The University of Iowa
IOWA INITIATIVE
FOR SUSTAINABLE COMMUNITIES

FINAL DELIVERABLE

Title	Clinton Sawmill Museum - Amphitheater Design & Engineering
Completed By	Mike Silfugarian, Mike Rangel
Date Completed	May 2021
UI Department	Department of Civil & Environmental Engineering
Course Name	CEE:4850:0001 Project Design & Management
Instructor	Christopher Stoakes
Community Partners	Clinton Sawmill Museum

This project was supported by the Iowa Initiative for Sustainable Communities (IISC), a community engagement program at the University of Iowa. IISC partners with rural and urban communities across the state to develop projects that university students and IISC pursues a dual mission of enhancing quality of life in Iowa while transforming teaching and learning at the University of Iowa.

Iowa Initiative for Sustainable Communities
The University of Iowa
347 Jessup Hall
Iowa City, IA, 52241
Phone: 319.335.0032
Email: iisc@uiowa.edu
Website: http://iisc.uiowa.edu/

Sawmill Museum Amphitheater Project

by

Mike Silfugarian
Student, Department of Civil and Environmental Engineering
The University of Iowa, Iowa City, Iowa

Mike Rangel
Student, Department of Civil and Environmental Engineering
The University of Iowa, Iowa City, Iowa

for

Matthew Parbs
Director
Sawmill Museum, Clinton, Iowa

May 7, 2021

Executive Summary

The Sawmill Museum in Clinton Iowa has requested a design proposal for an outdoor amphitheater with an accompanying stage and pavilion. The four blocks to the north and northwest of the museum are available for construction of the project. The block directly north of the museum is solely owned by the museum, while the remaining blocks the museum is a majority holder. The amphitheater must also cohabit the property with the existing museum as well as a proposed event center.

The project team consists of two senior civil engineering students at the University of Iowa enrolled in a senior capstone design course. The engineers have experience via coursework involving design using various materials, including foundations.

The facility is to accommodate both large and small-scale events. Larger events, such as the Lumberjack Festival and the Canadian Pacific Railway Holiday Train, draw in thousands. Smaller events, both public and private, will have crowds of 100 people or less. This facility is a new venue capable of hosting a wide array of events. This allows the town new event opportunities, boosting the local economy through tourism. When not hosting events, the facility is to be a friendly and inviting space, attracting the local residents to spend more time in the area. Features will be added to make the area an excellent place for outdoor gatherings and entertaining.

The amphitheater will be located two blocks north of the museum, in the southwest corner of the lot. This location has an orientation and shape that would best make use of the circular design of an amphitheater, maximizing the square footage while still keeping the audience close to the stage. The structure will be orientated so that the center of the amphitheater faces towards the railroad, allowing a clear line of sight to the railroad.

Figure 1: Project location

A 3-tier amphitheater facility will be constructed, primarily made out of engineered soil. The soil will be trucked in and built up to provide the tiers of the amphitheater. The tiers will be large enough for permanent seating such as benches and picnic tables to be installed on the tiers. The first two tiers will be supported by wooden tangent pile walls, while the final tier will be supported by reinforced concrete retaining walls. The amphitheater will have a capacity of 800 people. A 725 square foot stage will also be constructed, along with a pavilion structure on top of the stage. The stage and pavilion will be constructed out of a combination of wood and concrete. The pavilion will be open, without any walls to interfere with the line of sight to the railroad.

The stage will also have a hydraulic lift in the back, allowing large machinery and equipment to be moved and displayed on the stage. The lift will be accessed via a staging area with a driveway connecting it to Grant Street. The staging area will be made of reinforced concrete, and be large enough and strong enough to support machinery that is too large to fit on the stage. The staging area will wrap around the back half and sides of the stage, allowing the machinery to be displayed to the amphitheater audience.

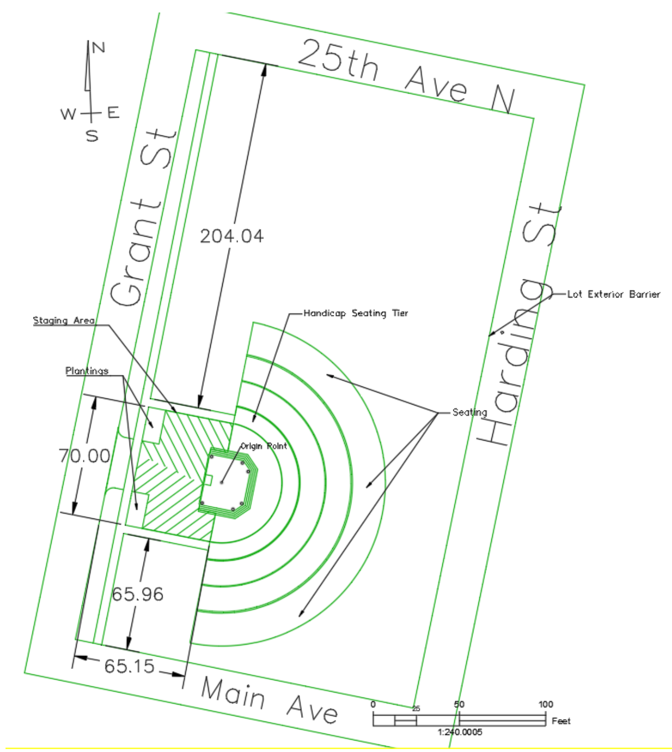


Figure 2: Plan view of project

All structures were analyzed for structural stability and a stormwater runoff analysis was performed for the pre and post-development of the project site. Plans for the final designs were provided through AutoDesk drawings. The final designs were submitted by May 14, 2021.

Organization Location and Contact Information

Iowa City, IA
Project Manager: Mike Silfugarian mike.silfu@gmail.com 630-640-9933

Organization and Team Description

Mike Silfugarian
Project Manager, Editor
University of Iowa, Class of 2021
Civil Engineering, Structural Concentration

Mike Rangel
Tech Support, Editor
University of Iowa, Class of 2021
Civil Engineering, Civil Practice Concentration

Description of Experience with Similar Projects

Mike Silfugarian has taken design courses at The University of Iowa regarding steel structures, wood structures, concrete structures, water resources, and foundations of structures. He has internship experience working with deep foundations, through Case Foundation Company. He also has construction experience, working as a construction intern with HR Green.

Mike Silfugarian will be responsible for the pavilion and amphitheater.

Mike Rangel has taken design courses at the University of Iowa regarding steel structures, wood structures, transportation, pavement, and foundations. He has unique concrete design experience through concrete canoe. He also has experience working on residential construction sites.

Mike Rangel will be responsible for the staging area and stage.

Proposed Services

1. Project Scope

The requested tasks to be completed for the project are the design of an amphitheater and a stage with a pavilion for both large, special events and regular use by the Sawmill Museum. The largest population use of the theater will be for the Canadian Pacific Railway Holiday Train that comes through each December. Seating for at least 250 people was requested. More seating will be available through green space and spread picnic tables. A hydraulic lift will be incorporated with the stage so that heavy equipment can be used for presentations and demonstrations.

The stage will work year round for the large holiday train event while smaller events such as concerts and movies can be shown during nicer weather. Lighting for night events will be present in the stage and throughout the amphitheater. Seating and green spaces will be a focus to provide a welcoming environment around the amphitheater. A handicap accessible area will be provided on the ground level of the amphitheater. The area will have sidewalks connecting to the main sidewalk on the western side of the block. Coordination with the other student design group responsible for an event center is necessary to determine areas of respective projects, whether the projects are incorporated or not. Shared restrooms and parking for both projects are handled by the other student design group.

The final design consists of a 725 square foot reinforced concrete stage, with a pavilion covering that also has a footprint of 725 square feet. The pavilion has an open concept, and starts at an elevation of 12 feet above the top of the stage.The amphitheater has a capacity for roughly 800 people when permanent seating is not furnished in the tiers. The handicap accessible area can accommodate up to 80 people. The three raised tiers have elevations of 1’-4”, 2’-8”, and 8’-8” respectively. These elevations allow a larger audience to be able spectate events on the stage, as well as the Holiday Train behind the stage, than if it were to remain a flat surface. The tiers will have horizontal depths of 15’, 15’, and 20’ respectively. The back tier will have a railing enclosing it.

2. Work Plan

The work plan seen below proposes a week minimum between each component of the construction. Four weeks are given for each component involving concrete to allow for proper curing. The stage cannot be poured until the pavilion columns are completely cured. Also, the framing of the pavilion roof cannot begin until the stage concrete has cured. The staging area, stage foundation, and retaining walls theoretically can be poured simultaneously as they do not depend on each other. Care will be taken to allow proper timing for concrete while spending the time waiting on other aspects of the construction like the cut/fill and landscaping. All time frames are a minimum and actual construction timing will be up to the contractor in charge.

Table 1. Work Plan

Component	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	W
Stage Foundation																				
Staging Area																				
Retaining Walls																				
Pavilion Columns																				
Stage																				
Cut/fill																				
Landscaping																				
Pavilion Framing																				

3. Methods and Design Guides

The methods and design guides used during the design of the project will be detailed in the FInal Design Details section of the report. Resources will be cited in Appendix E.

Constraints, Challenges and Impacts

1. Constraints

The project must accommodate both large and small events. The museum has requested a site that has a capacity of 250 people, but with the large crowd of thousands that are drawn to the Holiday Train, a larger capacity would be more advantageous. The amphitheater must be situated so that the audience will be able to observe the train as it comes through, and the stage not being a major obstruction to the line of sight.

The project must be constructed on a site that is owned by the museum. Of the available lots to build on, the two blocks north of the museum are the only ones that are fully owned by the museum. The northernmost block has a small portion in the northwest corner owned by a third party, but the client communicated that the owner of that land would be willing to sell or donate that land for a project such as this. The block directly north of the museum has been chosen as the site for another potential future project, an event center for the museum. A sense of continuity between the museum, event center, and amphitheater must exist, as well as a route connecting all three spaces. This will be accomplished by a sidewalk running along the west side of both blocks, leading to the museum.

As the client is a museum focusing on lumber, there is a desire to make wood a featured material throughout the design. There is also a desire to make this space friendly to the community, and therefore a large percentage of the amphitheater itself will be grass. There are large open spaces surrounding the amphitheater, as the proposed event center is on the current site of the annual Lumberjack Festival, and the Festival still needs space in the area. The Festival requires an area with minimum dimensions of 70 feet by 100 feet. This open space can be used by the community to use similar to a public park when the Festival is not occurring.

2. Challenges

One of the main challenges of the project is that the site is quite flat. There is a change in elevation of roughly 2 feet between the west and east sides of the block, causing a concern about drainage and stagnant water. There is also no storm sewer present for runoff to flow into, causing the runoff to be a concern. This will be mitigated by having a vast majority of the surface area of the amphitheater itself be grass.

As a result of this being a fairly flat site, large amounts of engineered soil will have to be brought in to be used as backfill and to level the site.

The site is also very close to both a railroad and a river, and both present their own set of codes and regulations that must be followed.

Another challenge is working with another senior design group working on an event center for the museum. We must work with them to make sure that the sites we choose for our projects do not interfere with each other or have conflicting styles of aesthetics. With two blocks being taken up by these projects, and the event center being planned to be built on a space that is currently used for parking and the Lumberjack Festival, we need to ensure that there still will be enough space for parking and for the Lumberjack Festival to occur.

3. Impacts

This project will provide the museum, as well as the public, with a site to put on events for education and entertainment, as well as many other types of events, such as weddings. This will allow the area to become a major attraction in the town, drawing in tourists with the events that are put on in this space and boosting the economic activity in the town of Clinton, Iowa.

The space will be open to the public, and create a space for the community to use for their events, as well as a nice environment for daily activities, such as picnics, barbeques, exercise, and other activities in the area surrounding the amphitheater and fixed seating in the amphitheater itself. Permanent fixtures such as picnic tables, benches, gazebos, and grills can be furnished and installed on site by the owners to provide amenities for the public to use while on site.

Alternative Solutions

With multiple lots being available for project sites, all of the locations were considered for construction of the project. Another potential option for the project would be incorporating the amphitheater with the event center project. These options created a number of potential locations and site plans.

Combining the amphitheater and the event center seemed to be a potential solution, but upon further inspection, the concept would limit the impact that the amphitheater would have. Combining the two projects would make it much easier for the museum to put on their own private, daily events, as the stage would most likely be connected to the event center, making it easy to move equipment onto the stage through the event center. However, this would limit the impact that the amphitheater would have on the public. Being connected to the event center would make for a much more uninviting space, and limit the amount of flat open area that would surround the amphitheater.

Simply put, there is not enough space on one block to accommodate the event center and the amphitheater, with the amphitheater effectively achieving the vision we have for it. It would be difficult for the audience in the amphitheater to see the train as it goes by, as the event center would be blocking one side of the field of view. The shape of the amphitheater would also have to be rectangular to fit with the amphitheater, and feel confined, which is not the desired atmosphere for the amphitheater. A large open area is the desired atmosphere, open and inviting with clear views of the surrounding area. The semi-circular shape was also desired, eliminating a space shared by the event center and the amphitheater.

The western sites did not have enough room either, and the block north of the museum made the most sense for the event center, so we decided on the northernmost lot.

The two smaller tiers, with the 1'-4" vertical steps, were designed for the ends to consist of soil with grass, at a slope of 5% going from the top of the tier to the surrounding area. This was chosen over having the tangent pile wall extend to the sides of the tiers with there being a steep drop at the ends of the tiers. The gentle slope was chosen mainly for aesthetic reasons, but it would also remove the need for steps on the sides.

The hydraulic lift was chosen instead of stairs or a rampage providing access for equipment as a ramp would end up using a large amount of material and space, and stairs are not an option for the larger pieces of equipment. The lift installed is 4' by 5'-8". This limits the size of equipment and machinery that can be shown on the stage. To make up for this, the staging area, initially intended as just a small area for vehicles to unload equipment, was extended to wrap around the stage. This allows for larger displays to still be seen by the audience seated in the amphitheater. Equipment that is too large for both the stage and staging area will be parked on Grant Street and shown from there.

The client had requested that the pavilion be made of cherry or mahogany. However, cherry does not perform well outdoors, and mahogany is quite expensive. Instead, we propose that Western Cedar is used, and stained mahogany. The same stain will be applied to the wooden tangent pile walls. The pavilion was chosen to be an open structure to allow a clear line of sight to the railroad behind it. A removal wall or curtain can be installed in the back to create a solid backdrop for events as well. The client requested that the pavilion be in the East Lake Movement architectural style, and a possible profile of the pavilion columns is provided, in that style. The client may choose to use this design or seek a different profile.

To reduce the cost of the project, changing the shape of the amphitheater from a full semicircle to an angled section was considered. Since the capacity of the semicircular design was larger than the requested capacity of 250, changing the amphitheater from a 180 degree semicircle to a 120 degree section of the circle with the same radii. However, the change in area still resulted in a large capacity, and the aesthetics of the full semicircle was decided to fit the layout better.

The idea behind the large horizontal depth of the tiers was that small groups seated together could still feel that they were together as a group, as opposed to fixed bench seating like a stadium. The tiers were designed so that permanent seating such as picnic tables, benches, and other tables could be furnished and installed throughout the amphitheater. This would reduce the capacity of the amphitheater by occupying space that could be used for attendants, but since the capacity is much larger than the requested 250, that is not a major concern.

The retaining walls of the final tier have several options for their aesthetics. To keep the theme of wood materials used throughout the projects, boards such as a 1”x12” could be secured to the outside of the retaining wall using brick anchors, spanning from the ground level to the top of the walls. Another option would be artwork. The client had mentioned the idea of graffiti art being present if a fence was to be constructed, and we believe that idea could be applied to the concrete retaining walls. Artwork, such as graffiti or a mural done by a local artist, could be painted on the concrete retaining walls to create a more inviting atmosphere than just the grey of concrete.

Final Design Details

The wind analysis done on the pavilion was done using the Directional Method, and used ASCE 7-16 as the main reference. A risk category of 1 was assigned, and the structure was treated as an open structure, with an internal pressure coefficient of zero. The wind directionality factor is 0.85, as the main wind force resisting system is being analyzed. The surface roughness and exposure category were found to both be C. The elevation factor was found to be approximately 1.0, and the topographic factor was assumed to be 1.0.

The roof was analysed as a simple gable roof, of which the mean roof height was 19'-4". The wind pressures were calculated, and are shown in the following pictures. The full wind loading calculations can be found in Appendix B.

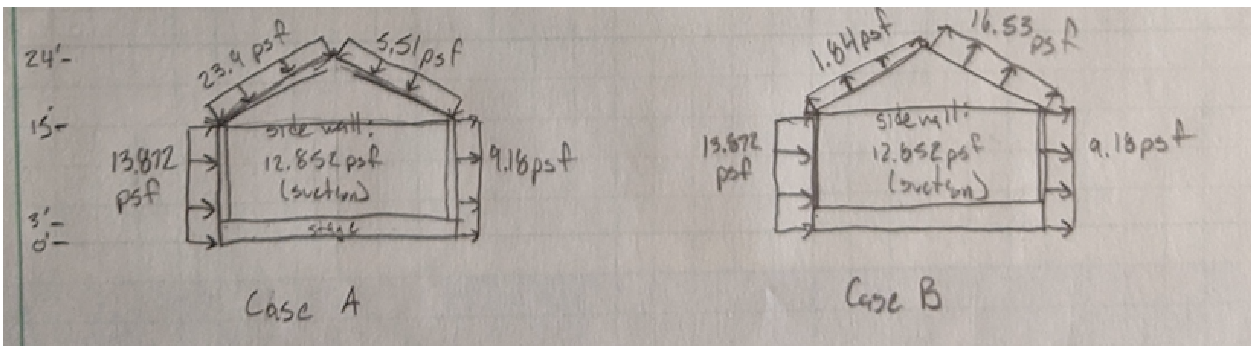


Figure 3: North-South wind loading for pavilion

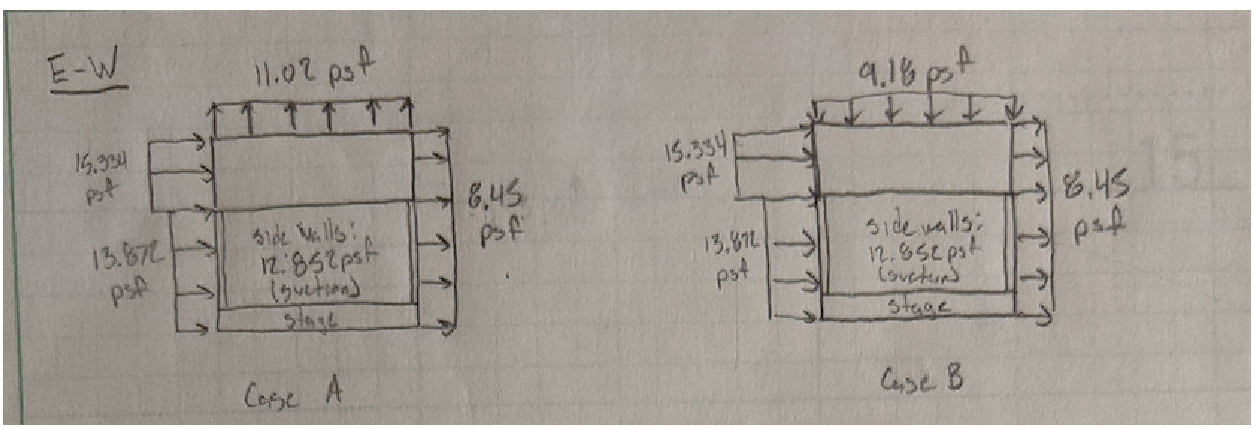


Figure 4: East-West wind loading for pavilion

The snow loading was also performed using ASCE 7-16. The flat roof snow load was found to be less than the minimum of 20 psf, so the value of 20 psf was used. The slope factor was found to be approximately 0.65 for a 30 degree sloped roof, unheated and unobstructed. This resulted in a snow load of 13 psf. The calculations can be found in Appendix B.

The roof dead load was calculated with ASCE 7-16. The roofing consists of ¾" plywood, single-ply felt waterproofing membrane, and asphalt shingles. This came to a total weight of 5.1 psf. This number was increased to 10 psf to account for the weight of the roof framing members.

For the individual members of the pavilion, load analysis was performed with the help of the FTool program, as well as the preliminary design equations for wood members, from the National Design Specification Design Values for Wood Construction. The results from the FTool analysis can be found in Appendix C.

Using the calculated dead load, snow load, and wind loading, the forces were applied to the members of the pavilion framing. With the help of the FTool software, forces in the members were calculated. The members were then sized based on the preliminary design equations from the NDS supplement. An adjustment factor of 0.75 was used for bending, a factor of 0.5 for compression, and a factor of 1.0 for both shear and tension. For the rafters and purlins, since they are attached to the roof sheathing, which provides a small increase in strength and rigidity, they used an adjustment factor of 1.0. SInce the columns were to have a complex design, the wind forces were calculated from an assumed diameter of 18", as the diameter of the columns would be larger in some areas than necessary for structural integrity. The moment created by the wind pressure on the roof itself was also taken into account.

The wood used for the pavilion is Western Cedar, No. 1 grade. This wood uses the following design values, in psi.

Table 1: Design values for No. 1 grade Western Cedar (psi)

	Bending	Tension	Shear	Perpendicular Compression	Parallel Compression	Modulus of Elasticity	Minimum Modulus
Design Value	750	425	155	425	825	1,000,000.00	370,000.00

A sample design of the retaining walls was provided as a reference, and is provided in Appendix E, as well as a reference for the stairs to be used in the final tier. The design was altered to have the correct dimensions for our project, and calculations were made to ensure that overturning would not occur.

The active earth pressure of the backfill was calculated, and assessed using Rankine's active earth pressure equations. The forces of the earth pressure, the weight of the soil and concrete, and the bearing pressure of the ground soil were all assessed as moments about the centroid of the retaining wall.

The unit weight of the granular backfill and the topsoil was assumed to be 120 pcf, with an active earth pressure coefficient of 0.33. The bearing capacity of the in-situ soil was assumed to be 4000 psf. The active earth pressure force was calculated to be 1,487.2 lbs, at a location of 35" above the top of the retaining wall foundation.

The moments of the forces of the weight of the soil and concrete, the moment created by the active earth pressure, and the moments created by the bearing pressure of the soil resisting overturning all resulted in a stable wall. Also, the shape of the retaining walls resists overturning. Due to its circular shape, the centroid of the wall as a whole lies within the area that the circle creates, and thus itself provides a force resisting overturning.

The foundations supporting the pavilion were designed to resist the total dead weight of the structure, as well as the snow loading and downward wind forces. 6 - 4' deep, 24" diameter foundations provide enough force to resist the total downward force of the pavilion, with an area large enough to not exceed the bearing capacity of the soil. The top of the foundations is at 7' below the ground level.

The maximum uplift from wind was calculated using the wind pressures, and the maximum uplift force was found to have a vertical component of 8.3 psf over the area of the roof, resulting in a total upward force of 3594 lb, which was rounded up to 4000 lb for a conservative approach. Providing uplift anchors that extend 3" horizontally at a depth of 6', the uplift resisting force is 4750 lbs, enough to resist the forces of uplift.

<u>Engineer's Cost Estimate</u>

Below is the total cost of each component of the project. Appendix D goes into further detail of the costs for each component.

Table 2: Total cost of project

Component		**Price**
Pavilion		$ 46,560.29
Amphitheater		$ 316,832.12
Stage		$ 223,167.00
Staging Area		$ 8,873.60
Total		$ 595,433.01
Contingencies	10%	$ 59,543.30
Engineering and Administration	20%	$ 119,086.60
Grand Total		$ 774,062.91

The unit prices were taken from bid data from Iowa DOT projects in the month of April 2021. The prices used were the weighted averages for the materials. The lumber prices were taken from a local lumberyard, however, a price of $1 per board foot was added to accommodate the materials and labor associated with the staining of the wood.

Appendix/Attachments

Appendix A: Project Location

Figure A1: Project location

Appendix B: Calculations

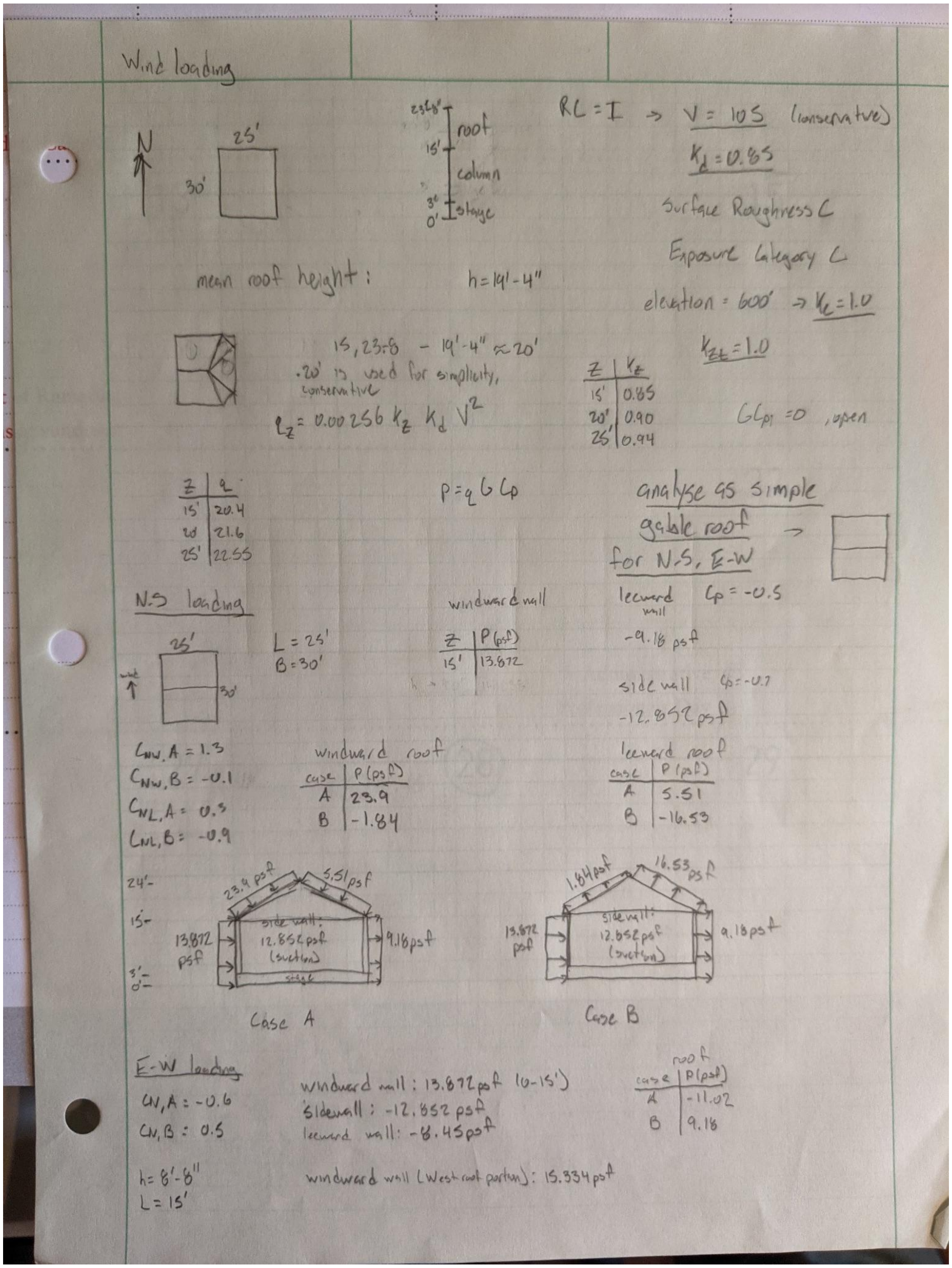


Figure B1: Pavilion wind pressure calculations (1 of 2)

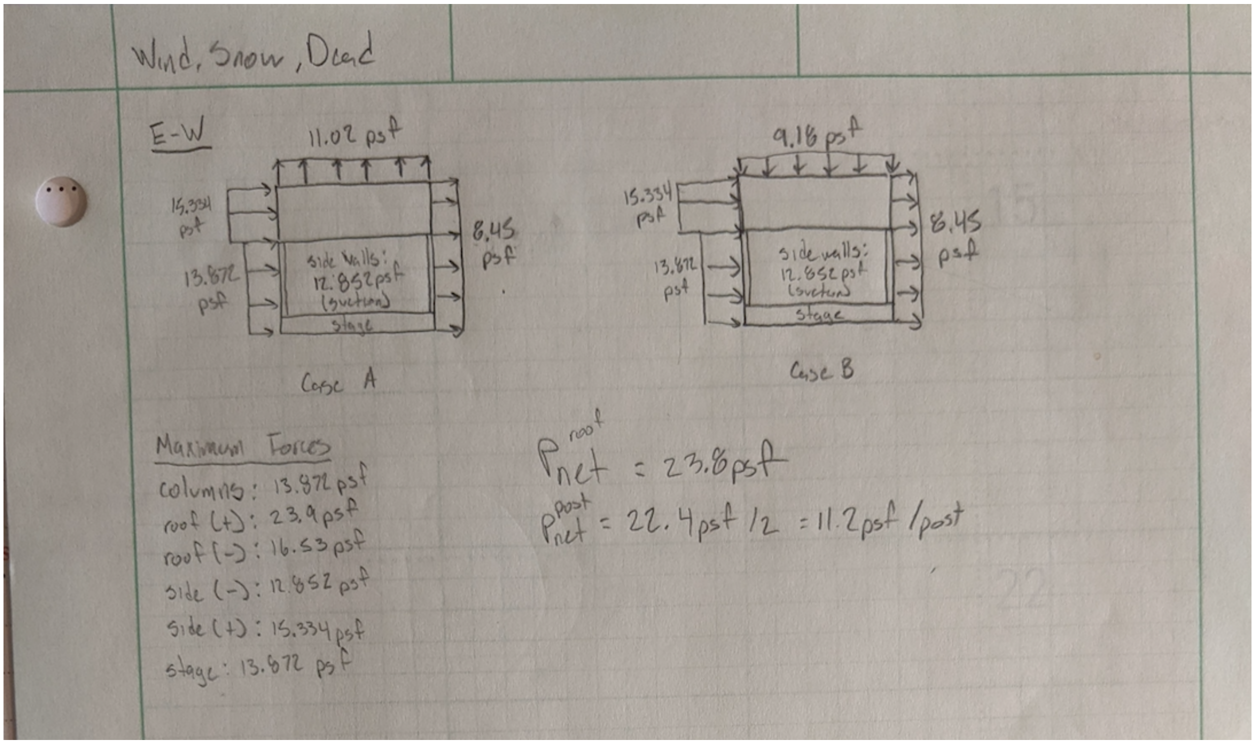
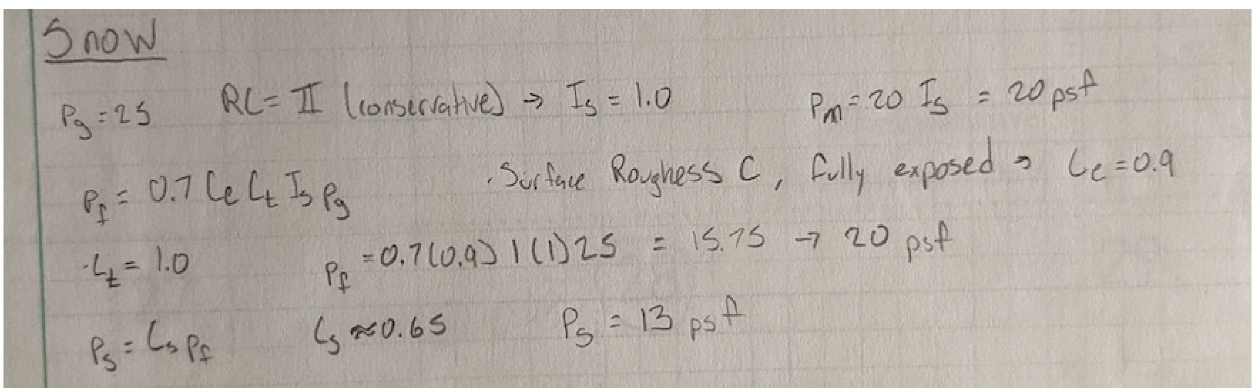


Figure B2: Pavilion wind pressure calculations (2 of 2)



Snow

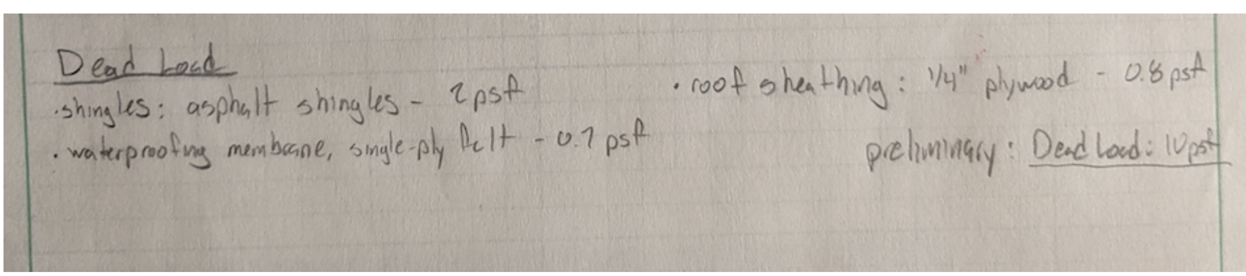
$P_g = 25$ RC = II (conservative) → $I_s = 1.0$ $P_m = 20\ I_s = 20$ psf

$P_f = 0.7\ C_e C_t I_s P_g$ · Surface Roughess C, fully exposed → $C_e = 0.9$

$\cdot C_t = 1.0$ $P_f = 0.7(0.9)1(1)25 = 15.75 \to 20$ psf

$P_s = C_s P_f$ $C_s \approx 0.65$ $P_s = 13$ psf

Figure B3: Pavilion snow load calculations



Dead Load

· shingles: asphalt shingles - 2 psf · roof sheathing: 1/4" plywood - 0.8 psf

· waterproofing membrane, single-ply felt - 0.7 psf preliminary: Dead Load: 10 psf

Figure B4: Pavilion roof dead load calculations

Pavilion Preliminary Sizing

Tension (+)
Compression (-)

Truss

Diagonals: max = 514 lb $A \geq P/0.5F_c$ $A \geq T/F_t$ $W_T = 2'$ $2 \times 24 = 48$ lb/ft

$A \geq \frac{519}{0.5(825)} \rightarrow A \geq 1.2582$

$A \geq 519/425 \rightarrow A \geq 1.221$ **Diagonals: 1x3** $A = 1.875$

Top: $M_{max} = 386$ lb·ft $= 4632$ lb·in

$P_{max} = 1428$ lb

$\left(\frac{1428/A}{0.5(825)}\right)^2 + \frac{4632/S}{0.75(750)} \leq 1.0$ **Top: 2x8**

2x8: $A = 10.88$ $S = 13.14$ $= 0.728$

2x6: $A = 8.25$ $S = 7.56$ $= 1.265$

Bottom: $T = 1169$ lb

$A \geq 1169/425 \rightarrow A \geq 2.751$ **Bottom: 2x3** $A = 3.75$

Rafter/Collar

Rafter: $M_{max} = 9503$ lb·ft $= 114{,}036$ lb·in

$P_{max} = 3084$ lb

$\left(\frac{3084/A}{0.5(825)}\right)^2 + \frac{114{,}036/S}{0.75(750)} \leq 1.0$ ~~Rafter: 12x12~~ X

2x8: $A = 10.88$ $S = 13.14$ $= 15.9$

4x6: $A = 19.25$ $S = 17.65$ $= 11.64$

4x12: $A = 39.38$ $S = 73.83$ $= 2.78$

8x8: $A = 56.25$ $S = 70.31$ $= 2.9$

4x16: $A = 53.38$ $S = 135.66$ $= 1.52$

12x12: $A = 132.3$ $S = 253.5$ $= 0.803$

Collar: $T_{max} = 3088$ $A \geq \frac{3088}{425}$ $A \geq 7.266$ **Collar: 1x12** $A = 8.438$

Purlins

$M_{max} = \frac{wL^2}{8}$ $L = \sqrt{8.66^2 + 10^2} = 13.24'$

$w = 24 \times 3' = 72$ plf $M_{max} = \frac{72(13.24)^2}{8} = 1578$ lb·ft $= 18{,}936$ lb·in

$S \geq \frac{18{,}936}{0.75(750)} \rightarrow S \geq 33.664$ X ~~Purlins: 2x10~~ $S = 35.65$

Figure B5: Pavilion member sizing (1 of 2)

Girders $M_{max} = 19760$ lb·ft $= 237120$ lb·in

$S \geq \frac{237120}{0.75(750)} \rightarrow S \geq 421.55$

or **Girder = 8x20** $S = 475.3$

Diagonal Rafters = 12x14

Moments from Wind

E-W: $P_{net}^{roof} = 23.8$ psf $A = 130$ ft^2 $\bar{y} = 2.9'$ from bottom of truss

$F = 130(23.8) = 3094$ lb

Rafter: $\left(\frac{3084/A}{825}\right)^2 + \frac{114{,}036/S}{750} \leq 1.0$

Rafters = 8x12

4x8: $A = 19.25$ $S = 17.65$ $= 8.65$

4x12: $A = 39.38$ $S = 73.83$ $= 2.07$

6x12: $A = 63.25$ $S = 121.2$ $= 1.26$

8x12: $A = 86.3$ $S = 165.3$ $= 0.922$

Purlin $S \geq \frac{18936}{750} \rightarrow S \geq 25.25$ **Purlins = 4x8**

Posts wind $= 22.4$ psf @ $d = 18''$ $\rightarrow M_{max} = 48{,}511$

$P_{max} = 6435$ lb

LL for posts: 8"

33psf x

trapezoid: 17.33' 5' B 10' A

18.03' 5 17.33

$A_{trap} = 131.8$ ft^2

$A_\Delta = 62.5$

18.03 8.66 18.03

$A^T_{max} = 195$ ft^2

195 x 33psf

$\left(\frac{6435/A}{0.5(825)}\right)^2 + \frac{48{,}511/S}{0.75(750)} \leq 1.0$

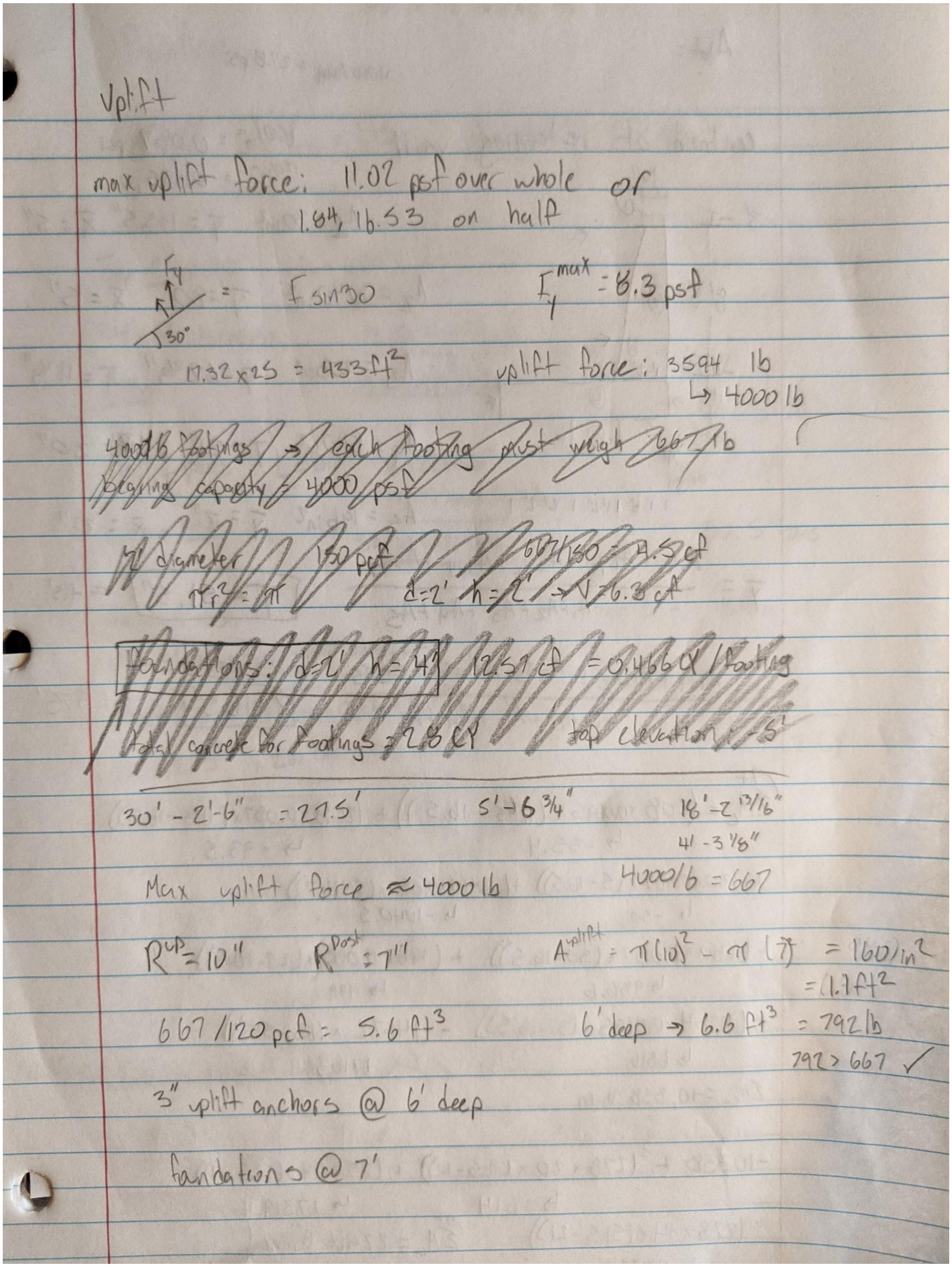
$d = 12'' \rightarrow A = 113$ $S = 1016 \rightarrow 0.1$

$d = 6'' \rightarrow A = 28.3$ $S = 63.5 \rightarrow 1.7$

$d = 8'' \rightarrow A = 50.2$ $S = 200 \rightarrow 0.53$

Posts = 8" diameter – min, max = 14"

Figure B6: Pavilion member sizing (2 of 2)



Uplift

max uplift force: 11.02 psf over whole or
1.84, 16.53 on half

$F_y = F \sin 30$ (30°) $F_y^{max} = 8.3$ psf

$17.32 \times 25 = 433 ft^2$ uplift force: 3594 lb
→ 4000 lb

4000lb footings → each footing must weigh 667 lb
bearing capacity = 4000 psf

$\frac{1}{2}$ diameter 150 pcf 667/150 = 4.5 cf
$\pi r^2 = \pi$ d=2' h=2' → V = 6.3 cf

Foundations: d=2' h=4' 12.57 cf = 0.466 CY / footing

total concrete for footings = 2.8 CY top elevation: -5'

30' - 2'-6" = 27.5' 5'-6 3/4" 18'-2 13/16"
4'-3 1/8"

Max uplift force ≈ 4000 lb 4000/6 = 667

$R^{cup} = 10"$ $R^{post} = 7"$ $A^{uplift} = \pi(10)^2 - \pi(7)^2 = 160 in^2$
$= 1.7 ft^2$

$667 / 120 pcf = 5.6 ft^3$ 6' deep → $6.6 ft^3$ = 792 lb
792 > 667 ✓

3" uplift anchors @ 6' deep

foundations @ 7'

Figure B7: Pavilion uplift calculations

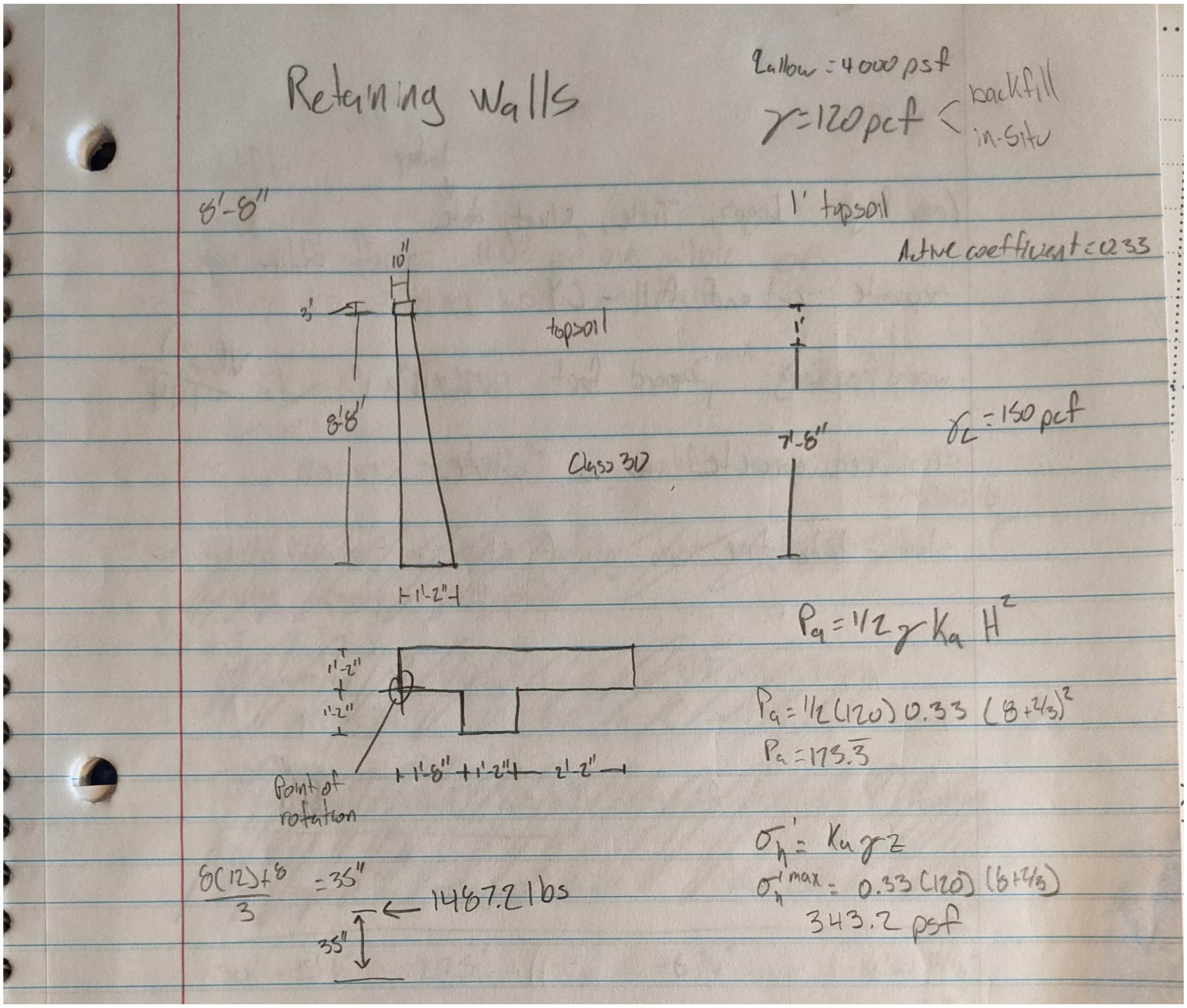


Figure B8: Rankine's active earth pressure calculations

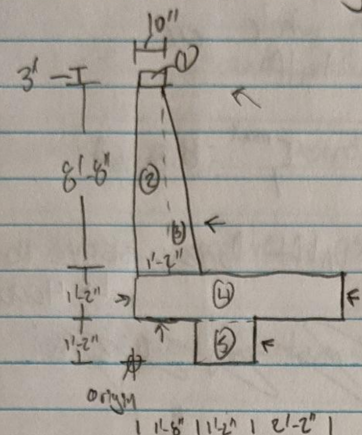
$A_{tot} =$

$4000/144 = 27.8$ psi

centroid of retaining wall

$130/12^3 = 0.087$ pci

$120/12^3 = 0.0695$ pci



$A_1 = 30\,in^2$ $\bar{y} = 133.5''$ $\bar{x} = 5''$

$A_2 = 1040\,in^2$ $\bar{y} = 80''$ $\bar{x} = 5''$

$A_3 = 208\,in^2$ $\bar{y} = 62\tfrac{2}{3}''$ $\bar{x} = 11\tfrac{1}{3}''$

$A_4 = 840\,in^2$ $\bar{y} = 21''$ $\bar{x} = 30''$

$A_5 = 196\,in^2$ $\bar{y} = 7''$ $\bar{x} = 27''$

$$\bar{y} = \frac{A_1y_1 + A_2y_2 + A_3y_3 + A_4y_4 + A_5y_5}{A_1 + A_2 + A_3 + A_4 + A_5} \qquad \boxed{\bar{y} = 51.5''} \approx 4.3'$$

$$\bar{x} = \frac{A_1x_1 + A_2x_2 + A_3x_3 + A_4x_4 + A_5x_5}{A_1 + A_2 + A_3 + A_4 + A_5} \qquad \boxed{\bar{x} = 16.5''} \approx 1.375'$$

$\overset{+}{\curvearrowleft}\Sigma M_c = (208 \times 0.0695 \times (12\tfrac{2}{3} - 16.5)) + (208 \times 0.087 \times (11\tfrac{1}{3} - 16.5))$

↳ -55.4 ↳ -93.5

$+ (30 \times 0.087 \times (5 - 16.5)) + (1040 \times 0.087 \times (5 - 16.7))$

↳ -30 ↳ -1040.5

$+ (840 \times 0.087 \times (30 - 16.5)) + (196 \times 0.087 \times (27 - 16.5))$

↳ 986.6 ↳ 179

$+ (4784 \times 0.0695 \times (37 - 16.5)) - (1487.2 \times (63 - 51.5))$

↳ 6816 17103

$\Sigma M_c = -10,338$ lb·in

$-10338 + (27.8 \times 20 \times (16.5 - 10)) + (27.8 \times 14 \times (51.5 - 7))$

↳ 3614 ↳ 17319.4

$+ (27.8 \times 14 \times (51.5 - 21))$ $\overset{+}{\curvearrowleft}\Sigma M_c = 22466$ lb·in

↳ 11870.6 <u>will not overturn</u>

Figure B9: Retaining wall overturning analysis

Appendix C: FTool Calculations

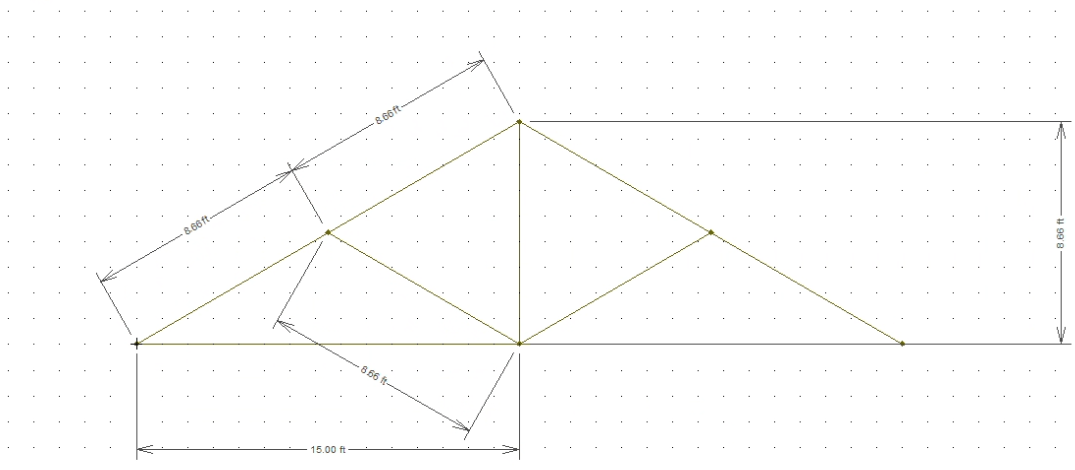


Figure C1: Truss Dimensions

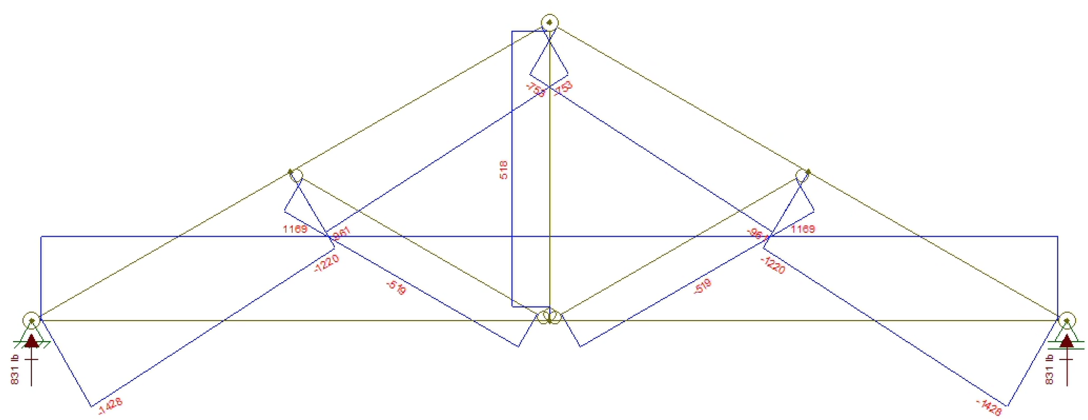


Figure C2: Truss Axial Forces

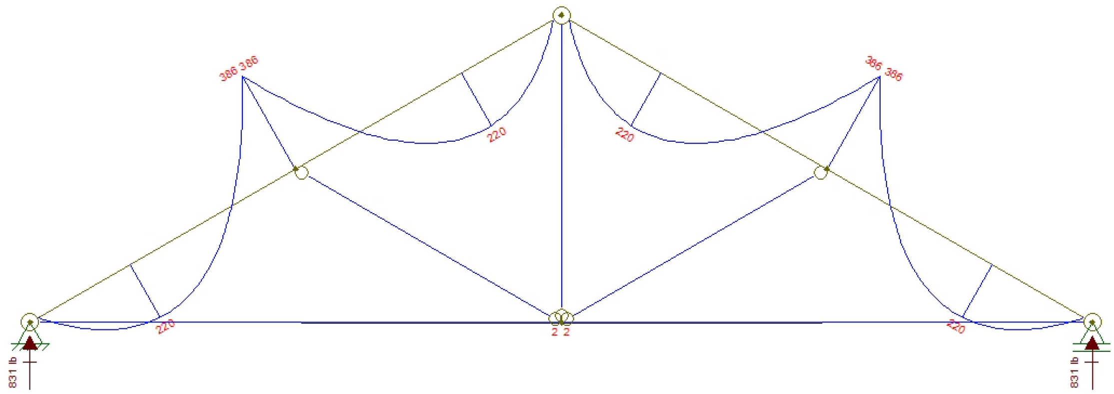


Figure C3: Truss Bending Moments

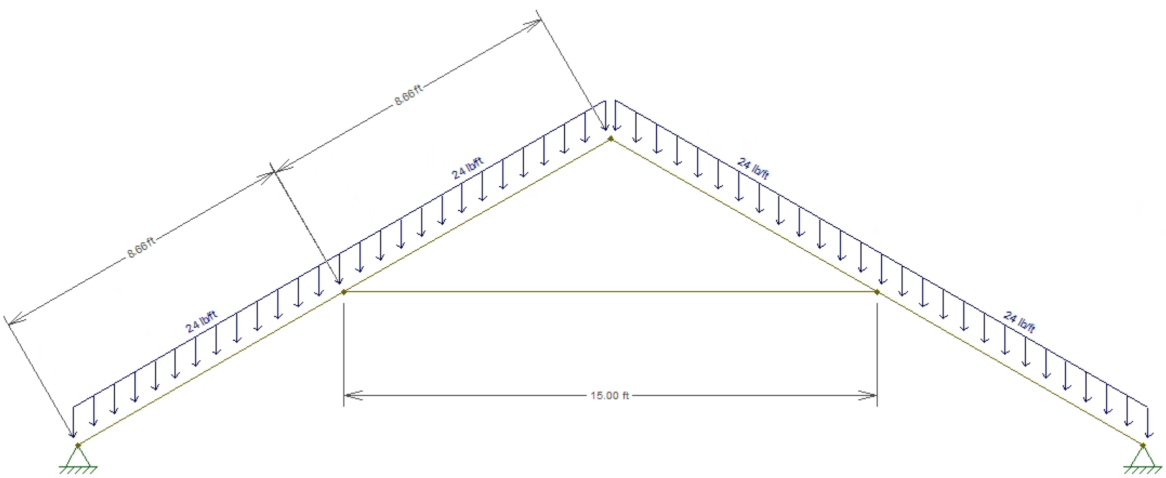


Figure C4: Rafter/Collar Dimensions

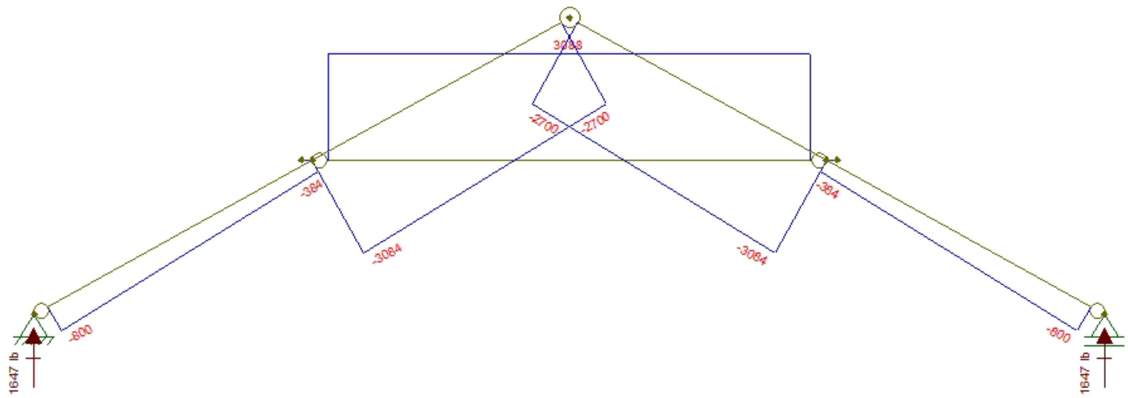


Figure C5: Rafter/Collar Axial Forces

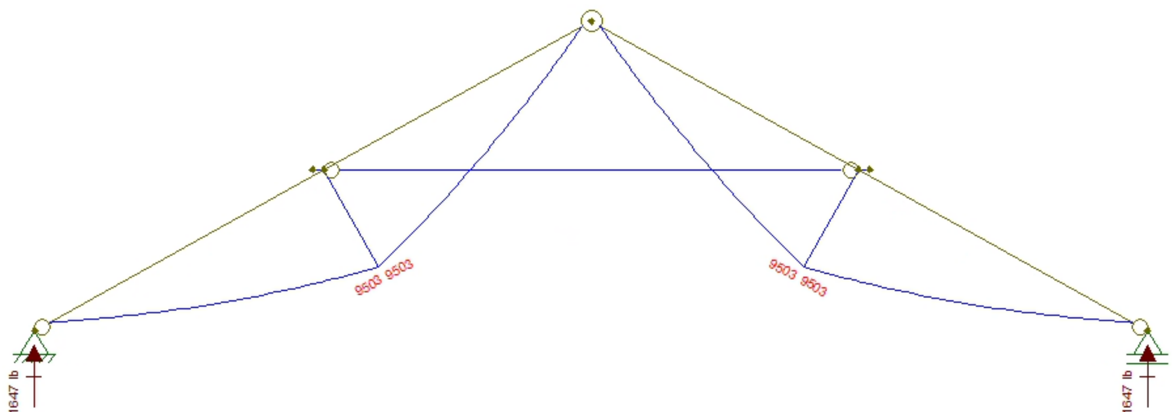


Figure C6: Rafter/Collar Bending Moments

Appendix D: Detailed Cost Estimates

Table D1: Final Cost Estimate

Component		Price
Pavilion		$ 46,560.29
Amphitheater		$ 316,832.12
Stage		$ 223,167.00
Staging Area		$ 8,873.60
Total		$ 595,433.01
Contingencies	10%	$ 59,543.30
Engineering and Administration	20%	$ 119,086.60
Grand Total		$ 774,062.91

Table D2: Pavilion Cost Estimate

		Quantity	Unit	Price/Unit	Total Price
Wood					
14" Diameter		1693.4	Board ft.	$ 8.20	$13,885.88
1x3		5.8	Board ft.	$ 8.20	$ 47.56
2x8		46	Board ft.	$ 8.20	$ 377.20
2x3		15	Board ft.	$ 8.20	$ 123.00
1x12		48	Board ft.	$ 8.20	$ 393.60
8x12		1109	Board ft.	$ 8.20	$ 9,093.80
12x14		969	Board ft.	$ 8.20	$ 7,945.80
4x8		115.5	Board ft.	$ 8.20	$ 947.10
8x20		988.6	Board ft.	$ 8.20	$ 8,106.52
3/4" plywood		433	Sq. ft.	$ 2.25	$ 974.25
Total					$41,894.71
Concrete					
Footings		2.8	CY	$ 367.00	$ 1,027.60
Other					
Waterproofing membrane		433	Sq. ft.	$ 4.72	$ 2,043.76
Shingles		433	Sq. ft.	$ 3.50	$ 1,515.50
Through Bolts		64	lb.	$ 1.23	$ 78.72
Total					$ 3,637.98
Grand Total					$46,560.29

Table D3: Amphitheater Cost Estimate

	Quantity	Unit	Price/Unit	Total Price
Wood				
6" piles	9124	Board ft.	$ 8.20	$ 74,816.80
Railroad Ties	840	Board ft.	$ 8.20	$ 6,888.00
Total	9964			$ 81,704.80
Reinforced concrete				
Retaining walls	355	CY	$ 367.00	$ 130,285.00
Stairs	12.6	CY	$ 367.00	$ 4,624.20
Total	367.6			$ 134,909.20
Earth				
Grade 30 crushed stone	1505	CY	$ 53.89	$ 81,104.45
Topsoil	624	CY	$ 18.00	$ 11,232.00
Total				$ 92,336.45
Other				
#8 rebar (for railroad ties)	729	lb.	$ 1.23	$ 896.67
Concrete (handicap area)	139.7	SY	$ 50.00	$ 6,985.00
Grand Total				$ 316,832.12

Table D4: Stage and Staging Area Cost Estimate

	Quantity	Unit	Price/Unit	Cost
PCC	110.92	CY	$ 80.00	$ 8,873.60
Gr. 30	110	CY	$ 53.89	$ 5,927.90
PCC (Reinforced)	222.22	CY	$ 977.59	$ 217,240.05
			Total	$ 232,041.55

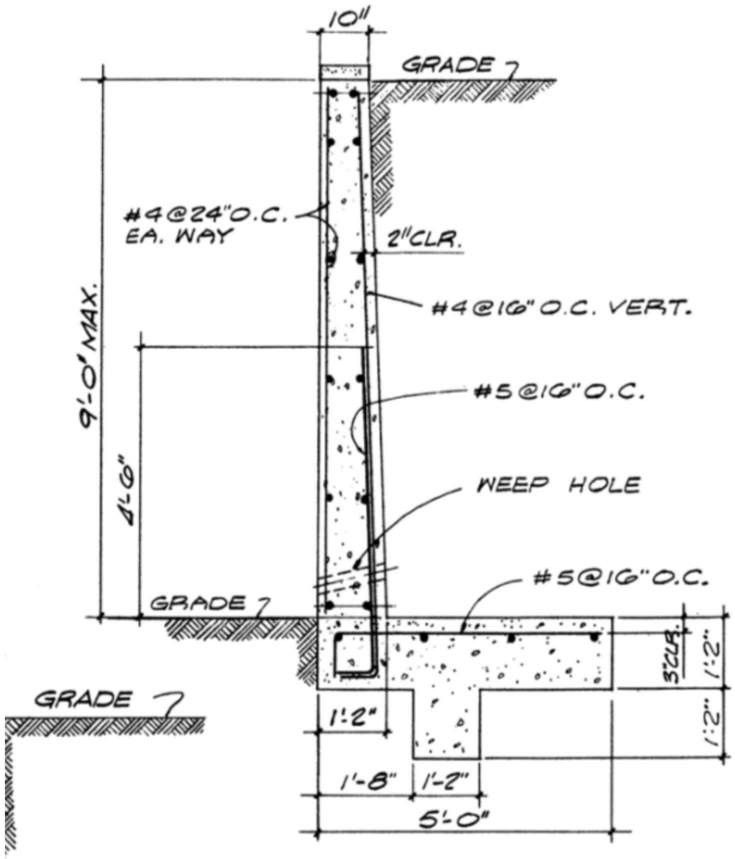
Appendix E: Sources

ASCE 7-16

2010 ADA Standards

American Wood Council NDS Supplement

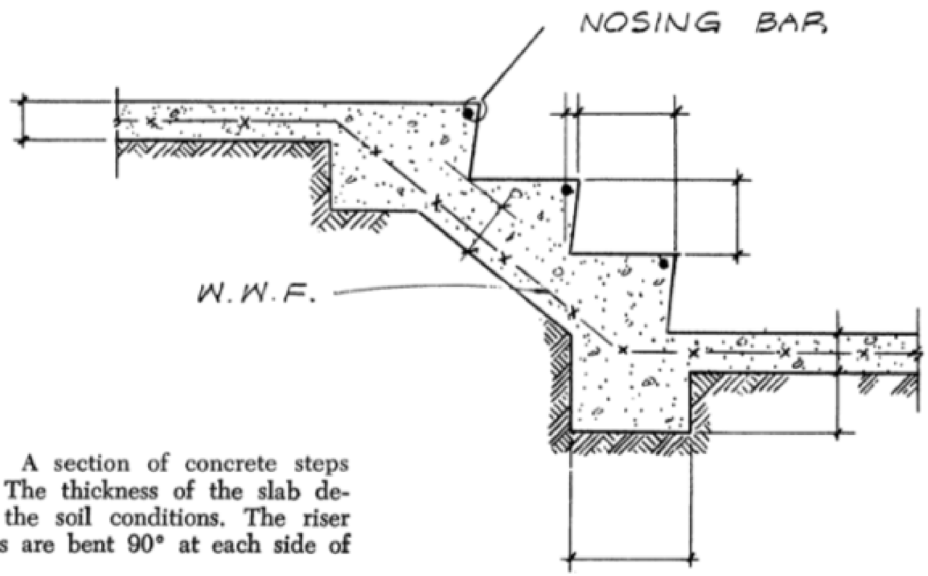
Iowa DOT April 2021 Bid Data



Detail 34(f). Stem height 9'0".

2"CLR.

Figure E1: Reference for reinforced concrete retaining walls



Detail 59. A section of concrete steps on grade. The thickness of the slab depends on the soil conditions. The riser nosing bars are bent 90° at each side of the step.

Figure E2: Reference used for amphitheater third-tier steps

SLABS ON GROUND*

For any slab on the ground, adequate preparation of subgrade for drainage and compaction is of prime importance. Dowelled expansion joints and weakened plane contraction joints should be carefully located, including expansion joints at all walls.

The design of slabs on the ground to distribute concentrated or uniform loads involves the elastic properties of the subsoil and the slab itself. An analysis can be made but is quite involved. Slabs for the very lightest occupancy should be not less than 4″ thick, and slabs for other occupancies may be empirically selected, the following being about minimum:—

Occupancy **	Min. Slab Thickness	Reinforcement ‡
Sub-slabs under other slabs	2″	None
Domestic or light commercial (loaded less than 100 psf)	4″	One layer 6 x 6 10/10 welded wire fabric, minimum for ideal conditions; 6 x 6 8/8 for average conditions.
Commercial—institutional—barns (loaded 100-200 psf)	5″	One layer 6 x 6 8/8 welded wire fabric or one layer 6 x 6 6/6.
Industrial (loaded not over 400-500 psf) and pavements for industrial plants, gas stations, and garages	6″	One layer 6 x 6 6/6 welded wire fabric or one layer 6 x 6 4/4.
Industrial (loaded 600–800 psf) and heavy pavements for industrial plants, gas stations, and garages	6″	Two layers 6 x 6 6/6 welded wire fabric or two layers 6 x 6 4/4
Industrial (loaded 1500 psf) †	7″	Two mats of bars (one top, one bottom), each of #4 bars @ 12″ c/c, each way
Industrial (loaded 2500 psf) †	8″	Two mats of bars (one top, one bottom), each of #5 bars @ 12″ c/c, each way
Industrial (loaded 3000–3500 psf) †	9″	Two mats of bars (one top, one bottom), each of #5 bars @ 8″ to 12″ c/c, each way

Figure 3E. Reference used for steel reinforcement of stage