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FINAL DELIVERABLE

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Community Partners	City of Manchester

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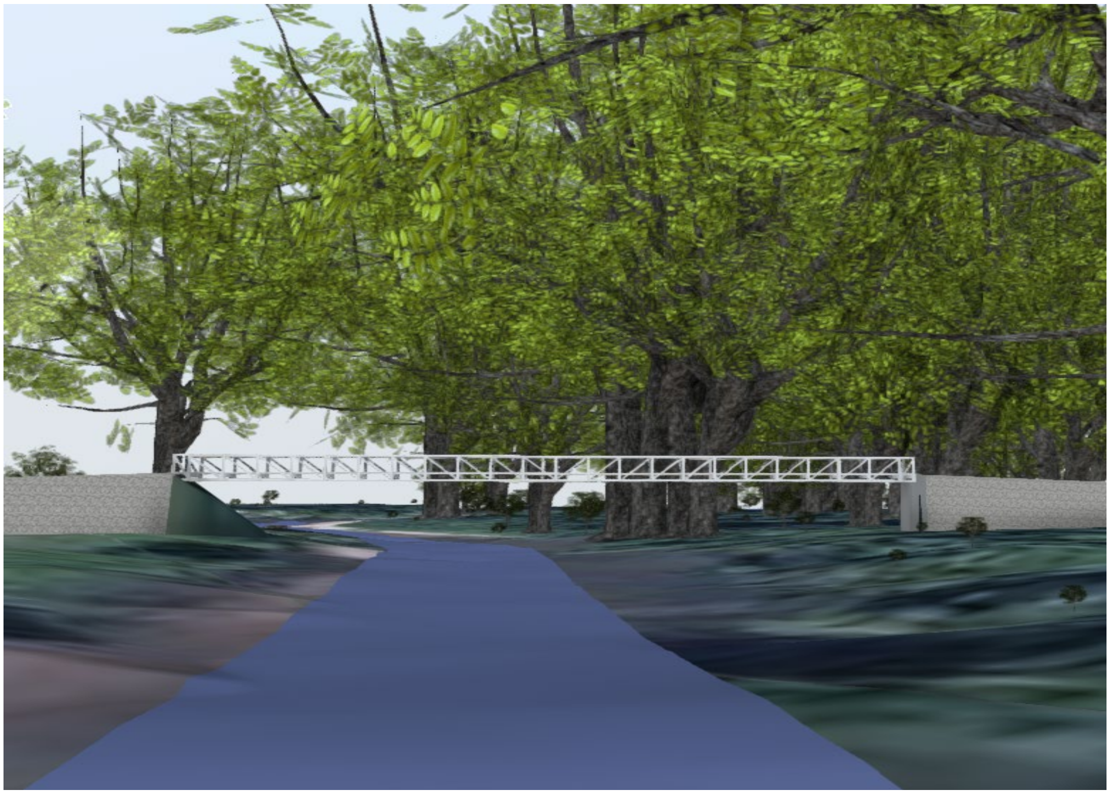
2020 Schram Park Redesign & Improvement

December 11, 2020

Tiger Hawk Engineering



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Section I: Executive Summary

The goal of this project was to revitalize the Schram Park area and provide an easier means of transportation between it and the City of Manchester. In order to increase the functionality and accessibility of the park itself, the parking lot area--which includes the lot's surface and layout, adjacent trail, boat ramp, and pond bank--had to be redesigned. The addition of storm sewer systems, a bleacher pad, and a set of limestone steps along the northern pond bank was required to mitigate erosion and ensure the park's new design is capable of withstanding storm and flood events. These improvements to the infrastructure are meant to refine the park's image, make it a more complete & more welcoming environment, and promote foot and bike traffic through the area. To further attract and accommodate this larger audience, the design of a quarter-mile long trail system with a pedestrian bridge over the Maquoketa River was used to connect the existing trail loop around the park's pond with the bike path that runs parallel to Brewer Street, northeast of the river. As the Maquoketa River is the project's largest geographical and environmental consideration, a detailed analysis of its hydrological conditions and behaviors was completed to assist in designing all these components for the project.

As mentioned before, the existing parking lot area does not handle heavy rain very well and becomes rutted during minor flooding events. Additionally, the lot does not have a specified layout for maneuvering or parking. Our team's design for the parking lot relies on a paved concrete or asphalt surface to redirect overland water flow and provide a smoother driving surface. The proposed lot's boundary is slightly larger than the existing one and the painted lines will provide the park with twenty-three parking stalls, one ADA accessible parking stall, and proper turning and parking conditions for the trucks, trailers and cars that frequent the lot. To assist in the removal of stormwater, the parking lot has been regraded to redirect all water entering the lot to either one of the two curb inlets located along the east and west side. The smaller of the sewers collects water from the east side of the parking lot and discharges it near the existing boat ramp. The western sewer has three drop-grate inlets downstream of the curb inlet that collect water from the field to the north of the pond's trail to prevent further erosion of the bank. In addition to the storm sewer, a set of stacked limestone steps--similar to those at Whitewater Park in downtown Manchester--was specified along the pond's bank in order to provide a good-looking, long-term solution to the geotechnical and aesthetic failure of the bank. To the east of these steps, the sandy soil condition underneath the bleachers has caused the area to become rutted and settle in an unbalanced manner. A concrete pad along the pond was designed to address this issue and improve the park's ability to handle crowds during large events like the ski shows.

Following the revitalization of Schram Park's functional area, the designed pedestrian bridge and connected trail system will open transportation options in the southern half of Manchester and attract families and visitors to the park. Several alternatives for the bridge's location were analyzed and the suggested location was selected based on its ease of construction, visibility, and accessibility. The bridge will be a single span of 184 feet with a 10-foot-wide, 6" concrete deck to accommodate two-way traffic and provide access for an emergency or maintenance vehicle. For the superstructure, a steel truss design was identified as the best option that met the criteria of cost effectiveness, aesthetics, and strength. As the bridge is being prefabricated and delivered to the site, concrete, stub abutments with spread footings and pile-support were required for the substructure. Due to the bridge's height requirement provided by the Maquoketa River's 100-year flood conditions, the deck and abutment height will reach over 20 feet above the existing ground. A retaining wall with proper safety features was added in the late stages of the design in order to successfully connect the bridge with the conjoining trail that's located at a much lower elevation. Granular backfill, a riprap base, subdrains, and geogrid are all included in the design of the retaining wall to ensure its longevity and strength. The final component of the park's design was the Type 3, quarter-mile paved trail that connects the park area with the rest of the city. On the east side of the river, the trail will wind through the existing trees and connect to the shared-use path and existing driveway along S. Brewer Street. To the west, the trail will run south down to the east side of the parking lot and connect into the existing trail loop around the pond. The design speed for the entire trail is 18 mph with a maximum grade of 5% at the retaining wall.

In order to work with the city's budgetary constraints and to build public support for the project, the implementation of the park's new design is recommended to be done in three phases. The first phase will involve the resurfacing of the existing trail on the northern pond bank and the construction of the stone step terrace, the storm sewer to the west of the parking lot, and the bleacher pad. This phase is anticipated to cost $785,500.00. Once this is completed, the second phase will include updating the parking lot's surface and layout, constructing the first section of the trail starting at the parking lot, and the installation of the eastern storm sewer. This phase is anticipated to cost $233,000.00. The third and primary phase of the project involves finishing the trail system, constructing the pedestrian bridge over the Maquoketa River, and the installation of the retaining walls. This phase is anticipated to cost $1,952,000.00, which brings the total cost of the project to an estimated $2,970,500.00.

Section II: Qualifications and Experiences

1. **Name of Organization**

   Tiger Hawk Engineering

2. **Organization Location and Contact Information**

   Christian Stekl – Project Manager
   Email: chritistian-stekl@uiowa.edu

3. **Organization and Design Team Description**

   Tiger Hawk Engineering consists of a team of engineering students from the University of Iowa whose specialties are in the structural, civil and environmental engineering practices. The project manager is Christian Stekl who specializes in the design of bridges and has experience with project management, on-site construction observation, and plan production. The rest of design team tasked to assist in the development of this project are Barrett Wise, Sam Landsteiner, Jun Li, and Tyler Tuttle.

Barrett Wise's focus is in structural engineering and he has experience with analyzing and designing highway bridges. He also has experience designing bridges with varying construction materials such as concrete, wood and steel. Jun Li's focus is in general civil engineering practice and he has experience with designing parking lots, roadways and trails under varying conditions and requirements. Sam Landsteiner's focus is in environmental engineering and he has experience with researching water quality issues and operating a surface water treatment plant. Tyler Tuttle's focus is in general civil practice and he has experience with public roadway construction, logistics, and quality control.

Section III: Design Services

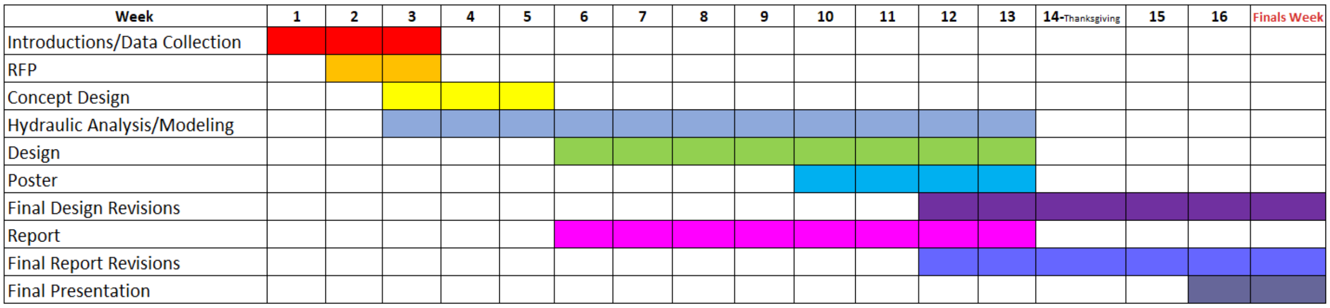
1. Project Scope

The goal of this project was to revitalize the Schram Park area and provide an easier means of transportation between it and the City of Manchester. A pedestrian bridge and trail system were designed to span over the Maquoketa River, ultimately connecting the current trail loop around the pond to the bike trail that runs parallel with Brewer Street to the north of the river. The parking lot was redesigned to increase the parking capacity and accessibility to the pavilion, trails and boat ramp, as well as to withstand rainfall and flood events that frequently wash out the current surface. Finally, erosion control measures were established at the northern pond bank and parking lot in order to mitigate creep and bank failure. A detailed analysis of the Maquoketa River's hydrological conditions and behaviors was completed to assist in the design of all these components of the project.

2. Work Plan

Tiger Hawk Engineering followed this Gantt Chart throughout the design process to ensure sufficient progress. The agenda and minutes from weekly team meetings were provided to the client in order to update them on problems or questions that had arisen, completed tasks, and the subsequent week's goals for each of the project's components.

Pedestrian Bridge - Manchester, Iowa



Section IV: Constraints, Challenges, and Impacts

1. Constraints

The primary constraint that impacted the overall design process was the geography of the park and its proximity to the Maquoketa River. In addition to Schram Park's inherent vulnerability to flooding, forecasting of peak discharges has also been consistently underestimated in the past (Grimley 2018). Due to the low elevation of Schram Park with respect to the rest of Manchester, the entire area has the tendency to become partially or fully submerged during flood events. These water levels played a key role in influencing a vast majority of the park's design elements such as the bridge deck's height, storm sewer inlet/outlet elevations, pipe sizing, and parking lot and trail surfaces.

The next constraint dealt with the aesthetic of the bridge and its visibility from Highway 20. One expectation that was made clear from the beginning of the project was that this park is meant to be a staple for the Manchester community and to draw attention from passers-by. The pedestrian bridge was selected to act as the "wow-factor" for the park and was the chief design element of the entire project.

2. Challenges

Tiger Hawk Engineering had to address a wide variety of challenges associated with the Schram Park project in order to ensure its success.

Challenges associated with the pedestrian bridge included poor soil quality, bank erosion, elevation gradients, and habitat loss/disruption. The banks surrounding the Maquoketa are composed of sandy soil which is prone to erosion and poses a threat to the structural integrity of the bridge and surrounding trails. The bridge and trail location and orientation were selected in order to minimize the elevation gradient between the east and west banks and maximize the ease of access.

Challenges involved in implementing erosion control on the oxbow to the north of the park are heavily dependent on the degree of erosion. More severe erosion will require more extreme intervention in an area that is not easily accessible. A flood mitigation strategy must be put in place that remains effective over a long period of time despite the existing erosion and the Maquoketa River's flood characteristics. The design must also be able to withstand the negative effects of a heavily saturated backfill in the inevitable event of an extended large-scale flood.

Working within the floodplain heavily influenced all components of the project throughout the design process. Hydraulic analysis and regard for the river's most extreme flooding conditions was used in the design of the bridge, trail, parking lot and erosion control measures.

Coordinating the grading elevations with the storm sewer systems was the primary challenge associated with the parking lot area of the project. The possible inlet locations were very limited due to the required trail and parking lot slopes in addition to the strict outlet location. As the original, single storm sewer on the west side of the parking lot was unable to meet velocity requirements and was projected to surcharge, a second storm sewer system on the east side and a parking lot regrade was necessary. Finally, a low spot in the pedestrian trail just south of the Brewer Street connection required a culvert to prevent flood waters from adversely affecting the trail's subgrade and surface.

3. Societal Impact

Implementation of the proposed design will not only expand the appeal and functionality of Schram Park but draw in public circulation that is vital to the currently stifled southern side of Manchester. Constructing the pedestrian bridge will increase foot and bicycle traffic in the greenspace by linking two trailheads. The redesign of the existing parking area to include pavement and a storm sewer system will also aid in increasing accessibility and functionality of Schram Park.

Design for the pedestrian bridge focused on attractive architecture without compromising infrastructure resilience. Implementation of aesthetically pleasing features into the bridge design will instill Manchester residents with a sense of pride in their community. Pairing bridge placement (to ensure visibility) with this aesthetic could also divert highway traffic to Schram Park and increase tourism.

Tiger Hawk Engineering expects some forms of ecosystem loss due to development of pedestrian bridge and erosion control strategies. All construction and displacement of wildlife has been conducted under the guidelines stated by the Iowa Department of Natural Resources (IDNR).

Section V: Alternative Solutions

1. Pedestrian Bridge

Tiger Hawk Engineering collaborated with the City of Manchester and Fehr Graham Engineering to produce alternatives for a bridge crossing that would best suit the city's needs. The two alternatives previously proposed by IIW and Fehr Graham were analyzed for drawbacks and a third alternative was established. Figure 1 shows the alternative bridge location that is being considered. The difference between the bank elevations was of primary concerns in finding the best location for the bridge. A large difference in the bank elevations would require a significant amount of reinforcing on one side to withstand a flood event--increasing the cost. Another important factor for the city was visibility and it was requested that the bridge will be illuminated at night and be visible from Highway 20. The final consideration in selecting the bridge's location was the accessibility by construction crews to the site.

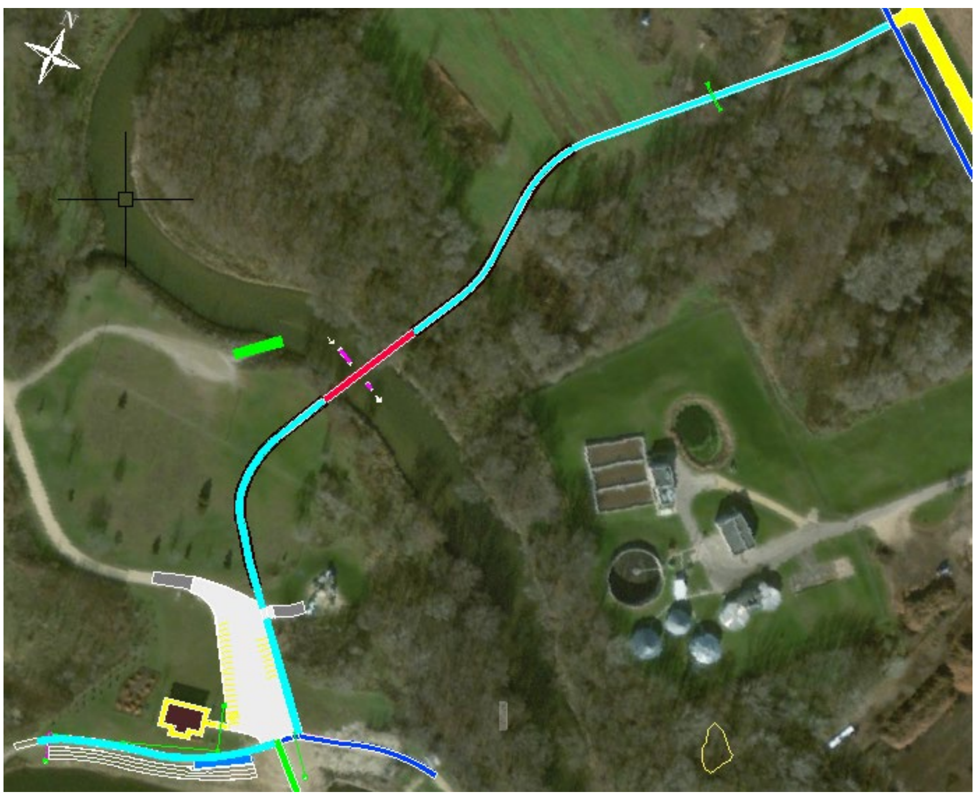


Figure 1: Aerial View of Schram Park Project

2. Parking Lot

The three different materials suggested for the parking lot and trail's surface are concrete, asphalt, and gravel. These materials will assist the city in choosing the surface that works within the budget and meets their expectations of the park. While gravel is an option, it is the least recommended option as the site's flood elevations and flow rates will eventually erode the surface, increasing maintenance costs and adversely affecting the lot's aesthetic and functionality.

3. Pond Erosion Control

Several alternatives were proposed to manage the bank loss on the north edge of the Schram Park Pond. These included a traditional retaining wall, a large block retaining wall, and natural steps like those at the Whitewater Park downtown. A retaining wall in this area was deemed unfeasible due to larger construction costs and safety considerations.

A drainage ditch system along the west side of the parking lot and along the northern pond trail was established as an alternative to the designed storm sewer system. These drainage ditches would be impacted less by the high flood levels that frequent the area in addition to having a lower installation and maintenance price.

Section VI: Final Design Details

The overall success of this project is defined by two overarching goals. First, the existing bike trail along Brewer St must be connected to Schram Park via a pedestrian bridge over the Maquoketa River. The second goal of the project is to enhance the functionality and aesthetic of Schram Park through the implementation of various erosion control measures, limiting overland flow, and improving the parking lot's layout. Several solutions were analyzed and presented by our team to determine the most appropriate design for the area. Design details for specific parts of our project are listed in this section.

1. Pedestrian Bridge

Superstructure

A steel truss bridge with a single span of 184 feet was chosen for the design of this project and is located just south of the northern boat ramp leading to the river. The truss design was chosen due to its strength capabilities, low construction costs, and simple, refined aesthetic. The loads for the bridge follow the AASHTO LRFD and Iowa DOT standards. Truss members were chosen to be HSS members as shown in Figure 3. The truss was designed to accommodate a 90 psf pedestrian load applied across the entire bridge deck as well as a 20 psf wind force applied vertically at 2.5 feet from the edge of the deck. The floor system consists of a doubly reinforced, 10-foot-wide by 6-inch-thick concrete slab poured over a trapezoidal metal deck and is supported by W14x43 steel floor beams. This was calculated by assuming a single ten-thousand-pound load at the center of the bridge that represents a maintenance vehicle as specified by the Iowa DOT. The lateral bracing is made of HSS members to resist a 30 psf wind load that was applied to the bridge and was designed as if it were enclosed. Weathering the steel members is recommended to provide corrosion resistance that is both cost effective and adds to the overall aesthetic of the bridge. Lastly, path lights on the bridge deck and streetlights on the abutments were included to keep the area visible at night.

<u>Abutments</u>

The abutments were designed using the AASHTO LRFD methods which are presented in the IADOT Bridge Design Manual (BDM). The bearing capacity calculations were based on methods presented in *Foundation Analysis and Design* by Joseph E. Bowles. As the designed bridge is intended to be prefabricated and delivered to the site, integral abutments are not feasible. To account for this, stub abutments with a spread footing supported by piles were selected. These piles will be essential in limiting settlement due to poor soil conditions in the area in addition to transferring the loads from the bridge to the ground. The abutments will be constructed of concrete and reach approximately 20 feet above the existing ground with an overall height of roughly 26 feet.

Since the Maquoketa River is considered a navigable waterway, a minimum freeboard requirement was necessary. New bridges and pedestrian bridges require a freeboard of 3 feet from the low point on the superstructure. However, with proper documentation, the freeboard requirement can be lowered if it can withstand the effects of ice & horizontal loading from the stream and uplift forces from a 100-year flood event. A freeboard of 3.5 feet was selected for the pedestrian bridge.

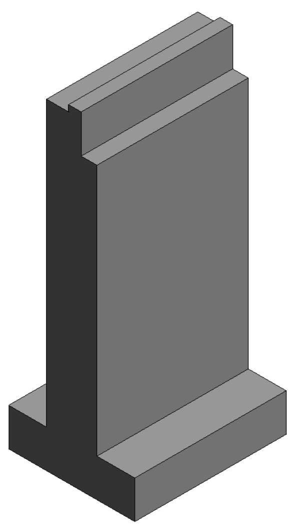


Figure 2: 3D View of Abutment

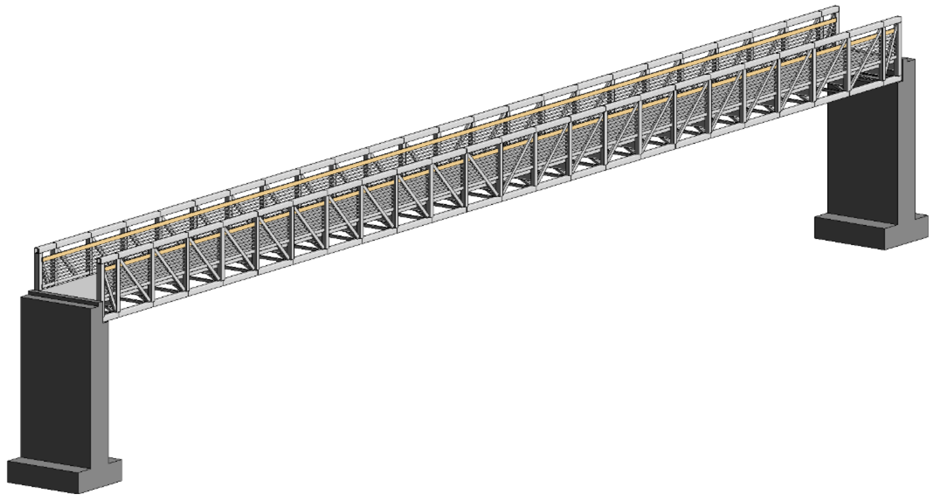


Figure 3: 3D Model of Bridge with Abutment

2. Pedestrian Trail

<u>Alignments</u>

The new trail near the pond follows the existing trail alignment, but ties into the proposed parking lot, bleacher pad, and existing trail near the boat ramp. The addition of a paved surface in this area is designed to improve drainage of storm water and to minimize the amount of overland flow which is currently causing erosion of the pond bank.

The horizontal alignment of the pedestrian trail was designed to connect the existing trail around Schram Park's pond, the proposed bridge, and the bike trail parallel to S. Brewer Street. The trail is composed of two parts (east and west) which are separated by the pedestrian bridge. The total length of proposed trail is 1542.56 feet, and the layout of the trail is shown in Appendix B.1. The trail was identified as Type 3 based on the Iowa DOT Design Manual Chapter 12B-2 and is intended to be used for recreation and fitness purposes. The design speed is 18 mph, and the associated minimum radius of the horizontal alignment is 60 feet. Based on the horizontal alignment data tables in Appendix B.2 to B.3, the designed trail meets all the requirements.

The vertical alignment of the pedestrian trail was designed to follow the existing site and proposed bridge elevations. The Iowa DOT Design Manual Chapter 12B-2 and ADA Handbook were used as the primary design aids. Balancing the cut and fill was difficult as the bridge elevation is much higher than the current ground level. The forward and backward grade of the vertical alignments were maintained at 5% or lower to provide adequate traversing conditions for people with disabilities. Based on the Iowa DOT Design Manual Chapter 12B-2, the vertical curve length and vertical curvature (K-value) can be any length given that the grade is smaller than 5%. Based on the vertical alignment data tables in Appendix B.4 and B.5, the designed trail meets the requirements.

Cross Sections

The cross section of the trail consists of a 10-feet wide by 6-inch-deep paved section with a 1-foot sub-base at a cross slope as 1.5% from the left to right edge. The shoulder on both sides of the trail will be 2 feet wide and 6 inches deep with a 16% cross slope. The left (west) shoulder of the trail along the east side of the parking lot was removed to allow for easier access and a better flow of foot traffic. Either concrete or asphalt is suggested for the trail's surface with compressed soil being used for the subgrade. The trail's shoulder will be composed of compressed soil. The cross section for the standard trail segment is shown in Appendix B.9 and the cross section for the atypical trail segment along the parking lot is shown in Appendix B.8.

The retaining wall cross section show in Appendix B.10 was used in Civil 3D. The retaining wall will be made of blocks as seen in figure 4 below. Figure 4 shows all the components of the of the retaining wall.

Cross Section Views

Cross-section views were completed using Civil 3D and can be found in the sheets of the drawing sheet set.

Material Volume Tables

The material volume tables were compiled using the built-in function of the Civil 3D and include the material takeoffs for the pavement, sub-base, and retaining wall of the trail as shown in Appendix B.11 to B.22. In calculating the net cut and fill values, it was assumed that the quality of cut soil is high enough to be used as fill soil. Since the bridge elevation is much higher than the ground elevation and the maximum grade was required to be 5%, the fill volume is much higher than the cut volume. This means the net value of total cut and fill—excluding the retaining wall's granular backfill--was found to be 83 cubic yards of cut.

Retaining Wall

A retaining wall was required at the bridge-trail connection due to the final elevation of the bridge deck. The deck elevation will be 934.5 feet and the existing ground elevation is approximately 914 feet. The minimum height of the retaining wall at its base (on both sides of the river) will be 1 foot and the wall will reach just over 20 feet in height above ground at its tallest point. As the vertical drop off exceeds three feet, the trail section on the retaining wall will be lined with a safety rail as shown in Appendix B.6.

The retaining wall units are the Keystone Standard Unit III. These are dimensioned at 18" x 8" x 18" and weigh between 80-100 pounds each. A granular material will be used as backfill between the blocks and will be compacted to proper density. This material will additionally provide a solid base for the trail to be paved on. Subdrains are required to avoid a buildup of pore pressure from water that is retained in the granular material. The wall will have approximately 2 feet of cover and be placed on a compacted gravel base. Geogrid which has been recommended to give the wall its strength. The specified geogrid is Miragrid (R) 8XT and all relevant information and calculations can be found in Appendix B.7.

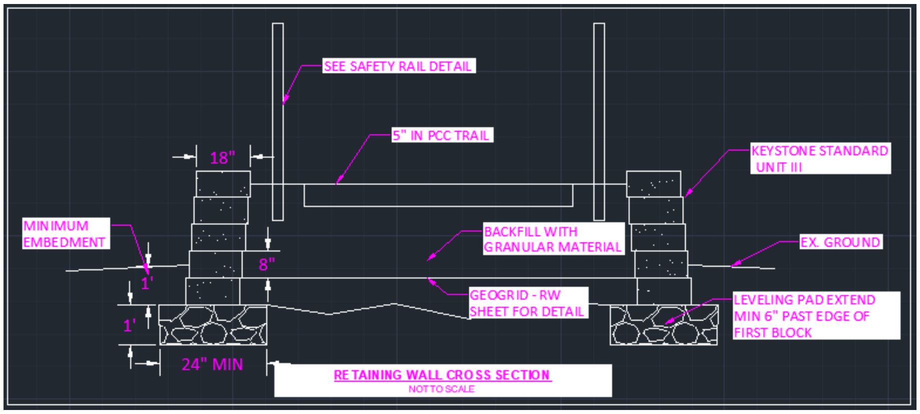


Figure 4: Retaining Wall Cross Section

3. Parking Lot

Layout

The number of parking stalls on the left side of the parking lot was designed to be 17, and the number of parking stalls on the right side was 7. Each stall has a length of 18 feet and width of 9 feet. Based on the ADA Standards for parking, one accessible parking space was designed at the bottom of the left side of the parking lot near the existing structure with 18 feet long, 9 feet wide, and 8 feet access aisle between the nearest parking stall. Based on the clients' requirement, the new design should allow a pickup truck with a boat trailer to do U-turn within the parking lot and backup to the pond; therefore, the new parking lot need to be widen based on the existing one to meet the requirement. A swept path analysis was conducted by the built-in function of the Civil 3D with the layout of the parking lot as shown in Appendix C.1.

Cross Section

The curb was designed as 6-inch standard curb. The parking lot pavement includes three options a 6-inch PCC option, a 7.5-inch HMA option with 6-inch standard curb and gutter. Both options will require 18-inches subgrade prep.

4. Maquoketa River

Hydrologic Information

Peak-flows statistics were collected from the USGS stream gauge (via StreamStats) just south of Schram Park and are shown in Appendix D.1 (U.S. Geological Survey 2016). A

1/3rd Arc-Second DEM of Delaware Country was sourced from the Iowa Geodata catalogue to accurately simulate Schram Park terrain (Iowa Geodata 2017).

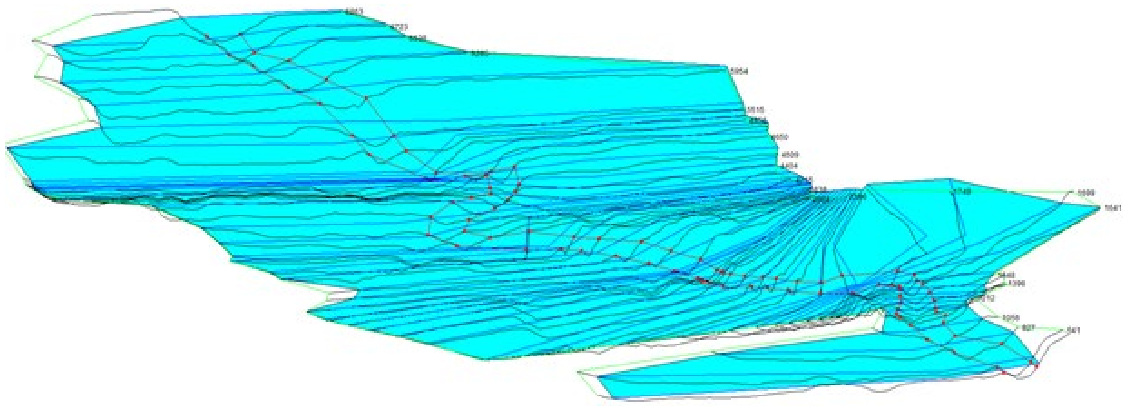


Figure 5: 3-D Rendering of HEC-RAS Schram Park Model (100-year Flood Inundation)

A 1-D backflow model of the Maquoketa River and Schram Park was created utilizing HEC-RAS, shown above in Figure 5. 1-D backflow models utilize the energy equation to generate inundation and velocity mapping (Hydrologic Engineering Center 2016). The extent of the model includes all relevant design sites encompassed by the scope of the design project. To ensure accuracy, the model was calibrated using stage/elevation data collected during a record flood event that devastated Manchester in July 2010 (Grimley 2018). The model reproduces stage and elevation data documented by multiple sources (Grimley 2018, Eash 2012). Following completion of the model without design infrastructure, the flood design parameters used to determine bridge height and trail gradings were observed as shown in Table 1.

Table 1: Calibrated Model Parameters for Relevant Design Floods

Event	Model Outputs			
	Stage (ft)	Elevation (ft)	Discharge (ft3/s)	Velocity (at bridge site) (ft/s)
StreamStats 100-yr Event	24	927	24,500	3.25
July 2010 Event	24.5	927.5	26,600	3.7

Hydraulic Design

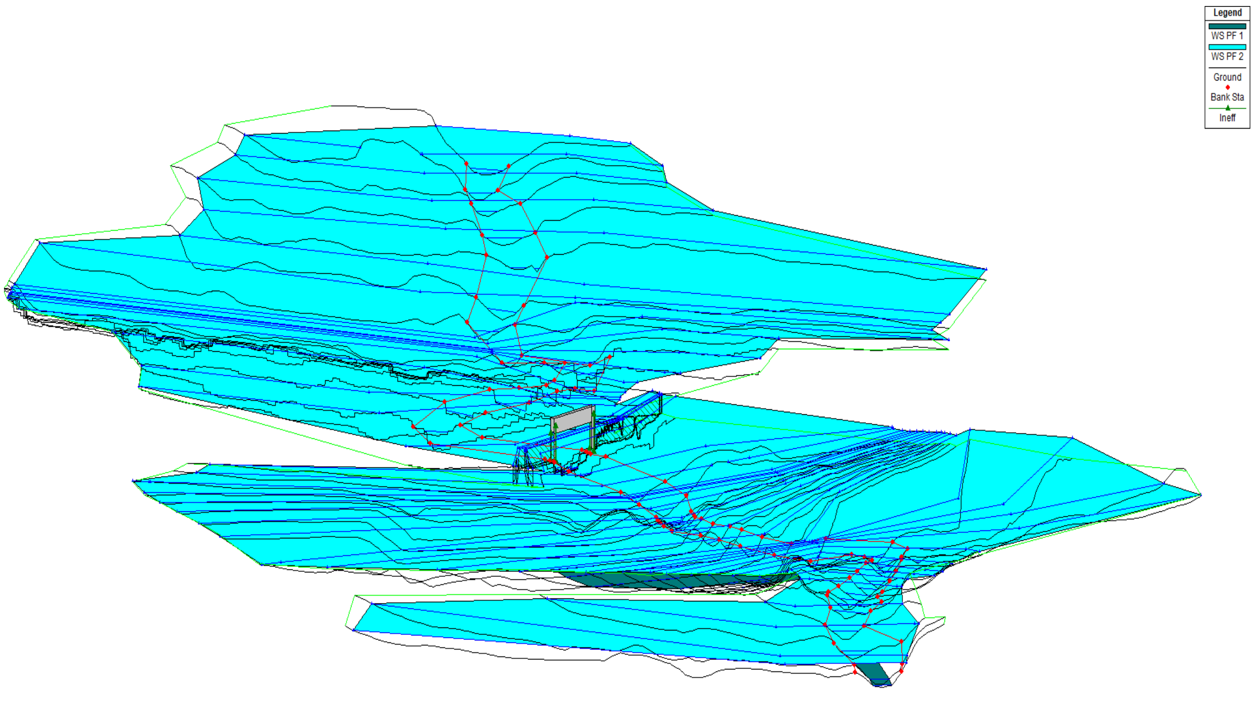


Figure 6: 3-D Rendering of HEC-RAS Model with Bridge (100-year Flood Event)

The final bridge design was implemented into the 1-D HEC-RAS model at the proposed location, as shown above in Figure 6. The retaining walls responsible for connecting the trail to the bridge were also implemented into the model to adequately simulate their effect on simulation results. The modeling extent of the flood plain around the bridge site was reduced to adequately simulate expansion and contraction of the flow through the structure. Due to this limitation specific to 1-D models, simulated inundation and velocity results are more extreme than would be observed after implementation.

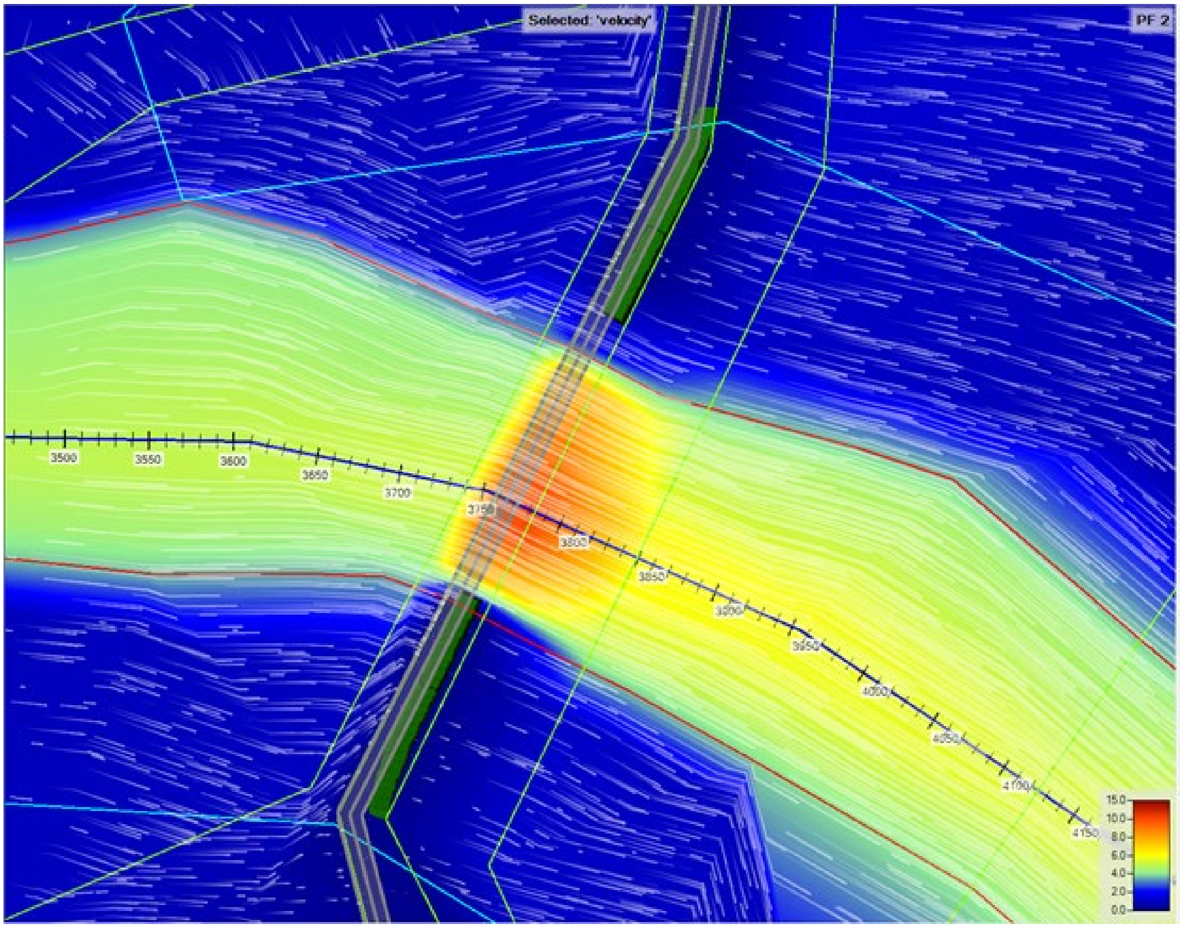


Figure 7: Velocity Mapping at Bridge (100-year Flood Event)

Simulation results supplied a detailed mapping of the velocity gradient around the structure, shown above in Figure 7. Because the bridge site is located downstream of a natural oxbow, velocity increases through the bridge opening until it experiences a sudden decrease at the pond spillway. Maximum velocity through the bridge does not surpass 8.4 ft/s. Scour protection is implemented to shield the abutments from erosion, shown in Appendix D.14.

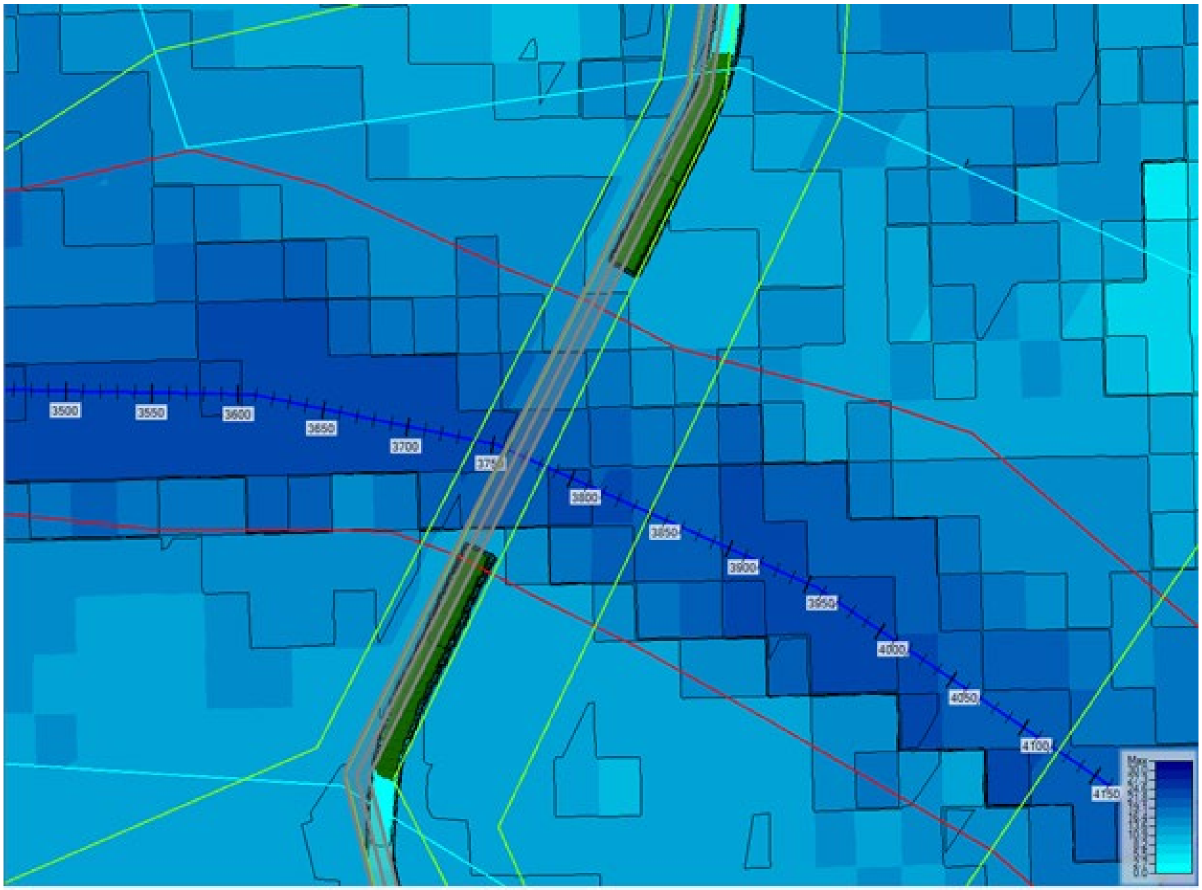


Figure 8: Inundation Mapping 100-yr design flood at the bridge structure

Simulation results included inundation mapping for the bridge site, as shown above in Figure 8. The maximum water surface elevation for the 100-yr design flood event was 928.22 feet. The simulation results confirm that the lower chord of the bridge remains more than 3 feet above the water surface elevation.

5. Erosion Control

Parking Lot Drainage System

Catchment areas and discharge points were established using Autodesk Civil 3D software as shown in Figure 9. Runoff coefficients were calculated based on the catchment area's ground cover proportions with the use of data from SUDAS Table 2B-4.01 (Appendix E.2). An average rainfall intensity of 0.1533 ft/s was found for a 1-hour, 5-year storm event using SUDAS Table 2B-2.04 (Appendix E.1). The overland water flow values (ft3/s) for the storm sewer systems were calculated using the Rational Method in SUDAS Eqn. 2B-4.01.

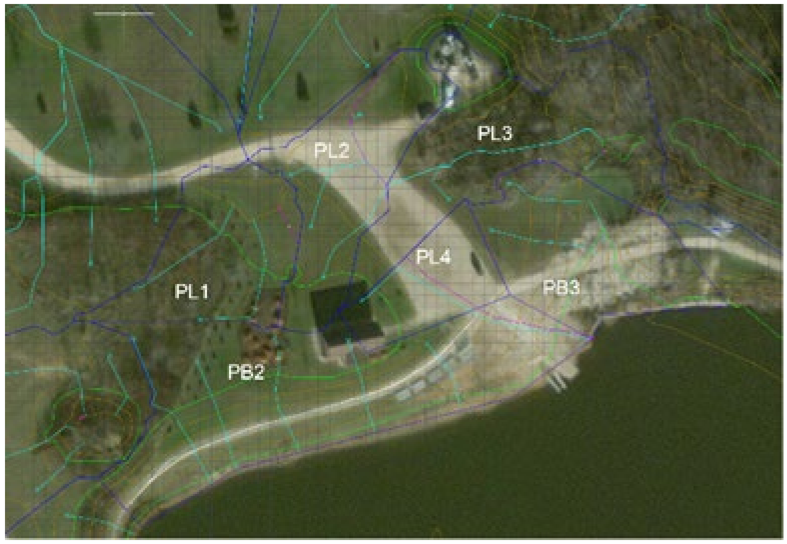


Figure 9: Schram Park Catchment Areas & Overland Flow Paths

Three storm sewer systems were designed to accommodate the total stormwater flow as shown in Appendix E.3-5. The inlets were located and sized using these flow values in combination with grading requirements. Inlet and outlet conditions were designed according to SUDAS Section 2C-3. and Section 2D-3, respectively. All structure and pipe materials are constructed using 12" thick PCC in accordance with the SUDAS Specifications Section 4020.

The first storm sewer system is located on the west side of the parking lot and is composed of one curb inlet just upstream of the ADA parking spots, three drop grate field inlets, (5) 12" circular pipes, and a flared end section outfall. The highest rim elevation is at 917.59' with a pipe invert of 914.59' at the curb intake. The outfall invert is 385' downstream of the first inlet and at an elevation of 910.20' which brings the average slope through the system to -1.14%. The curb intake is a Curb Only SW-507 and the three field inlets were selected as Area Intakes SW-512.

The second storm sewer system is located on the east side of the parking lot and consists of one curb inlet in the southeast corner, (1) 12" circular pipe, and a flared end section outfall. The intake's rim elevation is at 915.37' with a pipe invert at 912.00' and an outlet invert at 910.20'. The total pipe length is 91', bringing the slope through the system to -1.65%. The curb intake is a Curb Only SW-507.

The final storm sewer system is a drainage pipe that runs underneath the pedestrian trail at a low point just south of the S. Brewer Street connection. The network consists of two concrete flared end sections on each side of the trail with (1) 36' long, 12" circular, concrete pipe. The start invert is at an elevation of 915.00' with an end invert at 914.00', bringing the slope of the pipe to -2.78%.

SUDAS Section 2D-1 details the storm sewer's physical requirements. A ground cover minimum of 1.5' and a maximum of 7' is suggested to ensure the longevity of the pipes. A minimum drop of 0.1' between pipe inverts connected to the same structure is required. The design manual recommends a minimum velocity of 3 ft/s for cleaning and a maximum velocity of 15 ft/s. A 15" pipe diameter is recommended, but due to the projected conditions and budgetary constraints, the pipes have been selected as 12". A gravity analysis was completed using Civil 3D to ensure each of the storm sewer pipes met these requirements as shown in Appendix E.6-17.

<u>Natural Stone Steps</u>

Natural stone steps were selected to fix the current bank failure along the north side of the pond and to prevent further erosion. These stones are sourced from the River City Quarry just south of Manchester and will match the stone steps that are in Whitewater Park downtown. The stones are approximately 2' x 4' x 4' in size. A cross section view of the stone steps is shown in Figure 10. The voids are to be filled with grout to create a watertight bond between blocks. The elevation of last stone on the east side of the terrace will be flush with the adjacent bleacher pad to create a seamless transition from the bleachers down to the water's edge.

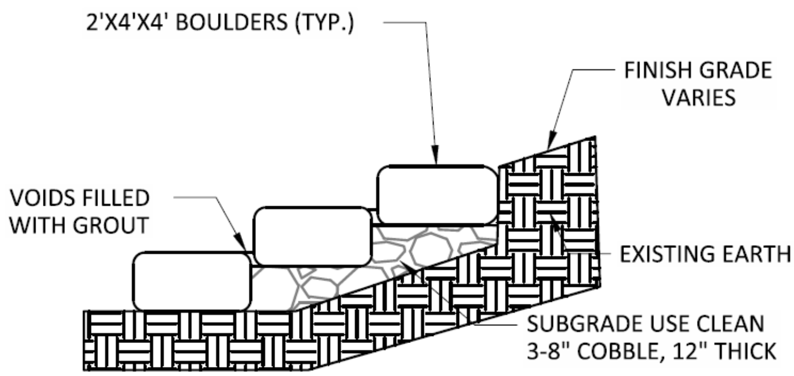


Figure 10: Natural Stone Step Cross Section

Section VII: Engineer’s Cost Estimate

The price per unit values were derived from Iowa DOT lettings for the month of November 2020. Some values were also taken from bid tabs for projects in the city of Manchester for the year 2020. All values are current, and no adjustments were made to match inflation of construction costs.

Unit Name	Unit Description
CY	Cubic Yard
EA	Each
SF	Square Foot
SY	Square Yard
AC	Acre
LF	Linear Foot
TON	Ton
LS	Lump Sum

Figure 11: Material Unit Legend

Phase 1 consists of adding the storm sewer to the west of the pond, replacing the existing gravel trail on the north pond bank with a paved surface, and adding a concrete pad for the bleachers. To mitigate the loss of bank on the north edge of the pond, natural stone steps – matching those at Whitewater Park – are proposed. This will add additional seating during events at the pond as well as eliminate any further loss of the bank.

Phase 2 consists of paving the parking lot and some additional trail along the eastern edge. Additional storm sewer will be installed on the east side of the parking lot to drain the new surface. Parking spaces will be painted as well as including a handicap stall that will be placed near the existing structure.

Phase 3 involves the installation of the pedestrian bridge over the Maquoketa River, a retaining wall leading up to the new bridge, and a trail connection to Brewer St on the east side of the river.

ESTIMATED PROJECT COST PHASE 1 - POND AREA			
Item No.	**Item**	**TOTAL**	
1	Erosion control Measures	$	10,000.00
2	Borrow	$	360.00
3	Rip Rap/Revetmetn Class E	$	52.00
4	Granular backfill	$	6,480.00
5	Natural Stone	$	544,000.00
6	Rectangular Area Intake	$	7,500.00
7	Seeding and Fertilizing (Urban)	$	200.00
8	5in PCC Trail	$	12,960.00
9	5in PCC Pad	$	420.00
10	Storm Sewer, 12 in	$	18,540.00
11	Pipe Apron, 12 in	$	600.00
12	Footing for Concrete Apron	$	600.00
13	Special Backfill for Trail		1,500.00
14	Mobilization	$	25,000.00
	Sub Total	$	628,212.00
	Engineering - 10%	$	62,822.00
	Contingency - 15%	$	94,232.00
	Grand Total	$	785,500.00

Figure 12: Phase 1 Cost Estimation

ESTIMATED PROJECT COST PHASE 2 - PARKING LOT		
Item No.	**Item**	**Total**
1	Storm Sewer, 12 in	$ 8,400.00
2	Pipe Apron, 12 in	$ 600.00
3	Footing for Concrete Apron	$ 600.00
4	Removal of Sidewalk	$ 220.00
5	Removal of Trail	$ 110.00
6	Sidewalk, 5in PCC Replacment	$ 880.00
7	Detectable Warnings	$ 480.00
8	Painted Pavement Markings	$ 1,572.00
9	SW-501 Intake with Grate	$ 3,000.00
10	SW-508 Intake	$ 5,200.00
11	Rip Rap/Revetment Class E	$ 52.00
12	Removal of Fence	$ 1,000.00
13	Bollard and Sign	$ 1,000.00
14	Seeding and Fertilizing (Urban)	$ 200.00
15	5 in PCC Trail	$ 7,410.00
16	Special Backfill for Trail	$ 1,950.00
17	Erosion Control Measures	$ 10,000.00
18	Class 10 Excavation	$ 2,080.00
19	Mobilization	$ 15,000.00
HMA Paving Option		
19	PCC Curb and Gutter, 30", 7.5 " Thick	$ 17,800.00
20	PCC 4 in Sloped Curb 30", 7.5" Thick	$ 1,530.00
21	Pavement, HMA, 7.5"	$ 59,010.00
22	Asphalt Binder PG 58-28S Standard Traffic- 5%	$ 20,210.00
PCC Paving Option		
23	Pavement, PCC, 6"	$ 126,500.00
Gravel Surface Option		
24	Gravel for Parking Lot	$ 6,384.00
		Grand Total
	PCC Option	$ 233,000.00

Figure 13: Phase 2 Cost Estimation

ESTIMATED PROJECT COST PHASE 3 - BRIDGE/RETAINING WALL			
Item No.	**Item**	**Total**	
1	Storm sewer, 12 in	$	2,160.00
2	Pipe apron, 12 in	$	1,200.00
3	Segmental block retaining wall	$	480,000.00
4	Granular backfill	$	153,200.00
5	Prefab bridge 180x10	$	274,000.00
6	Structural concrete	$	17,340.00
7	Bridge Installation	$	200,000.00
8	Abutments	$	120,000.00
9	Safety rail	$	128,000.00
10	HP 10x42	$	32,400.00
11	Clearing and Grubbing	$	600.00
12	Subdrain & Outlet	$	5,000.00
13	Class 10 Excavation	$	656.00
14	Seeding and fertilizing (Urban)	$	500.00
15	5in PCC trail	$	45,000.00
16	Mobilization	$	80,000.00
17	Erosion control measures	$	10,000.00
18	Rip Rap/Hard Armor	$	11,360.00
	Sub Total	$	1,561,416.00
	Engineering	$	156,141.60
	Contingency	$	234,212.40
	Grand Total	$	1,952,000.00

Figure 14: Phase 3 Cost Estimation

Phase 1	$	785,500.00
Pahse 2	$	233,000.00
Phase 3	$	1,952,000.00
Total Cost	$	2,970,500.00

Figure 15: Total Cost Estimate

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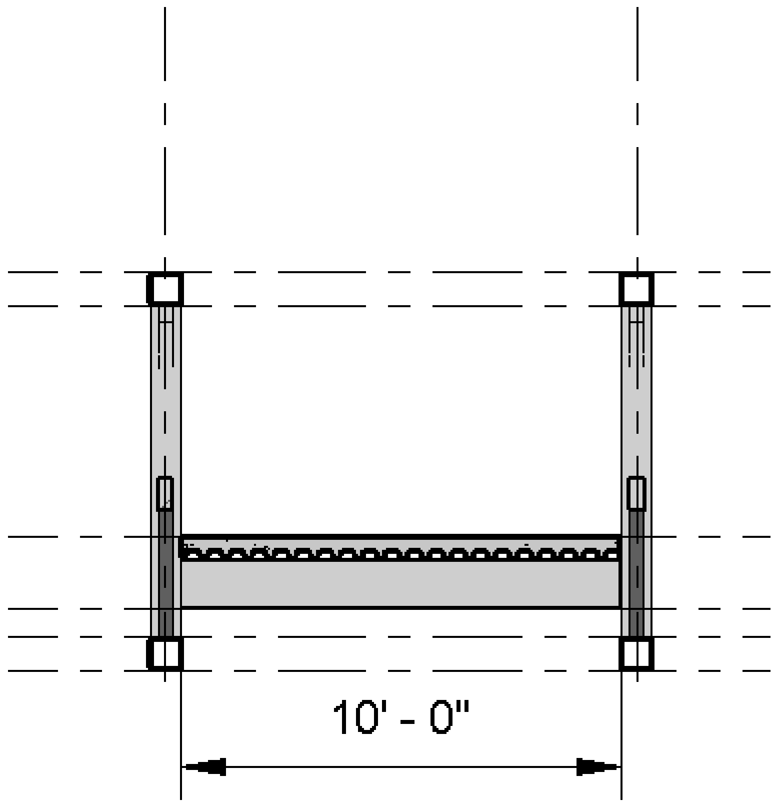
Appendices

Appendix A: Pedestrian Bridge

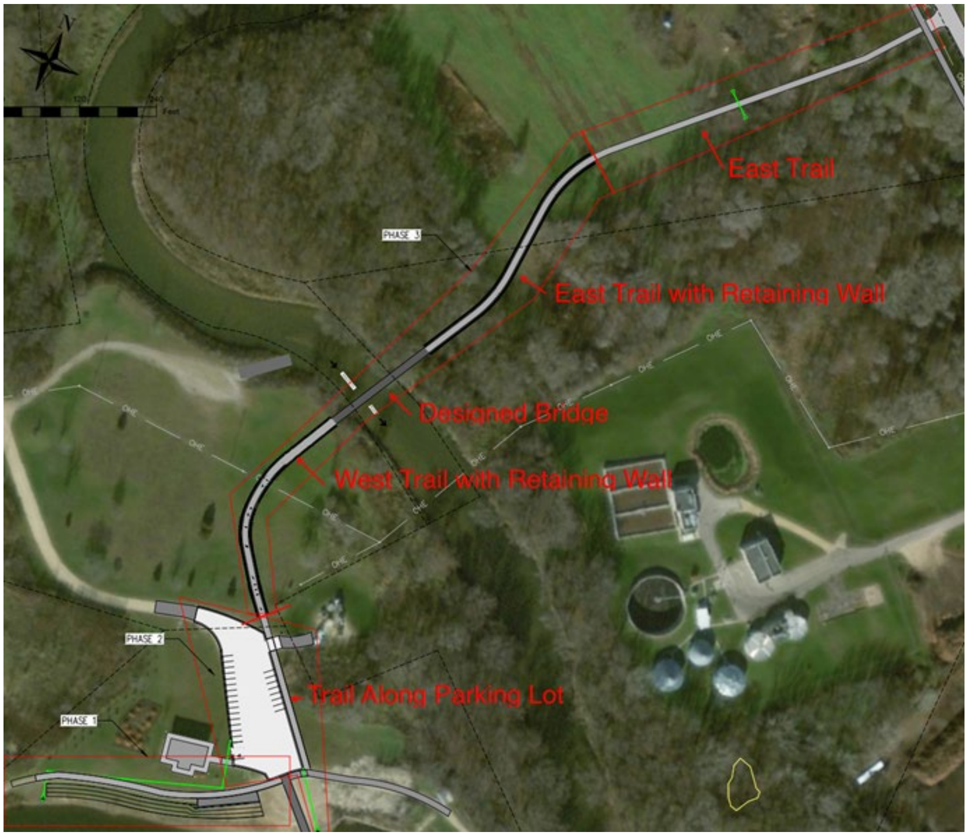


Appendix A.1: Cross Section of Bridge Superstructure

Member Schedule	
Truss members	
Top Chord	HSS 9x9x5/8
Bottom Chord	HSS 9x9x5/8
Vertical	HSS 8x8x3/8
End Post	HSS 9x9x5/8
Diagonal	HSS 6x4x5/16
Floor system	
Brace Diagonal	HSS 4x4x5/16
Brace Horizontal	HSS 4x4x5/16
Floor Beam	W 14x43
Railing	
Toe Rail	PL 6x5/16
Rub Rail	2x8
Safety Rail	HSS 2x1x1/8

Appendix A.2: Member Schedule for Bridge Superstructure

Appendix B: Pedestrian Trail



Appendix B.1: Pedestrian Trail Layout

No.	Type	Tangency Constraint	Parameter Constrai...	Parameter C...	Length	Radius	Direction	Start Station	End Station	Delta angle	Chord length	Degree of Curvature by Arc
1	Line	Not Constrained (Fixed)		Two points	70.679'		N42° 08' 34....	0+00.00'	0+70.68'			
2	Curve	Constrained on Both Sides (Free)		Radius	15.903'	200.000'		0+70.68'	0+86.58'	004.5560 (d)	15.899'	028.6479 (d)
3	Line	Not Constrained (Fixed)		Two points	60.820'		N37° 35' 13....	0+86.58'	1+47.40'			
4	Curve	Constrained on Both Sides (Free)		Radius	60.350'	100.000'		1+47.40'	2+07.75'	034.5779 (d)	59.438'	057.2958 (d)
5	Line	Not Constrained (Fixed)		Two points	1.395'		N03° 00' 32....	2+07.75'	2+09.15'			
6	Curve	Constrained on Both Sides (Free)		Radius	99.990'	200.000'		2+09.15'	3+09.14'	028.6450 (d)	98.952'	028.6479 (d)
7	Line	Not Constrained (Fixed)		Two points	88.376'		N25° 38' 09....	3+09.14'	3+97.51'			

Appendix B.2: Horizontal Alignment of the West Trail

No.	Type	Tangency Constraint	Parameter Constrai...	Parameter C...	Length	Radius	Direction	Start Station	End Station	Delta angle	Chord length
1	Line	Not Constrained (Fixed)		Two points	90.368'		N26° 55' 48....	0+00.00'	0+90.37'		
2	Curve	Constrained on Both Sides (Free)		Radius	84.742'	196.287'		0+90.37'	1+75.11'	024.7361 (d)	84.086'
3	Line	Not Constrained (Fixed)		Two points	112.302'		N02° 11' 39....	1+75.11'	2+87.41'		
4	Curve	Constrained on Both Sides (Free)		Radius	147.132'	200.000'		2+87.41'	4+34.54'	042.1502 (d)	143.836'
5	Line	Not Constrained (Fixed)		Two points	418.188'		N44° 20' 39....	4+34.54'	8+52.73'		
6	Line	Not Constrained (Fixed)		Two points	100.000'		N36° 22' 50....	8+52.73'	9+52.73'		

Appendix B.3: Horizontal Alignment of the East Trail

No.	PVI Station	PVI Elevation	Grade In	Grade Out	A (Grade Change)	Profile Curve Type	Profile Curve Length	K Value	Curve Radius
1	0+00.00'	917.465'		0.36%					
2	0+37.51'	917.600'	0.36%	4.80%	4.44%	Sag	50.000'	11.261	1126.102'
3	3+87.51'	934.400'	4.80%	1.00%	3.80%	Crest	10.000'	2.632	263.158'
4	3+97.51'	934.500'	1.00%						

Appendix B.4: Vertical Alignment of the West Trail

No.	PVI Station	PVI Elevation	Grade In	Grade Out	A (Grade Change)	Profile Curve Type	Profile Curve Length	K Value	Curve Radius
1	0+00.00'	934.500'		-0.50%					
2	0+10.00'	934.450'	-0.50%	-4.98%	4.48%	Crest	10.000'	2.231	223.403'
3	3+50.58'	917.481'	-4.98%	-0.89%	4.09%	Sag	100.000'	24.443	2444.306'
4	5+59.53'	915.619'	-0.89%	0.79%	1.68%	Sag	100.000'	59.592	5959.219'
5	7+01.24'	916.734'	0.79%	4.87%	4.09%	Sag	109.898'	26.896	2689.583'
6	8+13.26'	922.192'	4.87%	0.27%	4.60%	Crest	100.000'	21.737	2173.730'
7	9+52.73'	922.572'	0.27%						

Appendix B.5: Vertical Alignment of the East Trail

Appendix B.6: Safety Rail with Retaining Wall

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SOIL REINFORCEMENT

Miragrid® 8XT

Miragrid® 8XT geogrid is composed of high molecular weight, high tenacity polyester multifilament yarns woven in tension and finished with a PVC coating. Miragrid® 8XT geogrid is inert to biological degradation and resistant to naturally encountered chemicals, alkalis, and acids.

Miragrid® 8XT geogrid is used as soil reinforcement in MSE structures such as; segmental retaining walls, precast modular block walls, wire faced walls, geosynthetic wrapped faced walls and steepened slopes. Miragrid® 8XT is also used in MSE stabilized platforms for voids bridging, embankments on soft soils, landfill veneer stability, reducing differential settlement and for foundation seismic stability.

TenCate Geosynthetics Americas is accredited by Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP).

Mechanical Properties	Test Method	Unit	Machine Direction Value
Tensile Strength @ Ultimate (MARV[1])	ASTM D6637 (Method B)	lbs/ft (kN/m)	7400 (108.0)
Tensile Strength @ 5% strain (MARV[1])	ASTM D6637 (Method B)	lbs/ft (kN/m)	2520 (36.8)
Creep Rupture Strength[2]	ASTM D5262/D6992	lbs/ft (kN/m)	5139 (75.1)
Long Term Design Strength[3]		lbs/ft (kN/m)	4449 (64.9)

[1] Minimum Average Roll Values (MARV) shown above are based on QC Testing per a defined lot not to exceed 12 months. Testing Frequency follows ASTM D4354, Table 1.
[2] 75-year design life based on NTPEP Report REGEO-2016-01-066.
[3] Long Term Design Strength for sand, silt, clay. RF_{CR} = 1.44; RF_{ID} = 1.05; RF_{D} = 1.1
(Installation damage reduction factor for other soils available upon request).

Physical Properties	Unit	Roll Characteristic
Mass/Unit Area (ASTM D5261)	oz/yd² (g/m²)	10.8 (366)
Roll Dimensions[4] (width x length)	ft (m)	6 x 300 (1.8 x 91) 12 x 200 (3.6 x 61) 12 X 1000 (3.6 x 305)
Roll Area	yd² (m²)	200 (168) 267 (220) 1333 (1114)
Estimated Roll Weight	lbs (kg)	140 (64) 205 (93) 975 (442)

[4] Special order roll lengths are available upon request.

Miragrid® 8XT and Tensile Strength direction are continuously printed in white on the edge of the roll.

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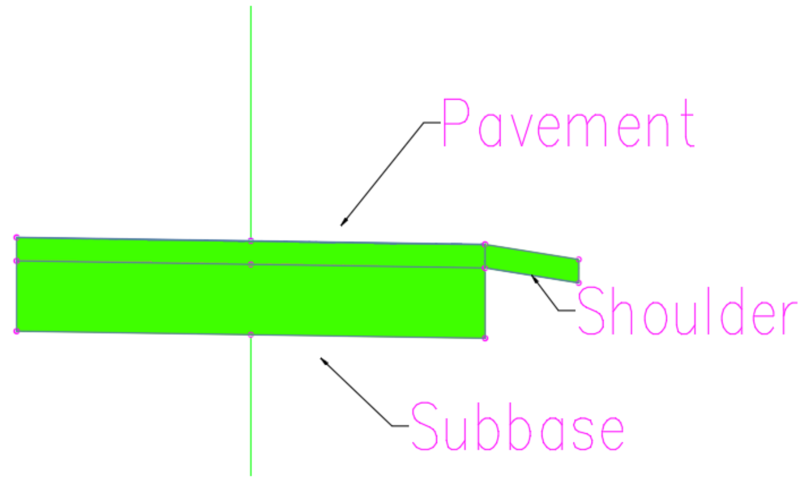
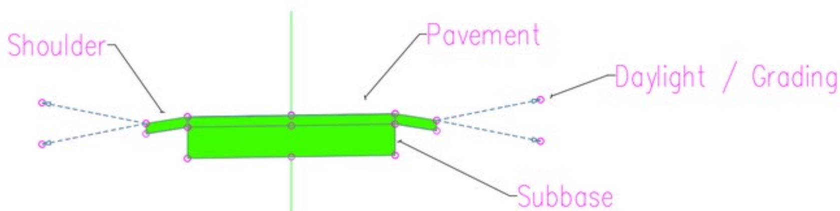
ETQR24

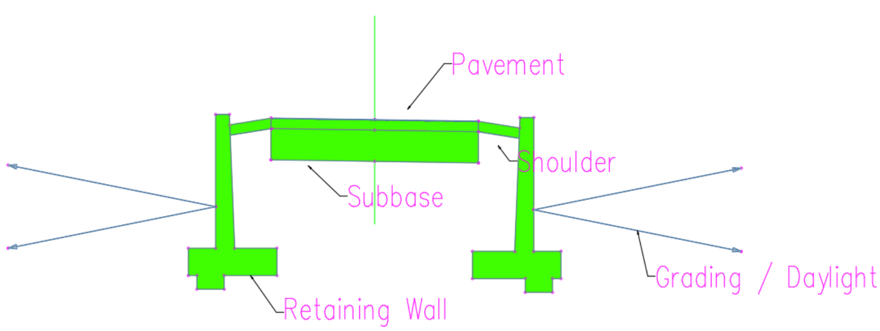
Appendix B.7: Information Sheet for Retaining Wall



Appendix B.8: Cross Section of Trail Along Parking Lot



Appendix B.9: General Trail Cross Section



Appendix B.10: General Retaining Wall Cross Section

CUT Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	0.00	0.00	0.00
0+25.00	0.00	0.00	0.00
0+50.00	0.00	0.00	0.00
0+75.00	0.00	0.00	0.00
1+00.00	0.00	0.00	0.00
1+25.00	0.00	0.00	0.00
1+50.00	0.01	0.00	0.00
1+75.00	0.01	0.01	0.01
2+25.00	0.00	0.01	0.02
2+50.00	0.00	0.00	0.02
2+75.00	0.00	0.00	0.02
3+00.00	0.00	0.00	0.02
3+25.00	0.00	0.00	0.02
3+50.00	0.00	0.00	0.02
3+75.00	0.00	0.00	0.02
4+00.00	0.00	0.00	0.02
4+25.00	0.08	0.04	0.06
4+50.00	0.49	0.26	0.32
4+75.00	2.04	1.17	1.49
5+00.00	4.83	3.18	4.67

CUT Volume Table			
Station	Area	Volume	Cumulative Volume
5+25.00	8.79	6.30	10.98
5+50.00	10.98	9.15	20.13
5+75.00	12.00	10.64	30.77
6+00.00	10.36	10.35	41.13
6+25.00	0.04	4.82	45.94
6+50.00	0.00	0.02	45.96
6+75.00	0.00	0.00	45.96
7+00.00	3.63	1.68	47.64
7+25.00	11.73	7.11	54.75
7+50.00	4.57	7.54	62.30
7+75.00	8.46	6.03	68.33
8+00.00	15.47	11.08	79.41
8+25.00	10.85	12.18	91.59
8+50.00	4.90	7.29	98.88
8+75.00	3.60	3.95	102.83
9+00.00	3.19	3.14	105.97
9+25.00	6.72	4.59	110.56
9+50.00	8.33	6.97	117.53

Appendix B.11: East Trail Soil Cut Volume Table

FILL Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	0.00	0.00	0.00
0+25.00	131.46	60.86	60.86
0+50.00	250.57	176.87	237.73
0+75.00	227.03	221.11	458.84
1+00.00	214.04	204.01	662.84
1+25.00	210.28	195.97	858.81
1+50.00	205.68	192.20	1051.01
1+75.00	197.58	186.40	1237.41
2+25.00	178.59	348.30	1585.71
2+50.00	136.21	145.74	1731.45
2+75.00	94.04	106.60	1838.05
3+00.00	52.33	67.80	1905.86
3+25.00	35.03	40.43	1946.28
3+50.00	19.61	25.26	1971.55
3+75.00	10.49	13.94	1985.49
4+00.00	7.31	8.26	1993.75
4+25.00	3.37	4.96	1998.71
4+50.00	0.90	1.98	2000.70
4+75.00	0.06	0.44	2001.14
5+00.00	0.00	0.03	2001.17

FILL Volume Table			
Station	Area	Volume	Cumulative Volume
5+25.00	0.00	0.00	2001.17
5+50.00	0.00	0.00	2001.17
5+75.00	0.00	0.00	2001.17
6+00.00	0.00	0.00	2001.17
6+25.00	8.57	3.97	2005.13
6+50.00	19.28	12.89	2018.03
6+75.00	10.44	13.76	2031.78
7+00.00	0.17	4.91	2036.69
7+25.00	0.00	0.08	2036.77
7+50.00	0.00	0.00	2036.77
7+75.00	0.00	0.00	2036.77
8+00.00	0.00	0.00	2036.77
8+25.00	0.00	0.00	2036.77
8+50.00	0.00	0.00	2036.77
8+75.00	0.00	0.00	2036.77
9+00.00	0.00	0.00	2036.77
9+25.00	0.00	0.00	2036.77
9+50.00	0.00	0.00	2036.77

Appendix B.12: East Trail Soil Fill Volume Table

Pavement Structure Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	7.00	0.00	0.00
0+25.00	7.00	6.48	6.48
0+50.00	7.00	6.48	12.96
0+75.00	7.00	6.48	19.44
1+00.00	7.00	6.48	25.93
1+25.00	7.00	6.48	32.41
1+50.00	7.00	6.48	38.89
1+75.00	7.00	6.48	45.37
2+25.00	7.00	12.96	58.33
2+50.00	7.00	6.48	64.81
2+75.00	7.00	6.48	71.29
3+00.00	7.00	6.48	77.78
3+25.00	7.00	6.48	84.26
3+50.00	7.00	6.48	90.74
3+75.00	7.00	6.48	97.22
4+00.00	8.00	6.96	104.18
4+25.00	8.00	7.43	111.61
4+50.00	8.00	7.42	119.03
4+75.00	8.00	7.41	126.44
5+00.00	8.00	7.41	133.84

Pavement Structure Volume Table			
Station	Area	Volume	Cumulative Volume
5+25.00	8.00	7.41	141.25
5+50.00	8.00	7.41	148.66
5+75.00	8.00	7.41	156.07
6+00.00	8.00	7.41	163.47
6+25.00	8.00	7.41	170.88
6+50.00	8.00	7.41	178.29
6+75.00	8.00	7.41	185.69
7+00.00	8.00	7.41	193.10
7+25.00	8.00	7.41	200.51
7+50.00	8.00	7.41	207.92
7+75.00	8.00	7.41	215.32
8+00.00	8.00	7.41	222.73
8+25.00	8.00	7.41	230.14
8+50.00	8.00	7.41	237.55
8+75.00	8.00	7.38	244.92
9+00.00	8.00	7.41	252.33
9+25.00	8.00	7.41	259.74
9+50.00	8.00	7.41	267.14

Appendix B.13: East Trail Pavement Volume Table

subbase Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	15.00	0.00	0.00
0+25.00	15.00	13.89	13.89
0+50.00	15.00	13.89	27.78
0+75.00	15.00	13.89	41.67
1+00.00	15.00	13.89	55.56
1+25.00	15.00	13.89	69.44
1+50.00	15.00	13.89	83.33
1+75.00	15.00	13.89	97.22
2+25.00	15.00	27.78	125.00
2+50.00	15.00	13.89	138.89
2+75.00	15.00	13.89	152.78
3+00.00	15.00	13.89	166.67
3+25.00	15.00	13.89	180.56
3+50.00	15.00	13.89	194.44
3+75.00	15.00	13.89	208.33
4+00.00	15.00	13.89	222.22
4+25.00	15.00	13.89	236.11
4+50.00	15.00	13.89	250.00
4+75.00	15.00	13.89	263.89
5+00.00	15.00	13.89	277.78

subbase Volume Table			
Station	Area	Volume	Cumulative Volume
5+25.00	15.00	13.89	291.67
5+50.00	15.00	13.89	305.56
5+75.00	15.00	13.89	319.44
6+00.00	15.00	13.89	333.33
6+25.00	15.00	13.89	347.22
6+50.00	15.00	13.89	361.11
6+75.00	15.00	13.89	375.00
7+00.00	15.00	13.89	388.89
7+25.00	15.00	13.89	402.78
7+50.00	15.00	13.89	416.67
7+75.00	15.00	13.89	430.56
8+00.00	15.00	13.89	444.44
8+25.00	15.00	13.89	458.33
8+50.00	15.00	13.89	472.22
8+75.00	15.00	13.89	486.11
9+00.00	15.00	13.89	500.00
9+25.00	15.00	13.89	513.89
9+50.00	15.00	13.89	527.78

Appendix B.14: East Trail Subbase Volume Table

RET WALL Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	104.08	0.00	0.00
0+25.00	98.47	93.77	93.77
0+50.00	88.55	86.58	180.35
0+75.00	80.94	78.47	258.82
1+00.00	76.50	72.87	331.69
1+25.00	75.75	70.42	402.11
1+50.00	73.54	69.10	471.21
1+75.00	72.03	67.41	538.62
2+25.00	65.26	127.12	665.74
2+50.00	49.89	53.31	719.05
2+75.00	39.61	41.44	760.49
3+00.00	28.59	31.60	792.09
3+25.00	23.82	24.30	816.39
3+50.00	21.54	21.01	837.40
3+75.00	20.05	19.26	856.66
4+00.00	0.00	9.28	865.94
4+25.00	0.00	0.00	865.94
4+50.00	0.00	0.00	865.94
4+75.00	0.00	0.00	865.94
5+00.00	0.00	0.00	865.94

RET WALL Volume Table			
Station	Area	Volume	Cumulative Volume
5+25.00	0.00	0.00	865.94
5+50.00	0.00	0.00	865.94
5+75.00	0.00	0.00	865.94
6+00.00	0.00	0.00	865.94
6+25.00	0.00	0.00	865.94
6+50.00	0.00	0.00	865.94
6+75.00	0.00	0.00	865.94
7+00.00	0.00	0.00	865.94
7+25.00	0.00	0.00	865.94
7+50.00	0.00	0.00	865.94
7+75.00	0.00	0.00	865.94
8+00.00	0.00	0.00	865.94
8+25.00	0.00	0.00	865.94
8+50.00	0.00	0.00	865.94
8+75.00	0.00	0.00	865.94
9+00.00	0.00	0.00	865.94
9+25.00	0.00	0.00	865.94
9+50.00	0.00	0.00	865.94

Appendix B.15: East Trail Retaining Wall Volume Table

Total Volume Table							
Station	Cut Area	Fill Area	Cut Vol	Fill Vol	Cum Cut Vol	Cum Fill Vol	Net Vol
0+00.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0+25.00	0.00	131.46	0.00	60.86	0.00	60.86	-60.86
0+50.00	0.00	250.57	0.00	176.87	0.00	237.73	-237.73
0+75.00	0.00	227.03	0.00	221.11	0.00	458.84	-458.84
1+00.00	0.00	214.04	0.00	204.01	0.00	662.84	-662.84
1+25.00	0.00	210.28	0.00	195.97	0.00	858.81	-858.81
1+50.00	0.01	205.68	0.00	192.20	0.00	1051.01	-1051.00
1+75.00	0.01	197.58	0.01	186.40	0.01	1237.41	-1237.40
2+25.00	0.00	178.59	0.01	348.30	0.02	1585.71	-1585.69
2+50.00	0.00	136.21	0.00	145.74	0.02	1731.45	-1731.43
2+75.00	0.00	94.04	0.00	106.60	0.02	1838.05	-1838.03
3+00.00	0.00	52.33	0.00	67.80	0.02	1905.86	-1905.84
3+25.00	0.00	35.03	0.00	40.43	0.02	1946.28	-1946.26
3+50.00	0.00	19.61	0.00	25.26	0.02	1971.55	-1971.53
3+75.00	0.00	10.49	0.00	13.94	0.02	1985.49	-1985.47
4+00.00	0.00	7.31	0.00	8.26	0.02	1993.75	-1993.73
4+25.00	0.08	3.37	0.04	4.96	0.06	1998.71	-1998.66
4+50.00	0.49	0.90	0.26	1.98	0.32	2000.70	-2000.38
4+75.00	2.04	0.06	1.17	0.44	1.49	2001.14	-1999.65
5+00.00	4.83	0.00	3.18	0.03	4.67	2001.17	-1996.49

Total Volume Table							
Station	Cut Area	Fill Area	Cut Vol	Fill Vol	Cum Cut Vol	Cum Fill Vol	Net Vol
5+25.00	8.79	0.00	6.30	0.00	10.98	2001.17	-1990.19
5+50.00	10.98	0.00	9.15	0.00	20.13	2001.17	-1981.03
5+75.00	12.00	0.00	10.64	0.00	30.77	2001.17	-1970.39
6+00.00	10.36	0.00	10.35	0.00	41.13	2001.17	-1960.04
6+25.00	0.04	8.57	4.82	3.97	45.94	2005.13	-1959.19
6+50.00	0.00	19.28	0.02	12.89	45.96	2018.03	-1972.06
6+75.00	0.00	10.44	0.00	13.76	45.96	2031.78	-1985.82
7+00.00	3.63	0.17	1.68	4.91	47.64	2036.69	-1989.05
7+25.00	11.73	0.00	7.11	0.08	54.75	2036.77	-1982.02
7+50.00	4.57	0.00	7.54	0.00	62.30	2036.77	-1974.47
7+75.00	8.46	0.00	6.03	0.00	68.33	2036.77	-1968.44
8+00.00	15.47	0.00	11.08	0.00	79.41	2036.77	-1957.36
8+25.00	10.85	0.00	12.18	0.00	91.59	2036.77	-1945.18
8+50.00	4.90	0.00	7.29	0.00	98.88	2036.77	-1937.89
8+75.00	3.60	0.00	3.95	0.00	102.83	2036.77	-1933.95
9+00.00	3.19	0.00	3.14	0.00	105.97	2036.77	-1930.80
9+25.00	6.72	0.00	4.59	0.00	110.56	2036.77	-1926.22
9+50.00	8.33	0.00	6.97	0.00	117.53	2036.77	-1919.25

Appendix B.16: East Trail Total Volume Table

Cut Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	0.00	0.00	0.00
0+50.00	3.68	3.40	3.40
1+00.00	0.00	3.40	6.81
1+50.00	0.00	0.00	6.81
2+00.00	0.01	0.01	6.82
2+50.00	0.00	0.01	6.83
3+00.00	0.00	0.00	6.83
3+50.00	0.07	0.06	6.90
3+97.51	0.00	0.06	6.96

Appendix B.17: West Trail Soil Cut Volume Table

Fill Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	0.00	0.00	0.00
0+50.00	0.00	0.00	0.00
1+00.00	45.13	41.79	41.79
1+50.00	81.57	117.32	159.10
2+00.00	123.00	189.42	348.52
2+50.00	166.78	268.32	616.84
3+00.00	211.93	350.65	967.49
3+50.00	266.01	442.54	1410.03
3+97.51	315.82	511.94	1921.97

Appendix B.18: West Trail Soil Fill Volume Table

Pavement Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	7.00	0.00	0.00
0+50.00	7.00	12.96	12.96
1+00.00	7.00	12.96	25.93
1+50.00	7.00	12.96	38.89
2+00.00	7.00	12.96	51.85
2+50.00	7.00	12.96	64.81
3+00.00	7.00	12.96	77.78
3+50.00	7.00	12.96	90.74
3+97.51	7.00	12.32	103.06

Appendix B.19: West Trail Pavement Volume Table

Subbase Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	15.00	0.00	0.00
0+50.00	15.00	27.78	27.78
1+00.00	15.00	27.78	55.56
1+50.00	15.00	27.78	83.33
2+00.00	15.00	27.78	111.11
2+50.00	15.00	27.78	138.89
3+00.00	15.00	27.78	166.67
3+50.00	15.00	27.78	194.44
3+97.51	15.00	26.40	220.84

Appendix B.20: West Trail Subbase Volume Table

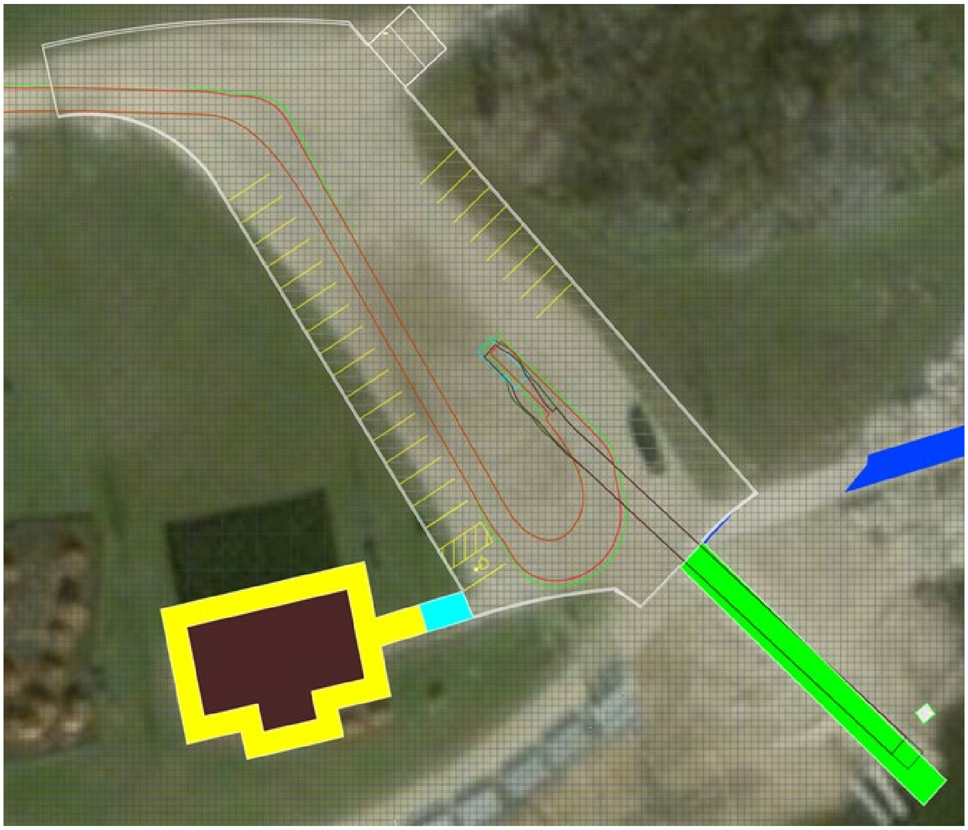
Retaining Wall Volume Table			
Station	Area	Volume	Cumulative Volume
0+00.00	0.00	0.00	0.00
0+50.00	18.00	16.66	16.66
1+00.00	25.32	40.11	56.77
1+50.00	34.97	55.83	112.60
2+00.00	47.68	76.53	189.13
2+50.00	60.96	100.59	289.72
3+00.00	77.49	128.19	417.91
3+50.00	92.13	157.05	574.96
3+97.51	109.15	177.10	752.07

Table B.21: West Trail Retaining Wall Volume Table

Total Volume Table							
Station	Cut Area	Fill Area	Cut Vol	Fill Vol	Cum Cut Vol	Cum Fill Vol	Net Vol
0+00.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0+50.00	3.68	0.00	3.40	0.00	3.40	0.00	3.40
1+00.00	0.00	45.13	3.40	41.79	6.81	41.79	-34.98
1+50.00	0.00	81.57	0.00	117.32	6.81	159.10	-152.29
2+00.00	0.01	123.00	0.01	189.42	6.82	348.52	-341.70
2+50.00	0.00	166.78	0.01	268.32	6.83	616.84	-610.00
3+00.00	0.00	211.93	0.00	350.65	6.83	967.49	-960.66
3+50.00	0.07	266.01	0.06	442.54	6.90	1410.03	-1403.13
3+97.51	0.00	315.82	0.06	511.94	6.96	1921.97	-1915.01

Table B.22: West Trail Total Volume Table

Appendix C: Parking Lot



Appendix C.1: Parking Lot Layout & Swept Path Analysis

Appendix D: Maquoketa River

Source		Peak Flow Statistics [100% (279 sq.mi.) Peak Region 2 2013 5086] (cfs)						
		2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	500 yr
USGS StreamStats @ Manchester	Value	4590	8620	12200	17700	21200	24500	33400
	PII	2210	5690	8710	12900	15300	17100	21300
	Plu	9540	13000	17100	24200	29400	35100	52400

Appendix D.1: StreamStats Peak Flow Statistics (U.S. Geological Survey 2016)

Source	July 2010 Event			
	Discharge (cfs)	Stage (ft)	Elevation (ft)	Location
Fehr Graham correspondance	N/A	N/A	926	Schram Park
Grimley Thesis	26600	24.51	N/A	Hwy20 (Model outlet)
USGS Report	26600	24.48	N/A	USGS Manchester stream gage
FEMA XS's [100 yr]	N/A	18	921	Schram Park

Appendix D.2: Comparison of Gathered Data for July 2010 Record Flood

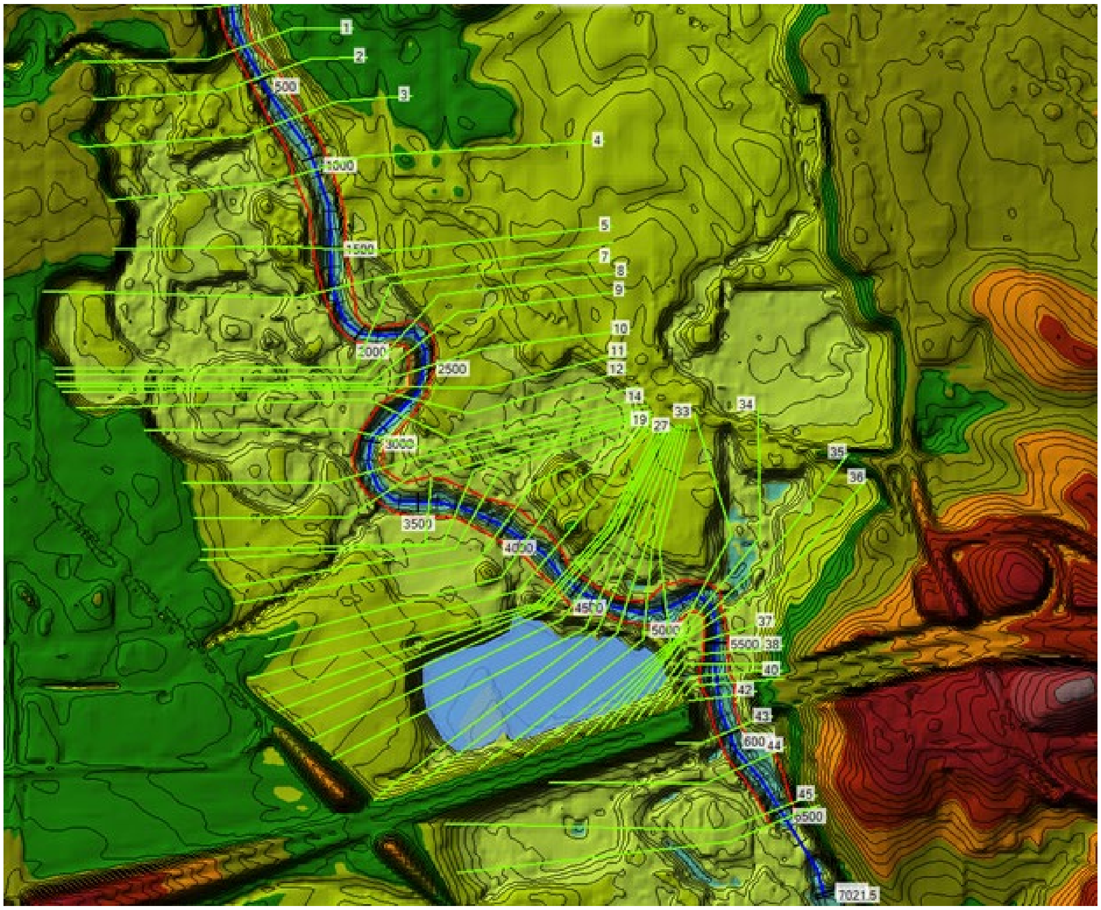
Event	Model Outputs			
	Stage (ft)	Elevation (ft)	Discharge (ft3/s)	Velocity (at bridge site) (ft/s)
StreamStats 100-yr Event	24	927	24,500	3.25
July 2010 Event	24.5	927.5	26,600	3.7

Appendix D.3: Calibrated Model Outputs for Relevant Design Floods

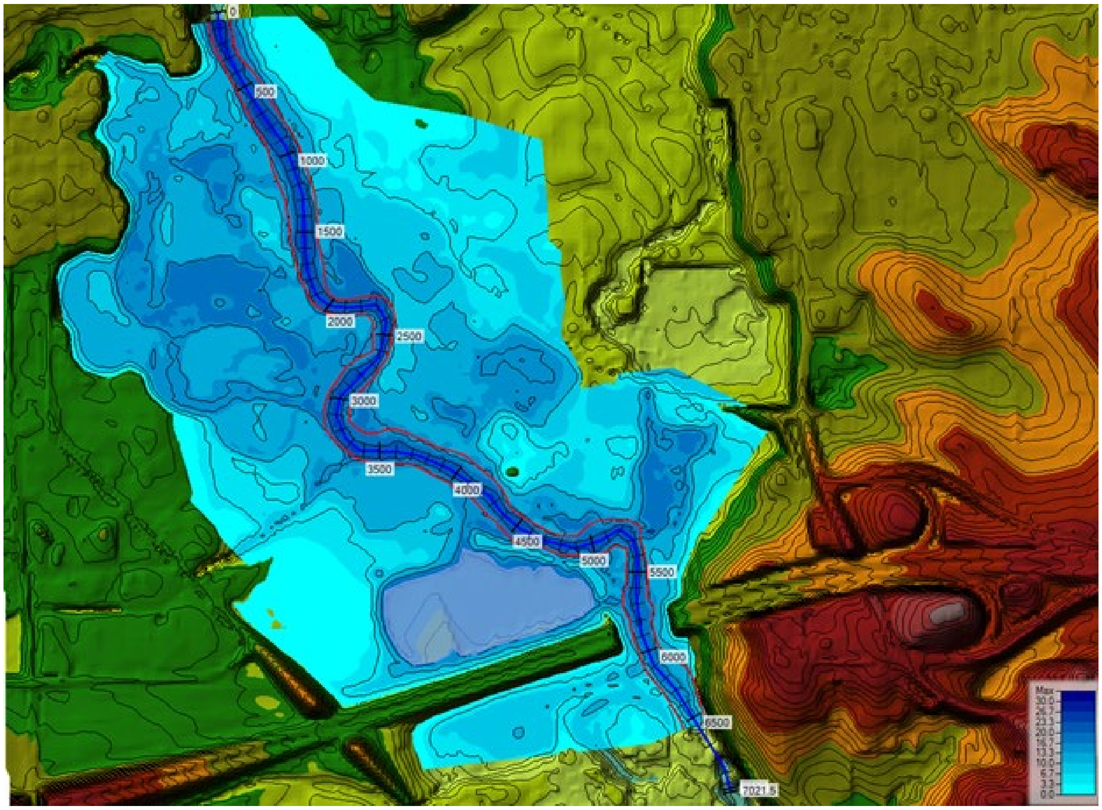
BRIDGE OUTPUT Profile #PF 2

E.G. US. (ft)	929.39	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	928.22	E.G. Elev (ft)	929.35	929.24
Q Total (cfs)	26600.00	W.S. Elev (ft)	928.16	928.03
Q Bridge (cfs)	26600.00	Crit W.S. (ft)	919.04	919.06
Q Weir (cfs)		Max Chl Dpth (ft)	22.69	21.56
Weir Sta Lft (ft)		Vel Total (ft/s)	8.33	8.36
Weir Sta Rgt (ft)		Flow Area (sq ft)	3192.25	3181.59
Weir Submerg		Froude # Chl	0.36	0.36
Weir Max Depth (ft)		Specif Force (cu ft)	37136.51	36889.66
Min El Weir Flow (ft)	936.01	Hydr Depth (ft)	18.14	18.08
Min El Prs (ft)	931.50	W.P. Total (ft)	213.16	211.36
Delta EG (ft)	0.19	Conv. Total (cfs)	319753.8	317149.8
Delta WS (ft)	0.22	Top Width (ft)	176.00	176.00
BR Open Area (sq ft)	3779.52	Frctn Loss (ft)	0.10	0.04
BR Open Vel (ft/s)	8.36	C & E Loss (ft)	0.01	0.00
BR Sluice Coef		Shear Total (lb/sq ft)	6.47	6.61
BR Sel Method	Energy only	Power Total (lb/ft s)	53.91	55.27

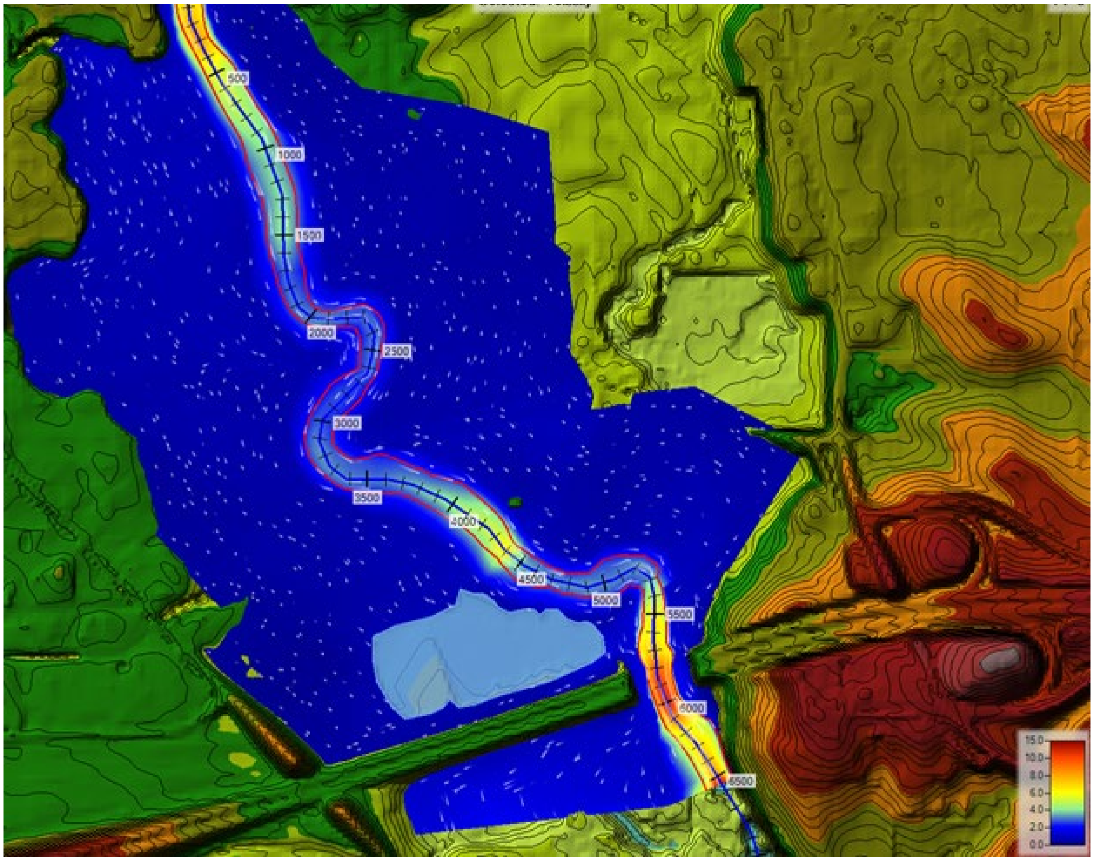
Appendix D.4: Model Results for the Bridge Structure



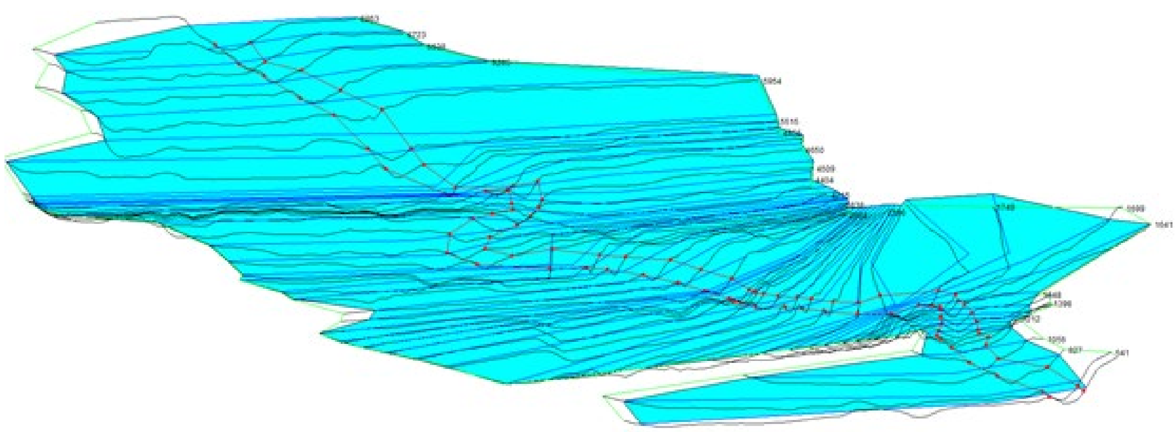
Appendix D.5: Model of River Geometry Displaying the Extents



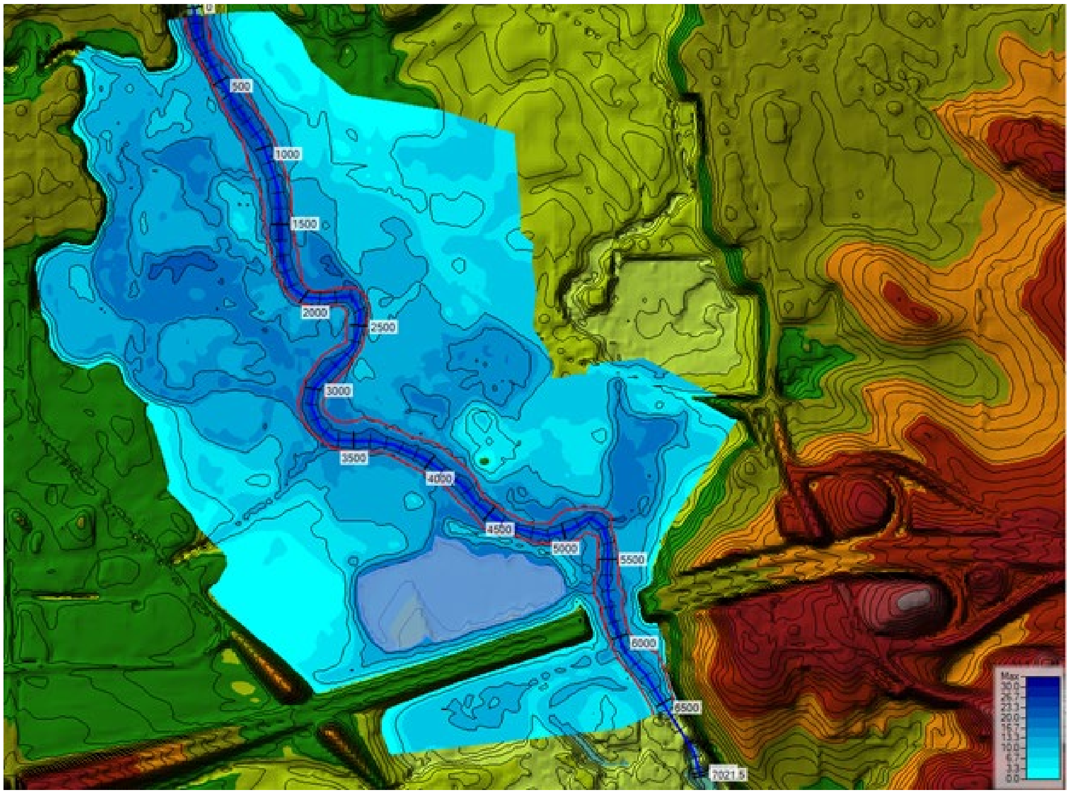
Appendix D.6: Model Inundation Results for the StreamStats 100-yr Flood Event



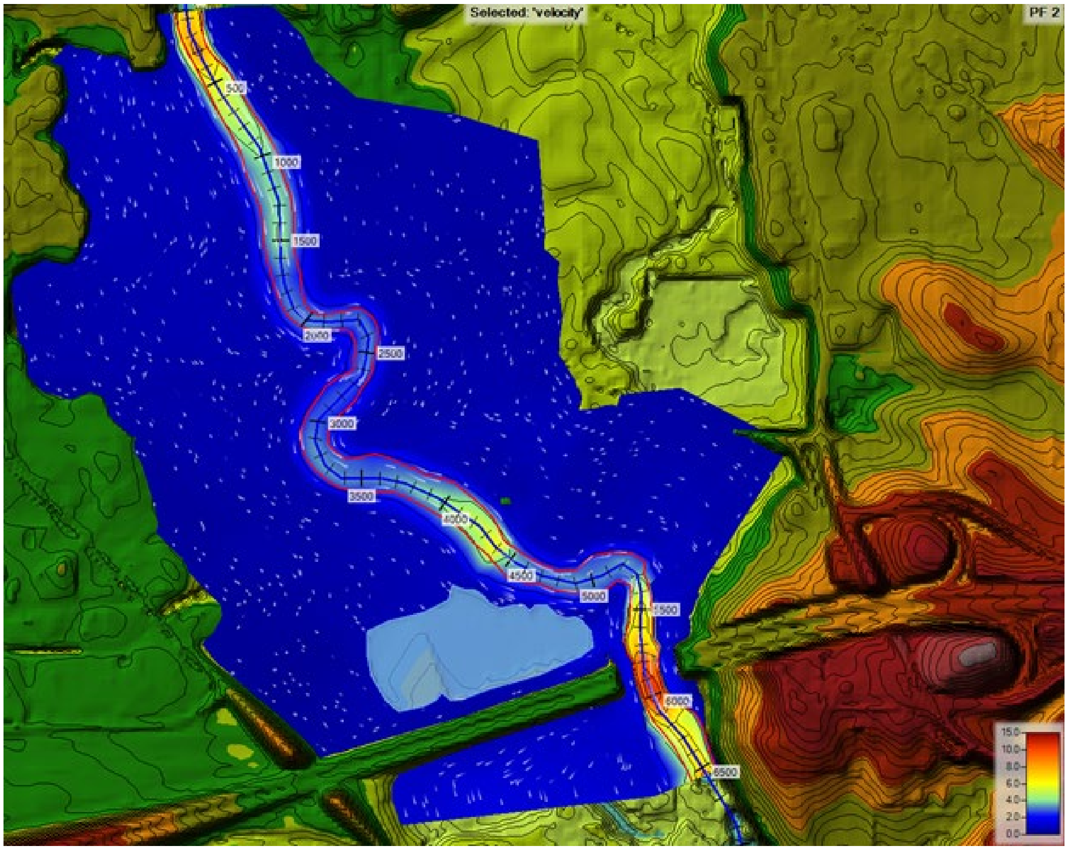
Appendix D.7: Model Velocity Profile for the StreamStats 100-yr Flood Event



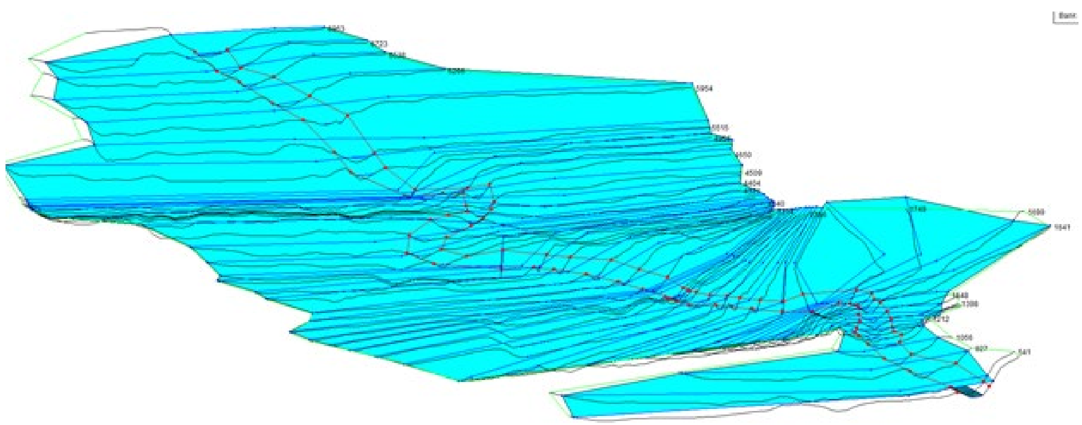
Appendix D.8: 3D Rendering of Inundation Results for the StreamStats 100-yr Flood Event



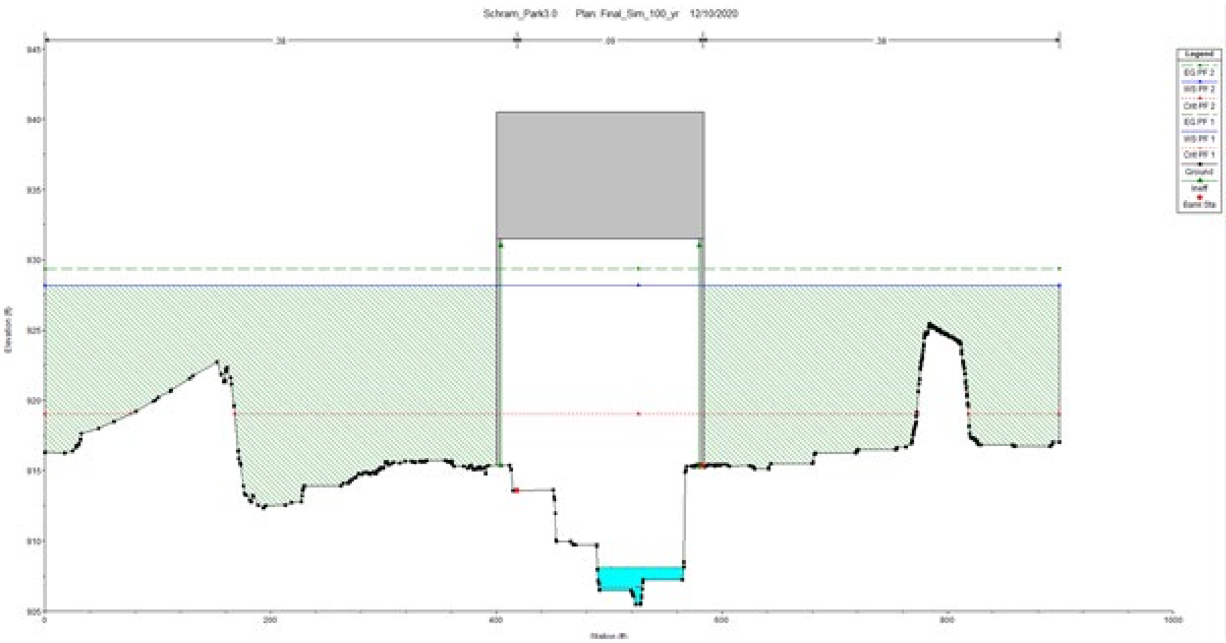
Appendix D.9: Model Inundation Results for the July 2010 Record Flood Event



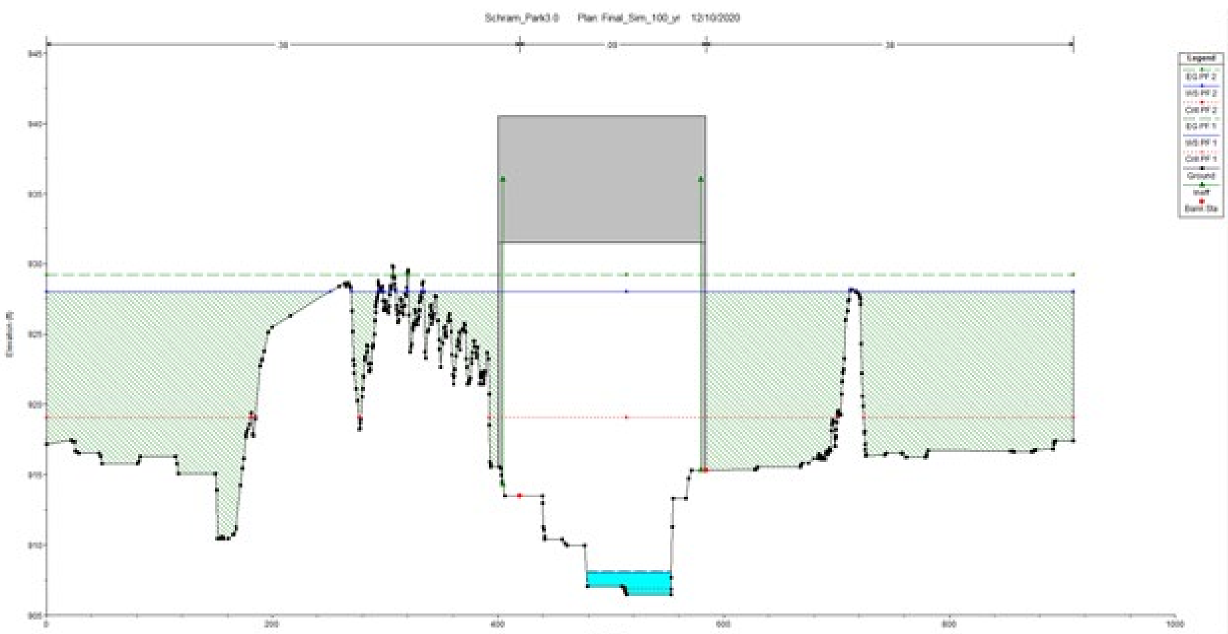
Appendix D.10: Model Velocity Profile for the July 2010 Record Flood Event



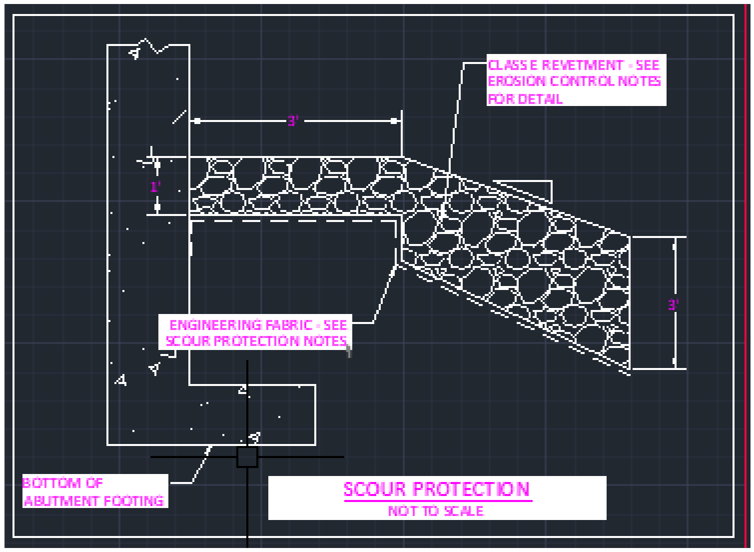
Appendix D.11: 3D Rendering of Inundation Results for the July 2010 Record Flood Event



Appendix D.12**:** Upstream Cross-Sectional View of the Bridge



Appendix D.13: Downstream Cross-Sectional View of the Bridge



Appendix D.14: Design drawing of scour protection around the bridge abutments

Appendix E: Erosion Control

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.390** (0.314-0.478)	**0.458** (0.367-0.561)	**0.569** (0.455-0.699)	**0.661** (0.526-0.816)	**0.790** (0.608-1.00)	**0.889** (0.670-1.14)	**0.989** (0.722-1.30)	**1.09** (0.766-1.47)	**1.23** (0.831-1.69)	**1.33** (0.880-1.86)
10-min	**0.572** (0.459-0.700)	**0.671** (0.538-0.822)	**0.833** (0.666-1.02)	**0.968** (0.770-1.20)	**1.16** (0.890-1.47)	**1.30** (0.981-1.67)	**1.45** (1.06-1.90)	**1.60** (1.12-2.15)	**1.80** (1.22-2.47)	**1.95** (1.29-2.72)
15-min	**0.697** (0.560-0.854)	**0.818** (0.656-1.00)	**1.02** (0.812-1.25)	**1.18** (0.939-1.46)	**1.41** (1.09-1.79)	**1.59** (1.20-2.04)	**1.77** (1.29-2.32)	**1.95** (1.37-2.62)	**2.19** (1.48-3.02)	**2.37** (1.57-3.32)
30-min	**0.959** (0.770-1.18)	**1.14** (0.910-1.39)	**1.42** (1.14-1.75)	**1.66** (1.32-2.04)	**1.98** (1.52-2.50)	**2.23** (1.68-2.85)	**2.47** (1.80-3.24)	**2.72** (1.91-3.65)	**3.05** (2.06-4.19)	**3.29** (2.18-4.60)
60-min	**1.22** (0.977-1.49)	**1.45** (1.16-1.78)	**1.84** (1.47-2.26)	**2.16** (1.72-2.67)	**2.62** (2.02-3.33)	**2.98** (2.24-3.83)	**3.34** (2.44-4.39)	**3.71** (2.61-5.00)	**4.22** (2.86-5.81)	**4.60** (3.05-6.43)
2-hr	**1.47** (1.20-1.79)	**1.76** (1.43-2.14)	**2.25** (1.82-2.74)	**2.67** (2.15-3.26)	**3.26** (2.54-4.11)	**3.72** (2.84-4.76)	**4.21** (3.11-5.49)	**4.70** (3.34-6.29)	**5.39** (3.68-7.38)	**5.91** (3.94-8.21)
3-hr	**1.63** (1.34-1.97)	**1.95** (1.60-2.36)	**2.50** (2.04-3.03)	**2.98** (2.42-3.62)	**3.68** (2.90-4.64)	**4.24** (3.26-5.41)	**4.83** (3.59-6.29)	**5.45** (3.89-7.28)	**6.31** (4.34-8.63)	**6.99** (4.67-9.66)
6-hr	**1.93** (1.60-2.30)	**2.29** (1.90-2.74)	**2.93** (2.42-3.51)	**3.51** (2.88-4.22)	**4.37** (3.50-5.49)	**5.09** (3.97-6.46)	**5.85** (4.40-7.59)	**6.67** (4.81-8.87)	**7.82** (5.43-10.7)	**8.75** (5.89-12.0)
12-hr	**2.27** (1.91-2.68)	**2.66** (2.23-3.14)	**3.36** (2.81-3.99)	**4.01** (3.34-4.78)	**5.00** (4.06-6.24)	**5.83** (4.60-7.35)	**6.73** (5.12-8.68)	**7.71** (5.62-10.2)	**9.10** (6.36-12.3)	**10.2** (6.93-14.0)
24-hr	**2.62** (2.23-3.07)	**3.05** (2.59-3.57)	**3.81** (3.23-4.47)	**4.52** (3.81-5.33)	**5.60** (4.60-6.94)	**6.52** (5.21-8.15)	**7.52** (5.78-9.61)	**8.60** (6.32-11.3)	**10.1** (7.15-13.7)	**11.4** (7.78-15.5)
2-day	**3.00** (2.59-3.47)	**3.46** (2.98-4.01)	**4.28** (3.68-4.97)	**5.04** (4.30-5.88)	**6.19** (5.15-7.58)	**7.17** (5.78-8.87)	**8.22** (6.38-10.4)	**9.37** (6.95-12.2)	**11.0** (7.81-14.7)	**12.3** (8.47-16.6)
3-day	**3.30** (2.87-3.80)	**3.75** (3.26-4.32)	**4.57** (3.95-5.27)	**5.33** (4.58-6.18)	**6.49** (5.43-7.90)	**7.48** (6.08-9.21)	**8.55** (6.68-10.8)	**9.72** (7.25-12.6)	**11.4** (8.13-15.2)	**12.8** (8.80-17.1)
4-day	**3.56** (3.11-4.07)	**4.01** (3.50-4.60)	**4.84** (4.21-5.56)	**5.60** (4.84-6.47)	**6.77** (5.69-8.21)	**7.77** (6.34-9.52)	**8.84** (6.94-11.1)	**10.0** (7.50-12.9)	**11.7** (8.37-15.5)	**13.1** (9.04-17.5)
7-day	**4.20** (3.71-4.77)	**4.73** (4.18-5.38)	**5.67** (4.98-6.46)	**6.50** (5.68-7.44)	**7.73** (6.53-9.22)	**8.74** (7.18-10.6)	**9.80** (7.73-12.2)	**10.9** (8.23-14.0)	**12.5** (9.01-16.5)	**13.8** (9.60-18.4)
10-day	**4.79** (4.26-5.41)	**5.40** (4.80-6.10)	**6.43** (5.69-7.29)	**7.32** (6.44-8.34)	**8.60** (7.30-10.2)	**9.63** (7.95-11.6)	**10.7** (8.47-13.2)	**11.8** (8.91-15.0)	**13.4** (9.63-17.4)	**14.6** (10.2-19.3)
20-day	**6.58** (5.94-7.35)	**7.33** (6.60-8.20)	**8.57** (7.69-9.61)	**9.61** (8.57-10.8)	**11.1** (9.48-12.9)	**12.2** (10.2-14.4)	**13.3** (10.7-16.2)	**14.5** (11.0-18.2)	**16.1** (11.7-20.8)	**17.3** (12.2-22.8)
30-day	**8.12** (7.39-9.01)	**9.02** (8.20-10.0)	**10.5** (9.49-11.7)	**11.7** (10.5-13.1)	**13.4** (11.5-15.4)	**14.6** (12.3-17.2)	**15.9** (12.8-19.2)	**17.1** (13.1-21.4)	**18.8** (13.7-24.2)	**20.1** (14.2-26.3)
45-day	**10.1** (9.27-11.1)	**11.3** (10.3-12.4)	**13.1** (12.0-14.5)	**14.6** (13.2-16.3)	**16.6** (14.4-19.0)	**18.1** (15.2-21.1)	**19.5** (15.8-23.4)	**20.9** (16.0-25.9)	**22.7** (16.6-29.0)	**24.0** (17.0-31.4)
60-day	**11.8** (10.9-13.0)	**13.2** (12.2-14.6)	**15.5** (14.2-17.1)	**17.3** (15.8-19.2)	**19.6** (17.1-22.3)	**21.3** (18.1-24.7)	**22.9** (18.6-27.3)	**24.5** (18.8-30.1)	**26.4** (19.3-33.5)	**27.7** (19.7-36.0)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

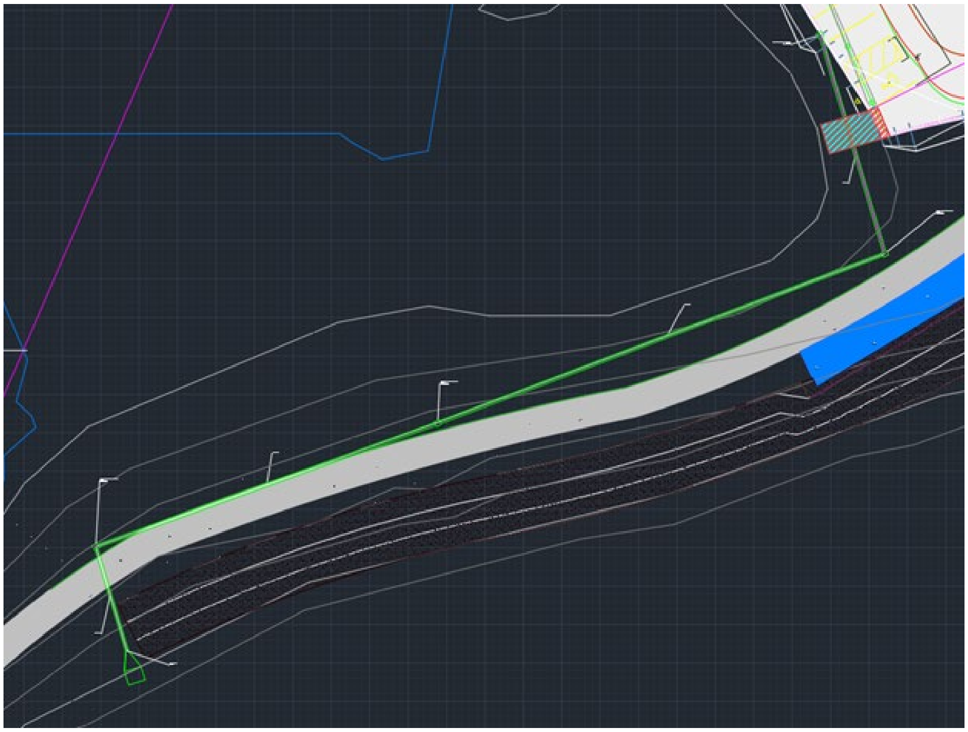
Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

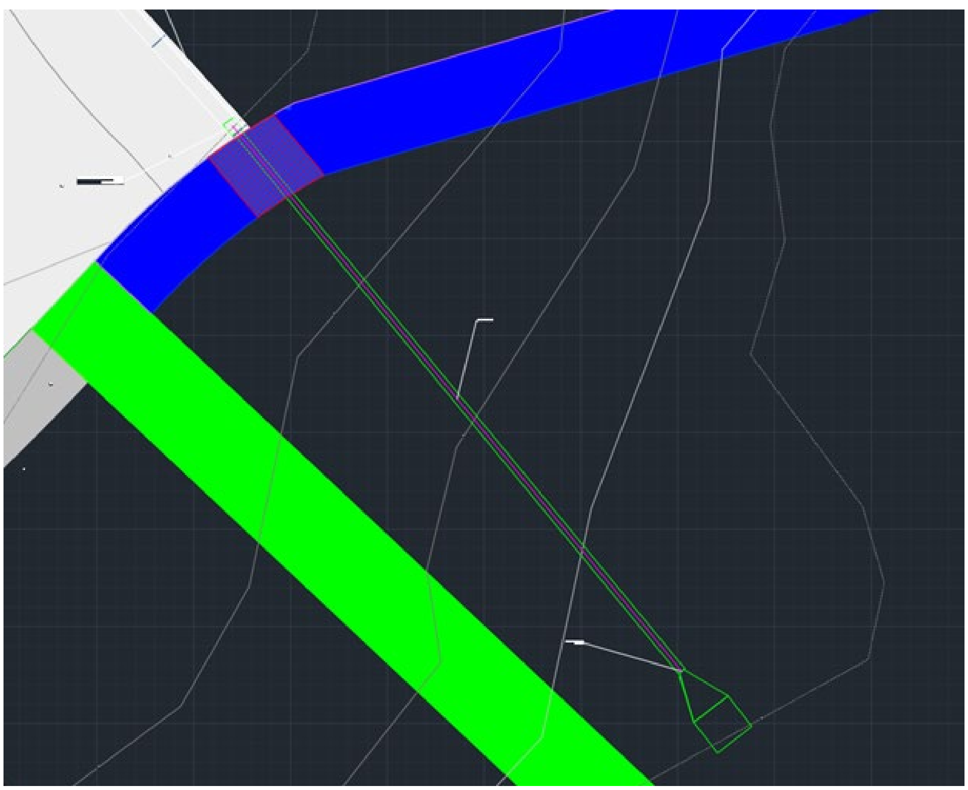
Appendix E.1: Rainfall Intensity Values for Schram Park

Ground Cover	Runoff Coefficient, c
Lawns	0.05 - 0.35
Forest	0.05 - 0.25
Cultivated land	0.08-0.41
Meadow	0.1 - 0.5
Parks, cemeteries	0.1 - 0.25
Unimproved areas	0.1 - 0.3
Pasture	0.12 - 0.62
Residential areas	0.3 - 0.75
Business areas	0.5 - 0.95
Industrial areas	0.5 - 0.9
Asphalt streets	0.7 - 0.95
Brick streets	0.7 - 0.85
Roofs	0.75 - 0.95
Concrete streets	0.7 - 0.95

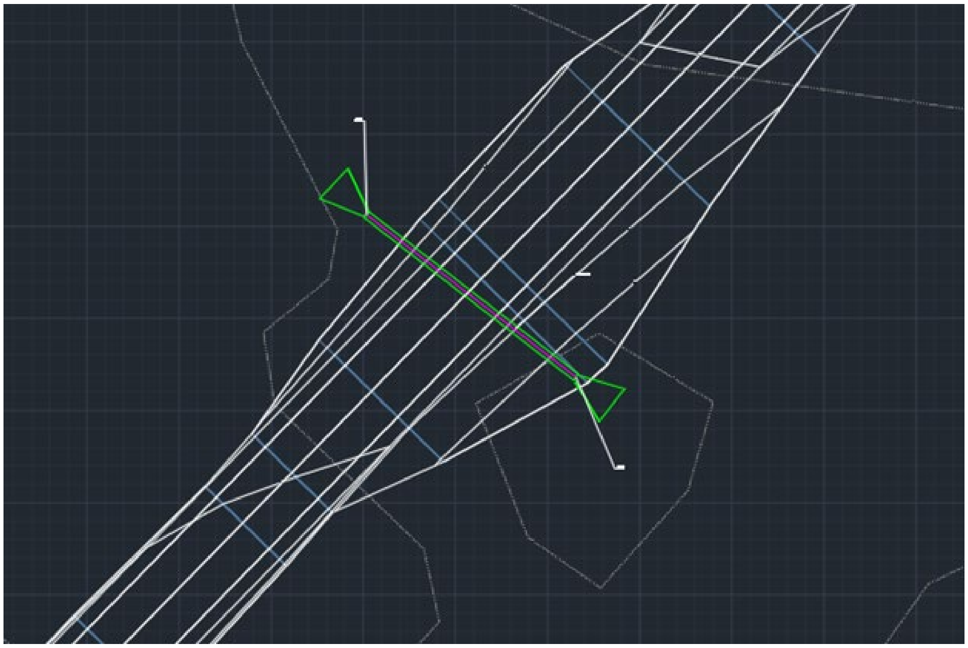
Appendix E.2: Runoff Coefficient Values for Rational Method



Appendix E.3: West Storm Sewer Plan View



Appendix E.4: East Storm Sewer Plan View



Appendix E.5: North Storm Sewer Plan View

Structure	Pipe	Pipe Shape	Pipe Diameter	Start Invert E...	End Invert El...	N Value	3D Length - ...	Slope	Start Inlet/Ri...	End Inlet/Ri...	Structure Type	Known Flow
Structure - 5W	---	---	---	---	---	---	---	---	---	---	Outfall	---
Structure - 4W	Pipe - 4W	Circular	12.000"	910.500'	910.200'	0.013	35.470'	0.85%	915.190'	911.450'	Grate inlet	0.247 cubic f
Structure - 3W	Pipe - 3W	Circular	12.000"	911.390'	910.500'	0.013	118.442'	0.75%	915.390'	915.190'	Grate inlet	0.247 cubic f
Structure - 2W	Pipe - 2W	Circular	12.000"	912.530'	911.390'	0.013	155.457'	0.73%	915.530'	915.390'	Grate inlet	0.165 cubic f
Structure - 1W	Pipe - 1W	Circular	12.000"	914.590'	912.530'	0.013	74.786'	2.76%	917.590'	915.530'	Curb inlet	0.680 cubic f

Appendix E.6: West Storm Sewer Details

Pipe	Pipe Diameter	Pipe Flow	Velocity	Pipe Slope	Performance	Structure	Spread	Inlet Depth
Pipe - 4W	12.000"	1.339 cubic f	3.940 ft/s	0.85%	Normal	Structure - 4	23.461"	1.173"
Pipe - 3W	12.000"	1.092 cubic f	3.582 ft/s	0.75%	Normal	Structure - 3	23.461"	1.173"
Pipe - 2W	12.000"	0.845 cubic f	3.295 ft/s	0.73%	Normal	Structure - 2	20.168"	1.008"
Pipe - 1W	12.000"	0.680 cubic f	4.921 ft/s	2.76%	Normal	Structure - 1	68.886"	2.098"

Appendix E.7: West Storm Sewer Gravity Analysis Results

Pipe - 1W	
HGL Up	914.822'
HGL Down	913.037'
EGL Up	915.198'
EGL Down	913.077'
Invert Up	914.590'
Invert Down	912.530'

Structure - 1W	
Structure Type	Curb inlet
Rim Elevation	917.590'
HGL	915.198'
EGL	915.198'
Flow	0.680 cubic feet per second
Captured Flow	0.680 cubic feet per second
Bypass Flow	0.000 cubic feet per second

Appendix E.8: West Storm Sewer – Pipe 1 Details

Pipe - 2W	
HGL Up	912.892'
HGL Down	912.000'
EGL Up	913.061'
EGL Down	912.040'
Invert Up	912.530'
Invert Down	911.390'

Structure - 2W	
Structure Type	Grate inlet
Rim Elevation	915.530'
HGL	913.061'
EGL	913.061'
Flow	0.165 cubic feet per second
Captured Flow	0.139 cubic feet per second
Bypass Flow	0.026 cubic feet per second

Appendix E.9: West Storm Sewer – Pipe 2 Details

Pipe - 3W	
HGL Up	911.802'
HGL Down	911.278'
EGL Up	912.001'
EGL Down	911.319'
Invert Up	911.390'
Invert Down	910.500'

Structure - 3W	
Structure Type	Grate inlet
Rim Elevation	915.390'
HGL	912.024'
EGL	912.024'
Flow	0.247 cubic feet per second
Captured Flow	0.247 cubic feet per second
Bypass Flow	0.000 cubic feet per second

Appendix E.10: West Storm Sewer – Pipe 3 Details

Pipe - 4W	
HGL Up	910.947'
HGL Down	910.647'
EGL Up	911.188'
EGL Down	910.888'
Invert Up	910.500'
Invert Down	910.200'

Structure - 4W	
Structure Type	Grate inlet
Rim Elevation	915.190'
HGL	911.302'
EGL	911.302'
Flow	0.247 cubic feet per second
Captured Flow	0.247 cubic feet per second
Bypass Flow	0.000 cubic feet per second

Appendix E.11: West Storm Sewer – Pipe 4 Details

Structure	Pipe	Pipe Shape	Pipe Diameter	Start Invert E...	End Invert El...	N Value	3D Length - ...	Slope	Start Inlet/Ri...	End Inlet/Ri...	Structure Type	Known Flow
FES EAST PLOT	---	---	---	---	---	---	---	---	---	---	Outfall	---
Structure - (1)	Pipe - (1)	Circular	12.000"	912.000'	910.200'	0.013	91.090'	1.98%	915.370'	911.307'	Curb inlet	0.213 cubic f

Appendix E.12: East Storm Sewer Details

Pipe	Pipe Diameter	Pipe Flow	Velocity	Pipe Slope	Performance	Structure	Spread	Inlet Depth
Pipe - (1)	12.000"	0.213 cubic f	3.036 ft/s	1.98%	Normal	Structure - ('	31.772"	1.355"

Appendix E.13: East Storm Sewer Gravity Analysis

Pipe - (1)	
HGL Up	912.145'
HGL Down	910.345'
EGL Up	912.288'
EGL Down	910.488'
Invert Up	912.000'
Invert Down	910.200'

Structure - (1)	
Structure Type	Curb inlet
Rim Elevation	915.370'
HGL	912.288'
EGL	912.288'
Flow	0.213 cubic feet per second
Captured Flow	0.213 cubic feet per second
Bypass Flow	0.000 cubic feet per second

Appendix E.14: East Storm Sewer – Pipe 1 Details

Structure	Pipe	Pipe Shape	Pipe Diameter	Start Invert E...	End Invert El...	N Value	3D Length - ...	Slope	Start Inlet/Rim ...	End Inlet/Rim Elevation	Known Flow
Structure - (2)	---	---	---	---	---	---	---	---	---	---	---
Structure - (1)	Pipe - (1)	Circular	12.000"	915.000'	914.000'	0.013	35.943'	2.78%	916.107'	915.107'	1.620 cubic f

Appendix E.15: North Storm Sewer Details

Pipe	Pipe Diameter	Pipe Flow	Velocity	Pipe Slope	Performance	Structure
Pipe - (1)	12.000"	1.620 cubic f	6.435 ft/s	2.78%	Normal	Structure - (1)

Appendix E.16: North Storm Sewer Gravity Analysis

Pipe - (1)	
HGL Up	915.357'
HGL Down	914.357'
EGL Up	916.001'
EGL Down	915.001'
Invert Up	915.000'
Invert Down	914.000'

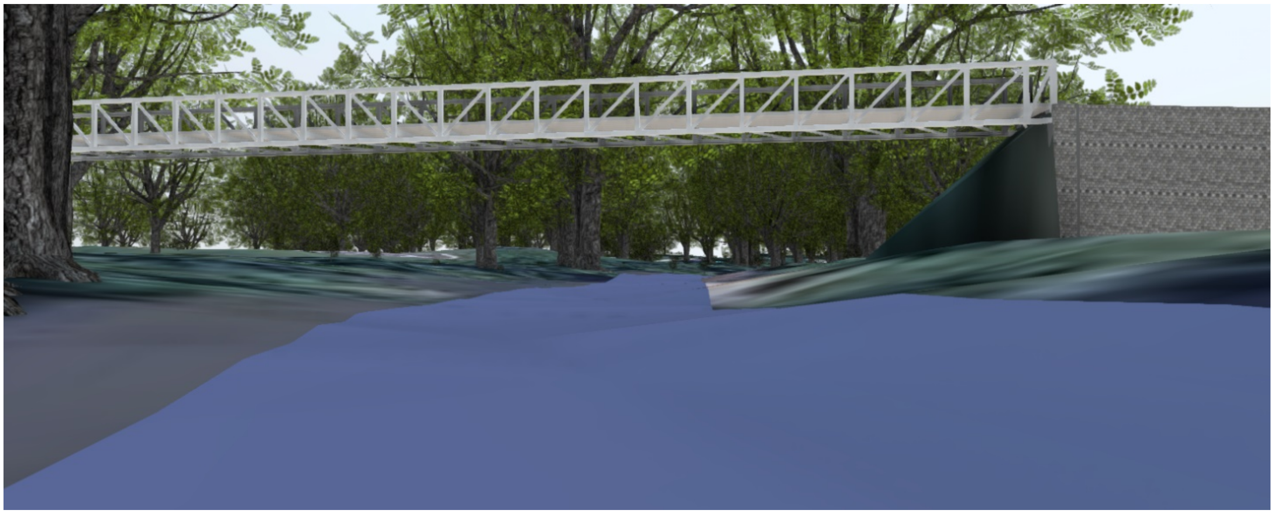
Structure - (1)	
Structure Type	<none>
Rim Elevation	916.107'
HGL	916.001'
EGL	916.001'

Appendix E.17: North Storm Sewer – Pipe 1 Details

Appendix F: Design Drawings

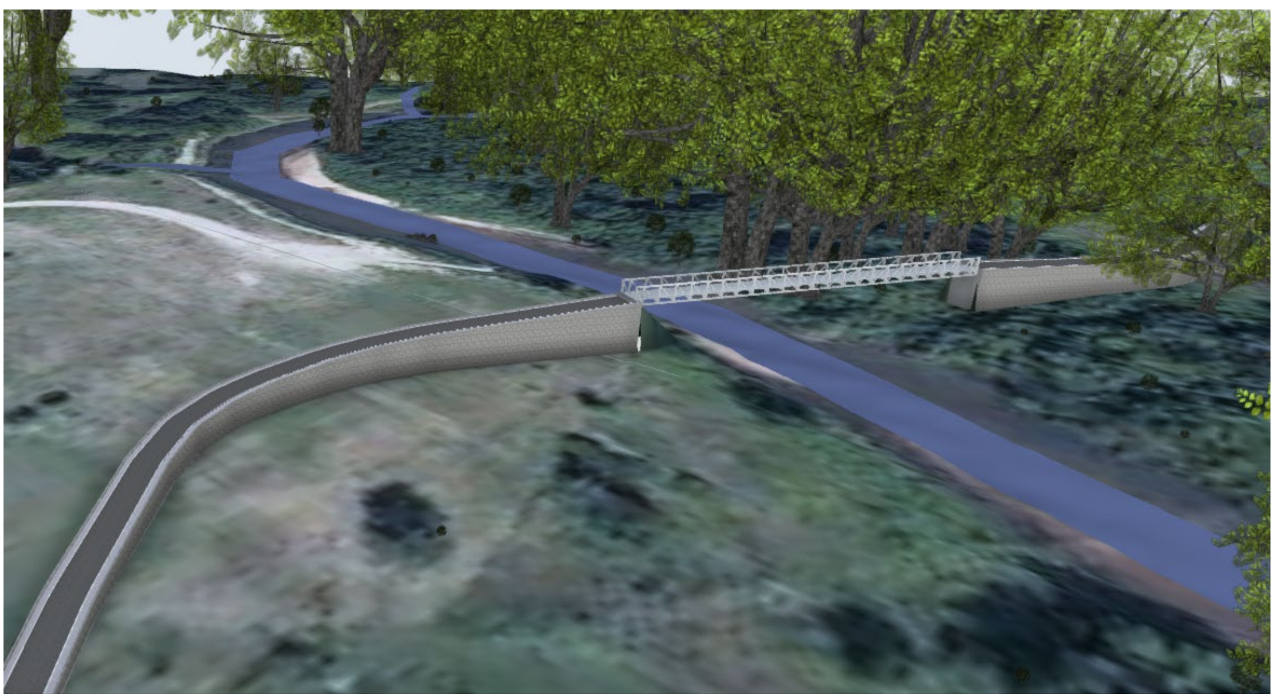
All detailed design drawings are included in the attached drawing set.

Appendix G: Design Renderings



Appendix G.1: Infraworks Rendering (View from South)

Appendix G.2: Infraworks Rendering (Aerial View from North)



Appendix H: Technical Calculations

Appendix H contains all calculations that were used in the design of the pedestrian bridge, retaining wall, natural stone steps and storm sewers.

H.1 Pedestrian Bridge Design

1.1 Settlement/Stability Analysis

Soil Properties

Soil (in-situ, assumed):

Unit weight:	$\gamma_{insitu} := 110$ **pcf**
Saturated unit weight:	$\gamma_{sat} := 125$ **pcf**
Unit weight of water:	$\gamma_{water} := 62.4$ **pcf**
Effective unit weight:	$\gamma_{eff} := \gamma_{sat} - \gamma_{water} = 62.6$ **pcf**
Active pressure coefficient:	$K_a := 0.4$
Internal friction angle:	$\phi := 30$ **deg**
Cohesion:	$c' := 0$ **psf**

Backfill (Granular):
Crushed Stone Gravel

Unit weight:	$\gamma_{backfill} := 120$ **pcf**
Active pressure coefficient:	$K_{abackfill} := 0.33$
Passive pressure coefficient:	$K_{pbackfill} := 3.0$
Internal friction angle:	$\phi := 35$ **deg**

	$+\Delta H/H$	$-\Delta H/H$	K_o	K_a	K_p
Granular	0.0005–0.002	0.005–0.01	0.5	0.33	3.0
Cohesive	0.01–0.02	0.02–0.04	0.6	0.4	2.4

Footing Dimensions:

Width:	$B := 10$ **ft**
Length:	$L := 14$ **ft**
Thickness:	$t_f := 3$ **ft**

Footing Depths:

Slab thickness:	$t_{slab} := 0.5$ **ft**
Backwall height:	$h_{bw} := 2.5$ **ft**
Stem height:	$h_{stem} := 20$ **ft**
Footing depth:	$D_f := h_{bw} + h_{stem} + t_f + t_{slab} = 26$ **ft**

Applied Loads:

Bridge weight (w/out deck):	$BW := 260.1$ **kip**
Safety features:	$SF := 8.178$ **kip**
Live load:	$LL := 82.8$ **kip**

Dead load: $DL := 0.25 \cdot (BW + SF) = 67.07\ \mathbf{kip}$

Vehicle load: $VL := 10\ \mathbf{kip}$

Bearing Capacity Analysis

Vesic's Bearing Capacity Equation:

$$q_n = c' N_q \left(s_c d_c i_c b_c g_c\right) + q_s N_q \left(s_q d_q i_q b_q g_q\right) + \frac{1}{2} B \gamma N_\gamma \left(s_\gamma d_\gamma i_\gamma b_\gamma g_\gamma\right)$$

Bearing Capacity Factors:

$$N_q := e^{\pi \cdot \tan(\phi)} \cdot \left(\tan\left(45\ \mathbf{deg} + \frac{\phi}{2}\right)\right)^2 = 18.401$$

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

$$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan(\phi) = 22.402$$

Shape Factors:

$$s_c := 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right) = 1.436$$

$$s_q := 1 + \left(\frac{B}{L}\right) \cdot \tan(\phi) = 1.412$$

$$s_\gamma := 1 - 0.4 \cdot \left(\frac{B}{L}\right) = 0.714$$

Depth Factors:

$$\frac{D_f}{B} = 2.6$$

$$k := \operatorname{atan}\left(\frac{D_f}{B}\right) = 1.204$$

$$d_c := 1 + 0.4 \cdot k = 1.481$$

$$d_q := 1 + 2 \cdot k \cdot \tan(\phi)\ (1 - \sin(\phi))^2 = 1.347$$

$$d_\gamma := 1$$

Load Inclination Factors:

$i_c := 1$ $\qquad i_\gamma := 1$ $\qquad i_q := 1$

Base Inclination Factors:

$b_c := 1$ $\quad b_q := 1$ $\quad b_\gamma := 1$

Ground Inclination Factor:

$\beta := 10$

$g_c := 1 - \dfrac{\beta}{147} = 0.932$

$g_q := (1 - \tan(\beta \cdot \mathbf{deg}))^2 = 0.678$

$g_\gamma := g_q = 0.678$

Soil Surcharge:

$q_s := \gamma_{backfill} \cdot D_f = 3120\ \mathbf{psf}$

Allowable Bearing Pressure:

$$q_n := q_s \cdot N_q \cdot (s_q \cdot d_q \cdot i_q \cdot b_q \cdot g_q) + \frac{1}{2} \cdot B \cdot \gamma_{insitu} \cdot N_\gamma \cdot (s_\gamma \cdot d_\gamma \cdot i_\gamma \cdot b_\gamma \cdot g_\gamma)$$

$q_n = 80.098\ \mathbf{ksf}$

Dead Load Eccentricity:

$e_{dl} := 13\ \mathbf{in}$

Reduction Factor Due to Eccentricity:

$$R_e := 1 - \left(\frac{e_{dl}}{B}\right)^{0.5} = 0.671$$

Reduced Allowable Bearing Pressure:

$q_n' := q_n \cdot (1 - R_e) = 26.364\ \mathbf{ksf}$

Applied Bearing Pressure:

$Area_{footing} := B \cdot L = 140\ \mathbf{ft}^2$

$Total_{load} := 2 \cdot DL + LL = 216.939\ \mathbf{kip}$

$q_{applied} := \dfrac{Total_{load}}{Area_{footing}} = 1.55\ \mathbf{ksf}$

Bearing Capacity Safety Factor Check:

Factor of Safety: $FS_q := 3$

$q_n' = 26.364\ \mathbf{ksf}$

$FS_q \cdot q_{applied} = 4.649\ \mathbf{ksf}$

$FS_{true} := \dfrac{q_n'}{q_{applied}} = 17.014$

As FS*q < qn' , the design is acceptable

Overturning Stability Analysis

Active Earth Pressure:

$P_a := 0.5 \cdot \gamma_{backfill} \cdot K_{abackfill} \cdot D_f^{\ 2} = 13.385\ \mathbf{klf}$

$h_a := \dfrac{D_f}{3} = 8.667\ \mathbf{ft}$

Overturning Moments About Footing Heel:

Active Earth Pressure:

$M_o := P_a \cdot (h_a \cdot \mathbf{ft}) = 116.002\ \mathbf{kip} \cdot \mathbf{ft}$

Live & Dead Load:

$M_L := LL \cdot (5\ \mathbf{ft} - 13\ \mathbf{in}) = 324.3\ \mathbf{kip} \cdot \mathbf{ft}$

$M_D := DL \cdot (5\ \mathbf{ft} - 13\ \mathbf{in}) = 262.689\ \mathbf{kip} \cdot \mathbf{ft}$

$M_r := M_L + M_D = 586.989\ \mathbf{kip} \cdot \mathbf{ft}$

Overturning Factor of Safety:

$FS_o := \frac{M_r}{M_o} = 5.06$

As FSo is > 3, the design is acceptable

Sliding Stability Analysis:

Vertical Loading:

$P_{total} := Total_{load} = 216.939\ \mathbf{kip}$

Frictional Resistance:

$F_{max} := P_{total} \cdot \tan(\phi) + B \cdot L \cdot c' = 125.25\ \mathbf{kip}$

Passive Pressure:

$P_p := 0.5 \cdot \gamma_{insitu} \cdot (5\ \mathbf{ft})^2 \cdot K_{pbackfill} = 4.125\ \frac{\mathbf{kip}}{\mathbf{ft}}$

Factor of Safety Against Sliding:

$FS_v := \frac{F_{max}}{P_a \cdot \mathbf{ft}} = 9.358$

> 1.5 ok

Settlement Analysis Using Bowle's Method:

Assumptions for In-situ Elastic Soil Properties:

Modulus of Elasticity: $E := 3\ \mathbf{ksi}$

Poisson's ratio: $\mu := 0.3$

Settlement (Footing Center):

$H_{eq} := 5 \cdot B = 50\ \mathbf{ft}$

$q_{net} := q_{applied} = 1.55\ \mathbf{ksf}$

$\alpha := 4$ $\qquad D := 5\ \mathbf{ft}$

$B' := \frac{B}{2} = 5\ \mathbf{ft}$ $\qquad L' := \frac{L}{2} = 7\ \mathbf{ft}$

$M := \frac{L'}{B'} = 1.4$ $\qquad N := \frac{H_{eq}}{B'} = 10$

$$Depth_{Ratio} := \frac{D}{B} = 0.5$$

$$Length_{Ratio} := \frac{L}{B} = 1.4$$

$I_f := 0.65$

Bowles textbook, pg 303. $\mu = 0.3$ from chart we got the value to the left.

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

$$I_1 = 0.57$$

$$I_2 := \frac{N}{2 \cdot \pi} \cdot \operatorname{atan}\left(\frac{M}{N \cdot \sqrt{M^2 + N^2 + 1}} \right) = 0.022$$

$$I_s := I_1 + \left(\frac{1 - 2 \cdot \mu}{1 - \mu} \right) \cdot I_2 = 0.583$$

$$\delta_{ERigidCenter} := 0.93 \cdot \left(\alpha \cdot I_s \cdot I_f \cdot \left(\frac{q_{net} \cdot \left(1 - \mu^2\right)}{E} \right) \cdot B' \right) = 0.276 \ \mathbf{in}$$

<u>Settlement (Corners):</u>

$\alpha := 1$

$B' := B = 10 \ \mathbf{ft}$ $L' := L = 14 \ \mathbf{ft}$

$M := \frac{L'}{B'} = 1.4$ $N := \frac{H_{eq}}{B'} = 5$

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

$$I_1 = 0.487$$

$$I_2 := \frac{N}{2 \cdot \pi} \cdot \operatorname{atan}\left(\frac{M}{N \cdot \sqrt{M^2 + N^2 + 1}} \right) = 0.042$$

$$I_s := I_1 + \left(\frac{1 - 2 \cdot \mu}{1 - \mu}\right) \cdot I_2 = 0.511$$

$$\delta_{Corner} := 0.93 \cdot \left(\alpha \cdot I_s \cdot I_f \cdot \left(\frac{q_{net} \cdot \left(1 - \mu^2\right)}{E}\right) \cdot B'\right) = 0.121 \text{ in}$$

Foundation center and corner selttlement are very small, the design is ok.
Settling limits are approximately 0.5 inches for footings.

1.2 Abutment Structural Analysis

Abutment Details:

Thickness of stem:	$t_{stem} := 3\ \mathbf{ft}$
Length of toe:	$l_{toe} := 4\ \mathbf{ft}$
Length of heel:	$l_{heel} := 3\ \mathbf{ft}$
Thickness of footing:	$t_{footing} := 3\ \mathbf{ft}$
Concrete cover:	$c_c := 3\ \mathbf{in}$
Stem steel:	#6 bar at 12 OC
Heel steel:	#6 bar at 12 OC
Transverse reinforcing:	#6 bar at 12 OC
Yield strength of steel:	$f_y := 60\ \mathbf{ksi}$
Resistance factor for tension controlled concrete:	$\phi_f := 0.90$
Resistance factor for shear:	$\phi_v := 0.90$
Concrete weight:	$w_c := 150\ \mathbf{pcf}$

Loading and Soil Data:

Allowable Bearing Capacity with Factor of Safety:

$$q_b := \frac{q_n'}{FS_q} = 8.788\ \mathbf{ksf}$$

Self Pressure:

$$q_{self} := t_{footing} \cdot w_c + \gamma_{backfill} \cdot \left(D_f - t_{footing}\right) = 3.21\ \mathbf{ksf}$$

Allowable Soil Pressure:

$$q_{allowable} := q_b - q_{self} = 5.578\ \mathbf{ksf}$$

Required Footing Area:

$$A_{needed} := \frac{P_{total}}{q_{allowable}} = 38.893\ \mathbf{ft}^2$$

Footing Weight:

$W_{footing} := w_c \cdot B \cdot L \cdot t_{footing} = 63 \textbf{ kip}$

Overburden Weight:

$W_{overburden} := 0.5 \cdot \gamma_{backfill} \cdot B \cdot L \cdot \left(D_f - t_{footing}\right) = 193.2 \textbf{ kip}$

Soil Pressure:

$$q_{soil} := \frac{P_{total} + W_{footing} + W_{overburden}}{L \cdot B} = 3.38 \textbf{ ksf}$$

$q_{allowable} = 5.578 \textbf{ ksf}$

Upward Pressure On the Footing for Flexural and Shear Design:

$P_u := \max\left(1.4 \cdot DL, 1.2 \cdot DL + 1.6\ LL\right) = 212.963 \textbf{ kip}$

Upward Pressure From Soil:

$$q_u := \frac{P_u}{Area_{footing}} = 1.521 \textbf{ ksf}$$

Steel Cover and Diameters:

$d_b := 0.75 \textbf{ in}$ #6 bars

$c_o := 3 \textbf{ in}$

$c_1 := c_o + 0.5 \cdot d_b = 3.375 \textbf{ in}$

$c_2 := c_o + d_b + 0.5 \cdot d_b = 4.125 \textbf{ in}$

$c_{avg} := 0.5 \cdot \left(c_1 + c_2\right) = 3.75 \textbf{ in}$

Effective Depth of Footing:

$d := t_{footing} - c_{avg} = 32.25\ \mathbf{in}$

One Shear at Critical Section - Distance d From Stem:

$V_{uOneWay} := q_u \cdot B \cdot \left(\frac{L - c_1}{2} - d\right) = 63.461\ \mathbf{kip}$

$\lambda := 1$

$V_c := 2 \cdot \lambda \cdot \sqrt{4000}\ \mathbf{psi} \cdot B \cdot d = 489.521\ \mathbf{kip}$

$\phi V_c := 0.75 \cdot V_c = 367.14\ \mathbf{kip}$ Vu < Vc

Punching Shear:

$V_{uPunch} := q_u \cdot \left(Area_{footing} - \left(c_1 + d\right)\left(c_2 + d\right)\right) = 199.274\ \mathbf{kip}$

$\beta := \frac{c_1}{c_2} = 0.818$ $\alpha_s := 40$

$b_o := 2 \cdot \left(c_1 + d\right) + 2 \cdot \left(c_2 + d\right) = 12\ \mathbf{ft}$

$V_{cPunch} := \min\left(4, \left(2 + \frac{4}{\beta}\right), \left(2 + \alpha_s \cdot \frac{d}{b_o}\right)\right) \cdot \lambda \cdot \sqrt{4000}\ \mathbf{psi} \cdot b_o \cdot d = \left(1.175 \cdot 10^3\right)\ \mathbf{kip}$

$\phi V_{cPunch} := 0.75 \cdot V_{cPunch} = 881.137\ \mathbf{kip}$ Vu < Vc

Flexural Reinforcement:

$b := B = 120\ \mathbf{in}$ Width

Bending Moment:

$M_u := q_u \cdot B \cdot \left(\frac{L - c_1}{2}\right) \cdot \left(\frac{L - c_2}{4}\right) = 356.232\ \mathbf{kip \cdot ft}$

Preliminary Steel:

$A_s = \dfrac{M_u}{4 \cdot d}$ $\qquad A_s := 4.42\ \mathbf{in}^2$

$A_b := 0.44\ \mathbf{in}^2$

$N_{bars} := \dfrac{A_s}{A_b} = 10.045$ use 11 #6 bars

Minimum Steel Area in Slab (S&T):

$\rho_{min} := 0.0018$

$A_s := 11 \cdot A_b = 4.84\ \mathbf{in}^2$ area provided

$A_{smin} := \rho_{min} \cdot b \cdot t_{footing} = 7.776\ \mathbf{in}^2$ minimum area required

$A_s := 18 \cdot A_b = 7.92\ \mathbf{in}^2$ 18 bar required

Bar Spacing Check:

$s_{max} := \min\left(18\ \mathbf{in}, 3 \cdot t_f\right) = 18\ \mathbf{in}$ max spacing allowed

$s := \dfrac{b}{18} = 6.667\ \mathbf{in}$ bar spacing provided

Flexural Strength of Rectangular Section Check:

$\beta_1 := 0.85$ $\qquad f'_c := 4000\ \mathbf{psi}$

$E_s := 29000\ \mathbf{ksi}$ $\qquad \varepsilon_{ty} := \dfrac{f_y}{E_s} = 0.002$

$$A_{sTensionControlled} := \frac{0.85 \cdot f'_c \cdot b \cdot \beta_1}{f_y} \cdot \left(\frac{3 \cdot d}{8}\right) = 69.902\ \mathbf{in}^2$$

$$a := \frac{A_s \cdot f_y}{0.85 \cdot f'_c \cdot b} = 1.165\ \mathbf{in}$$

$$M_n := A_s \cdot f_y \cdot \left(d - \frac{a}{2}\right) = 1254.039\ \mathbf{kip} \cdot \mathbf{ft}$$

$\phi M_f := 0.9 \cdot M_n = 1128.635 \ \mathbf{kip \cdot ft}$

$M_u = 356.232 \ \mathbf{kip \cdot ft}$ Design is Acceptable

Rebar Development Length Check:

$\psi_t := 1$ $\psi_e := 1$ $K_{tr} := 0$

$\psi_s := 1$ $\psi_g := 1$

$$R_s := \frac{M_u}{0.9 \cdot M_n} = 0.316$$

$$l_d := \max\left(12 \ \mathbf{in}, \left(\frac{1}{25}\right) \cdot R_s \cdot \frac{f_y}{\lambda \cdot \min\left(100 \ \mathbf{psi}, \sqrt{4000} \ \mathbf{psi}\right)} \cdot \psi_g \cdot \min\left(\psi_t \cdot \psi_e, 1.7\right) \cdot d_b\right)$$

$l_d = 1 \ \mathbf{ft}$

Analysis of Footing as Column:

$Column_{width} := 1 \ \mathbf{ft}$

$A_1 := Column_{width} \cdot Column_{width} = 144 \ \mathbf{in}^2$

$l := \min\left(L, 2 \cdot t_{footing} + Column_{width} + 2 \cdot t_{footing}\right) = 13 \ \mathbf{ft}$

$A_2 := l^2 = 169 \ \mathbf{ft}^2$

$N_1 := 0.65 \cdot \left(0.85 \cdot f'_c \cdot A_1\right) = 318.24 \ \mathbf{kip}$

$$N_2 := 0.65 \cdot \min\left(0.85 \cdot f'_c \cdot A_1 \cdot \sqrt{\frac{A_2}{A_1}}, 2 \cdot \left(0.85 \cdot f'_c \cdot A_1\right)\right) = 636.48 \ \mathbf{kip}$$

$\phi P_{nb} := \min\left(N_1, N_2\right) = 318.24 \ \mathbf{kip}$

$P_u := \max\left(1.2 \cdot DL, 1.2 \cdot DL + 1.6 \ LL\right) = 212.963 \ \mathbf{kip}$ As Pnb > Pu, the design is acceptable

Minimum Dowel Area (Dowel Bar Connection to Stem):

$A_{dminL} := 0.005 \cdot A_1 = 0.72\ \mathbf{in}^2$

$A_{b8} := 0.79\ \mathbf{in}^2$

provide at leat 2 #8 bars

$A_{sdowel} := 2 \cdot A_{b8} = 1.58\ \mathbf{in}^2$

$d_{bdowel} := 1.0\ \mathbf{in}$

Development of Dowel Bar (Compression):

$d := 1.0\ \mathbf{in}$

$f_y := 60000\ \frac{\mathbf{lb}}{\mathbf{in}^2}$

$$l_{dc} := \max\left(8\ \mathbf{in}, \frac{0.02 \cdot f_y \cdot d_b}{\lambda \cdot \min\left(100\ \frac{\mathbf{lb}}{\mathbf{in}^2}, \sqrt{4000}\ \frac{\mathbf{lb}}{\mathbf{in}^2}\right)}, 0.0003\ \frac{\mathbf{in}^2}{\mathbf{lb}} \cdot f_y \cdot d_b\right) = 14.23\ \mathbf{in}$$

Footing Thickness Check:

$t_f = 3\ \mathbf{ft}$

$h_{req} := l_{dc} + d_{bdowel} + d_b + 3\ \mathbf{in} = 18.98\ \mathbf{in}$

Extend dowel bars 2 feet into the stem

$$splice := \max\left(12\ \mathbf{in}, l_{dc}, 0.0005\ \frac{\mathbf{in}^2}{\mathbf{lb}} \cdot f_y \cdot d_b\right) = 22.5\ \mathbf{in}$$

1.3 Superstructure

Variables & Member Selection

Geometry

Span:	$S := 184\ \mathbf{ft}$	
Deck width:	$W_{deck} := 10\ \mathbf{ft}$	
CL-CL trusses:	$CL_{truss} := 10.66\ \mathbf{ft}$	
Width of bay:	$W_{bay} := 8\ \mathbf{ft}$	$W_{bay2} := 4\ \mathbf{ft}$
height of bay:	$H_{bay} := 9\ \mathbf{ft}$	
Clear distance between bottom chord:	$CLR_{chord} := 9\ \mathbf{ft} + 8\ \mathbf{in} = 9.667\ \mathbf{ft}$	

Material Properties

concrete unit weight (normal weight): $\gamma_c := 150\ \mathbf{pcf}$

$F_y := 65\ \mathbf{ksi}$

Member Selection

Chord (HSS 9x9x5/8):	$A_{chord} := 18.7\ \mathbf{in}^2$	$w_{chord} := 67.82\ \mathbf{plf}$	$H_{tchord} := 9\ \mathbf{in}$	
Verticals (HSS 8x8x3/8):	$A_{vert} := 10.4\ \mathbf{in}^2$	$w_{vert} := 37.69\ \mathbf{plf}$	$H_{tVert} := 8\ \mathbf{in}$	$I_x := 100\ \mathbf{in}^4$
End posts (HSS 9x9x5/8):	$A_{post} := 18.7\ \mathbf{in}^2$	$w_{post} := 67.82\ \mathbf{plf}$	$H_{tPost} := 9\ \mathbf{in}$	
Diagonals (HSS 6x4x1/4):	$A_{diagonal} := 4.3\ \mathbf{in}^2$	$w_{diag} := 19.08\ \mathbf{plf}$	$H_{tDiag} := 6\ \mathbf{in}$	$h_{Diag} := 4\ \mathbf{in}$
Floor beam (W 14x43):	$I_{xflr} := 428\ \mathbf{in}^4$	$d_{flr} := 13.7\ \mathbf{in}$	$S_{xflr} := 62.6\ \mathbf{in}^3$	$w_{flr} := 43\ \mathbf{plf}$
X-brace (HSS 4x4x0.25):	$w_{xbrace} := 14.83\ \mathbf{plf}$	$s := W_{bay}$		

Deck

$d_{deck} := 6\ \mathbf{in}$

Member Lengths

$$L_{post} := H_{bay} - 2 \cdot H_{tchord} = 7.5\ \mathbf{ft}$$

$$L_{chord} := 8\ \mathbf{ft}$$

$$L_{Diag} := \sqrt{W_{bay}^{\ 2} + H_{bay}^{\ 2}} = 12.042\ \mathbf{ft}$$

$$L_{Diag2} := \sqrt{W_{bay2}^{\ 2} + H_{bay}^{\ 2}} = 9.849\ \mathbf{ft}$$

$$L_{xbrace} := \sqrt{CLR_{chord}^{2} + (W_{bay})^{2}} = 12.548\ \mathbf{ft}$$

$$L_{xbrace2} := \sqrt{CLR_{chord}^{2} + (W_{bay2})^{2}} = 10.462\ \mathbf{ft}$$

<u>Railing</u>

Safety Rail (HSS 2x1x1/8): $w_{sRail} := 2.2\ \mathbf{plf}$

Rub Rail (2x8 treated wood): $w_{rubRail} := 2.643\ \mathbf{plf}$

Toe Plate (6x5/16): $\gamma_{st} := 0.49\ \dfrac{\mathbf{kip}}{\mathbf{ft}^3}$

$$A_{toePL} := 6\ \mathbf{in} \cdot \frac{5}{16}\ \mathbf{in} = 1.875\ \mathbf{in}^2$$

$$w_{toePL} := A_{toePL} \cdot \gamma_{st} = 6.38\ \mathbf{plf}$$

Applied Loading

<u>VEHICLE LOAD</u>

Vehicle: $veh := \mathbf{if}\left(W_{deck} \le 10\ \mathbf{ft}, \text{“H5”}, \text{“H10”}\right) = \text{“H5”}$

Front axel load: $w_{Faxel} := \mathbf{if}\left(veh = \text{“H10”}, 4\ \mathbf{kip}, 2\ \mathbf{kip}\right) = 2\ \mathbf{kip}$

Rear axel load: $w_{Raxel} := \mathbf{if}\left(veh = \text{“H10”}, 16\ \mathbf{kip}, 8\ \mathbf{kip}\right) = 8\ \mathbf{kip}$

axel spacing: $s_{axel} := 14\ \mathbf{ft}$

wheel spacing: $s_{wheel} := 6\ \mathbf{ft}$

<u>Horizontal Wind</u>

$V_B := 100\ \mathbf{mph}$ $V_{30} := 100\ \mathbf{mph}$ $V_o := 10.9\ \mathbf{mph}$ $Z := 30\ \mathbf{ft}$ $Z_o := 3.28\ \mathbf{ft}$

Base pressure for windward truss: $P_{BtrussW} := 0.05\ \mathbf{ksf}$
Base pressure for leeward truss: $P_{BtrussL} := 0.025\ \mathbf{ksf}$
Base pressure for beam (windward): $P_{Bbeam} := 0.025\ \mathbf{ksf}$
Base pressure for flat surface/ deck (windward): $P_{Bflat} := 0.04\ \mathbf{ksf}$

<u>Horizontal Wind Load</u>

Design wind velocity: $V_{dz} := 2.5 \cdot V_o \cdot \left(\dfrac{V_{30}}{V_B}\right) \cdot \ln\left(\dfrac{Z}{Z_o}\right) = 60.314\ \mathbf{mph}$

Design wind pressure (windward truss): $P_{DtrussW} := P_{BtrussW} \cdot \left(\frac{V_{dz}}{V_B}\right)^2 = 18.189$ **psf**

Design wind pressure (leeward truss): $P_{DtrussL} := P_{BtrussL} \cdot \left(\frac{V_{dz}}{V_B}\right)^2 = 9.094$ **psf**

Design wind pressure (flat surface): $P_{Dbeam} := P_{Bflat} \cdot \left(\frac{V_{dz}}{V_B}\right)^2 = 14.551$ **psf**

Projected Vertical Area (plf)

Chords: $A_{pvChord} := H_{tchord} \cdot \frac{L_{chord}}{W_{bay}} = 0.75$ **ft**

Verticals: $A_{pvVert} := H_{tVert} \cdot \frac{L_{post}}{W_{bay}} = 0.625$ **ft**

Vertical (1st interior): $A_{pvVert1} := H_{tVert} \cdot \frac{L_{post}}{0.5 \cdot W_{bay} + 0.5 \cdot W_{bay2}} = 0.833$ **ft**

Diagonals (Internal): $A_{pvDiag} := H_{tDiag} \cdot \frac{L_{Diag}}{W_{bay}} = 0.753$ **ft**

Diagonals (external): $A_{pvDiag2} := H_{tDiag} \cdot \frac{L_{Diag2}}{W_{bay2}} = 1.231$ **ft**

End Post: $A_{pvPost} := H_{tPost} \cdot \frac{L_{post}}{0.5 \cdot W_{bay2}} = 2.813$ **ft**

Deck: $A_{pvDeck} := 0.5$ **ft**

Loads for Abutments

$w_{Deck} := d_{deck} \cdot \gamma_c = 75$ **psf**

Weight of Each Truss

$w_{Dtruss} := (22 \cdot L_{Diag} \cdot w_{diag}) + (44 \cdot L_{chord} \cdot w_{chord}) + (4 \cdot W_{bay2} \cdot w_{chord}) + (23 \cdot L_{post} \cdot w_{vert}) + (2 \cdot L_{post} \cdot w_{post}) + (L_{Diag2} \cdot w_{diag} \cdot 2) = 37.907$ **kip**

Weight of Rails

$$w_{rail} := \left(w_{toePL} + 6 \cdot w_{sRail} + w_{rubRail}\right) \cdot S = 4.089 \ \mathbf{kip}$$

Weight of Floor System

$$w_{dFloor} := \left(W_{deck} \cdot S \cdot w_{Deck}\right) + \left(22 \cdot L_{xbrace} \cdot w_{xbrace}\right) + \left(25 \cdot w_{xbrace} \cdot CLR_{chord}\right) + \left(2 \cdot L_{xbrace2} \cdot w_{xbrace}\right) + \left(W_{deck} \cdot w_{flr} \cdot 25\right) = 156.738 \ \mathbf{kip}$$

$$w_{dFloor} = \left(1.567 \cdot 10^{5}\right) \ \mathbf{lbf}$$

$$w_{dflr} := \frac{w_{dFloor}}{2 \cdot S} = 425.919 \ \mathbf{plf}$$ <==For robot

Pedestrian Load

$$PL := 90 \ \mathbf{psf}$$

$$W_{PL} := W_{deck} \cdot S \cdot PL = 165.6 \ \mathbf{kip}$$

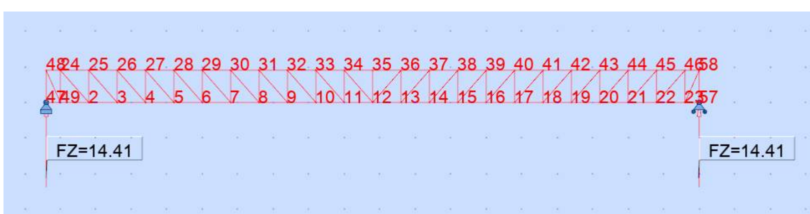
Total Bridge Load

$$R := \left(2 \cdot w_{Dtruss} + w_{dFloor} + 2 \cdot w_{rail}\right) + \left(W_{PL}\right) = 406.33 \ \mathbf{kip}$$ full bridge

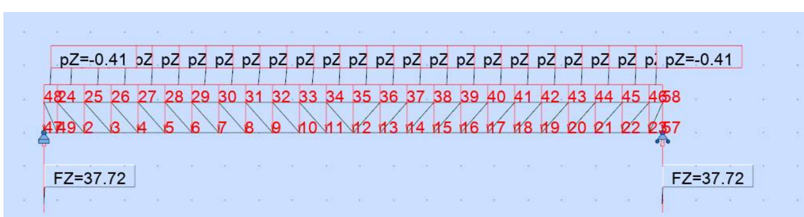
$$R_1 := \frac{R}{4} = 101.583 \ \mathbf{kip}$$ each corner

$$R_2 := \frac{R}{2} = 203.165 \ \mathbf{kip}$$ 1 abutment or truss

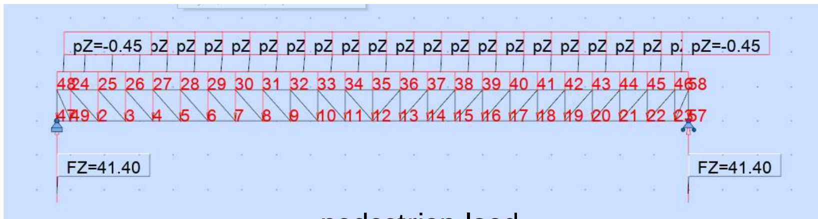
2-D Robot (Input/Output)



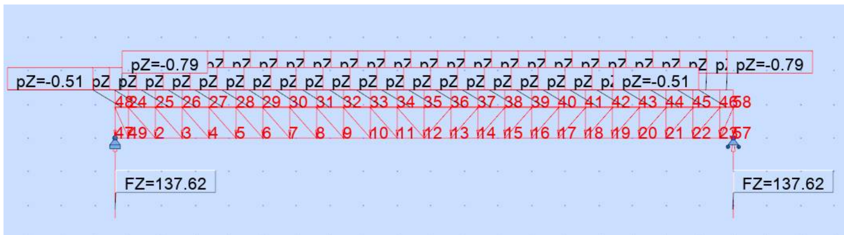
self weight



floor system



pedestrian load



strength 1 combo

<u>Loads on Truss Members</u>

Chords: $F_{Tchord} := 713\ \mathbf{kip}$ Ten. & Comp. (bot/top chord)

$F_{Bchord} := 708\ \mathbf{kip}$

Verticals: $F_{vert} := 120\ \mathbf{kip}$

End Posts: $F_{post} := 126\ \mathbf{kip}$

Diagonals: $F_{diagEXT} := 123\ \mathbf{kip}$ $F_{diagINT} := 171\ \mathbf{kip}$

<u>Design of Floor System</u>

*Iowa DOT: use a concentrated 10,000 lb plus 30% for impact load at mid span

<u>Floor Beams</u>

H5 truck $V_{Live} := 13\ \mathbf{kip}$ assuming load on very edge of deck

$M_{Live} := 65\ \mathbf{kip \cdot ft}$ assuming load at center of deck

Dead Load

$V := w_{Deck} \cdot W_{bay} \cdot (0.5 \cdot W_{deck}) = 3\ \mathbf{kip}$
$M := w_{Deck} \cdot W_{bay} \cdot W_{deck} \cdot (0.5 \cdot W_{deck}) = 30\ \mathbf{kip \cdot ft}$

$V_{floorbeam} := V_{Live} + V = 16\ \mathbf{kip}$
$M_{floorbeam} := M_{Live} + M = 95\ \mathbf{kip \cdot ft}$

Compression Members

Top Chord: HSS 9x9x5/8

Pinned-Pinned connection

$K := 1.0$
$L := 96\ \mathbf{in}$
$k := 1.4$
$F_y := 50\ \mathbf{ksi}$
$E := 29000\ \mathbf{ksi}$
$\phi_c := 0.9$

$b := 7.26\ \mathbf{in}$
$t := 0.625\ \mathbf{in}$
$A_g := 18.7\ \mathbf{in}^2$
$r_x := 3.4\ \mathbf{in}$
$r_y := 3.4\ \mathbf{in}$
$r := \min(r_x, r_y) = 3.4\ \mathbf{in}$

Calculations

$KLR := \frac{K \cdot L}{r} = 28.235$ $\mathbf{if}(KLR \le 120, \text{“ok”}, \text{“not ok”}) = \text{“ok”}$

$\mathbf{Q_1} := \mathbf{if}\left(\frac{b}{t} \le 1.4 \cdot \sqrt{\frac{E}{F_y}}, \text{“compact”}, \text{“not compact”}\right) = \text{“compact”}$

$Q := \mathbf{if}(\mathbf{Q_1} = \text{“compact”}, 1, \text{“calcuate”}) = 1$

$P_{eo} := \pi^2 \cdot \left(\frac{1}{KLR}\right)^2 \cdot \left(\frac{E}{F_y}\right) = 7.18$

$P_o := Q \cdot F_y \cdot A_g = 935\ \mathbf{kip}$

$P_e := \frac{\pi^2 \cdot E \cdot A_g}{KLR^2} = (6.714 \cdot 10^3)\ \mathbf{kip}$

$$P_n := \mathbf{if}\left(P_{eo} \geq 0.44, 0.658^{\left(P_{eo}^{-1}\right)} \cdot P_o, 0.877 \cdot P_e\right) = 882.056\ \mathbf{kip}$$

$$P_{design} := \phi_c \cdot P_n = 793.85\ \mathbf{kip}$$

$$\mathbf{if}\left(P_{design} \geq F_{Tchord}, \text{“ok”}, \text{“re - design”}\right) = \text{“ok”}$$

<u>Verticals:</u> <u>HSS 8x8/3/8</u>

$A_g := 10.4\ \mathbf{in}^2$ $\quad b := 6.95\ \mathbf{in}$

$r_x := 3.1\ \mathbf{in}$ $\quad h := 6.95\ \mathbf{in}$

$r_y := 3.1\ \mathbf{in}$ $\quad t := 0.349\ \mathbf{in}$

$L_{cx} := 7.333\ \mathbf{ft}$ $\quad C_1 := 0.2$

$L_{cy} := 7.333\ \mathbf{ft}$ $\quad C_2 := 1.38$

$F_y := 50\ \mathbf{ksi}$ $\quad \phi := 0.9$

<u>Axial resistance:</u>

$$F_{ex} := \frac{\pi^2 \cdot E}{\left(\frac{L_{cx}}{r_x}\right)^2} = 355.218\ \mathbf{ksi} \qquad F_{ey} := \frac{\pi^2 \cdot E}{\left(\frac{L_{cy}}{r_y}\right)^2} = 355.218\ \mathbf{ksi}$$

$$F_e := \min\left(F_{ex}, F_{ey}\right) = 355.218\ \mathbf{ksi}$$

$$F_{cr} := \mathbf{if}\left(\frac{F_y}{F_e} \leq 2.25, 0.658^{\left(\frac{F_y}{F_e}\right)} \cdot F_y, 0.877 \cdot F_e\right) = 47.139\ \mathbf{ksi}$$

$$\lambda_r := 1.4 \cdot \sqrt{\frac{E}{F_y}} = 33.716$$

$$F_{e1} := \left(C_2 \cdot \frac{\lambda_r}{\left(\frac{b}{t}\right)}\right)^2 \cdot F_y = 272.957\ \mathbf{ksi}$$

$$F_{e2} := \left(C_2 \cdot \frac{\lambda_r}{\left(\frac{h}{t}\right)}\right)^2 \cdot F_y = 272.957\ \mathbf{ksi}$$

$$b_e := \mathbf{if}\left(\frac{b}{t} \leq \lambda_r \cdot \sqrt{\frac{F_y}{F_{cr}}}, b, \left(1 - C_1 \cdot \sqrt{\frac{F_{e1}}{F_{cr}}}\right) \cdot \sqrt{\frac{F_{e1}}{F_{cr}}}\right) = 6.95\ \mathbf{in}$$

$$h_e := \mathbf{if}\left(\frac{h}{t} \leq \lambda_r \cdot \sqrt{\frac{F_y}{F_{cr}}}, h, \left(1 - C_1 \cdot \sqrt{\frac{F_{e2}}{F_{cr}}}\right) \cdot \sqrt{\frac{F_{e2}}{F_{cr}}}\right) = 6.95\ \mathbf{in}$$

$$A_e := A_g - ((b - b_e) \cdot t) - ((h - h_e) \cdot t) = 10.4\ \mathbf{in}^2$$

$$\phi P_n := \phi \cdot F_{cr} \cdot A_e = 441.224\ \mathbf{kip}$$

<u>Flexural Resistance:</u>

$B := 8\ \mathbf{in}$	$I_x := 100\ \mathbf{in}^4$	$h = 6.95\ \mathbf{in}$	$k_c := 4$
$H := 8\ \mathbf{in}$	$S_x := 24.9\ \mathbf{in}^3$	$b = 6.95\ \mathbf{in}$	
$t := 0.349\ \mathbf{in}$	$Z_x := 29.4\ \mathbf{in}^3$	$F_y = 50\ \mathbf{ksi}$	

<u>WLB</u>

$$\lambda_w := \frac{h}{t} = 19.914 \qquad \lambda_{pw} := 2.42 \cdot \sqrt{\frac{E}{F_y}} = 58.281 \qquad \lambda_{rw} := 5.7 \cdot \sqrt{\frac{E}{F_y}} = 137.274$$

$$a_w := \frac{2 \cdot h \cdot t}{b \cdot t} = 2 \qquad R_{pg} := 1 - \frac{a_w}{1200 + 300 \cdot a_w} \cdot \left(\lambda_w - 5.7 \cdot \sqrt{\frac{E}{F_y}}\right) = 1.13$$

$$F_{cr} := \frac{0.9 \cdot E \cdot k_c}{\left(\frac{b}{t}\right)} = (5.243 \cdot 10^3)\ \mathbf{ksi} \qquad M_p := F_y \cdot Z_x = 122.5\ \mathbf{kip \cdot ft}$$

$$\phi M_p := 0.9 \cdot M_p = 110.25\ \mathbf{kip \cdot ft}$$

$$\phi M_{n1} := 0.9 \cdot M_p$$

$$\phi M_{n2} := 0.9 \cdot \left(M_p - (M_p - F_y \cdot S_x) \cdot \left(-0.738 + 0.305 \cdot \frac{h}{t} \cdot \sqrt{\frac{F_y}{E}}\right)\right)$$

$$\phi M_{n3} := 0.9 \cdot R_{pg} \cdot S_x \cdot \min(F_y, F_{cr})$$

$$\phi M_{wlb} := \mathbf{if}\left(\lambda_w \le \lambda_{pw}, \phi M_{n1}, \mathbf{if}\left(\lambda_w > \lambda_{rw}, \phi M_{n3}, \phi M_{n2}\right)\right) = 110.25\ \mathbf{kip \cdot ft}$$

<u>FLB</u>

$$\lambda_f := \frac{b}{t} \qquad \lambda_{pf} := 1.12 \cdot \sqrt{\frac{E}{F_y}} \qquad \lambda_{rf} := 1.4 \cdot \sqrt{\frac{E}{F_y}}$$

$$b_e := 1.92 \cdot t \cdot \sqrt{\frac{E}{F_y}} \cdot \left(1 - \frac{0.38}{\lambda_f} \cdot \sqrt{\frac{E}{F_y}}\right) = 8.722\ \mathbf{in} \qquad b_L := b - b_e = -1.772\ \mathbf{in}$$

$$y_c := \frac{A_g \cdot \left(\frac{H}{2}\right) - b_L \cdot t \cdot \left(\frac{t}{2}\right)}{A_g - b_L \cdot t} = 3.785\ \mathbf{in}$$

$$I_{xe} := I_x + A_g \cdot \left(y_c - \left(\frac{H}{2}\right)\right)^2 - \left(\frac{1}{12} \cdot b_L \cdot t^3 + b_L \cdot t \cdot \left(y_c - \left(\frac{t}{2}\right)\right)^2\right) = 0.005\ \mathbf{ft}^4$$

$$S_e := \frac{I_{xe}}{y_c} = 28.675\ \mathbf{in}^3$$

$$M_{n1} := 0.9 \cdot M_p$$

$$M_{n2} := 0.9 \cdot \left(M_p - \left(M_p - F_y \cdot S_x\right) \cdot \left(-4 + 3.57 \cdot \left(\frac{b}{t}\right) \cdot \sqrt{\frac{F_y}{E}}\right)\right)$$

$$M_{n3} := 0.9 \cdot \left(F_y \cdot S_e\right)$$

$$\phi M_{flb} := \mathbf{if}\left(\lambda_f \le \lambda_{pf}, M_{n1}, \mathbf{if}\left(\lambda_f > \lambda_{rf}, M_{n3}, M_{n2}\right)\right) = 110.25\ \mathbf{kip \cdot ft}$$

$$\phi M_n := \min\left(\phi M_p, \phi M_{flb}, \phi M_{wlb}\right) = 110.25\ \mathbf{kip \cdot ft}$$

Lateral Force for Verticals

Assuming pinned connections $K := 1$

Lateral force applied on top of vertical $H_f := \frac{0.01}{K} \cdot \left(F_{Tchord}\right) = 7.13\ \mathbf{kip}$

$$L_{post} = 90\ \mathbf{in}$$

$$M := H_f \cdot L_{post} = 53.475\ \mathbf{kip \cdot ft}$$

Interaction Equation:

$\phi P_n = 441.224\ \mathbf{kip}$ $F_{vert} = 120\ \mathbf{kip}$

$\phi M_n = 110.25\ \mathbf{kip \cdot ft}$ $M = 53.475\ \mathbf{kip \cdot ft}$

$$\mathbf{if}\left(\left(\frac{F_{vert}}{\phi P_n} + \frac{M}{\phi M_n}\right) \le 1, \text{“okay”}, \text{“re-design”}\right) = \text{“okay”}$$

End Post Design: HSS 9x9x5/8

$A_g := 18.7\ \mathbf{in}^2$ $b := 7.26\ \mathbf{in}$

$r_x := 3.4\ \mathbf{in}$ $h := 7.26\ \mathbf{in}$

$r_y := 3.4\ \mathbf{in}$ $t := 0.625\ \mathbf{in}$

$L_{cx} := 7.333\ \mathbf{ft}$ $C_1 := 0.2$

$L_{cy} := 7.333\ \mathbf{ft}$ $C_2 := 1.38$

$F_y := 50\ \mathbf{ksi}$ $\phi := 0.9$

Axial resistance:

$$F_{ex} := \frac{\pi^2 \cdot E}{\left(\frac{L_{cx}}{r_x}\right)^2} = 427.297\ \mathbf{ksi} \qquad F_{ey} := \frac{\pi^2 \cdot E}{\left(\frac{L_{cy}}{r_y}\right)^2} = 427.297\ \mathbf{ksi}$$

$$F_e := \min\left(F_{ex}, F_{ey}\right) = 427.297\ \mathbf{ksi}$$

$$F_{cr} := \mathbf{if}\left(\frac{F_y}{F_e} \le 2.25, 0.658^{\left(\frac{F_y}{F_e}\right)} \cdot F_y, 0.877 \cdot F_e\right) = 47.61\ \mathbf{ksi}$$

$$\lambda_r := 1.4 \cdot \sqrt{\frac{E}{F_y}} = 33.716$$

$$F_{e1} := \left(C_2 \cdot \frac{\lambda_r}{\left(\frac{b}{t}\right)}\right)^2 \cdot F_y = 802.23\ \mathbf{ksi}$$

$$F_{e2} := \left(C_2 \cdot \frac{\lambda_r}{\left(\frac{h}{t}\right)}\right)^2 \cdot F_y = 802.23\ \mathbf{ksi}$$

$$b_e := \mathbf{if}\left(\frac{b}{t} \le \lambda_r \cdot \sqrt{\frac{F_y}{F_{cr}}}, b, \left(1 - C_1 \cdot \sqrt{\frac{F_{e1}}{F_{cr}}}\right) \cdot \sqrt{\frac{F_{e1}}{F_{cr}}}\right) = 7.26\ \mathbf{in}$$

$$h_e := \mathbf{if}\left(\frac{h}{t} \le \lambda_r \cdot \sqrt{\frac{F_y}{F_{cr}}}, h, \left(1 - C_1 \cdot \sqrt{\frac{F_{e2}}{F_{cr}}}\right) \cdot \sqrt{\frac{F_{e2}}{F_{cr}}}\right) = 7.26\ \mathbf{in}$$

$$A_e := A_g - \left(\left(b - b_e\right) \cdot t\right) - \left(\left(h - h_e\right) \cdot t\right) = 18.7\ \mathbf{in}^2$$

$$\phi\, P_n := \phi \cdot F_{cr} \cdot A_e = 801.279\ \mathbf{kip}$$

Flexural resistance:

$B := 10\ \text{in}$ $\quad I_x := 202\ \text{in}^4$ $\quad h = 7.26\ \text{in}$ $\quad k_c := 4$

$H := 10\ \text{in}$ $\quad S_x := 40.4\ \text{in}^3$ $\quad b = 7.26\ \text{in}$

$t := 0.349\ \text{in}$ $\quad Z_x := 47.2\ \text{in}^3$ $\quad F_y = 50\ \text{ksi}$

WLB

$$\lambda_w := \frac{h}{t} = 20.802 \qquad \lambda_{pw} := 2.42 \cdot \sqrt{\frac{E}{F_y}} = 58.281 \qquad \lambda_{rw} := 5.7 \cdot \sqrt{\frac{E}{F_y}} = 137.274$$

$$a_w := \frac{2 \cdot h \cdot t}{b \cdot t} = 2 \qquad R_{pg} := 1 - \frac{a_w}{1200 + 300 \cdot a_w} \cdot \left(\lambda_w - 5.7 \cdot \sqrt{\frac{E}{F_y}}\right) = 1.129$$

$$F_{cr} := \frac{0.9 \cdot E \cdot k_c}{\left(\frac{b}{t}\right)} = \left(5.019 \cdot 10^3\right)\ \text{ksi} \qquad M_p := F_y \cdot Z_x = 196.667\ \text{kip} \cdot \text{ft}$$

$$\phi M_p := 0.9 \cdot M_p = 177\ \text{kip} \cdot \text{ft}$$

$$\phi M_{n1} := 0.9 \cdot M_p$$

$$\phi M_{n2} := 0.9 \cdot \left(M_p - \left(M_p - F_y \cdot S_x\right) \cdot \left(-0.738 + 0.305 \cdot \frac{h}{t} \cdot \sqrt{\frac{F_y}{E}}\right)\right)$$

$$\phi M_{n3} := 0.9 \cdot R_{pg} \cdot S_x \cdot \min\left(F_y, F_{cr}\right)$$

$$\phi M_{wlb} := \mathbf{if}\left(\lambda_w \le \lambda_{pw}, \phi M_{n1}, \mathbf{if}\left(\lambda_w > \lambda_{rw}, \phi M_{n3}, \phi M_{n2}\right)\right) = 177\ \text{kip} \cdot \text{ft}$$

FLB

$$\lambda_f := \frac{b}{t} \qquad \lambda_{pf} := 1.12 \cdot \sqrt{\frac{E}{F_y}} \qquad \lambda_{rf} := 1.4 \cdot \sqrt{\frac{E}{F_y}}$$

$$b_e := 1.92 \cdot t \cdot \sqrt{\frac{E}{F_y}} \cdot \left(1 - \frac{0.38}{\lambda_f} \cdot \sqrt{\frac{E}{F_y}}\right) = 9.038\ \text{in} \qquad b_L := b - b_e = -1.778\ \text{in}$$

$$y_c := \frac{A_g \cdot \left(\frac{H}{2}\right) - b_L \cdot t \cdot \left(\frac{t}{2}\right)}{A_g - b_L \cdot t} = 4.845\ \text{in}$$

$$I_{xe} := I_x + A_g \cdot \left(y_c - \left(\frac{H}{2}\right)\right)^2 - \left(\frac{1}{12} \cdot b_L \cdot t^3 + b_L \cdot t \cdot \left(y_c - \left(\frac{t}{2}\right)\right)^2\right) = 0.01\ \mathbf{ft}^4$$

$$S_e := \frac{I_{xe}}{y_c} = 44.581\ \mathbf{in}^3$$

$$M_{n1} := 0.9 \cdot M_p$$

$$M_{n2} := 0.9 \cdot \left(M_p - \left(M_p - F_y \cdot S_x\right) \cdot \left(-4 + 3.57 \cdot \left(\frac{b}{t}\right) \cdot \sqrt{\frac{F_y}{E}}\right)\right)$$

$$M_{n3} := 0.9 \cdot \left(F_y \cdot S_e\right)$$

$$\phi M_{flb} := \mathbf{if}\left(\lambda_f \le \lambda_{pf}, M_{n1}, \mathbf{if}\left(\lambda_f > \lambda_{rf}, M_{n3}, M_{n2}\right)\right) = 177\ \mathbf{kip \cdot ft}$$

$$\phi M_n := \min\left(\phi M_p, \phi M_{flb}, \phi M_{wlb}\right) = 177\ \mathbf{kip \cdot ft}$$

Lateral Force for End Post

$$C := 0.1 \cdot F_{post} = 12.6\ \mathbf{kip}$$

$$L_{post} = 90\ \mathbf{in}$$

$$M := C \cdot L_{post} = 94.5\ \mathbf{kip \cdot ft}$$

Interaction Equation:

$\phi P_n = 801.279\ \mathbf{kip}$ $\qquad F_{post} = 126\ \mathbf{kip}$

$\phi M_n = 177\ \mathbf{kip \cdot ft}$ $\qquad M = 94.5\ \mathbf{kip \cdot ft}$

$$\mathbf{if}\left(\left(\frac{F_{post}}{\phi P_n} + \frac{M}{\phi M_n}\right) \le 1, \text{“okay”}, \text{“re-design”}\right) = \text{“okay”}$$

Tension Members

Bottom Chord: HSS 9x9x5/8

$A_g := 13.2\ \mathbf{in}^2$

$\phi := 0.95$

$F_y = 50\ \mathbf{ksi}$

$F_{Bchord} = 708\ \mathbf{kip}$

$\mathbf{if}\left(\phi \cdot F_y \cdot A_g \geq F_{Bchord}, \text{"okay"}, \text{"re - design"}\right) = \text{"re - design"}$

$DCR := \dfrac{F_{Bchord}}{\phi \cdot F_y \cdot A_g} = 1.129$

Exterior Diagonal: HSS 6x4x1/4

$A_g := 5.26\ \mathbf{in}^2$

$\phi := 0.95$

$F_y = 50\ \mathbf{ksi}$

$F_{diagEXT} = 123\ \mathbf{kip}$

$\mathbf{if}\left(\phi \cdot F_y \cdot A_g \geq F_{diagEXT}, \text{"okay"}, \text{"re - design"}\right) = \text{"okay"}$

$DCR := \dfrac{F_{diagEXT}}{\phi \cdot F_y \cdot A_g} = 0.492$

Interior diagonals: HSS 6x4x1/4

$A_g := 5.26\ \mathbf{in}^2$

$\phi := 0.95$

$F_y := 50\ \mathbf{ksi}$

$F_{diagINT} = 171\ \mathbf{kip}$

$\mathbf{if}\left(\phi \cdot F_y \cdot A_g \geq F_{diagINT}, \text{"okay"}, \text{"re - design"}\right) = \text{"okay"}$

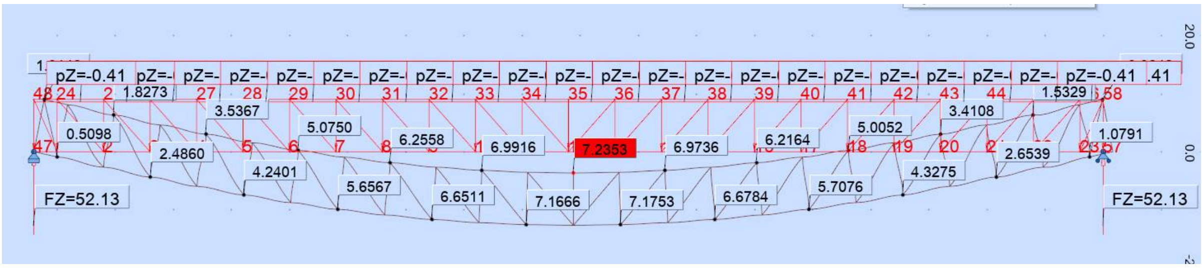
$DCR := \dfrac{F_{diagINT}}{\phi \cdot F_y \cdot A_g} = 0.684$

Allowable Dead Load

$S = \left(2.208 \cdot 10^3\right)\ \mathbf{in}$

$\Delta_{allow} := S \cdot 0.01 = 22.08\ \mathbf{in}$

$\Delta_{max} := 19.25\ \mathbf{in}$



$$\textbf{if}\left(\Delta_{allow} \geq \Delta_{max}, \text{“ok”}, \text{“re-design”}\right) = \text{“ok”}$$

Floor System Design

Floor Beam: W14x43

$t_w := 0.305\ \mathbf{in}$ $\quad I_x := 428\ \mathbf{in}^4$ $\quad t_f := 0.530\ \mathbf{in}$

$b_f := 8\ \mathbf{in}$ $\quad S_x := 62.6\ \mathbf{in}^3$

$d := 13.7\ \mathbf{in}$ $\quad D := d - 2 \cdot t_f = 12.64\ \mathbf{in}$

$C := \frac{d}{2} = 6.85\ \mathbf{in}$ $\quad \phi_f := 1$ $\quad R_h := 1$

Flexure

$\mathbf{if}\left(\frac{D}{t_w} \le 150, \text{"ok"}, \text{"not ok"}\right) = \text{"ok"}$

$\mathbf{if}\left(b_f \ge \frac{D}{6}, \text{"ok"}, \text{"not ok"}\right) = \text{"ok"}$

$\mathbf{if}\left(\frac{b_f}{2 \cdot t_f} \le 12, \text{"ok"}, \text{"not ok"}\right) = \text{"ok"}$

$\mathbf{if}\left(t_f \ge 1.1 \cdot t_w, \text{"ok"}, \text{"not ok"}\right) = \text{"ok"}$

Rolled section, I ratio equals 1

$$\frac{M_{floorbeam}}{S_x} = 18.211\ \mathbf{ksi}$$

$$\mathbf{if}\left(\frac{M_{floorbeam}}{S_x} \le \phi_f \cdot R_h \cdot F_y, \text{"ok"}, \text{"re-design"}\right) = \text{"ok"}$$

Shear

$\lambda_w := \frac{D}{t_w}$ $\quad k := 5$ $\quad \lambda_{pw} := 1.12 \cdot \sqrt{\frac{E \cdot k}{F_y}}$ $\quad \lambda_{rw} := 1.4 \cdot \sqrt{\frac{E \cdot k}{F_y}}$

$$C := \frac{1.57}{\left(\frac{D}{t_w}\right)^2} \cdot \left(\frac{E \cdot k}{F_y}\right) = 2.651$$

$$\phi\ V_n := 0.58 \cdot C \cdot F_y \cdot D \cdot t_w = 296.379\ \mathbf{kip}$$

Bracing

Chord Design Forces:
Design loads: 33 kip (compression), 11.5 kip (tension)

$F_{Tchord} := 111.25\ \mathbf{kip}$

$F_{Bchord} := 38.1\ \mathbf{kip}$

Top Chord: (HSS 9x9x5/8)

Compression

Pinned-Pinned connection

$K := 1.0$

$L := 96\ \mathbf{in}$

$k := 1.4$

$F_y := 50\ \mathbf{ksi}$

$E := 29000\ \mathbf{ksi}$

$\phi_c := 0.9$

$b := 7.26\ \mathbf{in}$

$t := 0.625\ \mathbf{in}$

$A_g := 18.7\ \mathbf{in}^2$

$r_x := 3.4\ \mathbf{in}$

$r_y := 3.4\ \mathbf{in}$

$r := \min(r_x, r_y) = 3.4\ \mathbf{in}$

Calculations:

$$KLR := \frac{K \cdot L}{r} = 28.235 \qquad \mathbf{if}(KLR \le 120, \text{“ok”}, \text{“not ok”}) = \text{“ok”}$$

$$\mathbf{Q_1} := \mathbf{if}\left(\frac{b}{t} \le 1.4 \cdot \sqrt{\frac{E}{F_y}}, \text{“compact”}, \text{“not compact”}\right) = \text{“compact”}$$

$$Q := \mathbf{if}(\mathbf{Q_1 =} \text{“compact”}, 1, \text{“calcuate”}) = 1$$

$$P_{eo} := \pi^2 \cdot \left(\frac{1}{KLR}\right)^2 \cdot \left(\frac{E}{F_y}\right) = 7.18$$

$$P_o := Q \cdot F_y \cdot A_g = 935\ \mathbf{kip}$$

$$P_e := \frac{\pi^2 \cdot E \cdot A_g}{KLR^2} = \left(6.714 \cdot 10^3\right)\ \mathbf{kip}$$

$$P_n := \mathbf{if}\left(P_{eo} \ge 0.44, 0.658^{\left(P_{eo}^{-1}\right)} \cdot P_o, 0.877 \cdot P_e\right) = 882.056\ \mathbf{kip}$$

$$P_{design} := \phi_c \cdot P_n = 793.85\ \mathbf{kip}$$

$$\mathbf{if}\left(P_{design} \ge F_{Tchord}, \text{“ok”}, \text{“re - design”}\right) = \text{“ok”}$$

Bottom chord: HSS 9x9x5/8

Tension

$A_g := 13.2\ \mathbf{in}^2$

$\phi := 0.95$

$F_y = 50\ \mathbf{ksi}$

$F_{Bchord} = 38.1\ \mathbf{kip}$

$\mathbf{if}\left(\phi \cdot F_y \cdot A_g \geq F_{Bchord}, \text{"okay"}, \text{"re-design"}\right) = \text{"okay"}$

$DCR := \dfrac{F_{Bchord}}{\phi \cdot F_y \cdot A_g} = 0.061$

Verticals: HSS 4x4x1/4

$F_{Cvert} := 23.3\ \mathbf{kip}$ $F_{Tvert} := 20.85\ \mathbf{kip}$

Compression

$K := 1.0$ Pinned-Pinned connection

$L := 120\ \mathbf{in}$

$k := 1.4$

$F_y := 50\ \mathbf{ksi}$

$E := 29000\ \mathbf{ksi}$

$\phi_c := 0.9$

$b := 3.3\ \mathbf{in}$

$t := 0.291\ \mathbf{in}$

$A_g := 4.1\ \mathbf{in}^2$

$r_x := 1.49\ \mathbf{in}$

$r_y := 1.49\ \mathbf{in}$

$r := \min\left(r_x, r_y\right) = 1.49\ \mathbf{in}$

Calculations:

$KLR := \dfrac{K \cdot L}{r} = 80.537$ $\mathbf{if}\left(KLR \leq 120, \text{"ok"}, \text{"not ok"}\right) = \text{"ok"}$

$\mathbf{Q_1} := \mathbf{if}\left(\dfrac{b}{t} \leq 1.4 \cdot \sqrt{\dfrac{E}{F_y}}, \text{"compact"}, \text{"not compact"}\right) = \text{"compact"}$

$Q := \mathbf{if}\left(\mathbf{Q_1} = \text{"compact"}, 1, \text{"calcuate"}\right) = 1$

$P_{eo} := \pi^2 \cdot \left(\dfrac{1}{KLR}\right)^2 \cdot \left(\dfrac{E}{F_y}\right) = 0.883$

$P_o := Q \cdot F_y \cdot A_g = 205\ \mathbf{kip}$

$P_e := \dfrac{\pi^2 \cdot E \cdot A_g}{KLR^2} = 180.922\ \mathbf{kip}$

$P_n := \textbf{if}\left(P_{eo} \geq 0.44, 0.658^{\left(P_{eo}^{-1}\right)} \cdot P_o, 0.877 \cdot P_e\right) = 127.582\ \textbf{kip}$

$P_{design} := \phi_c \cdot P_n = 114.824\ \textbf{kip}$

$\textbf{if}\left(P_{design} \geq F_{Cvert}, \text{“ok”}, \text{“re - design”}\right) = \text{“ok”}$

<u>Diagonals:</u> <u>(HSS 4x4x1/4)</u>

$T_{max} := 28.65\ \textbf{kip}$ $C_{max} := 29.47\ \textbf{kip}$

<u>Compression</u>

Pinned-Pinned connection

$K := 1.0$
$L := L_{xbrace} = 150.572\ \textbf{in}$
$k := 1.4$
$F_y := 50\ \textbf{ksi}$
$E := 29000\ \textbf{ksi}$
$\phi_c := 0.9$

$b := 3.3\ \textbf{in}$
$t := 0.291\ \textbf{in}$
$A_g := 4.1\ \textbf{in}^2$
$r_x := 1.49\ \textbf{in}$
$r_y := 1.49\ \textbf{in}$
$r := \min\left(r_x, r_y\right) = 1.49\ \textbf{in}$

<u>Calculations:</u>

$KLR := \dfrac{K \cdot L}{r} = 101.055$ $\textbf{if}\left(KLR \leq 120, \text{“ok”}, \text{“not ok”}\right) = \text{“ok”}$

$\mathbf{Q_1} := \textbf{if}\left(\dfrac{b}{t} \leq 1.4 \cdot \sqrt{\dfrac{E}{F_y}}, \text{“compact”}, \text{“not compact”}\right) = \text{“compact”}$

$Q := \textbf{if}\left(\mathbf{Q_1 =} \text{“compact”}, 1, \text{“calcuate”}\right) = 1$

$P_{eo} := \pi^2 \cdot \left(\dfrac{1}{KLR}\right)^2 \cdot \left(\dfrac{E}{F_y}\right) = 0.561$

$P_o := Q \cdot F_y \cdot A_g = 205\ \textbf{kip}$

$P_e := \dfrac{\pi^2 \cdot E \cdot A_g}{KLR^2} = 114.912\ \textbf{kip}$

$P_n := \textbf{if}\left(P_{eo} \geq 0.44, 0.658^{\left(P_{eo}^{-1}\right)} \cdot P_o, 0.877 \cdot P_e\right) = 97.157\ \textbf{kip}$

$P_{design} := \phi_c \cdot P_n = 87.441$ **kip**

$\textbf{if}\left(P_{design} \geq C_{max}, \text{“ok”}, \text{“re - design”}\right) = \text{“ok”}$

<u>Tension</u>

$A_g := 3.37$ **in**^{2}

$\phi := 0.95$

$F_y := 50$ **ksi**

$\textbf{if}\left(\phi \cdot F_y \cdot A_g \geq T_{max}, \text{“okay”}, \text{“re - design”}\right) = \text{“okay”}$

$$DCR := \frac{T_{max}}{\phi \cdot F_y \cdot A_g} = 0.179$$

Summary

<u>Truss Members</u>

Top chord:	HSS 9x9x5/8
Bottom chord:	HSS 9x9x5/8
Internal bay diagonals:	HSS 6x4x5/16
Exterior bay diagonals:	HSS 6x4x5/16
Interior posts:	HSS 8x8x3/8
End post:	HSS 9x9x5/8

<u>Floor System Members</u>

Floor beams:	W 14x43
bracing verticals:	HSS 4x4x5/16
Bracing diagonals:	HSS 4x4x5/16

<u>Railing</u>

Rub rail:	2x8 (treated wood)
Toe plate:	2x6 PL
Safety rail:	HSS 2x1x1/8

*Top and bottom chord of the bracing (floor system) is the same as the bottom chord of the truss

H.2 Keystone Ramp

Soil Properties:

Backfill Granular:

Unit weight: $\gamma_{backfill} := 120 \frac{lb}{ft^3}$

Internal friction angle: $\phi'_1 := 34\ deg$

Soil (in-situ, assumed)

Unit weight: $\gamma_1 := 110\ pcf$

Saturated unit weight: $\gamma_{sat} := 125\ pcf$

Unit weight of water: $\gamma_{water} := 62.4\ pcf$

Effective unit weight: $\gamma_{eff} := \gamma_{sat} - \gamma_{water} = 62.6\ pcf$

Active pressure coefficient: $K_a := 0.4$

Internal friction angle: $\phi'_2 := 30\ deg$

Cohesion: $c' := 0\ psf$

Keystone Retaining Wall Properties:

Unit weight (soil): $\gamma_{filled} := 120 \frac{lb}{ft^3}$

Level pad thickness: $t_f := 12\ in$

Width of single unit: $w_u := 18\ in$

Height of wall (EL = 934.5): $H := 20.5\ ft$

Height of single unit: $H_u := 8\ in$

Depth of embedment: $d_e := \max(H_u, 1.0\ ft) = 1\ ft$

Hinge Height:

$H_w := d_e + H = 21.5\ ft$

$\Delta := 0.125\ in$ offset of blocks

$w := 0.8\ deg$ batter angle taken as 0 deg for design purposes of this block

$H_{max} := \frac{w_u \cdot H_u}{\Delta} = 96\ ft$ hinge height

$H_w < H_{max}$ As Hw < Hmax, the design is acceptable, but it is still recommended to build in levels

Active Earth Pressure:

$\alpha := 90\ \mathbf{deg} + w = 90.8\ \mathbf{deg}$

$\beta := 0\ \mathbf{deg}$ flat fill surface at top of wall

$\phi' := 34\ \mathbf{deg}$ backfill

$\phi_w := 22\ \mathbf{deg}$

$$K_a := \frac{\sin(\alpha + \phi')^2}{\sin(\alpha)^2 \cdot \sin(\alpha - \phi_w) \cdot \left(1 + \sqrt{\frac{\sin(\phi' + \phi_w) \cdot \sin(\phi' - \beta)}{\sin(\alpha - \phi_w) \cdot \sin(\alpha + \beta)}}\right)^2} = 0.249$$

$K_{ah} := K_a \cdot \cos(\phi_w) = 0.231$

Geogrid

Place first layer of geogrid at the top of the first block

$L_1 := 0.66\ \mathbf{ft}$

Place subsequent layers every 3rd block on center

$L_2 := 2\ \mathbf{ft}$

Tension to bottom layer

$$T := 0.25 \cdot 120\ \frac{\mathbf{lb}}{\mathbf{ft}^3} \cdot \left(\frac{2.66\ \mathbf{ft}}{2}\right) \cdot (21.5\ \mathbf{ft} - 0.66\ \mathbf{ft}) = 831.516\ \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$surcharge := 0.25 \cdot \left(150\ \frac{\mathbf{lb}}{\mathbf{ft}^2}\right) \cdot \left(\frac{2.66\ \mathbf{ft}}{2}\right) = 49.875\ \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$T_u := T + surcharge = 881.391\ \frac{\mathbf{lb}}{\mathbf{ft}}$$

Select Geogrid - Miragrid® 8XT

$$T_{ult} := 7400 \frac{lb}{ft}$$

$$RF_{id} := 1.05$$

$$RF_{CR} := 1.44$$

$$RF_D := 1.1$$

$$LTDS := \frac{T_{ult}}{RF_{id} \cdot RF_{CR} \cdot RF_D} = \left(4.449 \cdot 10^3\right) \frac{lb}{ft}$$

$$FS := 1.5$$

$$LTADS := \frac{LTDS}{FS} = \left(2.966 \cdot 10^3\right) \frac{lb}{ft}$$ > Tu selection ok

Check Connection Strength

Peak connection strength - maximum = 4447

$$P(N) := 2197 \frac{lb}{ft} + 0.45 \cdot (N)$$

$$N := \gamma_{filled} \cdot w_u \cdot \left(H_w - H_u\right) = \left(3.75 \cdot 10^3\right) \frac{lb}{ft}$$

$$Peak := \frac{P(N)}{1.5} = \left(2.59 \cdot 10^3\right) \frac{lb}{ft}$$ > Tu ok

Serviceability connection strength - max = 3133

$$P(N) := 1977 \frac{lb}{ft} + 0.23\ (N)$$

$$N := \gamma_{filled} \cdot w_u \cdot \left(H_w - H_u\right) = \left(3.75 \cdot 10^3\right) \frac{lb}{ft}$$

> Tu ok

$$Serviceability := P(N) = \left(2.84 \cdot 10^3\right) \frac{lb}{ft}$$

Safety Factor - less of peak,service, or LTADS

$$SF := \frac{\min(LTADS, Peak, Serviceability)}{T_u} = 2.938$$ > 1.5 ok

No embedment needed, geogrid will span between adjacent units

Tension to Layer 2

$$T_2 := 0.25 \cdot 120 \, \frac{\mathbf{lb}}{\mathbf{ft}^3} \cdot \left(\frac{4 \, \mathbf{ft} - 0.66 \, \mathbf{ft}}{2} \right) \cdot (21.5 \, \mathbf{ft} - 2.66 \, \mathbf{ft}) = 943.884 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$surcharge_2 := 0.25 \cdot \left(150 \, \frac{\mathbf{lb}}{\mathbf{ft}^2} \right) \cdot \left(\frac{4 \, \mathbf{ft} - 0.66 \, \mathbf{ft}}{2} \right) = 62.625 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$T_{u2} := T_2 + surcharge_2 = 1006.509 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$

Check Connection Strength

Peak Connection Strength - maximum = 4447

$$P(N) := 2197 \, \frac{\mathbf{lb}}{\mathbf{ft}} + 0.45 \cdot (N)$$

$$N := \gamma_{filled} \cdot w_u \cdot (H_w - 2.66 \, \mathbf{ft}) = 3391.2 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$Peak := \frac{P(N)}{1.5} = 2482.027 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$ > Tu ok

Serviceability connection strength - max = 3133

$$P(N) := 1977 \, \frac{\mathbf{lb}}{\mathbf{ft}} + 0.23 \, (N)$$

$$N := \gamma_{filled} \cdot w_u \cdot (H_w - 2.66 \, \mathbf{ft}) = 3391.2 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$Serviceability := P(N) = 2756.976 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$ > Tu ok

Tension to Top Layer

$$T_{top} := 0.25 \cdot 120 \, \frac{\mathbf{lb}}{\mathbf{ft}^3} \cdot \left(\frac{21.5 \, \mathbf{ft} - 20 \, \mathbf{ft}}{2} \right) \cdot (21.5 \, \mathbf{ft} - 20.83 \, \mathbf{ft}) = 15.075 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$surcharge_{top} := 0.25 \cdot \left(150 \, \frac{\mathbf{lb}}{\mathbf{ft}^2} \right) \cdot \left(\frac{21.5 \, \mathbf{ft} - 20 \, \mathbf{ft}}{2} \right) = 28.125 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$T_{utop} := T_{top} + surcharge_{top} = 43.2 \, \frac{\mathbf{lb}}{\mathbf{ft}}$$

Check Geogrid

$$LTDS := \frac{T_{ult}}{RF_{id} \cdot RF_{CR} \cdot RF_D} = \left(4.449 \cdot 10^3\right) \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$FS := 1.5$$

$$LTADS := \frac{LTDS}{FS} = \left(2.966 \cdot 10^3\right) \frac{\mathbf{lb}}{\mathbf{ft}}$$ > Tu selection ok

Check Connection Strength

Peak connection strength - maximum = 4447

$$P(N) := 2197 \frac{\mathbf{lb}}{\mathbf{ft}} + 0.45 \cdot (N)$$

$$N := \gamma_{filled} \cdot w_u \cdot \left(H_w - 20.83\ \mathbf{ft}\right) = 120.6 \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$Peak := \frac{P(N)}{1.5} = 1500.847 \frac{\mathbf{lb}}{\mathbf{ft}}$$ > Tu ok

Serviceability connection strength - max = 3133

$$P(N) := 1977 \frac{\mathbf{lb}}{\mathbf{ft}} + 0.23\ (N)$$

$$N := \gamma_{filled} \cdot w_u \cdot \left(H_w - 20.83\ \mathbf{ft}\right) = 120.6 \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$Serviceability := P(N) = 2004.738 \frac{\mathbf{lb}}{\mathbf{ft}}$$ > Tu ok

Overturning Moments

Backfill Pressure

$$F_{backfill} := K_{ah} \cdot 120 \cdot \frac{21.5^2}{2} = 6397.509$$

$$F_{backfill} := 6397.509\ \mathbf{lb}$$

$$M_{backfill} := \frac{H_w}{3} \cdot F_{backfill} = 45848.815\ \mathbf{lb} \cdot \mathbf{ft}$$

Surcharge

$$surcharge := K_{ah} \cdot 150 \cdot 21.5 = 743.896$$

$$surcharge := 743.896\ \mathbf{lb}$$

$$M_{surcharge} := surcharge \cdot \frac{H_w}{2} = \left(7.997 \cdot 10^3\right)\ \mathbf{lb \cdot ft}$$

$$F_{sliding} := F_{backfill} + surcharge = \left(7.141 \cdot 10^3\right)\ \mathbf{lb}$$

$$M_{sliding} := M_{surcharge} + M_{backfill} = \left(5.385 \cdot 10^4\right)\ \mathbf{lb \cdot ft}$$

Resisting Moments

$$W_{wall} := 21.5\ \mathbf{ft} \cdot 120\ \frac{\mathbf{lb}}{\mathbf{ft}} = \left(2.58 \cdot 10^3\right)\ \mathbf{lb}$$

$$M_{wall} := W_{wall} \cdot 21\ \mathbf{in} = \left(4.515 \cdot 10^3\right)\ \mathbf{lb \cdot ft}$$ 21 in to heel for overturning

$$W_{backfill} := 21.5 \cdot 13 \cdot 120 = 3.354 \cdot 10^4$$ 13. ft wide at the top

$$W_{backfill} := 34830\ \mathbf{lb}$$

$$M_{backfill} := W_{backfill} \cdot \frac{H_w}{2} = \left(3.744 \cdot 10^5\right)\ \mathbf{lb \cdot ft}$$

$$W_{surcharge} := 150 \cdot 13.5 = 2.025 \cdot 10^3$$

$$W_{surcharge} := 2025\ \mathbf{lb}$$

$$M_{surcharge} := W_{surcharge} \cdot \left(\frac{13.5\ \mathbf{ft}}{2} + 21\ \mathbf{in}\right) = \left(1.721 \cdot 10^4\right)\ \mathbf{lb \cdot ft}$$

$$F_{vertical} := W_{wall} + W_{backfill} + W_{surcharge} = \left(3.944 \cdot 10^4\right)\ \mathbf{lb}$$

$$M_{resisting} := M_{surcharge} + M_{backfill} + M_{wall} = \left(3.962 \cdot 10^5\right)\ \mathbf{lb \cdot ft}$$

$$FS_{overturning} := \frac{M_{resisting}}{M_{sliding}} = 7.357$$ > 2 ok

Check Sliding at Base

Lateral Force

$F_{sliding} = (7.141 \cdot 10^3)\ \mathbf{lb}$

$F_{vertical} = (3.944 \cdot 10^4)\ \mathbf{lb}$

$Sliding_{resistance} := F_{vertical} \cdot \tan(30\ \mathbf{deg}) = (2.277 \cdot 10^4)\ \mathbf{lb}$

$FS_{sliding} := \dfrac{F_{vertical}}{F_{sliding}} = 5.522$ > 2 ok

Check for Bearing Capacity

$B := 16.67\ \mathbf{ft}$

$e := 0$ Center of reaction should be at the center of the two walls, therefore no eccentricity

Bearing Pressure

$q' := \dfrac{39435}{16.67} = 2.366 \cdot 10^3$

$q' := 2365.627\ \mathbf{psf}$

Allowable pressure

$N_c := 30.1$ $N_\gamma := 22.4$ $N_q := 18.4$

$D := 1\ \mathbf{ft}$

$q'_n := \gamma_1 \cdot D \cdot N_q + 0.5 \cdot \gamma_1 \cdot B \cdot N_\gamma = (2.256 \cdot 10^4)\ \mathbf{psf}$

$FS_{bearing} := \dfrac{q'_n}{q'} = 9.537$ > 3 ok

H.3 Natural Stone Steps

Soil Properties:

Backfill Granular:

Unit weight: $\gamma_{backfill} := 120\ \mathbf{pcf}$

Internal friction angle: $\phi'_1 := 34\ \mathbf{deg}$

Soil (in-situ, assumed):

Unit weight: $\gamma_1 := 110\ \mathbf{pcf}$

Saturated unit weight: $\gamma_{sat} := 125\ \mathbf{pcf}$

Unit weight of water: $\gamma_{water} := 62.4\ \mathbf{pcf}$

Effective unit weight: $\gamma_{eff} := \gamma_{sat} - \gamma_{water} = 62.6\ \mathbf{pcf}$

Active pressure coefficient: $K_a := 0.4$

Internal friction angle: $\phi'_2 := 30\ \mathbf{deg}$

Cohesion: $c' := 0\ \mathbf{psf}$

Natural Stone Properties:

Limestone unit weight: $\gamma_{limestone} := 150\ \dfrac{\mathbf{lb}}{\mathbf{ft}^3}$

Level pad thickness: $t_f := 12\ \mathbf{in}$

Width of single unit: $w_u := 4\ \mathbf{ft}$

Height of wall: $H := 6.5\ \mathbf{ft}$

Height of single unit: $H_u := 2\ \mathbf{ft}$

Depth of embedment: $d_e := \max(H_u, 1.0\ \mathbf{ft}) = 2\ \mathbf{ft}$

Hinge Height Check:

$H_w := d_e + H = 8.5\ \mathbf{ft}$

$\Delta := 2\ \mathbf{ft}$ offset of blocks

$$w := \operatorname{atan}\left(\frac{\Delta}{H_u}\right) = 45\ \mathbf{deg}$$ batter angle

$$H_{max} := \frac{w_u \cdot H_u}{\Delta} = 4\ \mathbf{ft}$$ hinge height

$H_w < H_{max}$

As Hw < Hmax, the design is not acceptable. The wall must be constructed in levels; backfilled and compacted as the height increases

Active Earth Pressure & Shear

$\alpha := 90\ \mathbf{deg} + w = 135\ \mathbf{deg}$

$\beta := -5\ \mathbf{deg}$ flat fill surface at top of wall

$\phi' := 34\ \mathbf{deg}$ backfill

$\phi_w := 22\ \mathbf{deg}$

$$K_a := \frac{\sin(\alpha + \phi')^2}{\sin(\alpha)^2 \cdot \sin(\alpha - \phi_w) \cdot \left(1 + \sqrt{\frac{\sin(\phi' + \phi_w) \cdot \sin(\phi' - \beta)}{\sin(\alpha - \phi_w) \cdot \sin(\alpha + \beta)}}\right)^2} = 0.023$$

$K_{ah} := K_a \cdot \cos(\phi_w) = 0.021$

$\gamma_1 := 110\ \frac{\mathbf{lb}}{\mathbf{ft}^3}$

$z := H - H_u = 4.5\ \mathbf{ft}$

$V_u := 0.5 \cdot \gamma_1 \cdot (z)^2 \cdot K_{ah} = 23.608\ \frac{\mathbf{lb}}{\mathbf{ft}}$

$shear_{angle} := 36\ \mathbf{deg}$

$min := 0$

$N := z \cdot w_u \cdot \gamma_{limestone} = (2.7 \cdot 10^3)\ \frac{\mathbf{lb}}{\mathbf{ft}}$

$F_u := N \cdot \tan(shear_{angle}) + min = (1.962 \cdot 10^3)\ \frac{\mathbf{lb}}{\mathbf{ft}}$

$FS_V := \frac{F_u}{V_u} = 83.095$ > 1.5

FSo Calculation:

$P_{ah} := 0.5 \cdot \gamma_{limestone} \cdot H_w^2 \cdot K_{ah} = 114.858\ \frac{\mathbf{lb}}{\mathbf{ft}}$

$z_{bar} := \frac{H}{3} = 2.167\ \mathbf{ft}$

$$W_1 := (H_w \cdot w_u) \cdot \gamma_{limestone} = (5.1 \cdot 10^3)\ \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$x_1 := 0.5 \cdot w_u + 0.5 \cdot H_w \cdot \tan(w) = 6.25\ \mathbf{ft}$$

$$M_o := P_{ah} \cdot z_{bar} = 248.86\ \mathbf{lb}$$

$$M_r := W_1 \cdot x_1 = (3.188 \cdot 10^4)\ \mathbf{lb}$$

$$FS_O := \frac{M_r}{M_o} = 128.084 \qquad > 2$$

FSv Calculation:

$$V_{slide} := P_{ah} = 114.858\ \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$V_n := W_1 \cdot \tan(\phi'_2) = (2.944 \cdot 10^3)\ \frac{\mathbf{lb}}{\mathbf{ft}}$$

$$FS_V := \frac{V_n}{V_{slide}} = 25.636 \qquad > 1.5$$

FSq Calculation:

$$B := w_u + t_f = 5\ \mathbf{ft}$$

$$x_r := \frac{M_r - M_o}{W_1} = 6.201\ \mathbf{ft}$$

$$e := 0.5 \cdot w_u - x_r = -4.201\ \mathbf{ft}$$

$$B' := B - 2 \cdot e = 13.402\ \mathbf{ft}$$

$$\Delta\sigma_D := \gamma_{limestone} \cdot (d_e + t_f) = 450\ \frac{\mathbf{lb}}{\mathbf{ft}^2}$$

$N_c := 30.1$ $\qquad N_q := 18.4$ $\qquad N_\gamma := 22.4$

$s_c := 1$ $\qquad s_q := 1$ $\qquad s_\gamma := 1$

$d_c := 1$ $\qquad d_q := 1$ $\qquad d_\gamma := 1$

$c' := 0$ $\qquad m := 2$

$H_i := V_{slide} = 114.858 \ \frac{lb}{ft}$

$a := \frac{V_n}{\tan(\phi'_2)} = (5.1 \cdot 10^3) \ \frac{lb}{ft}$

$i_c := 0$ $\qquad i_q := 1 - \frac{H_i}{a} = 0.977$ $\qquad i_\gamma := i_q^{1.5} = 0.966$

$q'_n := \Delta\sigma_D \cdot N_q \cdot i_q \cdot d_q \cdot s_q + 0.5 \cdot \gamma_1 \cdot B' \cdot N_\gamma \cdot i_\gamma \cdot s_\gamma \cdot d_\gamma = (2.405 \cdot 10^4) \ \frac{lb}{ft^2}$

$q' := \frac{W_1}{B'} = 380.529 \ \frac{lb}{ft^2}$

$FS_q := \frac{q'_n}{q'} = 63.203$ $\qquad > 3$

H.4 Erosion Control

Storm Sewer

Catchment Areas

Parking Lot:

$PL1 := 23890\ ft^2$ $\quad C_{PL1} := 0.3$ $\quad i_5 := 0.1533\ \frac{ft}{hr}$

$PL2 := 26207\ ft^2$ $\quad C_{PL2} := 0.6$

$PL3 := 41526\ ft^2$ $\quad C_{PL3} := 0.45$

$PL4 := 13887\ ft^2$ $\quad C_{PL4} := 0.72$

Pond Bank:

$PB2 := 77277\ ft^2$ $\quad C_{PB2} := 0.3$

$PB3 := 29778\ ft^2$ $\quad C_{PB3} := 0.6$

Inlet Flow Rates

West SS:

$$Q_{I1W} := \left(\frac{1}{2} \cdot PL2 \cdot C_{PL2} + \frac{1}{6}\ PL3 \cdot C_{PL3} + \frac{1}{2}\ PL4 \cdot C_{PL4}\right) \cdot i_5 = 0.68\ \frac{ft^3}{s}$$

$$Q_{I2W} := \left(\frac{1}{6} \cdot PB2 \cdot C_{PB2}\right) \cdot i_5 = 0.165\ \frac{ft^3}{s}$$

$$Q_{I3W} := \left(\frac{1}{4} \cdot PB2 \cdot C_{PB2}\right) \cdot i_5 = 0.247\ \frac{ft^3}{s}$$

$$Q_{I4W} := Q_{I3W} = 0.247\ \frac{ft^3}{s}$$

East SS

$$Q_{I1E} := \left(\frac{1}{2}\ PL4 \cdot C_{PL4}\right) \cdot i_5 = 0.213\ \frac{ft^3}{s}$$