 := -w_{1D} - w_{beam}$

Guess Values

$R_1 := 1\ lbf$ $R_2 := 1\ lbf$ $R_3 := 1\ lbf$ $R_4 := 1\ lbf$

Constraints

$$0\ lbf \cdot ft = R_2 \cdot L_1 + R_3 \cdot (L_1 + L_2) + R_4 \cdot (L_1 + L_2 + L_3) + q_1 \cdot L_1 \cdot \left(\frac{1}{2}\ L_1\right) + q_2 \cdot L_2 \cdot \left(L_1 + \frac{1}{2}\ L_2\right) + q_3 \cdot L_3 \cdot \left(L_1 + L_2 + \frac{1}{2}\ L_3\right)$$

$$0\ lbf = q_1 \cdot L_1 + q_2 \cdot L_2 + q_3 \cdot L_3 + R_1 + R_2 + R_3 + R_4$$

$$d_1(q_1, q_2, q_3) + f_{11} \cdot R_2 + f_{12} \cdot R_3 = 0\ ft$$

$$d_2(q_1, q_2, q_3) + f_{12} \cdot R_2 + f_{22} \cdot R_3 = 0\ ft$$

Solver

$$\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix} := \text{find}(R_1, R_2, R_3, R_4) = \begin{bmatrix} 18446.873 \\ 31835.516 \\ 41803.64 \\ 20915.971 \end{bmatrix} ft \cdot plf$$

$w_{3AD} := R_1 = (1.845 \cdot 10^4)\ ft \cdot plf$ $w_{3BD} := R_2 = (3.184 \cdot 10^4)\ ft \cdot plf$

$w_{3CD} := R_3 = (4.18 \cdot 10^4)\ ft \cdot plf$ $w_{3DD} := R_4 = (2.092 \cdot 10^4)\ ft \cdot plf$ $w_{3D} := R_3 = (4.18 \cdot 10^4)\ ft \cdot plf$

$w_1 := R_1 = (1.845 \cdot 10^4)\ ft \cdot plf$ $w_2 := R_2 = (3.184 \cdot 10^4)\ ft \cdot plf$ $w_3 := R_3 = (4.18 \cdot 10^4)\ ft \cdot plf$

$$M_1(x) := w_1 \cdot x + \frac{1}{2}\ q_1 \cdot x^2 \rightarrow 18446.873427672965879 \cdot plf \cdot x \cdot ft - 891.24999999999993 \cdot plf \cdot x^2$$

$$M_2(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2}\ L_1\right) + \frac{1}{2}\ q_2 \cdot (x - L_1)^2 \rightarrow -42779.99999999999664 \cdot ft \cdot p$$

$$M_3(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + w_3 \cdot (x - L_1 - L_2) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + q_2 \cdot L_2 \cdot \left(x - L_1 - \frac{1}{2} L_2\right) + \frac{1}{2} q_3 \cdot ($$

$$V_1(x) := \frac{d}{dx} M_1(x) \rightarrow -1782.49999999999986 \cdot plf \cdot x + 18446.873427672965879 \cdot ft \cdot plf$$

$$V_2(x) := \frac{d}{dx} M_2(x) \rightarrow -1269.49999999999995 \cdot plf \cdot x + 37970.389150943407672 \cdot ft \cdot plf$$

$$V_3(x) := \frac{d}{dx} M_3(x) \rightarrow -1782.49999999999986 \cdot plf \cdot x + 100294.02897574130433 \cdot ft \cdot plf$$

Solve Block 1	Solve Block 2	Solve Block 3
Guess Values: $x := 1\ ft$	Guess Values: $x := 1\ ft$	Guess Values: $x := 1\ ft$
Constraints: $V_1(x) = 0\ lbf$	Constraints: $V_2(x) = 0\ lbf$	Constraints: $V_3(x) = 0\ lbf$
Solver: $x_1 := find(x) = 10.349\ ft$	Solver: $x_2 := find(x) = 29.91\ ft$	Solver: $x_3 := find(x) = 56.266\ ft$

$L_1 = 24\ ft$ $\quad L_1 + L_2 = 40\ ft$ $\quad L_1 + L_2 + L_3 = 68\ ft$

$V_1(0\ ft) = (1.845 \cdot 10^4)\ ft \cdot plf$

$V_1(L_1) = -24333.127\ ft \cdot plf$ $\quad V_2(L_1) = 7502.389\ ft \cdot plf$

$V_2(L_1 + L_2) = -12809.611\ ft \cdot plf$ $\quad V_3(L_1 + L_2) = 28994.029\ ft \cdot plf$

$V_3(L_1 + L_2 + L_3) = -20915.971\ ft \cdot plf$ $\quad V_{2D} := V_3(L_1 + L_2) = 28994.029\ ft \cdot plf$

$M_1(0\ ft) = 0\ ft \cdot lbf$

$M_1(L_1) = -70635.038\ ft \cdot lbf$ $\quad M_2(L_1) = -70635.038\ ft \cdot lbf$

$M_2(L_1 + L_2) = -113092.811\ ft \cdot lbf$ $\quad M_3(L_1 + L_2) = -113092.811\ ft \cdot lbf$

$M_3(L_1 + L_2 + L_3) = 0\ ft \cdot lbf$ $\quad M_{2Dneg} := M_2(L_1 + L_2) = -1.131 \cdot 10^5\ ft \cdot lbf$

$M_1(x_1) = 95452.213\ ft \cdot lbf$

$M_2(x_2) = -48466.529\ ft \cdot lbf$

$M_3(x_3) = 122714.683\ ft \cdot lbf$ $\quad M_{2Dpos} := M_3(x_3) = 122714.683\ ft \cdot lbf$

Live Load Max Positive Moment

$q_1 := -1\ w_{1L}$ $q_2 := -0\ w_{2L}$ $q_3 := -1\ w_{1L}$

Guess Values

$R_1 := 1\ lbf$ $R_2 := 1\ lbf$ $R_3 := 1\ lbf$ $R_4 := 1\ lbf$

Constraints

$$0\ lbf \cdot ft = R_2 \cdot L_1 + R_3 \cdot (L_1 + L_2) + R_4 \cdot (L_1 + L_2 + L_3) + q_1 \cdot L_1 \cdot \left(\frac{1}{2}\ L_1\right) + q_2 \cdot L_2 \cdot \left(L_1 + \frac{1}{2}\ L_2\right) + q_3 \cdot L_3 \cdot \left(L_1 + L_2 + \frac{1}{2}\ L_3\right)$$

$$0\ lbf = q_1 \cdot L_1 + q_2 \cdot L_2 + q_3 \cdot L_3 + R_1 + R_2 + R_3 + R_4$$

$$d_1(q_1, q_2, q_3) + f_{11} \cdot R_2 + f_{12} \cdot R_3 = 0\ ft$$

$$d_2(q_1, q_2, q_3) + f_{12} \cdot R_2 + f_{22} \cdot R_3 = 0\ ft$$

Solver

$$\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix} := \text{find}(R_1, R_2, R_3, R_4) = \begin{bmatrix} 9764.316 \\ 10784.34 \\ 16069.842 \\ 10961.503 \end{bmatrix} ft \cdot plf$$

$w_{3AD} := R_1 = (9.764 \cdot 10^3)\ ft \cdot plf$ $w_{3BD} := R_2 = (1.078 \cdot 10^4)\ ft \cdot plf$

$w_{3CD} := R_3 = (1.607 \cdot 10^4)\ ft \cdot plf$ $w_{3DD} := R_4 = (1.096 \cdot 10^4)\ ft \cdot plf$ $w_{3D} := R_3 = (1.607 \cdot 10^4)\ ft \cdot plf$

$w_1 := R_1 = (9.764 \cdot 10^3)\ ft \cdot plf$ $w_2 := R_2 = (1.078 \cdot 10^4)\ ft \cdot plf$ $w_3 := R_3 = (1.607 \cdot 10^4)\ ft \cdot plf$

$$M_1(x) := w_1 \cdot x + \frac{1}{2}\ q_1 \cdot x^2 \rightarrow 9764.3160377358595801 \cdot plf \cdot x \cdot ft - 457.500000000000055 \cdot plf \cdot x^2$$

$$M_2(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2}\ L_1\right) + \frac{1}{2}\ q_2 \cdot (x - L_1)^2 \rightarrow -21960.00000000000264 \cdot ft \cdot p$$

$$M_3(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + w_3 \cdot (x - L_1 - L_2) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2}\ L_1\right) + q_2 \cdot L_2 \cdot \left(x - L_1 - \frac{1}{2}\ L_2\right) + \frac{1}{2}\ q_3 \cdot ($$

$$V_1(x) := \frac{d}{dx} M_1(x) \rightarrow -915.00000000000011 \cdot plf \cdot x + 9764.3160377358595801 \cdot ft \cdot plf$$

$$V_2(x) := \frac{d}{dx} M_2(x) \rightarrow -1411.3443396226404349 \cdot ft \cdot plf$$

$$V_3(x) := \frac{d}{dx} M_3(x) \rightarrow -915.00000000000011 \cdot plf \cdot x + 51258.497304582219608 \cdot ft \cdot plf$$

Guess Values

$x := 1\ ft$

Constraints

$V_1(x) = 0\ lbf$

Solver

$x_1 := \text{find}(x) = 10.671\ ft$

Guess Values

$x := 1\ ft$

Constraints

$V_2(x) = 0\ lbf$

Solver

$x_2 := \text{find}(x) = ?$

Guess Values

$x := 1\ ft$

Constraints

$V_3(x) = 0\ lbf$

Solver

$x_3 := \text{find}(x) = 56.02\ ft$

$L_1 = 24\ ft$ $\quad L_1 + L_2 = 40\ ft$ $\quad L_1 + L_2 + L_3 = 68\ ft$

$V_1(0\ ft) = (9.764 \cdot 10^3)\ ft \cdot plf$

$V_1(L_1) = -12195.684\ ft \cdot plf$ $\quad V_2(L_1) = -1411.344\ ft \cdot plf$

$V_2(L_1 + L_2) = -1411.344\ ft \cdot plf$ $\quad V_3(L_1 + L_2) = 14658.497\ ft \cdot plf$

$V_3(L_1 + L_2 + L_3) = -10961.503\ ft \cdot plf$

$M_1(0\ ft) = 0\ ft \cdot lbf$

$M_1(L_1) = -29176.415\ ft \cdot lbf$ $\quad M_2(L_1) = -29176.415\ ft \cdot lbf$

$M_2(L_1 + L_2) = -51757.925\ ft \cdot lbf$ $\quad M_3(L_1 + L_2) = -51757.925\ ft \cdot lbf$

$M_3(L_1 + L_2 + L_3) = 0\ ft \cdot lbf$

$M_1(x_1) = 52099.381\ ft \cdot lbf$

$M_2(x_2) = ?\ lbf$

$M_3(x_3) = 65658.219\ ft \cdot lbf$ $\quad M_{2Lpos} := M_3(x_3) = 65658.219\ ft \cdot lbf$

Live Load Max Negative Moment and Shear

$q_1 := -0\ w_{1L}$ $\quad q_2 := -1\ w_{2L}$ $\quad q_3 := -1\ w_{1L}$

Guess Values

$R_1 := 1\ lbf$ $\quad R_2 := 1\ lbf$ $\quad R_3 := 1\ lbf$ $\quad R_4 := 1\ lbf$

Constraints

$$0\ lbf \cdot ft = R_2 \cdot L_1 + R_3 \cdot (L_1 + L_2) + R_4 \cdot (L_1 + L_2 + L_3) + q_1 \cdot L_1 \cdot \left(\frac{1}{2} L_1\right) + q_2 \cdot L_2 \cdot \left(L_1 + \frac{1}{2} L_2\right) + q_3 \cdot L_3 \cdot \left(L_1 + L_2 + \frac{1}{2} L_3\right)$$

$$0\ lbf = q_1 \cdot L_1 + q_2 \cdot L_2 + q_3 \cdot L_3 + R_1 + R_2 + R_3 + R_4$$

$$d_1(q_1, q_2, q_3) + f_{11} \cdot R_2 + f_{12} \cdot R_3 = 0\ ft$$

$d_2(q_1, q_2, q_3) + f_{12} \cdot R_2 + f_{22} \cdot R_3 = 0\ ft$

Solver

$$\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{bmatrix} := \text{find}(R_1, R_2, R_3, R_4) = \begin{bmatrix} 244.863 \\ -252.632 \\ 23906.04 \\ 10505.729 \end{bmatrix} ft \cdot plf$$

$w_{3AD} := R_1 = 244.863\ ft \cdot plf \quad w_{3BD} := R_2 = -252.632\ ft \cdot plf$

$w_{3CD} := R_3 = (2.391 \cdot 10^4)\ ft \cdot plf \quad w_{3DD} := R_4 = (1.051 \cdot 10^4)\ ft \cdot plf \quad w_{3D} := R_3 = (2.391 \cdot 10^4)\ ft \cdot plf$

$w_1 := R_1 = 244.863\ ft \cdot plf \quad w_2 := R_2 = -252.632\ ft \cdot plf \quad w_3 := R_3 = (2.391 \cdot 10^4)\ ft \cdot plf$

$M_1(x) := w_1 \cdot x + \frac{1}{2} q_1 \cdot x^2 \rightarrow 244.86320754718208661 \cdot plf \cdot x \cdot ft$

$M_2(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + \frac{1}{2} q_2 \cdot (x - L_1)^2 \rightarrow -274.5 \cdot plf \cdot (x - 24.0 \cdot ft)^2 - 25$

$M_3(x) := w_1 \cdot x + w_2 \cdot (x - L_1) + w_3 \cdot (x - L_1 - L_2) + q_1 \cdot L_1 \cdot \left(x - \frac{1}{2} L_1\right) + q_2 \cdot L_2 \cdot \left(x - L_1 - \frac{1}{2} L_2\right) + \frac{1}{2} q_3 \cdot ($

$V_1(x) := \frac{d}{dx} M_1(x) \rightarrow 244.86320754718208661 \cdot ft \cdot plf$

$V_2(x) := \frac{d}{dx} M_2(x) \rightarrow -549.0 \cdot plf \cdot x + 13168.231132075449147 \cdot ft \cdot plf$

$V_3(x) := \frac{d}{dx} M_3(x) \rightarrow -915.00000000000011 \cdot plf \cdot x + 51714.27088948788793 \cdot ft \cdot plf$

Solve Block 1	Solve Block 2	Solve Block 3
Guess Values: $x := 1\ ft$	Guess Values: $x := 1\ ft$	Guess Values: $x := 1\ ft$
Constraints: $V_1(x) = 0\ lbf$	Constraints: $V_2(x) = 0\ lbf$	Constraints: $V_3(x) = 0\ lbf$
Solver: $x_1 := \text{find}(x) = ?$	Solver: $x_2 := \text{find}(x) = 23.986\ ft$	Solver: $x_3 := \text{find}(x) = 56.518\ ft$

$L_1 = 24\ ft \quad L_1 + L_2 = 40\ ft \quad L_1 + L_2 + L_3 = 68\ ft$

$V_1(0\ ft) = 244.863\ ft \cdot plf$

$V_1(L_1) = 244.863\ ft \cdot plf \quad V_2(L_1) = -7.769\ ft \cdot plf$

$V_2(L_1 + L_2) = -8791.769\ ft \cdot plf \quad V_3(L_1 + L_2) = 15114.271\ ft \cdot plf$

$V_3(L_1+L_2+L_3)=-10505.729\ ft \cdot plf$ $V_{2L}:=V_3(L_1+L_2)=15114.271\ lbf$

$M_1(0\ ft)=0\ ft \cdot lbf$

$M_1(L_1)=5876.717\ ft \cdot lbf$ $M_2(L_1)=5876.717\ ft \cdot lbf$

$M_2(L_1+L_2)=-64519.585\ ft \cdot lbf$ $M_3(L_1+L_2)=-64519.585\ ft \cdot lbf$

$M_3(L_1+L_2+L_3)=0\ ft \cdot lbf$ $M_{2Lneg}:=M_3(L_1+L_2)=-64519.585\ ft \cdot lbf$

$M_1(\mathbf{x_1})=?\ lbf$

$M_2(\mathbf{x_2})=5876.772\ ft \cdot lbf$

$M_3(\mathbf{x_3})=60311.663\ ft \cdot lbf$

Summary

$V_{1D}=11538.67\ lbf$ $M_{1Dneg}=30509.993\ ft \cdot lbf$ $M_{1Dpos}=22012.817\ ft \cdot lbf$

$V_{1L}=3155.84\ lbf$ $M_{1Lneg}=9238.466\ ft \cdot lbf$ $M_{1Lpos}=7604.556\ ft \cdot lbf$

$V_{2D}=28994.029\ lbf$ $M_{2Dneg}=-113092.811\ ft \cdot lbf$ $M_{2Dpos}=122714.683\ ft \cdot lbf$

$V_{2L}=15114.271\ lbf$ $M_{2Lneg}=-64519.585\ ft \cdot lbf$ $M_{2Lpos}=65658.219\ ft \cdot lbf$

$V_{Dbeam}:=\max(\text{abs}(V_{1D}), \text{abs}(V_{2D}))=(2.899 \cdot 10^4)\ lbf$

$V_{Lbeam}:=\max(\text{abs}(V_{1L}), \text{abs}(V_{2L}))=(1.511 \cdot 10^4)\ lbf$

$M_{Dnegbeam}:=\max(\text{abs}(M_{1Dneg}), \text{abs}(M_{2Dneg}))=113092.811\ lbf \cdot ft$

$M_{Lnegbeam}:=\max(\text{abs}(M_{1Lneg}), \text{abs}(M_{2Lneg}))=64519.585\ lbf \cdot ft$

$M_{Dposbeam}:=\max(\text{abs}(M_{1Dpos}), \text{abs}(M_{2Dpos}))=122714.683\ lbf \cdot ft$

$M_{Lposbeam}:=\max(\text{abs}(M_{1Lpos}), \text{abs}(M_{2Lpos}))=65658.219\ lbf \cdot ft$

$V_{beam}:=1.2\ V_{Dbeam}+1.6\ V_{Lbeam}+1.0\ V_b=61\ kip$ $P_{beam}:=P_b=4\ kip$

$M_{neg\_beam}:=1.2\ M_{Dnegbeam}+1.6\ M_{Lnegbeam}+1.0\ M_b=252\ kip \cdot ft$

$M_{pos\_beam}:=1.2\ M_{Dposbeam}+1.6\ M_{Lposbeam}=252\ kip \cdot ft$

ORIGIN := 1

Include << H:\Finite Element\mathCAD-FEA1-UtilityFunctions.mcdx

Include << H:\Finite Element\trussElement.mcdx

Truss A Design

Define Variables

$e := 10100000 \quad a1 := 0.438 \quad a2 := 0.688 \quad r1 := 0.361 \quad r2 := 0.693 \quad k := 0.75 \quad S1 := 0.114 \quad S2 := 0.332$

$sp := 2\ ft \quad p_d := 5\ psf \quad p_s := 30\ psf \quad b := 36 \quad h := 48 \quad s := 0.33333$

Design Calculations

$$nodalCoords := \begin{bmatrix} 0 & 0 \\ 0 & h \\ b & 0 \\ b & h - s \cdot b \\ 2\ b & 0 \\ 2\ b & h - 2\ s \cdot b \\ 3\ b & 0 \\ 3\ b & h - 3\ s \cdot b \\ 4\ b & 0 \\ 4\ b & h - 4\ s \cdot b \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 48 \\ 36 & 0 \\ 36 & 36 \\ 72 & 0 \\ 72 & 24 \\ 108 & 0 \\ 108 & 12 \\ 144 & 0 \\ 144 & 0 \end{bmatrix} \qquad elemNodes := \begin{bmatrix} 1 & 2 \\ 3 & 4 \\ 5 & 6 \\ 7 & 8 \\ 9 & 10 \\ 1 & 3 \\ 3 & 5 \\ 5 & 7 \\ 7 & 9 \\ 2 & 4 \\ 4 & 6 \\ 6 & 8 \\ 8 & 10 \\ 2 & 3 \\ 3 & 6 \\ 6 & 7 \\ 7 & 10 \end{bmatrix}$$

$$assembLocs := \left\| \begin{array}{l} \text{for } i \in 0 .. \text{rows}(elemNodes) - 1 \\ \quad \left\| \begin{array}{l} assembLocs_{i+1,1} \leftarrow 2\ elemNodes(i, 0) - 1 \\ assembLocs_{i+1,2} \leftarrow 2\ elemNodes(i, 0) \\ assembLocs_{i+1,3} \leftarrow 2\ elemNodes(i, 1) - 1 \\ assembLocs_{i+1,4} \leftarrow 2\ elemNodes(i, 1) \end{array} \right. \end{array} \right\| \quad \text{return } assembLocs$$

$$matProps := [e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e\ \ e]$$

$$secProps := [a1\ \ a1\ \ a1\ \ a1\ \ a1\ \ a1\ \ a1\ \ a1\ \ a1\ \ a2\ \ a2\ \ a2\ \ a2\ \ a1\ \ a1\ \ a1\ \ a1]$$

$nd := \max(assembLocs)$ $K := zerosMat(nd, nd)$ $R := zerosVec(nd)$

$P := \frac{p_d + p_s}{lbf} \cdot sp \cdot \frac{b \cdot ft}{12} = 210$

$R_4 := \frac{-P}{2}$ $R_8 := -P$ $R_{12} := -P$ $R_{16} := -P$ $R_{20} := \frac{-P}{2}$

$$K := \left\| \begin{array}{l} \text{for } en \in 1..\text{rows}(elemNodes) \\ \quad \left\| \begin{array}{l} e \leftarrow matProps_{1,en} \\ a \leftarrow secProps_{1,en} \\ nodes \leftarrow elemNodes^{\langle en \rangle} \\ coord \leftarrow extractRows(nodalCoords, nodes) \\ lm \leftarrow assembLocs^{\langle en \rangle} \\ k \leftarrow trussElementK(e, a, coord) \\ K \leftarrow assembleK(K, k, lm) \end{array} \right. \\ \text{return } K \end{array} \right.$$

$ebc := [2 \;\; 18]$ $ebcVals := [0 \;\; 0]$

$d := nodalSolution(K, R, ebc, ebcVals)$

$d^T = [0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; -0.1 \;\; 0 \;\; -0.1 \;\; 0 \;\; -0.1 \;\; 0 \;\; -0.1 \;\; 0 \;\; 0 \;\; 0 \;\; 0]$

$reacts := reactionSolution(K, R, ebc, d)$

$reacts^T = [420 \;\; 420]$ $W_a := 0.5 \; reacts(0) = 210$

$$F := \left\| \begin{array}{l} \text{for } en \in 1..\text{rows}(elemNodes) \\ \quad \left\| \begin{array}{l} e \leftarrow matProps_{1,en} \\ a \leftarrow secProps_{1,en} \\ nodes \leftarrow elemNodes^{\langle en \rangle} \\ coord \leftarrow extractRows(nodalCoords, nodes) \\ lm \leftarrow assembLocs^{\langle en \rangle} \\ de \leftarrow extractVec(d, lm) \\ [eps \;\; sigma \;\; force] \leftarrow trussElementSolution(e, a, coord, de) \\ F_{en,1} \leftarrow force \end{array} \right. \\ \text{return } F \end{array} \right.$$

$F^T = [-420 \;\; -210 \;\; 0 \;\; -210 \;\; -420 \;\; 0 \;\; 630 \;\; 630 \;\; 0 \;\; -332 \;\; -332 \;\; -996 \;\; -996 \;\; 525 \;\; -379 \;\; 379 \;\; 945]$

Tension Design

$\max(F) = 945$ $\sigma_{allow} := 4.8\ ksi$ ADM 2010 $P_{allow} := \sigma_{allow} \cdot a1 \cdot in^2 = 2102\ lbf$

Compression Design

$secProps2 := [r1\ r1\ r1\ r1\ r1\ r1\ r1\ r1\ r1\ r2\ r2\ r2\ r2\ r1\ r1\ r1\ r1]$

$$P_{cr} := \left\| \begin{array}{l} \text{for } en \in 1..\text{rows}(elemNodes) \\ \quad \left\| \begin{array}{l} a \leftarrow secProps_{1,en} \\ r \leftarrow secProps2_{1,en} \\ nodes \leftarrow elemNodes^{\langle en \rangle} \\ coord \leftarrow extractRows(nodalCoords, nodes) \\ L \leftarrow \sqrt{(coord(1,0)-coord(0,0))^2 + (coord(1,1)-coord(0,1))^2} \\ Pcr \leftarrow \left(4.5 - 0.016 \cdot k \cdot \frac{L}{r}\right) \cdot a \cdot 1000 \\ P_{en,1} \leftarrow Pcr \end{array} \right. \\ \text{return } P \end{array} \right.$$

$P_{cr}^{T} = [1272\ 1447\ 1622\ 1796\ 1971\ 1447\ 1447\ 1447\ 1447\ 2644\ 2644\ 2644\ 2644\ 1097\ 1341\ 1341\ 1447]$

$\left(\frac{F}{P_{cr}}\right)^{T} = [-0.33\ -0.15\ 0\ -0.12\ -0.21\ 0\ 0.44\ 0.44\ 0\ -0.13\ -0.13\ -0.38\ -0.38\ 0.48\ -0.28\ 0.28\ 0.65]$

Bending and Compression Design for Top Chord Members

$C := min(F) = -996$ $M := \frac{1}{10}\left(p_d + p_s\right) \cdot sp \cdot \left(\sqrt{(36\ in)^2 + (12\ in)^2}\right)^2 = 840\ lbf \cdot in$

$\sigma_{allow} := 6.3\ ksi$ ADM 2010 $M_{allow} := \sigma_{allow} \cdot S2 \cdot in^3 = 2092\ lbf \cdot in$

$\frac{-C}{P_{cr}(9)} + \frac{M}{M_{allow}} = 0.778$

Truss C Design (Truss B Doesn't Govern)

Define Variables

$sp := 2\ ft \quad p_d := 5\ psf \quad p_s := 30\ psf \quad b := 24 \quad h := 12 \quad s := 0$

Design Calculations

$$nodalCoords := \begin{bmatrix} 0 & 0 \\ 0 & h \\ b & 0 \\ b & h - s \cdot b \\ 2\ b & 0 \\ 2\ b & h - 2\ s \cdot b \\ 3\ b & 0 \\ 3\ b & h - 3\ s \cdot b \\ 4\ b & 0 \\ 4\ b & h - 4\ s \cdot b \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 12 \\ 24 & 0 \\ 24 & 12 \\ 48 & 0 \\ 48 & 12 \\ 72 & 0 \\ 72 & 12 \\ 96 & 0 \\ 96 & 12 \end{bmatrix} \qquad elemNodes := \begin{bmatrix} 1 & 2 \\ 3 & 4 \\ 5 & 6 \\ 7 & 8 \\ 9 & 10 \\ 1 & 3 \\ 3 & 5 \\ 5 & 7 \\ 7 & 9 \\ 2 & 4 \\ 4 & 6 \\ 6 & 8 \\ 8 & 10 \\ 2 & 3 \\ 3 & 6 \\ 6 & 7 \\ 7 & 10 \end{bmatrix}$$

```
assembLocs := | for i ∈ 0 .. rows(elemNodes) − 1
              |   | assembLocs_(i+1,1) ← 2 elemNodes(i,0) − 1
              |   | assembLocs_(i+1,2) ← 2 elemNodes(i,0)
              |   | assembLocs_(i+1,3) ← 2 elemNodes(i,1) − 1
              |   | assembLocs_(i+1,4) ← 2 elemNodes(i,1)
              | return assembLocs
```

$matProps := [e\ e\ e\ e\ e\ e\ e\ e\ e\ e\ e\ e\ e\ e\ e\ e\ e]$

$secProps := [a1\ a1\ a1\ a1\ a1\ a1\ a1\ a1\ a1\ a2\ a2\ a2\ a2\ a1\ a1\ a1\ a1]$

$nd := \max(assembLocs) \qquad K := zerosMat(nd, nd) \qquad R := zerosVec(nd)$

$reacts = \begin{bmatrix} 420 \\ 420 \end{bmatrix} \qquad P := reacts(0,0) = 420$

$R_4 := \frac{-P}{2} \qquad R_8 := -P \qquad R_{12} := -P \qquad R_{16} := -P \qquad R_{20} := \frac{-P}{2}$

$$K := \left\| \begin{array}{l} \text{for } en \in 1..\text{rows}(elemNodes) \\ \quad \left\| \begin{array}{l} e \leftarrow matProps_{1,en} \\ a \leftarrow secProps_{1,en} \\ nodes \leftarrow elemNodes^{\langle en \rangle} \\ coord \leftarrow extractRows(nodalCoords, nodes) \\ lm \leftarrow assembLocs^{\langle en \rangle} \\ k \leftarrow trussElementK(e, a, coord) \\ K \leftarrow assembleK(K, k, lm) \end{array} \right. \\ \text{return } K \end{array} \right.$$

$ebc := [2 \;\; 18]$ $\qquad$ $ebcVals := [0 \;\; 0]$

$d := nodalSolution(K, R, ebc, ebcVals)$

$d^{T} = [0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; -0.1 \;\; 0 \;\; -0.1 \;\; 0 \;\; -0.1 \;\; 0 \;\; -0.1 \;\; 0 \;\; -0.1 \;\; 0 \;\; -0.1 \;\; 0 \;\; 0 \;\; 0 \;\; 0]$

$reacts := reactionSolution(K, R, ebc, d)$

$reacts^{T} = [840 \;\; 840]$

$$F := \left\| \begin{array}{l} \text{for } en \in 1..\text{rows}(elemNodes) \\ \quad \left\| \begin{array}{l} e \leftarrow matProps_{1,en} \\ a \leftarrow secProps_{1,en} \\ nodes \leftarrow elemNodes^{\langle en \rangle} \\ coord \leftarrow extractRows(nodalCoords, nodes) \\ lm \leftarrow assembLocs^{\langle en \rangle} \\ de \leftarrow extractVec(d, lm) \\ [eps \;\; sigma \;\; force] \leftarrow trussElementSolution(e, a, coord, de) \\ F_{en,1} \leftarrow force \end{array} \right. \\ \text{return } F \end{array} \right.$$

$F^{T} = [-840 \;\; -420 \;\; 0 \;\; -420 \;\; -840 \;\; 0 \;\; 1680 \;\; 1680 \;\; 0 \;\; -1260 \;\; -1260 \;\; -1260 \;\; -1260 \;\; 1409 \;\; -470 \;\; -470 \;\; 1409]$

Tension Design

$\max(F) = 1680$ $\qquad$ $\sigma_{allow} := 4.8 \; ksi$ ADM 2010 $\qquad$ $P_{allow} := \sigma_{allow} \cdot a1 \cdot in^{2} = 2102 \; lbf$

Compression Design

$$secProps2 := [r1\ r1\ r1\ r1\ r1\ r1\ r1\ r1\ r1\ r2\ r2\ r2\ r2\ r1\ r1\ r1\ r1]$$

$P_{cr} :=$ for $en \in 1..\text{rows}(elemNodes)$

$a \leftarrow secProps_{1,en}$

$r \leftarrow secProps2_{1,en}$

$nodes \leftarrow elemNodes^{\langle en \rangle}$

$coord \leftarrow extractRows(nodalCoords, nodes)$

$L \leftarrow \sqrt{(coord(1,0) - coord(0,0))^2 + (coord(1,1) - coord(0,1))^2}$

$Pcr \leftarrow \left(4.5 - 0.016 \cdot k \cdot \frac{L}{r}\right) \cdot a \cdot 1000$

$P_{en,1} \leftarrow Pcr$

return P

$$P_{cr}^{T} = [1796\ 1796\ 1796\ 1796\ 1796\ 1622\ 1622\ 1622\ 1622\ 2810\ 2810\ 2810\ 2810\ 1580\ 1580\ 1580\ 1580]$$

$$\left(\frac{F}{P_{cr}}\right)^{T} = [-0.47\ -0.23\ 0\ -0.23\ -0.47\ 0\ 1.04\ 1.04\ 0\ -0.45\ -0.45\ -0.45\ -0.45\ 0.89\ -0.3\ -0.3\ 0.89]$$

Bending and Compression Design for Top Chord Members

$C := min(F) = -1260$

$M := \frac{1}{10}\left(p_d + p_s\right) \cdot sp \cdot (24\ in)^2 = 336\ lbf \cdot in$

$\sigma_{allow} := 6.3\ ksi$ ADM 2010

$M_{allow} := \sigma_{allow} \cdot S2 \cdot in^3 = 2092\ lbf \cdot in$

$$\frac{-C}{P_{cr}(9)} + \frac{M}{M_{allow}} = 0.609$$

Truss Design Summary

For All Top Chord Members of All Trusses **Use RT2x1x1/8 (6063-T6 Welded)**

For Rest **Use RT1x1x1/8 (6063-T6 Welded)**

Canopy Post and Post Anchorage for Wind Uplift

$p_w := 25\ psf$ $p_d + p_s = 35\ psf$ $P_{d\_s} := 2\ reacts(0) = 1680$

$P_{uplift} := P_{d\_s} \cdot \frac{5}{7} = 1200$ $T_{all} := 1412$ For one bolt, per HILTI

Use HSS2.875x0.203 Post (A500-B) w/ 5" x 5" x 3/8" Base Plate with (2) 1/2" dia. KB-TZ anchors with 2" min. embed.

Canopy Anchorage to Wall

Minimal shear reaction in bolt assuming two per truss: $W_a = 210$

Also no pullout force present. Simply anchor into facade assuming brick ties.