

# **Pedestrian Bridge Design in Fultonville, New York**

**Major Qualifying Project Report:**

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## Abstract

The purpose of this project was to design and analyze four pedestrian bridge design options for a 30-foot wide ravine in Fultonville, New York. A demonstration version of RISA-2D software and hand calculations were used to investigate all four bridge options. Each alternative was evaluated based on a weighted scale consisting of multiple criteria to best fit the constraints of this project. A timber Whipple Truss bridge was chosen to be recommended to the Board of Cemetery Commissioners and Trustees.

## Acknowledgements

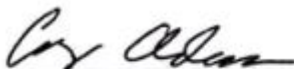
We would like to thank everyone for their help and assistance of this project. We could not have completed the project to its fullest extent without all of the support. We would first like to thank our project advisors, Professor Albano and Professor LePage for their help and feedback each week. We would also like to thank those at Rick Franklin Corp. especially John and Melissa, for their help and information about flatcar bridges. We would also like to acknowledge Giovanna Olson and Ryan Weitz for their complementing MQP, *Recreational Trail Design in Fultonville, New York*.

## Authorship


The authors Scott Gould and Cory Adams have each contributed to the designs, writing, and editing of this report. Scott contributed to the following: Capstone Design Statement, Abstract, Introduction, Background, Methodology, and Results of the Whipple Truss and Flatcar Bridge, as well as background about RISA-2D and pedestrian bridges. Scott also contributed to the final recommendation and conclusion chapters. Cory contributed to the background about the Pratt Truss design and the design criteria. Cory also contributed to the methodology and results for the aluminum Pratt Truss Bridge and simple girder bridge as well as the purlin and decking designs. Cory also contributed to the AutoCAD drawings.


Both students contributed equally to the RISA-2D analyses, the design calculations, and the evaluation process. Both students also contributed to the evaluation process to ensure there was no added bias of any kind while evaluating the bridge alternatives. We would also like to acknowledge Ryan Weitz and Giovanna Olson for their contribution to the history of the site in the background and their contribution to the executive summary.

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## **Executive Summary**

Two Major Qualifying Projects (MQP) involved the design of a site development plan for a recreational trail in Fultonville, New York on lands currently used as a cemetery and natural burial ground. The site offers scenic vistas and is located adjacent to a statewide trail system. A number of issues have limited the construction of a trail including the lack of a bridge crossing, stormwater management, and steep slopes. Recreational Trail Design in Fultonville, New York investigated trail, stormwater management, and slope retention design. Pedestrian Bridge Design in Fultonville, New York investigated bridge design. The designs were approached with sustainability in mind to be congruent with the natural setting of the site. This executive summary outlines the methods used to design alternatives and present recommended designs to be implemented in the construction of a recreational trail in the Fultonville Cemetery & Natural Burial Ground.

## **Trail Design**

The design of the trail as a whole was comprised of the determination of a route, a use characteristic, construction specifications, and a surfacing material. Data was gathered through Geographic Information Systems (GIS) databases as well as informal community input. A number of alternatives were investigated for each part of this design. The trail is suggested to roughly follow the perimeter of the parcel utilizing mostly existing roadbeds. One section of the trail will require new construction. It is recommended that all motorized vehicles be prohibited on the trail, but that any pedestrian uses be acceptable. A trail width of 10 feet is recommended with a clearing width of 14 feet and clearing height of 12 feet. Out of three surfacing materials investigated, it is recommended that gravel be used to surface the trail due to its durability, while

remaining permeable. Five hundred cubic yards of gravel will be required to surface the trail, costing approximately \$5,300 from Cushing Stone Company in Amsterdam, New York. The next steps in the implementation of this component require clearing the recommended path of all vegetation, grading said path, and surfacing the same.

## **Bridge Design**

Currently there is a ravine with existing stone abutments that interrupts the trail. It was clear that a new bridge needed to be designed to continue the trail. Four bridge designs were considered in order to connect the trail – a Whipple Truss design, a Flatcar Bridge design, an aluminum Pratt Truss design, and a simple girder design. Each of the bridge options needed to fit the purpose of the trail and accommodate pedestrian traffic. Since the trail will need to be maintained, each bridge design must also accommodate small utility vehicles such as John Deere Gators. Each option was evaluated on cost, constructability, aesthetics, and environmental impact. After evaluating each of the four designs, it was found that the Whipple Truss Bridge would be best suited for the site. The next step for this element of the design will require the review and approval by a licensed engineer.

## **Stormwater Management Design**

One portion of the trail, in particular, experiences issues due to stormwater runoff. The trail remains muddy much of the time with standing water sometimes present. A hydrologic analysis was conducted for the area to determine peak runoff rates for 2-, 25-, and 100-year design storms. This information was used in designing three alternatives to alleviate the stormwater runoff concerns. It is recommended that a 60-foot long portion of the trail in this area be paved with a permeable paver known as Turfstone by Belgard. This product aids in the

retention and stabilization of soils exposed to erosive conditions. Six hundred square feet of pavers will be required to pave this area, costing approximately \$1,900 from Cranesville Block Company in Amsterdam, New York. The next step in the implementation of this component is the installation of the product.

### **Slope Retention Design**

Very steep slopes abut many areas along the trail. One area, along the entrance trail, has exhibited signs of failure due to the lack of any means of retention. A topographic survey was conducted to gather information related to the existing slopes. Three design alternatives were generated to stabilize the slope and prevent future failure. It is recommended that a two-foot tall timber wall be constructed along the base of the slope to aid in retention while the hillside itself be planted with a combination of Black Chokeberry and Red Oak to stabilize the soil. The construction of an 84-foot long timber wall and the installation of two-dozen Black Chokeberry bushes and Red Oak trees will cost approximately \$1,200 from Tree Nursery Company online and Lowe's Home Improvement. The next steps in the implementation of this component will require clearing the slope of any debris, planting said slope with the aforementioned vegetation, and constructing the timber wall. Once these steps are carried out, the trail in the area will be able to be cleared to the required 10-foot width.

### **Next Steps**

The next step in the development of the proposed recreational trail will require the approval of this project by the Fultonville Board of Cemetery Commissioners and the Village Board of Trustees. Following their approval, funding must be located to move this project forward. Many aspects can be advanced at this point. Others, however, such as the construction

of a bridge, will require professional consultation to finalize designs. For these costs, grant funding may be sought.

## **Capstone Design**

This project team held itself to certain design and method standards. We ensured the design constituted the utmost integrity in the following areas: economic, environmental, sustainability, constructability, ethical, health and safety, and social and political. Each of these aspects was carefully thought out while each design decision was made. Also, in order to graduate from a college accredited by the Accreditation Board for Engineering and Technology (ABET), a student must complete a capstone requirement.

### **Economic**

Economics is a key factor that governs the design of all engineering projects. There has to be a balance between a project that is too expensive and one that is too low-cost to fulfill other design criteria. A cost analysis was performed for all aspects of each bridge design. The main concerns were construction costs, transportation costs, and labor costs. If a project cannot be afforded, then it will not be built regardless of the quality of the design.

### **Environmental**

The project solution included an effort to minimize the effect on the environment. Destruction of vegetation due to construction was considered and it was a priority to be kept to a minimum. Transportation would also have an effect on the environment. The amount of time required for construction vehicles and personnel to be on site also needed to be kept to a minimum.

## Sustainability

Designing with sustainable practices ensures that these bridge designs will be enjoyed for years to come. All aspects of the project should be as easy and inexpensive as possible to maintain. This means designing the bridges to last as long as possible.

## Constructability

Located in the woods on a dirt trail, the bridge components would have to be transported over rough terrain. Depending on the final bridge design chosen, the bridge or bridge sections could be pre-fabricated or assembled on site. Construction vehicles would be required to place the bridge in its final location. It is also important to assess how easy the bridge is to assemble based on the amount and type of connections.

## Ethical

This project was conducted in accordance with the American Society of Civil Engineers Code of Ethics. This project sought to provide the best possible solutions for each party affected by the design. The design does not convey any falsified information or violate any regulations of a governing body. The first Fundamental Canon of Engineers is: Hold paramount the safety, health, and welfare of the public (National Society of Professional Engineers, 2013). Safety of the public comes first.

## Health and Safety

Safety and health regulations have already been put in place by the *Americans with Disabilities Act*, and *New York State Building Code*. These regulations were closely followed to ensure the safety of the public since this trail is in the woods and may pose more danger to

pedestrians and users. Structural integrity of each design was one of the most important factors throughout all stages of the project.

## **Social and Political**

The overall success of this project depends on the community's acceptance and use of the trail and bridge. The Board of Cemetery Commissioners and Board of Trustees must ensure the adoption of the final plan. Incorporating these social and political aspects will aid in the overall success of the project.

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## 1 Introduction

The Village of Fultonville is interested in constructing a recreational trail utilizing land in the Fultonville Cemetery and Natural Burial Ground. Currently there is a gap that interrupts the existing trail that runs through the site. The gap spans thirty feet over a small stream. The existing stone abutments on the site are a reminder of the bridge that used to be there.

The purpose of this project was to create four different bridge design options to evaluate before finally recommending one of the designs to the Fultonville Board of Cemetery Commissioners and Board of Trustees.

Four different bridge alternatives were prepared for evaluation:

1. The first design to be evaluated was a Whipple Truss Bridge. This option was considered because of the historical significance of the design and its relationship to the area.
2. The second alternative design to be evaluated was a Flatcar Bridge. This option was identified because it serves as a pre-fabricated design. This would also fit into the area's rich history because they are fabricated from train railcars.
3. The third bridge design was an aluminum Pratt Truss bridge. This option was explored as a low maintenance solution that would offer a more modern look.
4. The fourth alternative was a simple girder bridge. This option was developed for its simplicity in construction.

Each of the bridge designs was created to fit the purpose of the trail and accommodate pedestrian traffic. Since the trail will need to be maintained, each bridge design was also sized to accommodate small utility vehicles such as John Deere Gators. Each bridge alternative was evaluated on cost, constructability, aesthetics, and environmental impact.

## 2 Background

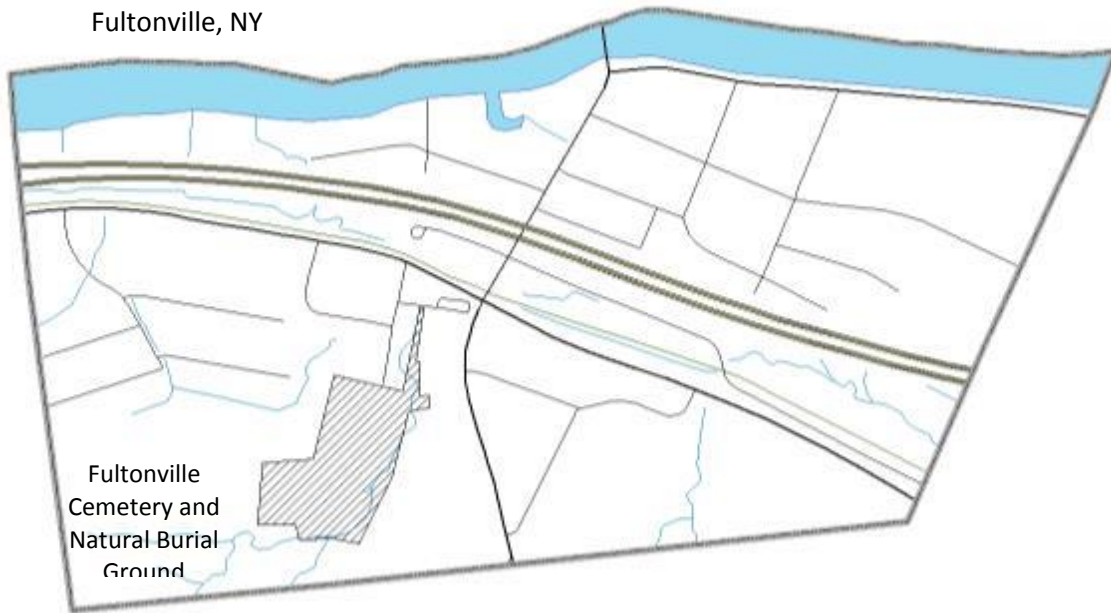
This chapter introduces the history of the site in Fultonville, New York. Several bridge designs are discussed including the Whipple Truss Bridge, Pratt Truss Bridge, and Flatcar Bridge. Allowable Stress Design and Load and Resistance Factor Design are also presented.

### 2.1 History of the Site

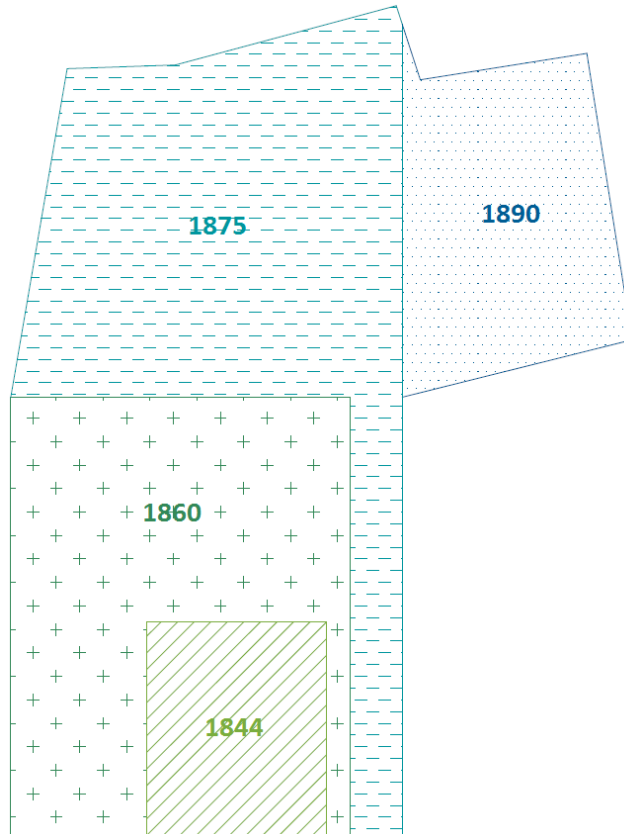
Located along the south bank of New York's Mohawk River, the village of Fultonville is a small, rural community surrounded by agriculture. Established as a canal town in 1823, Fultonville grew to become a widely known stop on the Erie Canal until its removal to the Mohawk River in the early twentieth century. The surrounding Mohawk Valley is rich in history and has placed an amplified value upon its heritage in recent years.

In 1844, the minister, elders, and deacons of the Reformed Protestant Dutch Church of Fultonville purchased an acre of land in the northwest corner of Garret Yates' upper field for use as a burying ground (Deed Liber, Montgomery County). The parcel was laid out into large, square lots and sold at auction (*History of Montgomery and Fulton Counties*, F. W. Beers & Co.). Shortly after the incorporation of Fultonville as a village in 1848, the Church turned the burying ground over to the municipality. Additional land was purchased from Yates in 1860 that more than doubled the size of the cemetery (Deed Liber, Montgomery County). In 1861, a right of way to "construct, use, and maintain a road" to access the cemetery was granted to the village by Samuel Donaldson. Please refer to Figures 1 and 2 which show the Fultonville burial ground. Construction of a bridge was required to cross a ravine at a "point called the falls." A dozen years later, a deed registered that Lewis J. Bennett, a former Fultonville merchant now of Buffalo, for the consideration of one dollar and interest in a "family lot," conveyed to the village "the iron super structure of the bridge now erected over the stream running past the Fultonville

Cemetery, and in the road leading to said Cemetery.”(Deed Liber, Montgomery County) There are no other known accounts referencing the cemetery bridge.



*Figure 1: The Fultonville Cemetery and Natural Burial Ground encompasses nearly 10 acres in the southwestern portion of the village.*



*Figure 2: The cemetery is made up of four additions, spanning from 1844-1890.*

Beginning in 2007, a large revitalization effort began in the cemetery. Decades of neglect allowed many areas to become overgrown that have since been cleared. Dozens of grave markers have been restored. Part of the ongoing work included drafting and adopting regulations for the proper functioning of the cemetery. These regulations were adopted by the Fultonville Board of Trustees in 2009 and created a Board of Cemetery Commissioners. Currently there are two existing stone abutments at the site of the bridge. These abutments will be preserved during the new bridge construction and placed in front of the new concrete abutments to keep this historical look.



## **2.2 Overview of Committees and Approval Process**

The site development of the Fultonville Cemetery and Natural Burial Ground falls under two main public entities. The land is owned by the Village of Fultonville, of which the responsible parties are an elected Board of Trustees and Mayor. The Trustees and Mayor appoint a Board of Cemetery Commissioners biannually. The Commissioners oversee all cemetery business. Their actions are only binding if approved by the Trustees and Mayor. The final design for the site development will be presented to the Board of Cemetery Commissioners. Upon their acceptance, the plan must be then approved by the Board of Trustees and Village Mayor.

## **2.3 Bridge Designs**

Several different bridge designs were created and analyzed in this project. A wooden pedestrian bridge and a Whipple truss bridge were designed and assessed and they were compared with a reused flatcar and an aluminum truss design. Each type of bridge has unique characteristics that lend to different strengths and weaknesses in terms of environmental impact, ease of construction, and other constraints.

### **2.3.1 Flatcar Bridge Design**

Flatcar bridges are fabricated from either retired or unused flatbed railway cars. Figure 3 shows a flatcar bridge. These flatcars do not have any structural problem which may have forced them into retirement (Rick Franklin Corporation, 2012). Flatcars are made from top grade steel and require little maintenance, making them ideal bridge structures for hard to reach locations such as farmland cut off by streams. Flatcar bridges are constructed off-site to eliminate the downtime of a site. The cars are pre-cut before being shipped to the site with the desired span, and then fastened to the abutments at the site when they are being installed.



*Figure 3: Flatcar Bridge (Rick Franklin Corp.)*

### **2.3.2 Whipple Truss Bridge Design**

In 1841 Squire Whipple patented a bridge truss called The Whipple Arch Truss (Fonzi, 2008). The first Whipple Truss Bridge was made from cast iron for compression members and wrought iron for tension members. Squire Whipple's design was so well thought of by the community, that New York State later adopted the design as their official standard. The first Whipple Truss Arch was built in Buffalo, New York; it spanned Buffalo's Commercial Slip. The 100 foot Commercial Slip Whipple Truss had three arches, each with nine panels. The arches separated two lanes of traffic, and two outward pedestrian walkways. The image below shows a portion of the original Commercial Slip Whipple Truss; it was taken around 1870.



*Figure 4: Whipple Truss Bridge circa 1870 (Fonzi, 2008)*

### **2.3.3 Aluminum Pratt Truss**

In 1844 Thomas and Caleb Pratt designed a truss bridge that has come to be known as the Pratt Truss Bridge. There are many variations of this but the main concept is that the diagonal members are sloping toward the center of the truss and there are vertical members at each node. The vertical members are under compression while the diagonal members are under tension as long as there is balanced loading. Pratt Truss bridges became very popular for railway bridges as the main construction material switched from wood to steel in the late 19<sup>th</sup> century. An example of this bridge is the Governor's Bridge in Maryland which is shown in the following photo.



*Figure 5: Pratt Truss Bridge*  
<http://www.flickr.com/photos/sparks1524/2212838461/>

## **2.4 Pedestrian Bridge Design**

Pedestrian bridges serve a distinct purpose. Rather than accommodating vehicular traffic, they usually accommodate foot traffic and in some cases cyclists. Pedestrian bridges also complement the landscape that encompasses them. There are many types of pedestrian bridges including footbridges, simple truss bridges, suspension bridges, and joist bridges. Materials used for pedestrian bridges also vary as well ranging from wood to steel to concrete to even railcars. Residential pedestrian bridges generally span short distances. These bridges provide a safer means of travel to users who want to cross certain areas, especially those in heavily forested areas.

### **2.4.1 Design Criteria**

The proposed trailhead determined by the sponsor requires that the trail pass over a ravine. There are many different factors that determine the design of the bridge. These range from local and state laws that have to be upheld all the way to something as simple as being aesthetically pleasing and fitting in with the atmosphere of the surrounding area. Bridge loading, environmental conditions, and materials were all factors used in designing the various solution alternatives.

### 2.4.2 LRFD and ASD

Load and Resistance Factor Design (LRFD) and Allowable Stress Design (ASD) are both used to design structures for adequate strength. LRFD uses factored load equations to determine maximum loading while ASD does not use factored loads. The Allowable Stress Design method has been around longer than the Load and Resistance Factor Design. While both methods have limitations, one advantage of using ASD is that it's simplistic and an advantage of LRFD is that there is a load factor applied to each load combination. This means that LRFD has a probability approach to the loads on a structure. In LRFD design, a resistance factor,  $\phi$ , is used to reduce the design values for a factor of safety. The Values of  $\phi$  used for our wood and aluminum bridge designs can be seen in the following table. These values are from the *National Design Specification For Wood Construction*.

Table 1:  $\phi$  values for LRFD

Property	Symbol	Value
$F_b$	$\phi_b$	.85
$F_t$	$\phi_t$	.80
$F_v, F_{rt}, F_s$	$\phi_v$	.75
$F_c, F_{c-p}$	$\phi_c$	.90
$E_{min}$	$\phi_z$	.85

### **2.4.3 RISA-2D**

This project utilized the demonstration version of RISA-2D to analyze the truss members for each bridge alternative. This computer program allows the user to draw and create two-dimensional designs including frames and trusses. According to RISA, the demonstration version is simple structural analysis software that produces powerful results (RISA, 2014). The demonstration version of RISA-2D makes designing and analyzing member forces due to moving loads much easier to conceptualize and implement.

## 3 Methodology

This chapter discusses the step-by-step design of four different bridge options. These include a wood girder bridge, an aluminum truss bridge, a Whipple Truss bridge, and a railway flatcar bridge. The majority of calculations were done using the Load Resistance Factor Design method (LRFD). This method was utilized because it is more widely used than the allowable stress design method (ASD).

### 3.1 Design Criteria

The current trail design proposal requires the crossing of a small ravine. The dimensions of the crossing and the original abutments that are in place are defined in the AutoCAD drawing shown in the following diagram. The design of each bridge was proportioned to withstand the loading from a John Deere Gator or similar sized small vehicle. In addition each bridge option was designed to withstand the load of pedestrian traffic, snow, and wind loading. These required loading criteria defined the sizing of all members.

The maximum deflection allowed was calculated by using the equation  $L/240$ , where  $L$  is the length of the span in inches, and the value 240 is a constant. Since the span is 30 feet, or 360 inches, the maximum permissible deflection for the span is 1.5” inches.

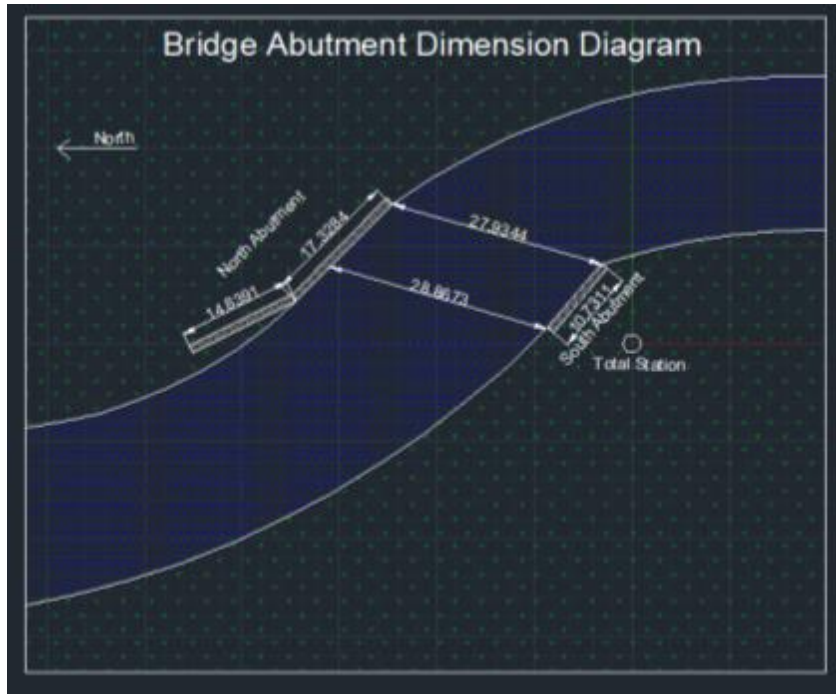


Figure 6: Site Data in AutoCad

### 3.2 Loading

All of the proposed bridge designs utilized the same loading in the calculations. In addition to foot traffic, the bridge must be able to support small emergency vehicles and recreational vehicles such as Gators. The weight of a fully loaded John Deere Pro Gator 2030A is approximately 4,820 lbs (John Deere, 2014). Of this weight, 2,170 lbs is the weight of the Gator itself including the cargo box, while the other 2,650 lbs refers to its loading capacity (John Deere, 2013). A distributed dead load must also be included in calculations to accommodate the weight of the material of the bridge itself. This included the weight of the structural members, decking, and handrails. Truss member weights of Douglas-Fir range from 2 lb/ft to 56 lb/ft (Engineering Toolbox, 2014). Calculations that include snow loading must also be added to the Gator load in case of emergencies in the winter where both loads may be present on the bridge.



The load combination  $1.2D + 1.6L + 0.5S$  was determined to be the critical loading combination, where D represents the dead load and self-weight, L represents the live load from the Gator vehicle, and S represents the snow load, at 50 pounds per square foot (New York State Building Code, 2007). For the DL, a gravity of “-1” was chosen when inputted into RISA-2D. This means that the DL would only be affected by the weight of the members at a value of gravity. The negative sign indicates the force is a downward vertical force with a factor of 1 multiplied by gravity

### **3.3 Structural Design**

This section addresses member sizing, purlin design, decking, and abutment design. This section introduces the methods for designing the bridge alternatives.

#### **3.3.1 Member Sizing Using RISA-2D**

Douglas Fir-Larch was chosen as a material for the wooden bridges for its high strength and its availability in a large range of structural sizes. Douglas Fir-Larch is also best known for its tough fiber and dense grain structure (Western Wood Species Association, 2002). Aluminum was chosen as a material for one of the truss bridges for its durability and lightweight characteristics. The specific aluminum that was chosen was 6061-T6 aluminum for its increased strength. Aluminum also requires very little maintenance.

#### **3.3.2 Member Sizing Using RISA-2D**

A demonstration version of the computer program RISA-2D was used to determine the size of most members in each bridge design. The process of analyzing structures in RISA-2D starts by selecting materials and constructing the members in the design. Boundary conditions at the joints are then selected. In this case a simply supported bridge was used, consisting of a pin and a roller supports. Then the basic load cases are inserted into the program. These are all of

the loads discussed in the previous section. Finally, a load combination equation based on the LRFD load cases was constructed and set to solve the system. RISA then provided a suggested member size that would support the desired load. RISA-2D uses Steel Design Codes from AISC 360-10/05 as well as LRFD Wood Design (RISA, 2014). After initial member sizes were defined, the program was run again to determine the stresses and deflections in each member with the new member sizes, as well as the loads at the boundary conditions. Appendix B shows the hand calculations that confirm these results. Figure 7 and Figure 8 show the RISA design of the aluminum truss bridge and Whipple truss bridge, respectively.

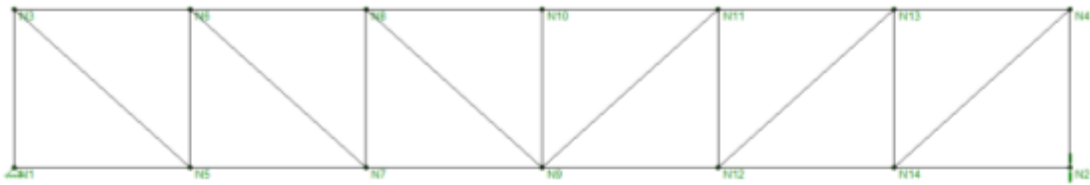


Figure 7: RISA Diagram of Aluminum Truss Design

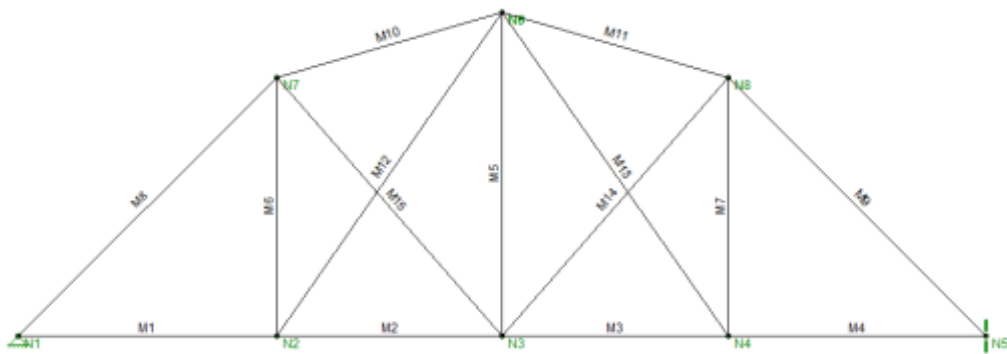


Figure 8: RISA Diagram of Whipple Truss Design

For the flatcar bridge, four different scenarios were considered when using the equation to find the point with the most shear force. The shear equation  $V_A = P_1(V_1) + P_2(V_2)$ , where  $P_{\#}$  is

the wheel load and  $V_{\#}$  is the shear value from the influence lines, was used to determine the maximum shear at point A; point A changing between all four cases (Hibbeler, 2011). Case 1 was used when the Gator vehicle is almost halfway across the bridge. Case 2 was used when the Gator is almost a quarter ways across the bridge. Case 3 was used when Gator is just passed the halfway point of the bridge, and case 4 was used when the front tire of the Gator is just passed the halfway point of the bridge. Once the maximum shear point is found, the same case was used to determine the maximum moment produced.

The equation used was  $\Delta M = Ps(x_2 - x_1)$  where  $x_2 - x_1$  is the horizontal movement,  $s$  is the slope of the line segments, and  $P$  is the concentrated force. Yield strength of the flatcar also had to be determined to find the allowable stress limit of the bridge. The design load also had to be calculated in order to determine the size and strength of the abutments to be used.

### **3.3.3 Purlin Design**

Purlins are simply supported beams that span across the girders or truss members to support the decking. The purlins for the aluminum truss bridge were designed by first deciding on a particular spacing. It was decided that there would be 4 purlins per truss panel as this was the only value that provided a tributary width that led to the purlins requiring a similar size member to the truss members. This resulted in 15 inch spacing. The 3-inch square aluminum tubing was assumed in the initial calculations for the purlins. The loading on the purlins can be seen in the hand calculations in Appendix B for aluminum purlin design. It was analyzed in RISA to determine the final member sizes.

Purlin sizes for the two wooden bridges were determined through hand calculations that can be seen in Appendix B. The spacing was based on the aluminum truss design. It was

decided that they would be on a 15” spacing pattern. From here it was possible to determine the member size by treating them as simply supported beams.

#### **3.3.4 Decking**

The three bridges that were designed will utilize composite decking from Trex. The 1” x 6” decking was analyzed to determine if it is strong enough for the bridge loading, as the company does not promote it as a structural material. The strength values and member sizes necessary for these calculations were found on the Trex website. Sections of the decking were checked for shear and bending after finding the tributary area based on the spacing of the purlins.

Decking for the flatcar bridge will be installed after the primary framing is erected, by Rick Franklin Corporation. The decking will be completed after the bridge is placed on the concrete abutments and fastened. The decking will span across the nine-foot width of the bridge and be fastened. According to Rick Franklin Corporation, the decking will be 4” x 12” x 10’ and the bridge will have 18” curbs. This bridge will be wider than the other three because of the safety curbs.

#### **3.3.5 Abutments**

The concrete abutments must be able to support nearly a 10-kip load, or 10,000lb load, when a Gator passes over with snow covering the bridge. On the flatcar design this value had to be increased to 26,000 lbs to account for the dead load of the railcar.

After a visual inspection of the existing stone abutments was completed, it was decided that cast-in-place concrete will be used; however, designs for the new abutments were not prepared. General costs for the concrete were found using the 2014 version of *National Construction Estimator 62<sup>nd</sup> Edition*. The existing stone abutments were not capable of supporting the bridge designs due to weathering and cracking of the stone. The cast-in-place

concrete will be bought locally to reduce transportation costs. The existing stone currently in place of the abutments will be taken down, and reassembled as a facing to the new concrete abutments. Doing this recreates the old historical look to the bridge.

### 3.4 Cost

Cost is a critical part of the design solution. The bridge options were designed to have the lowest cost possible. Costs of the Douglas-Fir lumber needed to construct the Whipple Truss Bridge and Simple Girder design were based on pricing from a local lumber yard. The price was determined by taking the size of the lumber multiplied by the total length required. This price does not include tax, transportation cost, and construction costs as well as other needed materials, such as bolts and brackets. Transportation costs will vary based on how far the lumber must travel to get to the site. The added costs were determined from the *2014 National Construction Estimator 62<sup>nd</sup> Edition*.

Costs of the aluminum for this bridge were estimated using ThyssenKrupp Materials, which ship out of Wallingford, CT. They have a wide variety of the desired aluminum that can be custom made to any size. This price does not include tax, transportation cost, and construction costs as well as other needed materials, such as welding. The added costs were found from the *2014 National Construction Estimator 62<sup>nd</sup> Edition*.

The cost of the flatcar bridge includes the cost of the railcar itself, the cost of transportation, and the cost of decking used. Installation costs depend on contractors in the area who will install the preassembled bridge onto the abutments. Pricing information was obtained from Rick Franklin Corporation.

### 3.5 Evaluation of Alternatives

The next step was to develop a basic score sheet to evaluate which bridge option would be the best for the site. The final design recommendation was based on these evaluations. The score sheet needed to consist of different criteria including construction cost, lifecycle cost, constructability, safety, environmental impact, accessibility, and aesthetic appeal.

For each criterion, each bridge alternative was rated on a scale from one to five. Table 2 offers a summary of the evaluation criteria and how they were graded. Certain criteria have an importance factor, or “weight factor”. This means that if a criterion has a weight factor of two instead of one, we thought that criterion is twice as important as the others. Construction Cost was broken up into sections which included materials costs, ease of construction, abutment costs, and transportation costs. These scores were weighted and then added together and averaged for its final rating on the score sheet. Table 3 shows the score sheet with which each bridge option was evaluated.

Table 2: Summary of Evaluation Criteria

Criteria	Grading scale	Description
Material Costs	High-Low 1-5	Cost of all materials required for the design.
Ease of Construction	High-Low 1-5	How easy the bridge is to assemble based on the quantity of connections.
Abutment Cost	High-Low 1-5	Graded based on how much weight they need to support.
Transportation Cost	High-Low 1-5	Graded based on how far the materials had to be shipped from.
Lifecycle Cost	High-Low 1-5	Graded based on required maintenance.
Environmental Impact	High-Low 1-5	How much land is disturbed for the construction of the bridge.
Aesthetics	Low-High 1-5	How appealing each bridge option is.

Table 3: Evaluation Criteria

Criteria	Weight Factor	Score					Weighted Score
		1	2	3	4	5	
Material Costs High-Low	2						0
Ease of Construction Low-High	1						0
Abutment Cost High-Low	2						0
Transportation Costs High-Low	2						0
Lifecycle Cost High-Low	2						0
Environmental Impact High-Low	1						0
Aesthetics Low-High	1						0
<b>Total Score</b>						<b>0</b>	



## 4.0 Results

### 4.1 Design Criteria

The equation  $1.2D + 1.6L + 0.5S$  was used to determine the maximum loading on the bridge designs. A uniform dead load (DL) was put into RISA-2D by using the load combination function. The weights of the members (DL) are already preset into the RISA-2D program.

The live load (LL) was also put into RISA-2D by using the load combination function. RISA-2D contains a “Gator” LL function. This was used in the load combination function as a vehicle live load, or moving load. RISA-2D would take the vehicle load and analyze the progression of the Gator as it moved from one side of the bridge to the other. This would prove useful in determining which members and nodes experienced the most tension and compression forces.

The snow load (SL) was also put into RISA-2D by using the load combination function. The snow load value used for the area was 50 lbs/ft. Figure 9 shows the load combination function of the three loads and their factors. The description shows the three loads used: moving load, dead load, and snow load. BLC stands for basic loading combination. This is where the values of each load were defined either by RISA-2D or by physically entering them into the program. The “factor” allows the user to enter the loading factors from the equation  $1.2D + 1.6L + 0.5S$ .

The allowable deflection is based on the overall length of the bridge. The deflection limit, while taking into account only the live load, is  $L/240$ . With our 30 foot bridge length, this resulted in each member of our bridge designs permitted less than 1.5 inches of deflection.

Load Combinations										
Combinations		Design								
	Description	Solve	PDelta	SRSS	BLC	Factor	BLC	Factor	BLC	Factor
1	ML + DL + SL	<input checked="" type="checkbox"/>			M1	1.6	DL	1.2	SL	.8

Figure 9: Load Combinations

## 4.2 Simple Girder Bridge

### 4.2.1 Bridge Design

The primary girders were first drawn in RISA 2D. The software was used to analyze and design the girders as simple beams for a span length of 30 feet and the given loading. It was found that a nominal size of 16x16 Douglas-Fir was required for this bridge. This size was confirmed in hand calculations that can be found in Appendix B. The initial timber size was then entered into the program and analyzed again to find the new stresses and deflections and confirm acceptability.

Purlin sizes for the simple girder bridge were determined through hand calculations. They were designed using a 15" spacing. After the tributary area and the subsequent loading were taken into account, 25- 4x6" Douglas-Fir lumber was chosen as the preferred design.

### 4.2.2 Structural Analysis Results

After "solving" the internal forces in the girders, the joint reactions were displayed. One support was a pin and the other was a roller. These represent the two abutments that will support the bridge. The figure below shows the joint reactions from RISA-2D. This shows that the abutments will have to sustain a maximum load of 11 kips or 11,000 lbs.

	Joint		X [k]	L...	Y [k]	L...	Mome...	L...
1	N1	max	0	1	8.822	1	0	1
2		min	0	1	1.489	1	0	1
3	N2	max	0	1	8.822	1	0	1
4		min	0	1	1.489	1	0	1
5	Totals:	max	0	1	10.978	1		
6		min	0	1	6.978	1		

Figure 10: Joint Reactions in Girder Bridge

The maximum deflection allowed was calculated by using the equation  $L/240$ . L is the length of the span, which is 360 inches. This allows for a maximum deflection of 1.5 inches. The deflections across the span are shown in the following figure. The maximum deflection due to the specified loading in the center of the girder is about 1.3 inches.

	Member	Sec		x [in]	L...	y [in]	LC	L/y Ratio	LC
1	M1	1	max	0	1	0	1	NC	1
2			min	0	1	0	1	NC	1
3		2	max	0	1	-.179	1	2014.972	1
4			min	0	1	-.907	1	397.011	1
5		3	max	0	1	-.251	1	1435.668	1
6			min	0	1	-1.285	1	280.243	1
7		4	max	0	1	-.179	1	2014.972	1
8			min	0	1	-.907	1	397.011	1
9		5	max	0	1	0	1	NC	1
10			min	0	1	0	1	NC	1

Figure 11: Deflection in Girder Bridge

## 4.3 Aluminum Truss Bridge

### 4.3.1 Bridge Design

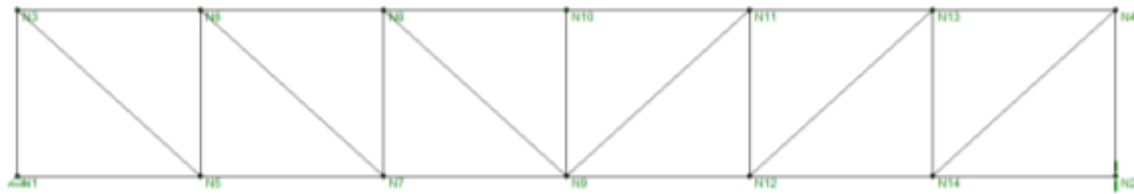


Figure 12: RISA Model of Truss Bridge

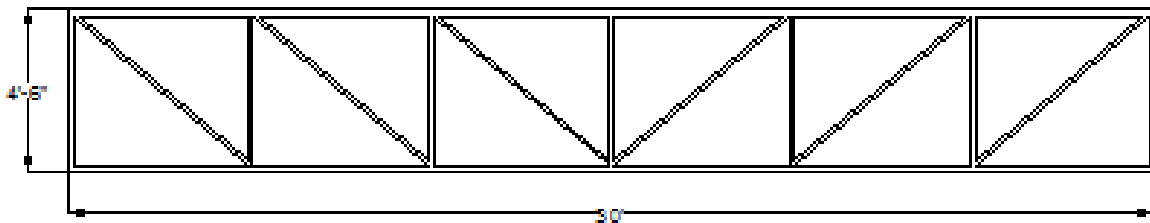


Figure 13: AutoCAD Drawing of Truss Bridge

The members were first constructed in RISA 2D. Each member was assigned a number to help differentiate them. Then the required load combinations were entered into the RISA-2D program. RISA 2D analyzed the truss and provided suggestions for the recommended aluminum square tubing size. Initially the suggested design included 1.5", 2.", and 3" square tubing.

Different sizes of members are not ideal for several reasons. For one it is not aesthetically pleasing. It looks much better when they are all the same size. It also aids in the welding process as it is more difficult to connect varying sizes of members. For this reason a final design was constructed using the largest required member size, RT 3 x 3 x 0.125. RISA 2D was then used to analyze the structure using this size to make sure that the size was still adequate.

The purlin design can be found in the appendix. They were designed using a 15” spacing, and after taking into consideration the tributary area and the loading, it was determined that 2.5 inch square tubing with a 1/8 in wall thickness would be adequate to support the design loading.

#### 4.3.2 Structural Analysis Results

After “solving” the internal forces in the truss members, the joint reactions were displayed. One support was a pin and the other was a roller. These represent the two abutments that will support the bridge. The figure below shows the joint reactions from RISA-2D. The results show that the maximum loads at the ends are very similar to the simple girder bridge. The abutment would have to support a load of 11.3 kips.

	Joint		X [k]	L...	Y [k]	L...	Mome...	L...
1	N1	max	0	1	8.97	1	0	1
2		min	0	1	1.637	1	0	1
3	N2	max	0	1	8.97	1	0	1
4		min	0	1	1.637	1	0	1
5	Totals:	max	0	1	11.273	1		
6		min	0	1	7.273	1		

Figure 14: Joint Reactions in Truss Bridge

The maximum deflection allowed was calculated by using the equation  $L/240$ . The length of the bridge is 360 inches, so the maximum deflection is 1.5 inches. These calculations were performed by RISA 2D in the analysis. The following table shows the deflections in each member. Although a RISA diagram showing the deflected shape would be very useful, unfortunately the software is not able to construct a diagram when a moving load is involved because the output is an envelope of the values obtained from multiple analyses and not the

response to a specific loading.

Envelope Joint Displacements								
	Joint		X [in]	LC	Y [in]	LC	Rotation [rad]	LC
1	N1	max	0	1	0	1	-2.254e-3	1
2		min	0	1	0	1	-2.112e-2	1
3	N2	max	.147	1	0	1	2.112e-2	1
4		min	.034	1	0	1	2.254e-3	1
5	N3	max	.209	1	-.005	1	1.469e-3	1
6		min	.045	1	-.027	1	-4.575e-3	1
7	N4	max	-.008	1	-.005	1	4.575e-3	1
8		min	-.064	1	-.027	1	-1.469e-3	1
9	N5	max	.002	1	-.071	1	9.009e-3	1
10		min	0	1	-.333	1	-1.285e-2	1
11	N6	max	.183	1	-.075	1	-9.393e-4	1
12		min	.038	1	-.35	1	-4.641e-3	1
13	N7	max	.034	1	-.12	1	7.477e-3	1
14		min	.007	1	-.584	1	-1.145e-2	1
15	N8	max	.133	1	-.121	1	-1.338e-4	1
16		min	.028	1	-.588	1	-3.276e-3	1
17	N9	max	.085	1	-.137	1	7.857e-3	1
18		min	.017	1	-.669	1	-7.857e-3	1
19	N10	max	.074	1	-.137	1	8.508e-4	1
20		min	.017	1	-.669	1	-8.508e-4	1
21	N11	max	.024	1	-.121	1	3.276e-3	1
22		min	.005	1	-.588	1	1.338e-4	1
23	N12	max	.123	1	-.12	1	1.145e-2	1
24		min	.027	1	-.584	1	-7.477e-3	1
25	N13	max	.002	1	-.075	1	4.641e-3	1
26		min	-.037	1	-.35	1	9.393e-4	1
27	N14	max	.146	1	-.071	1	1.285e-2	1
28		min	.033	1	-.333	1	-9.009e-3	1

Figure 15: Deflection in Truss Bridge

## 4.4 Whipple Truss Bridge

### 4.4.1 Bridge Design

First, the members were drawn in RISA-2D. As each member was placed it was assigned a member number. For example, M1 represents the first member drawn. The order is not important, but accurately assigning a member name and linking it to the actual RISA-2D line is important. Then the required load combinations were entered into the RISA-2D program. From here the “solve” function was used to solve the structural analyses for reactions and member forces. The design capabilities within the software use the analysis results to establish appropriate member sizes. The figure below shows the RISA-2D model with member lengths. Table 2 presents the recommended nominal sizes from RISA-2D.

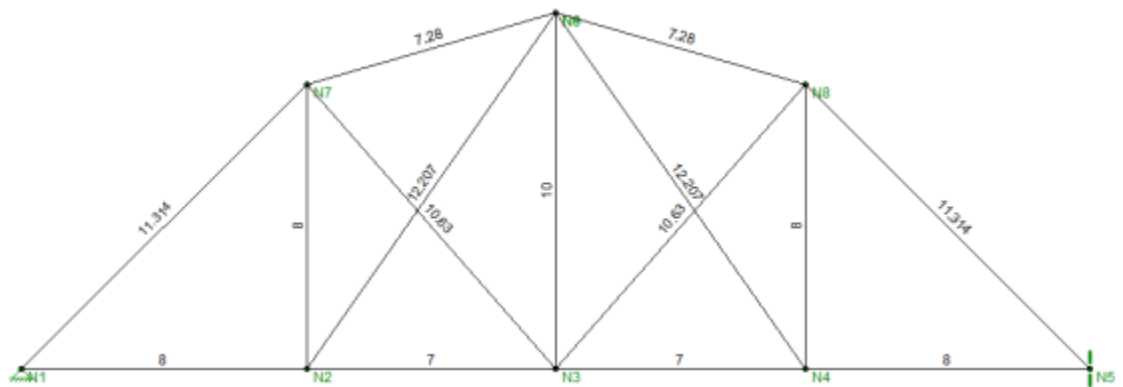


Figure 16: Whipple Truss Design with Member Lengths

Table 4: Member Labels and Nominal Sizes

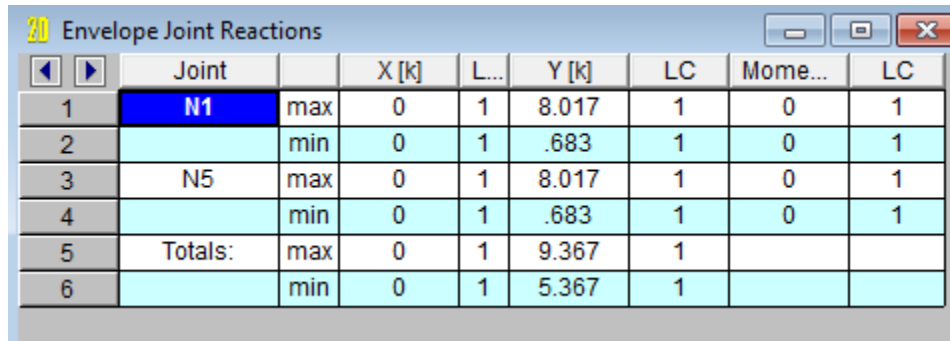
Member	Nominal Size (inches)
M1	4X14
M2	3X16
M3	3X16
M4	4X14
M5	2X8
M6	2X16
M7	2X16
M8	4X10
M9	4X10
M10	4X4
M11	4X4
M12	4X6
M13	4X4
M14	4X6
M15	4X4

Since different sizes of members would not be aesthetically pleasing to the pedestrian crossing the bridge, a uniform nominal member size of 6”X10” was chosen to support the loading. The member sizes defined from the first analysis influenced the decision of a 6”X10” uniform size. The largest members from the suggested design by RISA-2D were 3”X16” and 4”X14”. Therefore, the new uniform size was selected to have the same properties in regard to strength and resistance to deformation as the two others mentioned. The new size of 6”X10” was then inserted into RISA-2D to be analyzed and confirmed using the same loading conditions. The purlin design for the Whipple truss is the same as the simple girder bridge. This design utilized 15” spacing and 25- 4x6” Douglas-Fir lumber was chosen as the preferred design.



#### 4.4.2 Structural Analysis Results

After “solving” the truss member forces, the joint reactions were displayed. One support was a pin and the other was a roller. These represent the two abutments that will support the bridge. The figure below shows the joint reactions from RISA-2D.



	Joint		X [k]	L...	Y [k]	LC	Mome...	LC
1	N1	max	0	1	8.017	1	0	1
2		min	0	1	.683	1	0	1
3	N5	max	0	1	8.017	1	0	1
4		min	0	1	.683	1	0	1
5	Totals:	max	0	1	9.367	1		
6		min	0	1	5.367	1		

Figure 17: Joint Reactions of Whipple Truss

The 1.5” deflection limit was compared with the deflection of the original suggested member sizes, not the uniform 6X10 size. The figure below shows the joint displacement due to the vehicle load plus the dead load and snow load. The maximum deflection was 1.136”

Envelope Joint Displacements							
	Joint		X [in]	L...	Y [in]	L...	Rotatio... L...
1	<b>N1</b>	max	0	1	0	1	3.096e-4
2		min	0	1	0	1	-1.927e-2
3	N2	max	.018	1	-.01	1	9.121e-3
4		min	.002	1	-.097	1	-6.81e-3
5	N3	max	.03	1	-.012	1	5.359e-3
6		min	.003	1	-.103	1	-5.66e-3
7	N4	max	.039	1	-.011	1	8.969e-3
8		min	.005	1	-.108	1	-1.048e-2
9	N5	max	.053	1	0	1	1.973e-2
10		min	.007	1	0	1	-7.885e-4
11	N6	max	.028	1	-.011	1	6.065e-4
12		min	.003	1	-.092	1	-5.938e-4
13	N7	max	.041	1	-.01	1	1.046e-3
14		min	.005	1	-.086	1	-4.361e-4
15	N8	max	.012	1	-.01	1	3.346e-4
16		min	.002	1	-.091	1	-1.003e-3
17	N9	max	.869	1	.529	1	1.348e-2
18		min	-1.445	1	-1.136	1	-5.973e-3

Figure 18: Displacements of Whipple Truss

## 4.5 Flatcar Bridge

The vehicle live load was considered at four different points. The first case was when the Gator was nearly halfway across the bridge, meaning the front tire had not yet crossed the halfway point. The second case was when the Gator was almost a quarter ways across the bridge. The third case was when the Gator was just passed the halfway point of the bridge, meaning the rear tire had just crossed the halfway point. The fourth and final case considered was when the Gator vehicle's front tire had just passed the halfway point of the bridge. Appendix B shows the calculations used to find these values.

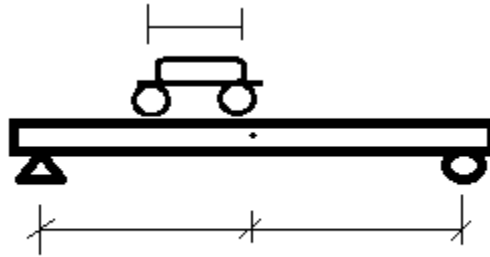


Figure 19: Example Loading Case for Flatcar

The table below shows the maximum shear for each corresponding case.

Table 5: Shear in Flatcar Bridge

	Maximum Shear (lbs)
Case 1	3,540
Case 2	590
Case 3	2,290
Case 4	660

These values were then used to find the maximum moment induced by the forces acting on the railcar. Appendix B shows the calculations used to find these values. Each of the individual shear values was used in four new cases. Case 1 yielded the maximum moment, having a value of 2,910 ft\*lb.

The maximum moment produced by the dead load was 53,100 ft\*lb. The maximum moment produced by the snow load was 5,625 ft\*lb. Therefore, the maximum moment from the Gator, dead load, and snow load combined was 61,635 ft\*lb. This occurred with case 1, when the Gator vehicle had just crossed the halfway point of the bridge. The railcar has a yield strength of 40 ksi (Wipf, Terry J. et al, 2007). The permissible stress in the member due to the bending moment is 22 ksi. The maximum bending moment capacity is 464,640 ft\*lb. Therefore, the flatcar bridge will not exceed its bending moment capacity when it is fully loaded. Refer to the figure below for a cross section of the flatcar.

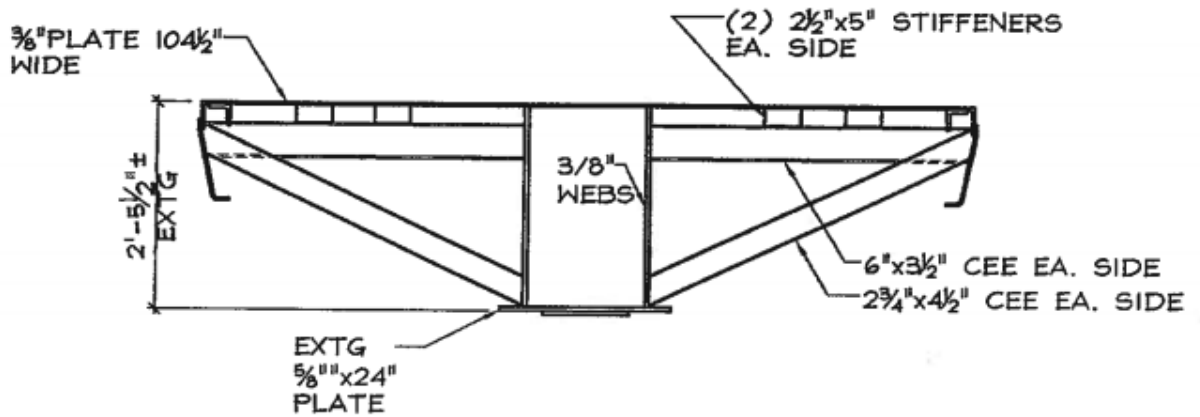


Figure 20: Cross Section of Flatcar (Rick Franklin Corporation, 2012)

Using the load combination equation,  $1.2D + 1.6L + 0.5S$ , the loading was found to be 26,000 lbs, rounding up. 26,000 pounds divided by the 30' length gives a value of 867 pounds per foot acting on the bridge. Therefore, the loading the bridge will actually experience is far less than the loading the bridge can safely sustain.

#### **4.6 Decking**

The Trex composite decking that is being used on all of the designs proved to be adequate to support the required loading. Hand calculations showing that the material has the required shear strength and bending strength can be found in Appendix B. The allowable stress is based on the material properties of the decking while the calculated stress is based on the loading. The calculated stress needed to be lower than the allowable stress. The calculated shear was found to be 970 lbs while the allowable stress was much higher at 2525 lbs. The bending stress was calculated in a similar way resulting in 2333 psi while the allowable stress was 4355 psi. The composite material offers a more durable finish than traditional wooden decking. The decking also spans between the purlins and is subjected to bending effects. The pieces come in 12 foot lengths and will be arranged 16 across. 40 pieces will be necessary to completely cover the bridge and they are available for purchase from Lowes. Decking can be secured with brackets and will follow ADA and NY State Building Code requirements.

## 4.7 Cost

### 4.7.1 Simple Girder Bridge

The final cost of the lumber needed for the 16”X16” members was \$2031.00. Since there are two beams, this cost needs to be multiplied by a factor of two bringing the cost to \$4062.00. This price does not include sales tax, lumber for decking, transportation costs, brackets, or bolts needed to secure the lumber in place. The price of the purlins is \$15.80 each. They are spaced 15” apart so 25 are required for the final design. This brings the total price of the purlins up to \$395.00. The table below shows the member sizes, number of member sizes needed and total costs.

*Table 6: Simple Girder Bridge Cost*

Simple Beam Bridge						
Material	Element	Section Size	Section Length	Cost per Section	Number of Sections	Total Cost
No1 Douglas Fir Larch	Girder	16x16	30'	\$2,031.00	2	\$4,062.00
	Purlin	4x6	8'	\$15.80	25	\$395.00
Trex Decking	Decking	1”x6”	12'	\$34.57	40	\$1,382.80
					Total	\$5839.80

### 4.7.2 Aluminum Truss Bridge

The final cost of the 6061 T-6 aluminum needed for the RT3x3x0.125 members was determined for each required member length. The prices were found from ThyssenKrupp Materials. Since there are two trusses, the total cost needed to be multiplied by two. The size of the purlins is 2.5 in square tubing. This price does not include sales tax, decking, transportation costs, or welding needed to connect the members. The decking is by Trex and the price reflects their cost at Lowes. The table below shows the member sizes, number of member sizes needed and total costs.

Table 7: Aluminum Truss Bridge Cost

Aluminum Truss Bridge						
Material	Element	Section Size	Section Length	Cost per Section	Number of Sections	Total Cost
6062 T-6 Aluminum	Vertical	RT3X3X0.125	4'6"	\$53.76	14	\$752.64
	Diagonal	RT3X3X0.125	6'7"	\$72.68	12	\$872.16
	Top and Bottom Chord	RT3X3X0.125	5'	\$40.19	24	\$964.56
	Purlin	RT2.5X2.5X0.125	8'	\$49.17	25	\$1,229.25
Trex Decking	Decking	1"x6"	12'	\$34.57	40	\$1,382.80
					Total	\$5201.41

#### 4.7.3 Whipple Truss Bridge

The final cost of the lumber needed for the 6"x10" members was \$899.44. Since there are two trusses, this cost needs to be multiplied by two bringing the cost to \$1798.88. This price does not include sales tax, lumber for decking, transportation costs, brackets, or bolts needed to secure the lumber in place. This price was found by determining the number of members and their individual lengths and multiplying each needed length by their individual cost. For example, eight foot members cost \$47.97. Six eight-foot members were needed so the total cost of the eight-foot members was \$287.82. Member lengths that were fractions, such as 7.28', were rounded up to eight-foot members. To install the wood, it would cost laborers about \$5.16 per linear foot for the 6"x10" timber. The table below shows the member sizes, number of member sizes needed and total costs for one truss, excluding labor.

Table 8: Whipple Truss Bridge Cost

Whipple Truss Bridge						
Material	Element	Section Size	Section Length	Cost per Section	Number of Sections	Total Cost
No1 Douglas Fir Larch	Bottom Chord	4x6	7' (used 8')	\$47.97	4	\$191.88
	Bottom Chord		8'	\$47.97	37	\$1774.89
	Vertical		10'	\$59.96	2	\$119.92
	Diagonal		12'	\$71.96	8	\$575.68
	Diagonal		14'	\$83.94	4	\$335.76
Trex Decking	Decking	1"x6"	12'	\$34.57	40	\$1,382.80
					Total	\$4,380.93

#### 4.7.4 Flatcar Bridge

The bridge would be transported by RAM Trucking and would cost \$7,500. A nine-foot wide bridge with curbs would cost \$12,000. The table below shows the cost of the decking, abutments, railcar, excavation and transportation.

Table 9: Flatcar Bridge Cost

	Cost	Cost/day	Cost/unit	Total Cost
Transportation	\$7500	-		\$7500
Decking	-	-	\$45/ft	\$1,350
Railcar	\$12,000	-	-	\$12,000
			Total	\$20,850

#### 4.7.5 Abutments

Contracting costs will vary to move the existing stone in front of the new concrete abutments. Excavation costs will also vary in order to install the abutments. The average excavation cost is \$500 minimum, plus \$340 a day to rent a 1 cubic yard backhoe. For delivery of 20 miles or less, 4,000 psi concrete costs \$110 per cubic yard (*National Construction Estimator*, 2014). ¼" diameter reinforcing #2 rebar costs \$1.07 per pound, or \$0.18 per linear foot. Installing one-cubic-yard of concrete for a wall costs \$112 per hour for one laborer.



## 5.0 Evaluation Process

A weighted assessment method was used to evaluate the four bridge designs. This was used to develop a recommendation for the best solution. The first step taken was choosing the appropriate criteria and weights.

### 5.1 Criteria

The guiding criteria chosen had to be applicable to all four bridges. These criteria could not be biased in any way. The chosen criteria included material costs as well as ease of construction, abutment costs, transportation costs, lifecycle costs, environmental impact, and aesthetics.

#### 5.1.1 Material Costs

The material costs of each bridge were determined by calculating the length of the total number of wood or aluminum members used in their relative designs. Costs of these materials were estimated by finding the different prices for each material from different supply companies. The rating scale was from 1-5, with 5 being the best option and least cost. The range of values was set to fit the calculated costs for each option. This is shown in Table 10.

*Table 10: Material Cost Evaluation*

Score	5	4	3	2	1
Cost (\$)	0-2500	2500-5000	5000-7500	7500-10000	10000+

Bridge	Whipple Truss	Flatcar	Pratt Truss	Simple Girder
Cost of Materials	\$4,380.93	\$12,000	\$5201.41	\$5839.80
Score	4	1	3	3

### 5.1.2 Ease of Construction

Ease of construction was based off of the number of connections of each bridge design. Bridge designs that had a lower number of connections received a higher score in the scale. The flatcar bridge option was rated a 5 on the scale because this option would already be preassembled before being shipped to the site. It would just have to be placed on the abutments and fastened once it had arrived. The range of values was set to fit the calculated number of connections for each option. This is shown in Table 11.

Table 11: Ease of Construction Evaluation

Score	1	2	3	4	5
Number Connections	80+	60-80	40-60	20-40	0-20

Bridge	Whipple Truss	Flatcar	Pratt Truss	Simple Girder
Connections	66	N/A	78	50
Score	2	5	2	3

### 5.1.3 Abutment Cost

The abutments were rated based on the weight of the bridge that they would need to support. The range of values was set to fit the calculated weight for each option. This is shown in Table 12.

Table 12: Abutment Cost Evaluation

Score	1	2	3	4	5
Weight (kips)	12-15	9-12	6-9	3-6	0-3

Bridge	Whipple Truss	Flatcar	Pratt Truss	Simple Girder
Bridge Weight (kips)	8	14.2	9	8.82
Score	3	1	2	3

### 5.1.4 Transportation Costs

Transportation costs were based on the distance from where the materials were purchased to the site where the bridge would be constructed, in miles. If the materials needed to construct the design were available locally, the design received a higher score. The bridge received a lower score if the materials needed for that option were farther away from the site. The range of values was set to fit the calculated distances for each option. This is shown in Table 13.

Table 13: Transportation Cost Evaluation

Score	1	2	3	4	5
Distance (miles)	200+	150-200	100-150	50-100	Less than 50

Bridge	Whipple Truss	Flatcar	Pratt Truss	Simple Girder
Score	5	1	4	5

### 5.1.5 Lifecycle Cost

Lifecycle costs were based on a high-low average and how often they would need service or repair. The costs included in this section were decking repair and replacement and removal of debris. Lifecycle repair costs did not include servicing costs to the abutments. The score for each option is shown in Table 14.

Table 14: Lifecycle Cost Evaluation

Score	1	2	3	4	5
	High	Medium-High	Medium	Medium-Low	Low

Bridge	Whipple Truss	Flatcar	Pratt Truss	Simple Girder
Score	3	4	5	3

### 5.1.6 Environmental Impact

The environmental impact made by the bridge construction is based on how much land is disturbed by constructing each bridge option. Bridges were scored on how much area was affected on a high-low basis around the site. This was based off of a number of factors including reuse of materials, disturbance to the environment, and amount of material to be used. Since the flatcar bridge option reuses a railcar that is out of commission, it will receive a higher score. This is shown in Table 15.

*Table 15: Environmental Impact Evaluation*

Score	1	2	3	4	5
	High	Medium-High	Medium	Medium-Low	Low

Bridge	Whipple Truss	Flatcar	Pratt Truss	Simple Girder
Score	3	4	2	3

### 5.1.7 Aesthetics

Aesthetics were scored on how well the bridge option conformed to the environment and how appealing each option is to the design. Scores were based on a high-low scale. This is shown in Table 16.

*Table 16: Aesthetics Evaluation*

Score	5	4	3	2	1
Conformity	High	Medium-High	Medium	Medium-Low	Low

Bridge	Whipple Truss	Flatcar	Pratt Truss	Simple Girder
Score	5	2	4	2

## 5.2 Final Bridge Scores Summary

Table 17: Final Bridge Design Scores

		Whipple Truss Design	Flatcar Design	Aluminum Pratt Truss Design	Simple Girder Design
<b>Criteria</b>	<b>Weight Factor</b>				
Material Cost	2	4	1	3	3
Ease of Construction	2	2	5	2	3
Abutment Cost	1	3	1	2	3
Transportation Cost	1	5	1	4	5
Lifecycle Cost	1	3	4	5	3
Environmental Impact	2	3	4	2	3
Aesthetics	1	5	2	4	2
	<b>Total</b>	<b>34</b>	<b>28</b>	<b>29</b>	<b>31</b>

The maximum possible score would be a 50 and the minimum score would be a 10.

## 6 Final Recommendation

Based on the final evaluation scores, the Whipple Truss Bridge is recommended for further investigation for implementation in the Fultonville Cemetery and National Burial Ground. Out of the maximum 50 points that a bridge design could receive, the Whipple Truss design received a 34. The Flatcar Bridge option received a score of 28; the aluminum Pratt Truss design a 29, and the simple girder design a 31. A discussion of pros and cons of each of the four options is presented in this chapter.

The Flatcar Bridge received a score of 28 as the final evaluation score. It received moderately high lifecycle cost and environmental impact scores. Although this option is simple to install on the site, it is expensive and unrealistic to transport to New York, which is why it received the lowest score of the four options.

The aluminum Pratt Truss design received the highest lifecycle cost score of the four options. It also received a high aesthetic score; however, compared to the other designs, it had a large environmental impact and did not receive a high ease of construction score. The final evaluation score for this option was a 29.

The simple girder design received a score of 31 out of the possible 50. This is because it had a great ease of construction score. However, this option was not the highest scoring of the four options because of aesthetics and its averaging scores in the other criteria.

The Whipple Truss design received a 34 out of possible 50 when it was evaluated. Although it did not have the best ease of construction score, the design excelled in the areas of aesthetics and transportation cost areas.

The Whipple Truss Bridge design is the final recommendation. It received the highest score on the evaluation without any bias. Therefore, the positive aspects of the Whipple Truss design greatly outweigh the negative aspects, whereas with the other three alternatives the positive and negative aspects are more equal.

## 7 Conclusion and Next Steps

Several factors need to be considered when designing a bridge. Aesthetics, environmental impacts, economics, social constraints and constructability all need to be considered rather than just structural integrity. This project offered a one-of-a-kind opportunity to explore bridge design in the context of a real-world problem. Many aspects needed to be considered rather than just designing a structure based on what was learned in educational courses. This proved to be more difficult than originally foreseen.

One necessary step that was taken in order to complete the project was the use of assumptions. Many assumptions were used throughout the entire evaluation process. For example, it was near impossible to determine the exact cost to construct each bridge design with all of the factors included. From this, an assumption needed to be made in order to simplify the evaluations within the given time constraints to complete the project.

Being able to bring together all of the different factors of bridge design was an invaluable experience. Not only did it prove difficult to complete, it showed that there are many more aspects than just designing a structure that fits the basic requirements.

This project has the potential to be investigated further, whether by professional engineers working to take the recommendation and build on the site or future MQP students looking to further the advancement of this project.

One consideration that can be taken into account is the soil at the site. There was no investigation into the soil type or how it will be affected by the proposed abutments and bridge. Another consideration that can be taken into account is a further investigation on how earthquake



loads will affect the bridge designs. A third consideration that can be taken into account is a more efficient way to reuse the existing stone abutments that are currently at the site. Whether there is a more efficient way to move the abutments or a way to build behind them can be investigated.

The major part of the realization of this project is funding. The funding for this project was not explored. Whether village funds or grant money is used is something that can be further investigated as well, or something that town officials can apply for if available.

Overall the project encompassed many real-world design aspects that are vital in any learning experience. Working within time constraints and the scope of the project it was impossible to encompass every detail, however, the amount learned from this project was incomparable to other experiences.

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**Appendix**

**Appendix A: Project Proposal**

**FULTONVILLE TRAIL DESIGN**

A Proposal for a Major Qualifying Project Report:

Submitted to Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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## Capstone Design

This project team will hold itself to certain design and method standards. We will ensure the design constitutes the utmost integrity in the following aspects: economic, environmental, sustainability, constructability, ethical, health and safety, and social and political. Each of these areas will be carefully thought out while each design decision made.

### *Economic*

Economics is a key factor that governs the design of all engineering projects. The project must be determined to be economically feasible before a project can get past the design stage. There has to be a balance between a project that is too expensive and one that is too low-cost to fulfill other design criteria. A cost analysis will be performed for both the trail design and the bridge design. The main concerns are material, maintenance, and construction costs.

### *Environmental*

This project will include various designs for erosion control. All hydrological designs will comply with *New York Standards and Specifications for Erosion and Sediment Controls*. The design will be sized for a 100-year storm as to minimize erosion impact on the surrounding environment from water runoff. To minimize environmental impacts that construction may have on surrounding areas, various procedures during the construction process must be evaluated. For example, setting the appropriate time for construction activities as to not disturb the community. Further, environmental protection methods should be put in place as to not disturb the natural state of the ecosystem.

### *Sustainability*

Sustainability is very important on this project to ensure that this trail could be enjoyed for years to come. All parts of the project should be as easy and inexpensive as possible to



maintain. This means designing the bridge, trail surface, and culverts to last as long as possible. Maintenance costs will have to be factored into the overall cost of the project to show a better representation of the project's economic feasibility. It is also crucial that the environmental sustainability of the bridge design is minimized by assessing the lifecycle of materials and manufacturing necessary for the bridge development. Recycled bridges and bridge materials may be used.

#### *Constructability*

Located in the woods on a dirt trail, the bridge components would have to be transported over rough terrain. Depending on the final bridge design chosen, pre-fabricated or to-be-constructed on site, the parts would have to be maneuvered through the woods. Construction vehicles would be needed to place the bridge in its final location. The bridge design will be heavily influenced by its location. The environmental impact made by the construction of the bridge and trail is a top priority when going through the planning and designing stages.

#### *Ethical*

This project will be conducted in accordance with the American Society of Civil Engineers Code of Ethics. This project will aim to provide the best possible solutions for each party affected by the design. The design will not convey any falsified information or violate any regulations of a governing body. The first Fundamental Canon of Engineers is: Hold paramount the safety, health, and welfare of the public (National Society of Professional Engineers, 2013). Safety of the public comes first.

#### *Health and Safety*

Safety and health regulations have already been put in place by the *Americans with Disabilities Act*, and *New York State Building Code*. These regulations will be closely followed

to ensure the safety of the public since this trail is in the woods and may pose more danger to pedestrians and users. Culvert designs will comply with *New York Standards and Specifications for Erosion and Sediment Controls*. This ensures the wellbeing of the environment which pedestrians will be utilizing.

*Social and Political*

The overall success of this project depends on the community's acceptance and use of the trail. To accomplish this, public input will be sought to determine a handful of design constraints including trail use and bridge design. Additionally, we must work with the Board of Cemetery Commissioners and Board of Trustees to ensure the adoption of the final plan. Incorporating these social and political aspects will aid in the overall success.

## **1 PROBLEM STATEMENT**

The village of Fultonville is interested in constructing a recreational trail utilizing land in the Fultonville Cemetery and Natural Burial Ground. Due to its proximity to the New York State Erie Canalway Trail, the proposed project would serve as an additional point of interest. The proposed trail project requires identifying a preferred route, developing erosion control methods, and designing a bridge.

## **2 OBJECTIVE**

The objective of this project is to complete a site development plan for a recreational trail in the Fultonville Cemetery and Natural Burial Ground. Multiple design options for the trail route, erosion controls, and bridge will be prepared. Factors governing the designs include cost, environmental impact, sustainability, constructability, ethical practices, health and safety standards, and social and political facets.

## **3 SCOPE OF WORK**

This Major Qualifying Project will be divided into two segments. The first segment entails identification of a preferred trail route and design, including hydrological analysis and drainage considerations. The second segment entails designing a bridge to span a ravine. Both segments will be divided into four main phases: site visits and data collection, analysis, design, evaluation of alternatives and preparation of a final proposal.

Throughout the data collection period a series of site visits and discussions with The Fultonville Board of Cemetery Commissioners and Board of Trustees will determine the vision for the recreational trail. Field data will be collected and analyzed to design multiple trail routes. Additionally, trail surfacing options and erosion control methods will be created. The different

options will be evaluated with consideration towards cost, environmental impact, sustainability, constructability, ethical practices, health and safety standards, and social and political facets.

Due to given constraints by The Fultonville Board of Cemetery Commissioners and Board of Trustees, the trail is required to cross a ravine. Existing limestone bridge abutments will be visually inspected to assess their ability to be reused. The design is dependent upon trail use. Multiple bridge designs will be prepared with various construction materials and aesthetics. All of the bridge designs will be evaluated with consideration towards the aforementioned factors. These designs will be outlined to supply the village with multiple possibilities. Finally, a completed design package will be presented.

#### **4 BACKGROUND**

Located along the south bank of New York's Mohawk River, the village of Fultonville is a small, rural community surrounded by agriculture. Established as a canal town in 1823, Fultonville grew to become a widely known stop on the Erie Canal until its removal to the Mohawk River in the early twentieth century. The surrounding Mohawk Valley is rich in history and has placed an amplified value upon its heritage in recent years.



Figure 1: Fultonville is located less than 40 miles west of the state capital at Albany.

#### 4.1 History of the Fultonville Cemetery and Natural Burial Ground

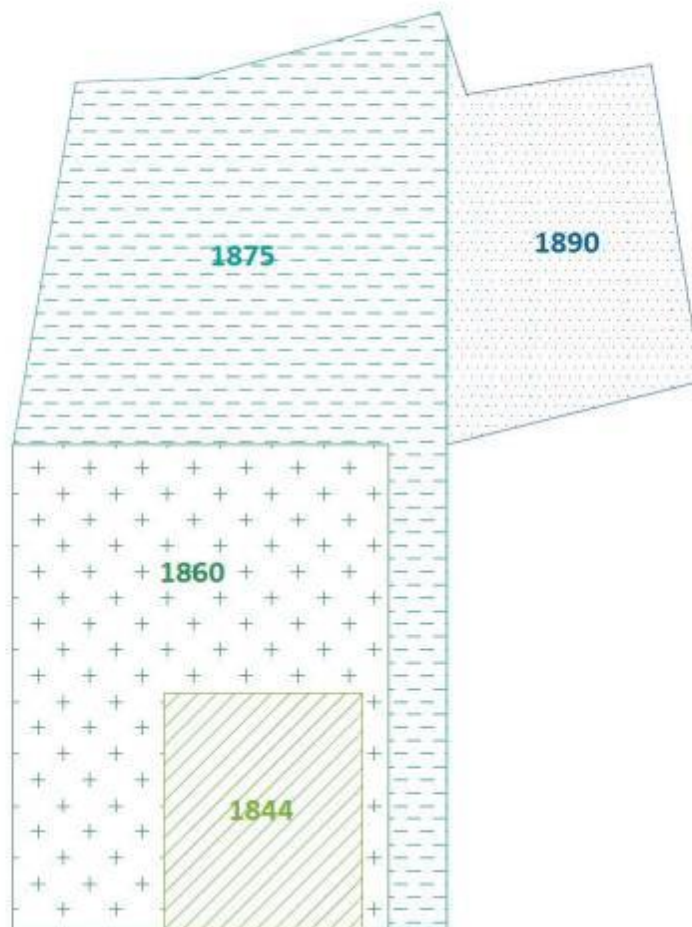
In 1844, the minister, elders, and deacons of the Reformed Protestant Dutch Church of Fultonville purchased an acre of land in the northwest corner of Garret Yates' upper field for use as a burying ground (Deed Liber, Montgomery County). The parcel was laid out into large, square lots and sold at auction (*History of Montgomery and Fulton Counties*, F. W. Beers & Co.). Shortly after the incorporation of Fultonville as a village in 1848, the Church turned the burying ground over to the municipality. Additional land was purchased from Yates in 1860 that more than doubled the size of the cemetery (Deed Liber, Montgomery County). In 1861, a right of way to "construct, use, and maintain a road" to access the cemetery was granted to the village by Samuel Donaldson. Construction of a bridge was required to cross a ravine at a "point called the falls." A dozen years later, a deed registered that Lewis J. Bennett, a former Fultonville merchant now of Buffalo, for the consideration of one dollar and interest in a "family lot," conveyed to the village "the iron super structure of the bridge now erected over the stream

running past the Fultonville Cemetery, and in the road leading to said Cemetery.”(Deed Liber, Montgomery County) There are no other known accounts referencing the cemetery bridge.



**Figure 2:** The Fultonville Cemetery and Natural Burial Ground encompasses nearly 10 acres in the southwestern portion of the village.

Two large additions were made by donation in 1875 and 1890 by Hon. John H. Starin. Starin, who grew up in Fultonville, founded a shipping empire in New York City prior to the Civil War. At one time, it is said that his shipping fleet was the largest in the world. He served two terms in Congress representing Fultonville from 1877 to 1881. His time in New York City and Washington, D.C. made him many influential and memorable friends including Presidents Grant and Arthur as well as Lewis Comfort Tiffany. The acreage he purchased adjacent to the Fultonville Cemetery was “[laid] out beautifully” most likely by one of his close friends (*History of Montgomery and Fulton Counties*, F. W. Beers & Co.). He erected a large mausoleum for his family in the addition and donated the remainder to the village. The mausoleum, which included windows designed by Tiffany, eventually fell into disrepair and was demolished in the 1970s. Its absence leaves a large, open space in the cemetery.



**Figure 3:** The cemetery is made up of four additions, spanning from 1844-1890.

Beginning in 2007, a large revitalization effort began in the cemetery. Decades of neglect allowed many areas to become overgrown that have since been cleared. Dozens of grave markers have been restored. Part of the ongoing work included drafting and adopting regulations for the proper functioning of the cemetery. These regulations were adopted by the Fultonville Board of Trustees in 2009 and created a Board of Cemetery Commissioners. The Commissioners then investigated the prospect of creating a “natural burial” section. The

alternative burial method, which has grown in popularity nationally in recent years, is a commonsense, traditional, and affordable alternative to what is most commonly practiced today. Deceased persons are not chemically preserved and are interred only in biodegradable containers. In June 2013, the Trustees adopted regulations to establish a natural burial ground in a wooded area in the south west corner of the cemetery. This area, used for natural burial, will be forever preserved as woodland. The low-impact, conservation-minded ethos at the core of natural burial has been espoused to the Fultonville Cemetery and Natural Burial Ground.

#### **4.2 Trail Background**

The proposed trail to be constructed throughout cemetery grounds will utilize existing roads. A majority of the roads, however, have become overgrown and are completely unusable in their current form. The Commissioners' design request is for a ten-foot wide trail (topography permitting) that, in part, follows the ravine along the eastern property line. They also require that the trailhead be located along West Church Street to allow for easy access from the Erie Canalway Trail and a municipal parking lot. With these constraints in mind, the trail requires the crossing of the ravine where a bridge formerly stood. The remaining length of the trail shall be decided based on environmental constraints and aesthetic factors. Trail use and surfacing have not been strictly defined, yet the Commissioners wish to minimize environmental impacts in the final design.



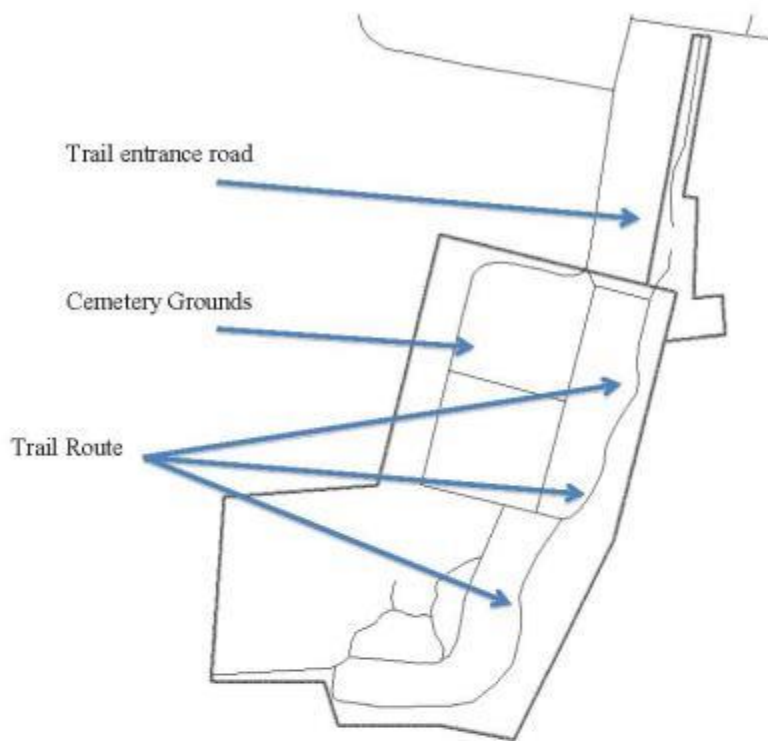


Figure 4: Numerous existing roads transverse the cemetery grounds.

#### 4.3 Erosion Control Background

Portions of the requested ravine trail experience varying degrees of erosion. As the trail in this section follows along a very steep ravine, there are a handful of areas that will need to be visually assessed for stability. If there are any areas that are of concern, further investigation will have to be conducted. Runoff also poses a concern in some areas. One of which, pictured in Figure 5, frequently becomes a rivulet following precipitation events. This area, in particular, will require a focused hydrological assessment. Using available weather data and approximating a catchment area will aid in developing an adequate solution that aligns with the minimalist tone taken on by the Commissioners.



**Figure 5:** A portion of the proposed ravine trail that experiences frequent drainage issues.

#### **4.4 Bridge Background**

##### *4.4.1 Intro*

The proposed trailhead determined by the sponsor requires that the trail pass over a ravine. There are many different factors that determine the design of the bridge. These range from local and state laws that have to be upheld all the way to something as simple as being aesthetically pleasing and fitting in with the atmosphere of the surrounding area.

##### *4.4.2 ADA Requirements*

One of the more important regulations that will be influencing this design is the American Disabilities Act (ADA) which guarantees a project is safe and accessible to all people regardless of disabilities (Department of Justice, 2010). These requirements include clauses regulating design and construction. Design specifics include the slope of the bridge, handrail width, handrail height from the finish floor, and handrail geometry and design loads. Most importantly, there are clauses that directly apply to pedestrians. The following table illustrates some of the requirements:

**Table 1:** ADA specific requirements

<b>Handrails</b>	<b>Walking Surface</b>
Space between wall and rail: 1 ½"	Slope Grade: 1:20 or 5%
Installation height: between 33" and 36"	Slope perpendicular to travel: Grade: 1:48 or 2%
Diameter: 0.95" minimum and 1.55" maximum	36" minimum distance between handrails
Must hold horizontal and vertical force of 250lbs	Planks cannot be more than ½" apart in direction perpendicular to travel

*4.4.3 New York Building Code*

The village of Fultonville uses New York State's Building Code as its own. The Building Code of New York State was modeled after The International Code Council's building codes. These codes are written for adoption by state or local governments by reference only and guide the design of projects to help ensure public safety (New York State Department of State, 2010).

Structures of all kinds must be designed to account for dead and live loads, as well as wind, snow, and seismic loads that depend on location. The dead load is the force acting upon the members due to their own weight as well as the weight of any permanent attachments. Live loads can be defined as variable loads that account for all possible loading combinations in the life of the structure. These need to be incorporated in the design in order to ensure the safety of the public. New York State Building Code, for walkways and elevated platform, specifies the maximum live load capacity at 60 pounds per square foot (psf).

The bridge is going to be designed to accommodate small maintenance vehicles. To account for these forces, the New York State Building Code states that the concentrated wheel load shall be applied on an area of twenty square inches. This requirement addresses local stresses in the deck due to the wheels on the vehicle.

In order to determine the size and position of the members, accurate computations must be made in order to withstand maximum forces acting upon the bridge. New York State Building Code states that all calculations made with sizes of members must be done with actual sizes rather than their nominal dimensions.

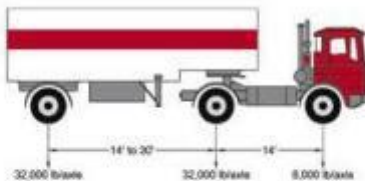
#### *4.4.4 Bridge Designs*

Several different bridge designs will be designed and analyzed in this project. A wooden pedestrian bridge and a Whipple truss bridge will be designed and assessed and they will be compared with a reused flatcar and another prefabricated design. Each type of bridge has unique characteristics that lend to different strengths and weaknesses in terms of the capstone design requirements.

##### *4.4.4.1 Flatcar Bridge*

Flatcar bridges are made from either retired or unused flatbed railway cars. These flatcars do not have any structural problem which may have forced them into retirement (Rick Franklin Corporation, 2012). These cars are made from top grade steel and require little maintenance, making them ideal for hard to reach locations such as farmland cut off by streams. Flatcar bridges are constructed off-site to eliminate the downtime of a site. The cars are pre-cut before being shipped to the site with a desired span, and then fastened to the abutments at the site when they are being installed. Flatcar bridges made by Rick Franklin Corporation provide a HS-25 load capacity (Rick Franklin Corporation, 2012). This rating comes from the American

Association and Highway Transportation Officials, or AASHTO. The rating means that two-axial trucks are given an “H” rating. The “HS” loading comes from a truck with a semi-trailer as seen in the figure below:



**Figure 6: An HS-20 Loading**

This loading system allows the load of a truck to be distributed to certain points along the bridge it is traveling on. Since flatcar bridges have a high HS rating and are able to hold up to an 180,000lb load, they are ideal for reaching all corners of any property and easily accommodate a variety of pedestrian applications

#### **4.4.4.2 Whipple Truss Bridge**

In 1841 Squire Whipple patented a bridge truss called The Whipple Arch Truss (site attachment from Mr. Fonzi). The first Whipple Truss Bridge was made from cast iron for compression members and wrought iron for tension members. Squire Whipple’s design was so well thought of by the community, that New York State later adopted the design as their official standard. The first Whipple Truss Arch was built in Buffalo, New York, spanned Buffalo’s Commercial Slip. The 100 foot Commercial Slip Whipple Truss had three arches, each with nine panels. The arches separated two lanes of traffic, and two outward pedestrian walkways. The image below shows the original Commercial Slip Whipple Truss, taken around 1870:



**Figure 7:** Whipple Truss Bridge circa 1870

#### *4.4.4.3 Prefabricated Bridge*

Prefabrication has been practiced throughout history. Prefabricated structures can be anything that is assembled or partially assembled before being brought to the work site. Prefabricated structures can be shipped in sections and connected at the site. This applies to bridges as well as buildings. Some houses have been built and shipped in this same way. In this project a separate prefabricated bridge designed by a company will be evaluated and compared with other bridge designs. These bridges will be designed and built by a third party so much of the engineering aspect of them will be already taken care of by their respective company.

#### *4.4.4.4 Wooden Pedestrian Bridge*

The first bridges dating back to ancient times consisted of laying trees across a river to cross. The ancient Romans constructed wooden bridges that were up to 20 feet wide. Wooden bridges can be constructed with numerous species of trees and can be designed to resist heavy loading combinations. They are still used today primarily for pedestrian bridges.

#### **4.5 Overview of Committees and Approval Process**

The site development of the Fultonville Cemetery and Natural Burial Ground falls under two main public entities. The land is owned by the Village of Fultonville, of which the responsible parties are an elected Board of Trustees and Mayor. The Trustees and Mayor appoint a Board of Cemetery Commissioners biannually. The Commissioners oversee all cemetery business. Their actions are only binding if approved by the Trustees and Mayor. The final design for the site development will be presented to the Board of Cemetery Commissioners. Upon their acceptance, the plan must be then approved by the Board of Trustees and Village Mayor.

#### **4.6 Summary**

An economic, sustainable, and safe option exists to create a recreational trail and bridge through the Fultonville cemetery grounds. Through extensive research and data collection, an achievable option will be presented to the Board of Cemetery Directors.



## 5 PRELIMINARY RESULTS

### 5.1 Bridge Abutments

An initial site assessment was used to determine the needed dimensions of the bridge. Measurements of the existing abutments were recorded, as well as measurements over the stream from side to side. A visual assessment was also conducted to see if existing stone abutments would be able to hold the desired dead and live loads. The image below shows an example of measurements taken on site from a bird's eye view.

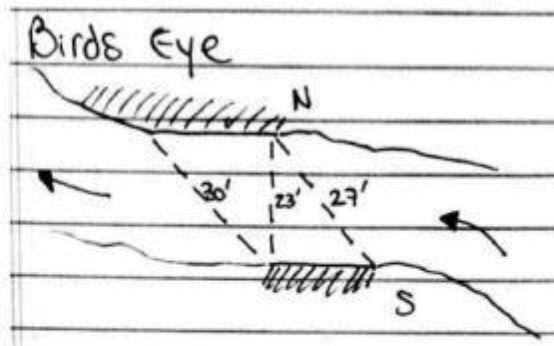


Figure 8: Bird's eye view of bridge site with measurements



Figure 9: Existing stone abutment



From the image below one can see that the existing stone is still in place, but has been cracked and eroded away over time.



**Figure 10:** Existing abutment worn over time by cracks and erosion

The weathering of these stones makes the use of these abutments a judgment call based on safety.

## **5.2 Trail Assessment**

An initial survey was conducted using *Rammeter*, a mobile application on the iPhone. The exported data did not meet the accuracy standards required for the project. This finding has necessitated a second site survey utilizing professional grade equipment.

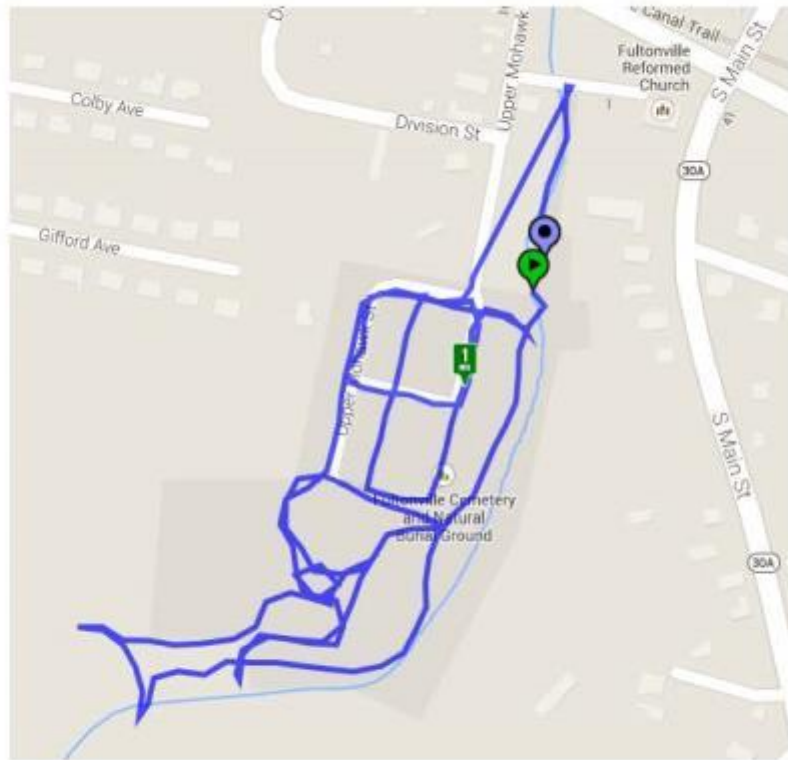


Figure 11: Runmeter GPS data of trail route

## **6 METHODOLOGY**

This section will outline how exactly we plan on coming up with our designs. Certain elements of this project will require site analysis and site-specific research, where other areas such as bridge design will require more outside data collection for applicable feasibility. We were able to utilize the data collected on our initial site assessment to analyze what else we needed to complete the design successfully.

### **6.1 Trail Design**

In order to ensure the most accurate design for the trail, detailed site data must be collected. To collect more accurate data than was found from the initial site assessment, a second site visit will be done. During the second visit, we will use GPS and total station surveying equipment to gather the most accurate data we can. The data collected will be used in the selection of a trail route, including ingress, egress, and grading; and a hydrological analysis to determine necessary erosion control methods.

A finalized trail route will be determined primarily upon sponsor constraints. Unless determined to be necessary, the trail will follow previously established roadways, many of which have been completely reclaimed by nature. These roadways will be the focus of the site survey. Additionally, the sponsor has requested a trail width of approximately ten feet. Coupled with elevation data and trail use preference, this constraint will be used to determine a finalized grading plan including the selection of a trail surface. These determinations will be heavily based upon aesthetic appeal, consistency with the natural setting, and cost.

Utilizing rainfall data collected at a nearby weather station, hydrological flow calculations will be based on analysis of a 100-year design storm. These calculated flows will be employed in the designs of the erosion control plan.

## **6.2 Geographic Information Systems (GIS)**

ESRI's ArcMAP will be used as the primary means of organizing all geospatial data collected and created throughout this project. Utilizing information available from the New York State GIS Clearinghouse and the Montgomery County, New York Real Property Tax Service, base maps will be constructed to include orthoimagery, hydrology, elevation, and approximate parcel outlines. Data collected in the field will increase the accuracy of the aforementioned features while also providing site-specific data that is not available at any repository.

## **6.3 Bridge Design**

### *6.3.1 Intro*

Several bridges will be designed using the Load and Resistance Factor Design (LRFD) method. The LRFD approach is less conservative than the Allowable Stress Design (ASD) method when the live loads are low. Pedestrian bridges have very low live loads so the more conservative ASD design would be less economical and not necessary for these designs.

### *6.3.2 Load Combinations*

The bridge design will start with finding all possible loads associated with the bridge. These values can be used with the LRFD load combination equations to determine the total factored load. These calculations will be used in all of the bridge designs. The LRFD load combination equations from ASCE 7 are:

1.4D

$1.2D+1.6L+.5(Lr \text{ or } S \text{ or } R)$

$1.2D+1.6(Lr \text{ or } S \text{ or } R)+(.5L \text{ or } .8W)$

$1.2D+1.6W+.5L+.5(Lr \text{ or } S \text{ or } R)$

$1.2\pm 1.0E+.5L+.2S$

$.9D\pm(1.6W \text{ or } 1.0E)$

D= Dead Load

L= Live Load

Lr= Roof Live Load

S= Snow Load

R= Rain Load

W= Wind Load

E= Earthquake Load

### 6.3.3 *Abutments*

The existing abutments must be analyzed to assess their current structural condition and to determine their capability for reuse. Since the tools and technologies needed to scientifically test the abutments are not readily available to our group, we visually investigated the structures.

Since safety is a top priority, our group has decided to use an alternative bridge support design to hold the bridge in place. The next step is to decide whether to use new concrete abutments in place of the old ones, or to use wooden posts of a prefabricated bridge. Deciding whether cast-in-place concrete or wooden posts are to be used is the next step. This depends on

the type of bridge chosen, wooden prefabricated or a bridge that can be fastened to concrete abutments. Lastly, we will need to make sure the option chosen will be sustainable in the environment in which it will stand.

#### *6.3.4 Wooden pedestrian*

The first step in designing any bridge is determining the maximum load combination using the equations shown above. This is the loading that will be used to design every aspect of the bridge. The load will start at the deck of the bridge and be distributed through the entire bridge and down to the abutments.

The next step involves designing the members of the bridge. First the decking material is determined. Then the beam size will be chosen and a spacing will be determined. Then the girders will be designed. After that, connections to the girders will be designed based on the loading on each connection. Finally, the abutments will be designed that will support the entire bridge.



**Figure 12:** Example of a typical wooden pedestrian bridge

### 6.3.5 Prefab 1

Several companies will be considered to determine a possible prefabricated bridge design to test. We will have to compare requirements such as cost and aesthetics to determine which bridge will be used in the project. With these designs bridge abutments would be designed and then the chosen bridge would arrive at the site preassembled and dropped into place. Several possible companies are Pioneer Bridges, York Bridge Concepts, and Big R Bridge. These different companies use a variety of designs and materials such as wood and steel. Another possibility here would be to adapt one of the other design options for prefabrication. The wooden pedestrian bridge could be designed for this. However, a separate prefabricated bridge will still be evaluated to give more alternative designs.



Figure 13: Prefabricated bridge by Pioneer Bridges as it is shipped to the construction site

### 6.3.6 Flatcar Bridge

Flatcar railway cars are being used to create bridges. These flatcars can be designed to custom lengths to fit the desired span. Flatcars installed properly will provide a HS-25 load capacity rating. Custom concrete abutments can be installed as well. The image below shows a flatcar being used as a bridge:





**Figure 14:** Flatcar Bridge

The first step to determining if this would be a feasible option would be to determine the site specific loading conditions. Snow, wind, live, and seismic loads all apply to this site. The next step would be to determine the length of the flatcar we would need to have a bridge span from abutment to abutment. The following step is to design the connection between the flatcar and the abutments. Lastly, we will need to design, or order, handrails that are ADA compliant and factor them into the design. The figure below shows a flatcar with handrails and concrete abutments:



**Figure 15:** Flatcar pedestrian bridge

### *6.3.7 Whipple Truss Bridge Design*

Our group will obtain the design plans from the Civil Engineers who worked on a Whipple Truss replica bridge in Buffalo, New York. We will modify the design to fit the new conditions, including loading, length, and size. The next step is to design the connection between the bridge and the abutments to ensure maximum safety. The last step will be to decide if the Whipple Truss Bridge will be prefabricated and brought in, or if it will be built on site.

6.4 Schedule

Table 2: Proposed Work Schedule for A Term, B Term and C Term

Task	A							B					C								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
<b>Proposal</b>																					
Problem, Objective, Scope	■	■	■																		
Background		■	■	■	■	■															
Capstone				■																	
Methodology					■	■	■														
Final Proposal							10/1	5													
<b>Site Visits</b>																					
Preliminary Assessment				■	■																
Survey							■	■													
<b>Analysis</b>																					
Data organization								■	■												
Bridge Design Analysis								■	■	■	■	■									
Trail Data Analysis									■	■	■	■	■								
Application of Evaluation										■	■	■	■	■	■						
<b>Final Report</b>																					
Background									■	■	■	■	■								
Methodology									■	■	■	■	■	■	■						
Establish Designs													■	■	■	■	■	■			
Determine Preferred Design/Recommendations																		■	■	■	■
Final MCP Report																					2/2 6

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## Appendix B: Hand Calculations

### Simple Girder Design

Wood Girder Design Check *Simple Beam Bridge*

Material  
 16 X 16 in Douglas Fir-Nat Actual size  $15\frac{1}{2} \times 15\frac{1}{2}$  in Area =  $2403 \text{ in}^2$   
 $S_x = 620.6 \text{ in}^3$   $I_x = 4810 \text{ in}^4$   $F_b = 1000 \text{ psi}$   
 $F_v = 180 \text{ psi}$   
 $E = 1700000 \text{ psi}$

Wet Service Factor  $C_{ms} = 1.0$   
 Temperature Factor  $C_t = 1.0$   
 Size Factor  $C_F = 1.0$   
 Incising Factor  $C_i = 1.0$

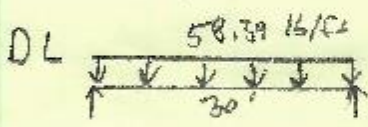
Resistance Factors  $\phi_b = .85$   $\phi_v = .75$   
 Form Conversion Factor  $K_{E-F} = \frac{2.16}{\phi_b}$   $K_{E-F\phi} = \frac{2.16}{\phi_v}$   
 Time Effect Factor  $\lambda = 1.8$


Tributary area =  $4' \cdot 30' = 120 \text{ ft}^2$   
 DL @  $35 \text{ lb/ft}^2 = 58.39 \text{ lb/ft}$

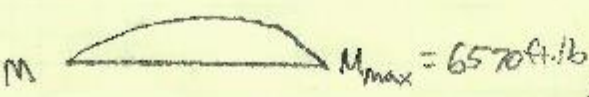
LL Pedestrian  
 $60 \text{ psf} \cdot 4 \text{ ft} = 240 \text{ lb/ft}$

LL Vehicle Point Load  
 $4800 \text{ lbs}$

SL =  $50 \text{ psf} \cdot 4 \text{ ft} = 200 \text{ lb/ft}$   
 WL =  $25 \text{ psf} \cdot 4 \text{ ft} = 100 \text{ lb/ft}$

DL   $\frac{58.39 \cdot 30}{2} = 876 \text{ lb}$

V   $V_{max} = 876 \text{ lb}$

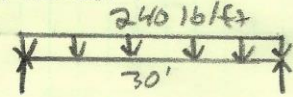
M   $M_{max} = 6570 \text{ ft} \cdot \text{lb}$

$\frac{58.39 \text{ lb/ft}}{5 \text{ ft}} = 8 \times 16$   
 $\sum M = 876 \cdot 15 - 876 \cdot 7.5 - M$   
 $M = 6570 \text{ ft} \cdot \text{lb}$

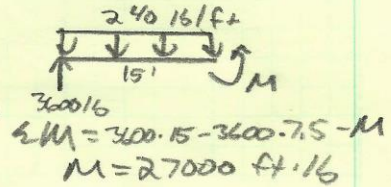
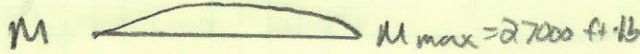
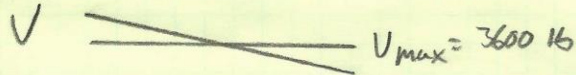


# Wood Girder Design

LL Pedestrian

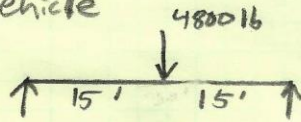


$$\frac{240 \cdot 30}{2} = 3600 \text{ lb}$$

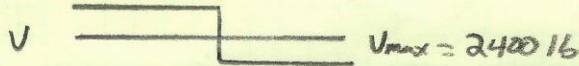


LL Vehicle

Position 1

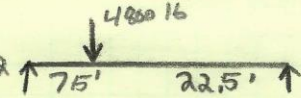


$$\frac{4800}{2} = 2400 \text{ lb}$$

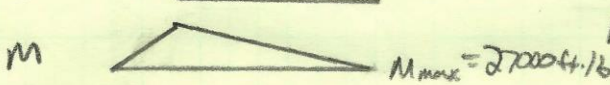


$$M = \frac{PL}{4} = \frac{4800 \cdot 30}{4} = 36000 \text{ ft}\cdot\text{lb}$$

Position 2



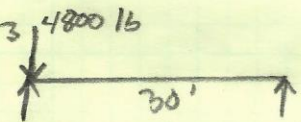
$$\frac{4800 \cdot 22.5}{30} = 3600 \text{ lb}$$



$$M = \frac{Pab}{L} = \frac{4800 \cdot 7.5 \cdot 22.5}{30}$$

$$M = 27000 \text{ ft}\cdot\text{lb}$$

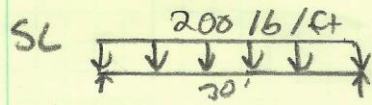
Position 3



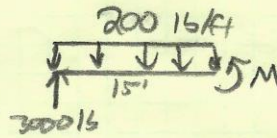
$$\frac{4800 \cdot 30}{30} = 4800 \text{ lb}$$



# Wood Girder Design

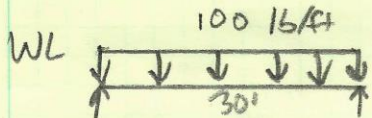


$$\frac{200 \cdot 30}{2} = 3000 \text{ lb}$$

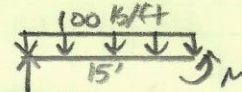
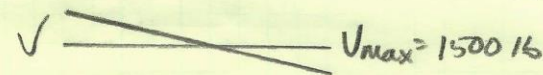


$$\sum M = 3000 \cdot 15 - 3000 \cdot 7.5 - M$$

$$M = 22500 \text{ ft} \cdot \text{lb}$$



$$\frac{100 \cdot 30}{2} = 1500 \text{ lb}$$



$$\sum M = 1500 \cdot 15 - 1500 \cdot 7.5 - M$$

$$M = 11250 \text{ ft} \cdot \text{lb}$$

## Shear

$$1.4 \cdot 876 = 1226 \text{ lb}$$

$$1.2 \cdot 876 + 1.6 \cdot 4800 + 5 \cdot 3000 = 10231 \text{ lb}$$

$$1.2 \cdot 876 + 1.6 \cdot 3000 + 5 \cdot 4800 = 8251 \text{ lb}$$

$$1.2 \cdot 876 + 1.6 \cdot 3000 + 5 \cdot 1500 = 6601 \text{ lb}$$

$$1.2 \cdot 876 + 1.6 \cdot 1500 + 5 \cdot 4800 + 5 \cdot 3000 = 7351 \text{ lb}$$

## Moment

$$1.4 \cdot 6570 = 9198 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot 6570 + 1.6 \cdot 36000 + 5 \cdot 22500 = 76734 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot 6570 + 1.6 \cdot 22500 + 5 \cdot 36000 = 61884 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot 6570 + 1.6 \cdot 22500 + 5 \cdot 11250 = 49509 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot 6570 + 1.6 \cdot 11250 + 5 \cdot 3000 + 5 \cdot 22500 = 55134 \text{ lb}$$

$$\text{Max Shear} = 10231 \text{ lb}$$

$$\text{Max Moment} = 76734 \text{ ft} \cdot \text{lb} = 920800 \text{ in} \cdot \text{lb}$$



## Wood Girder Design

### Bending Checks

Nominal Depth 16 in  
Nominal Width 16 in

$$\frac{16}{16} = 1$$

Stability Factor  $C_L = 1.0$

$$F'_b = \lambda \cdot K_{F_b} \cdot \Phi_b \cdot F_b \cdot C_m \cdot C_T \cdot C_F \cdot C_L$$

$$F'_b = 1.8 \cdot \frac{2.16}{.85} \cdot .85 \cdot 1000 \text{ psi} \cdot 1.0 \cdot 1.0 \cdot 1.0 \cdot 1.0$$

$$F'_b = 1728 \text{ psi}$$

$$f_b = \frac{M}{S_x}$$

$$f_b = \frac{920800 \text{ in}\cdot\text{lb}}{620.6 \text{ in}^3} = 1484 \text{ psi}$$

$$1484 \text{ psi} < 1728 \text{ psi} \quad \checkmark$$

### Shear Checks

$$F'_v = \lambda \cdot K_{F_v} \cdot \Phi_v \cdot F_v \cdot C_m \cdot C_T \cdot C_F \cdot C_L$$

$$F'_v = .8 \cdot \frac{2.16}{.75} \cdot .75 \cdot 180 \text{ psi} \cdot 1.0 \cdot 1.0 \cdot 1.0 \cdot 1.0$$

$$F'_v = 311 \text{ psi}$$

$$f_v = \frac{3}{2} \cdot \frac{V}{A}$$

$$f_v = \frac{3}{2} \cdot \frac{10231}{240.3} = 63.9 \text{ psi}$$

$$63.9 \text{ psi} < 311 \text{ psi} \quad \checkmark$$

## Wood Girder Design

### Deflection Check

$$\frac{\text{Length}}{240} = \frac{30' \cdot 12}{240} = 1.5 \text{ in}$$

$$\Delta = \frac{PL^3}{48EI} + \frac{5wL^4}{384EI}$$

$$\Delta = \frac{4800 \text{ lb} \cdot (30' \cdot 12 \text{ in})^3}{48 \cdot 1700000 \text{ psi} \cdot 4810 \text{ in}^4} + \frac{5 \cdot 58.39 \text{ lb/ft} \cdot 12 \text{ in} \cdot (30' \cdot 12 \text{ in})^4}{384 \cdot 1700000 \text{ psi} \cdot 4810 \text{ in}^4}$$

$$\Delta = .57 \text{ in} + .13 \text{ in} = .70 \text{ in}$$

$$.70 \text{ in} < 1.5 \text{ in} \checkmark$$

## Purlin Design for simple girder bridge and Whipple truss

Wood Joist Design      Simple Beam + Whipple Truss

Nominal      15" spacing

Single 4x6      Actual size 3½ in x 5½ in      Area = 19.25 in<sup>2</sup>

Douglas Fir, Select Structural      S<sub>xx</sub> = 17.65 in<sup>3</sup>      I<sub>xx</sub> = 48.53 in<sup>4</sup>

F<sub>b</sub> = 1500 psi      F<sub>v</sub> = 180 psi      E = 1 900 000 psi

L = 8 ft = 96 in

Wet service Factor      C<sub>m</sub> = 1.0

Repetitive Member Factor      C<sub>r</sub> = 1.15

Temperature Factor      C<sub>t</sub> = 1.0

Size Factor      C<sub>F</sub> = 1.2

Incising Factor      C<sub>i</sub> = 1.0

Resistance Factors      φ<sub>b</sub> = .85      φ<sub>v</sub> = .75

Form + Conversion Factors      K<sub>F-F<sub>b</sub></sub> = 2.16 / φ<sub>b</sub>      K<sub>F-F<sub>v</sub></sub> = 2.16 / φ<sub>v</sub>

Time Effect Factor      λ = .8

DL @ 35 lb/ft<sup>3</sup>      Density = 4.679 lb/ft

LL - Pedestrian  
60 psf ·  $\frac{15 \text{ in}}{12 \text{ in}}$  = 75 lb/ft

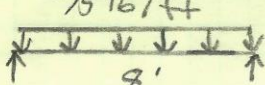
LL - Vehicle  
 $\frac{4800 \text{ lbs}}{4 \text{ wheels}} = (2) 1200 \text{ lbs @ } 50.8 \text{ in}$


SL = 50 psf ·  $\frac{15 \text{ in}}{12 \text{ in}}$  = 62.5 lb/ft


WL = 25 psf ·  $\frac{15 \text{ in}}{12 \text{ in}}$  = 31.25 lb/ft

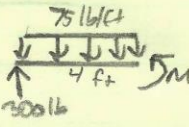


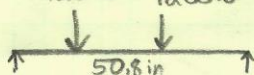
Wood Joist Design


LL Ped  $75 \text{ lb/ft}$   

 $75 \text{ lb/ft} \cdot 8 \text{ ft} = \frac{600 \text{ lb}}{2} = 300 \text{ lb}$

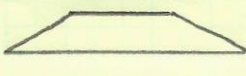
V   $V_{\max} = 300 \text{ lb}$

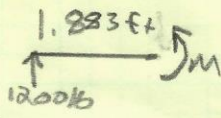
M   $M_{\max} = 600 \text{ ft} \cdot \text{lb}$

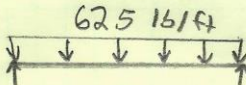
$75 \text{ lb/ft}$   

 $\sum M = 300 \cdot 4 - 300 \cdot 2 - M$   
 $M = 600 \text{ ft} \cdot \text{lb}$


LL Veh  $1200 \text{ lb}$   $1200 \text{ lb}$   


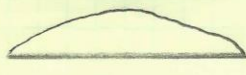
V   $V_{\max} = 1200 \text{ lb}$

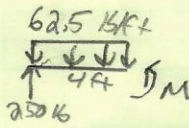
M   $M_{\max} = 2260 \text{ ft} \cdot \text{lb}$

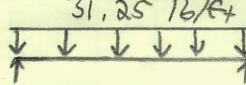
$1200 \text{ lb}$   

 $\sum M = 1200 \cdot 1.883 - M$   
 $M = 2260 \text{ ft} \cdot \text{lb}$

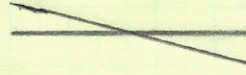
SL  $62.5 \text{ lb/ft}$   

 $\frac{62.5 \text{ lb/ft} \cdot 8 \text{ ft}}{2} = 250 \text{ lb}$

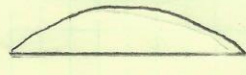
V   $V_{\max} = 250 \text{ lb}$

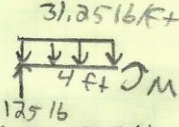
M   $M_{\max} = 500 \text{ ft} \cdot \text{lb}$

$62.5 \text{ lb/ft}$   

 $\sum M = 250 \cdot 4 - 250 \cdot 2 - M$   
 $M = 500 \text{ ft} \cdot \text{lb}$

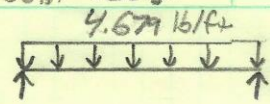
WL  $31.25 \text{ lb/ft}$   

 $\frac{31.25 \text{ lb/ft} \cdot 8 \text{ ft}}{2} = 125 \text{ lb}$

V   $V_{\max} = 125 \text{ lb}$

M   $M_{\max} = 250 \text{ ft} \cdot \text{lb}$

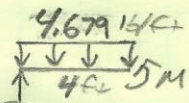
$31.25 \text{ lb/ft}$   

 $\sum M = 125 \cdot 4 - 125 \cdot 2 - M$   
 $M = 250 \text{ ft} \cdot \text{lb}$

### Wood Joist Design

DL   $\frac{4.679 \cdot 8}{2} = 18.716 \text{ lb}$

V   $V_{max} = 18.7 \text{ lb}$

M   $M_{max} = 37.4 \text{ ft} \cdot \text{lb}$

  
 $\sum M = 18.7 \cdot 4 - 18.7 \cdot 2 - M$   
 $M = 37.4 \text{ ft} \cdot \text{lb}$

### Shear

$$1.4 \cdot 18.7 = 26.18 \text{ lb}$$

$$1.2 \cdot 18.7 + 1.6 \cdot 1200 + 1.5 \cdot 250 = 2067 \text{ lb/lb}$$

$$1.2 \cdot 18.7 + 1.6 \cdot 250 + 1.5 \cdot 1200 = 1022 \text{ lb}$$

$$1.2 \cdot 18.7 + 1.6 \cdot 250 + 1.8 \cdot 125 = 522.4 \text{ lb}$$

$$1.2 \cdot 18.7 + 1.6 \cdot 125 + 1.5 \cdot 1200 + 1.5 \cdot 250 = 947.4 \text{ lb}$$

### Moment

$$1.4 \cdot 37.4 = 52.36 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot 37.4 + 1.6 \cdot 2260 + 1.5 \cdot 500 = 3911 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot 37.4 + 1.6 \cdot 500 + 1.5 \cdot 2260 = 1975 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot 37.4 + 1.6 \cdot 500 + 1.8 \cdot 250 = 1045 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot 37.4 + 1.6 \cdot 250 + 1.5 \cdot 2260 + 1.5 \cdot 500 = 1825 \text{ ft} \cdot \text{lb}$$

$$\text{Max Shear} = 2067 \text{ lb}$$

$$\text{Max Moment} = 3911 \text{ ft} \cdot \text{lb} = 46932 \text{ in} \cdot \text{lb}$$

## Wood Joist Design

### Bending Check

$$\text{Nominal depth} = 6 \text{ in}$$

$$\text{Nominal width} = 4$$

$$\frac{6}{4} = 1.5$$

$$\text{Stability Factor } C_L = 1.0$$

$$F'_b = \lambda \cdot K_{Fb} \cdot \phi_b \cdot F_b \cdot C_m \cdot C_t \cdot C_r \cdot C_F \cdot C_L$$

$$F'_b = .8 \cdot \frac{2.16}{1.95} \cdot .85 \cdot 1500 \text{ psi} \cdot 1.0 \cdot 1.0 \cdot 1.15 \cdot 1.2$$

$$F'_b = 3040 \text{ psi}$$

$$F_b = \frac{M}{S_x}$$

$$F_b = \frac{46932 \text{ in} \cdot \text{lb}}{17.65 \text{ in}^3} = 2659 \text{ psi}$$

$$2659 \text{ psi} < 3040 \text{ psi} \quad \checkmark$$

### Shear Check

$$F'_v = \lambda \cdot K_{Fv} \cdot \phi_v \cdot F_v \cdot C_m \cdot C_t \cdot C_i$$

$$F'_v = .8 \cdot \frac{2.16}{1.75} \cdot .75 \cdot 180 \cdot 1.0 \cdot 1.0 \cdot 1.0$$

$$F'_v = 311 \text{ psi}$$

$$F_v = \frac{3}{2} \cdot \frac{V}{A}$$

$$F_v = \frac{3}{2} \cdot \frac{2067}{19.25} = 161 \text{ psi}$$

$$161 \text{ psi} < 311 \text{ psi} \quad \checkmark$$



## Wood Joist Design

### Deflection Check

$$\frac{\text{Length}}{240} = \frac{8' \cdot 12}{240} = .40 \text{ in}$$

$$\Delta = \frac{5wL^4}{384EI}$$

$$\Delta = \frac{5 \cdot (60 \frac{1}{4} + 35 \frac{1}{4}) / 12 \text{ in} \cdot (8 \text{ ft} \cdot 12 \text{ in})^4}{384 \cdot 1900000 \text{ psi} \cdot 48.53 \text{ in}^3}$$

$$\Delta = .09 \text{ in}$$

$$.09 \text{ in} < .40 \text{ in} \quad \checkmark$$

## Loading and Moments For aluminum truss bridge purlins

### Aluminum Joist Design

3x3x3/16 6061-T6 Aluminum

4 Joists per block

$$\frac{60}{4} = 15 \text{ in spacing} \quad L = 8ft = 96 \text{ in}$$

$$DL @ \frac{\text{Density}}{12 \text{ in}} = 1.73 \text{ lb/ft}$$

LL = Pedestrian

$$60 \text{ psf} \cdot \frac{15 \text{ in}}{12 \text{ in}} = 75 \text{ lb/ft}$$

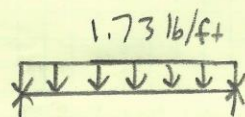
LL = Vehicle

$$\frac{4800 \text{ lbs}}{4 \text{ wheels}} = (2) 1200 \text{ lb} @ 50.8 \text{ in}$$

$$SL = 50 \text{ psf} \cdot \frac{15 \text{ in}}{12 \text{ in}} = 62.5 \text{ lb/ft}$$

$$WL = 25 \text{ psf} \cdot \frac{15 \text{ in}}{12 \text{ in}} = 31.25 \text{ lb/ft}$$

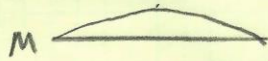
DL



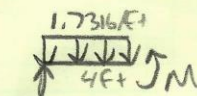
$$\frac{1.73 \text{ lb/ft} \cdot 8 \text{ ft}}{2} = 6.92 \text{ lb}$$

V

$V_{\text{max}} = 6.92 \text{ lb}$



$$M_{\text{max}} = 13.84 \text{ ft} \cdot \text{lb}$$



$$\Sigma M = 6.92 \cdot 4 - 6.92 \cdot 2 = M$$

$$M = 13.84 \text{ ft} \cdot \text{lb}$$

All other Load Cases are the Same as Wooden Bridges



## Aluminum Joist Design

### Shear

$$1.4 \cdot 6.92 = 9.716$$

$$1.2 \cdot 6.92 + 1.6 \cdot 1200 + .5 \cdot 250 = 2055 \text{ lb}$$

$$1.2 \cdot 6.92 + 1.6 \cdot 250 + .5 \cdot 1200 = 1010 \text{ lb}$$

$$1.2 \cdot 6.92 + 1.6 \cdot 250 + .8 \cdot 125 = 570 \text{ lb}$$

$$1.2 \cdot 6.92 + 1.6 \cdot 125 + .5 \cdot 1200 + .5 \cdot 250 = 935 \text{ lb}$$

### Moment

$$1.4 \cdot 13.84 = 19 \text{ ft}\cdot\text{lb}$$

$$1.2 \cdot 13.84 + 1.6 \cdot 2260 + .5 \cdot 500 = 3883 \text{ ft}\cdot\text{lb}$$

$$1.2 \cdot 13.84 + 1.6 \cdot 500 + .5 \cdot 2260 = 1947 \text{ ft}\cdot\text{lb}$$

$$1.2 \cdot 13.84 + 1.6 \cdot 500 + .8 \cdot 250 = 1019 \text{ ft}\cdot\text{lb}$$

$$1.2 \cdot 13.84 + 1.6 \cdot 250 + .5 \cdot 2260 + .5 \cdot 500 = 1797 \text{ ft}\cdot\text{lb}$$

$$\text{Max Shear} = 2055 \text{ lb}$$

$$\text{Max Moment} = 3883 \text{ ft}\cdot\text{lb} = 46596 \text{ in}\cdot\text{lb}$$

# Decking Assessment

## Trex Decking Assessment

Specs from Trex website

	Ultimate Value	Design Value
Compression Parallel	1806 psi	550 psi
Compression Perpendicular	1944 psi	625 psi
Tensile Strength	854 psi	250 psi
Shear Strength	561 psi	200 psi
Modulus of Rupture	1423 psi	250 psi
Modulus of Elasticity	175 000 psi	100 000 psi

Purlin spacing = 15"

Density = 60 lb / CL3

Decking = 6" wide

$$\text{Dead Load} = 1" \cdot 6 \cdot \frac{60}{144} = 2.5 \text{ lb/ft}$$

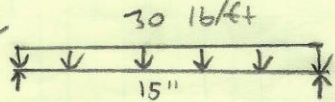
$$\text{Live Load Pedestrian} = 60 \text{ psf} \cdot \frac{6 \text{ in}}{12 \text{ in}} = 30 \text{ lb/ft}$$

Vehicle = 1200 lb

$$\text{Snow Load} = 50 \text{ psf} \cdot \frac{6 \text{ in}}{12 \text{ in}} = 25 \text{ lb/ft}$$

$$\text{Wind Load} = 25 \text{ psf} \cdot \frac{6 \text{ in}}{12 \text{ in}} = 12.5 \text{ lb/ft}$$

Ped LL



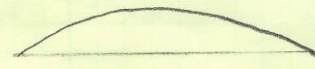
$$\frac{30 \cdot \frac{15}{12}}{2} = 18.75 \text{ lb}$$

V



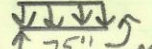
$$V_{\text{max}} = 18.75 \text{ lb}$$

M



$$M_{\text{max}} = 5.9 \text{ ft} \cdot \text{lb}$$

30 lb/ft

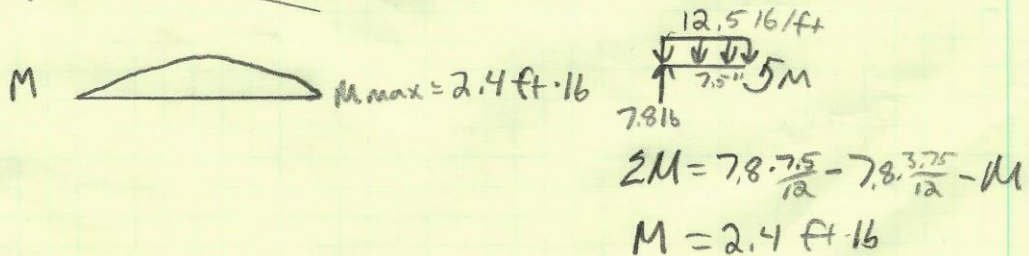
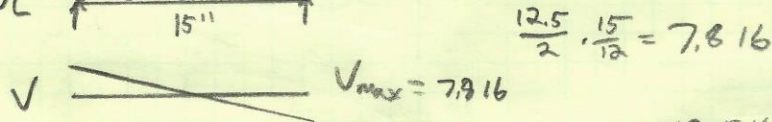
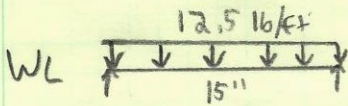
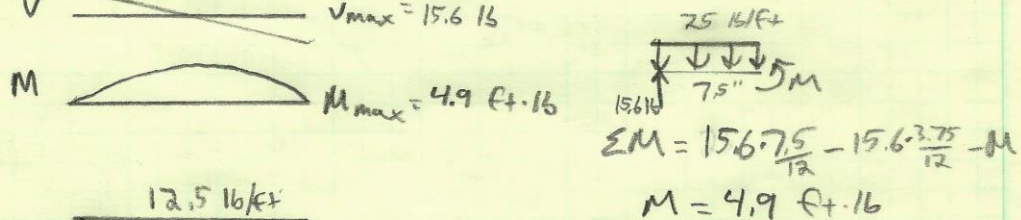
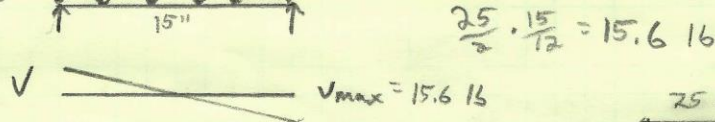
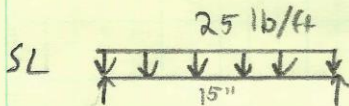
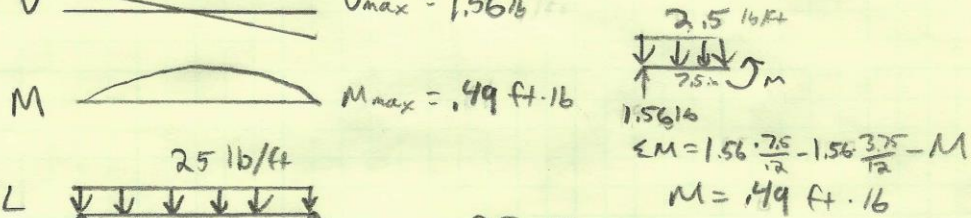
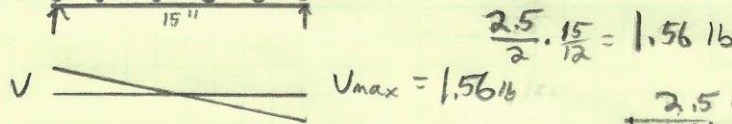
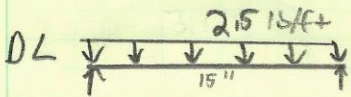
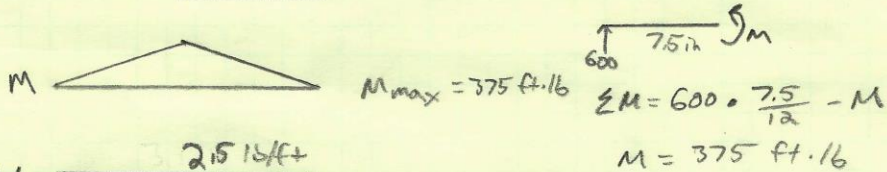
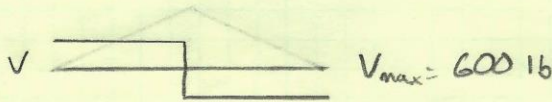
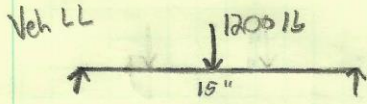


18.75 lb

$$\Sigma M = 18.75 \cdot \frac{7.5}{12} = 18.75 \cdot \frac{3.75}{12} = M$$

$$M = 5.9 \text{ ft} \cdot \text{lb}$$

# Decking Assessment





## Decking Assessment

Load Check

$$1.4 \cdot 1.56 = 2.18 \text{ lb}$$

$$1.2 \cdot 1.56 + 1.6 \cdot 6.00 + 5 \cdot 15.6 = 970 \text{ lb}$$

$$1.2 \cdot 1.56 + 1.6 \cdot 15.6 + 5 \cdot 6.00 = 327 \text{ lb}$$

$$1.2 \cdot 1.56 + 1.6 \cdot 15.6 + 8 \cdot 7.8 = 331 \text{ lb}$$

$$1.2 \cdot 1.56 + 1.6 \cdot 7.8 + 5 \cdot 6.00 + 5 \cdot 15.6 = 322 \text{ lb}$$

Shear Check

$$V_{\max} = 970 \text{ lb}$$

$$\phi P_n = .75 \cdot 561 \cdot 6 \text{ in} \cdot 1 \text{ in} = 2525 \text{ lb}$$

$$970 \text{ lb} < 2525 \text{ lb} \quad \checkmark$$

## Bending Check

$$1.4 \cdot .49 = 6.86 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot .49 + 1.6 \cdot 3.75 + 5 \cdot 4.9 = 603 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot .49 + 1.6 \cdot 4.9 + 5 \cdot 3.75 = 196 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot .49 + 1.6 \cdot 4.9 + 8 \cdot 2.4 = 10.3 \text{ ft} \cdot \text{lb}$$

$$1.2 \cdot .49 + 1.6 \cdot 2.4 + 5 \cdot 3.75 + 5 \cdot 4.9 = 194 \text{ ft} \cdot \text{lb}$$

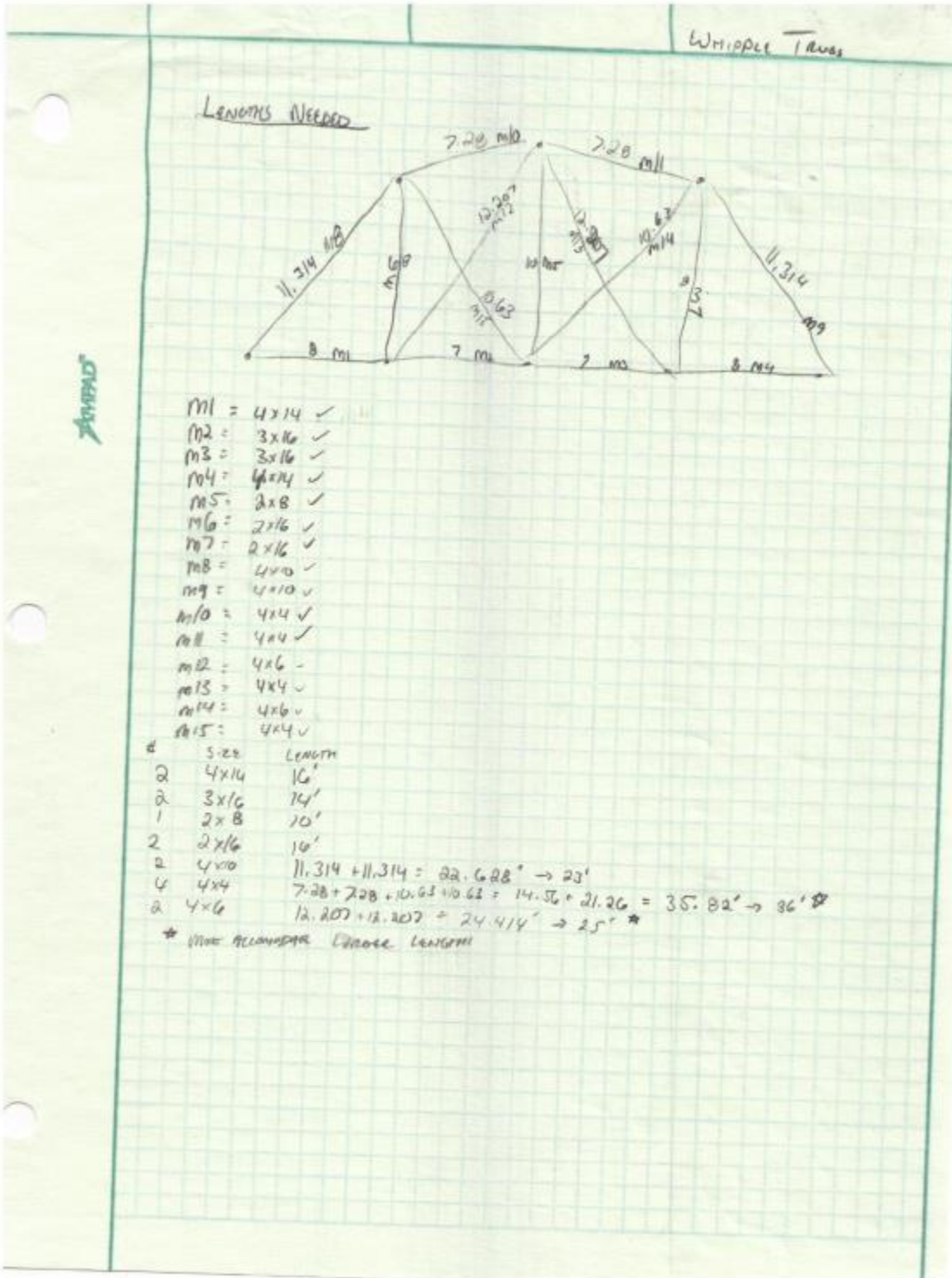
$$M_{\max} = 603 \text{ ft} \cdot \text{lb} = 2333 \text{ in} \cdot \text{lb}$$

$$f_b = \frac{M}{S_x} = \frac{2333 \text{ in} \cdot \text{lb}}{1 \text{ in}^3} = 2333 \text{ psi} \quad S_x = \frac{bh^2}{6} = \frac{6 \text{ in} \cdot 1 \text{ in}^2}{6} = 1 \text{ in}^3$$

$$\phi F_n = .85 \cdot 854 \text{ psi} \cdot 6 \text{ in} \cdot 1 \text{ in} = 4355 \text{ psi}$$

$$2333 \text{ psi} < 4355 \text{ psi} \quad \checkmark$$

# Whipple Truss Design



- m1 = 4x14 ✓
- m2 = 3x16 ✓
- m3 = 3x16 ✓
- m4 = 4x14 ✓
- m5 = 2x8 ✓
- m6 = 2x16 ✓
- m7 = 2x16 ✓
- m8 = 4x10 ✓
- m9 = 4x10 ✓
- m10 = 4x4 ✓
- m11 = 4x4 ✓
- m12 = 4x6 -
- m13 = 4x4 -
- m14 = 4x6 ✓
- m15 = 4x4 ✓

#	SIZE	LENGTH
2	4x14	16'
2	3x16	14'
1	2x8	10'
2	2x16	10'
2	4x10	
4	4x4	
2	4x6	

$11.314 + 11.314 = 22.628' \rightarrow 23'$   
 $7.28 + 7.28 + 10.63 + 10.63 = 35.82' \rightarrow 36'$   
 $12.207 + 12.207 = 24.414' \rightarrow 25'$  \*

\* Note: RECOMMEND EXACT LENGTHS

# Whipple Truss

According to Grand River Supply

Dimension	Quantity	Length & Cost
4x4	2	8' pieces = $57.93 \times 2$
3x6	2	7' pieces = UNAVAILABLE
8x8	1	10' piece = \$10.80
2x6	2	8' pieces = UNAVAILABLE
4x6	2	12' pieces = $47.97 \times 2$
4x6	2	8' pieces + 2 11' pieces $\rightarrow$ $(15.80 \times 2) + (23.70 \times 2)$
4x4	2	13' pieces $\rightarrow$ 14' = $18.43 \times 2$

TOTAL  $115.86 + 10.80 + 95.94 + 31.60 + 47.40 + 36.86$

$= 338.46$

FOR UNAVAILABLE: ASSUMED 4x4 PRICE OF \$57.93 TO BE SAFE.  
 $= 57.93 \times 4 = 231.72$

ASSUMED TOTAL:  $231.72 + 338.46$

$= \boxed{\$570.18}$  COST OF DOUGLAS FIR LARCH TIMBER

- METAL BRACKETS WILL BE USED
- METAL BOLTS WILL BE USED
- COST TO TRANSPORT TIMBER TO SITE



USING 6"x10" Douglas Fir Timber

Whipple Tower

Member Sizes Needed	# Needed	TOTAL
8' LONG	2+2+2 = 6	
7' LONG	2	= 2
10' LONG	1	= 1
12' LONG	2+2	= 4
13' LONG = 14'	2	= 2

8' LONG COST PER PIECE	= \$47.97 x 6 = 287.82
7' LONG COST	(use 8') = \$47.97 x 2 = 95.94
10' LONG COST	= \$59.96 x 1 = 59.96
12' LONG COST	= \$71.96 x 4 = 287.84
14' LONG COST	= \$83.94 x 2 = 167.88

TOTAL 899.44

USING 7% SALES TAX: 62.97

TOTAL: 962.41

Amount

## Whipple Member Check

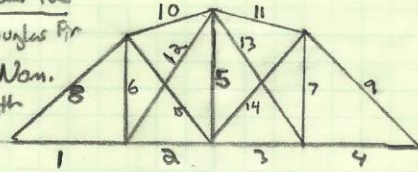
Member 12

Not Douglas Fir

4x6 Nom.

12' length

= 144 in



Forces

From Risa Analysis

Axial max = 478 k (+)  
min = -2.637 k (-)

Shear max = .163 k  
min = -.130 k

Moment max = .738 ft.k  
min = -1.154 ft.k

Actual size  $3\frac{1}{2}$  in x  $5\frac{1}{2}$  in Area = 19.25 in<sup>2</sup>

$S_{xx} = 17.65$  in<sup>3</sup>  $I_{xx} = 48.53$  in<sup>4</sup>

$F_b = 1000$  psi  $F_v = 180$  psi  $E = 1700000$  psi  $F_t = 675$  psi  $F_c = 1500$  psi

$C_m = 1.0$   $C_R = 1.0$   $C_T = 1.0$   $C_i = 1.0$

$\phi_b = .85$   $\phi_v = .75$   $\phi_T = .80$   $\phi_c = .90$

$\lambda = .8$   $K_F = \frac{2.16}{\phi}$

### Bending Check

Normal Depth = 6 in

Normal width = 4 in

$S_y = 1.5$   $C_L = 1.0$   $C_F = 1.3$

$$F'_b = \lambda K_{F-F_b} \cdot \phi_b \cdot F_b \cdot C_m \cdot C_T \cdot C_F \cdot C_i \cdot C_L \cdot C_R$$

$$F'_b = .8 \cdot \frac{2.16}{.85} \cdot .85 \cdot 1000 \cdot 1.0 \cdot 1.3 \cdot 1.0 \cdot 1.0 \cdot 1.0 \cdot 1.0$$

$$F'_b = 2246 \text{ psi}$$

$$f_b = \frac{M}{S_x} = \frac{1.154 \text{ ft.k} \cdot 1000 \text{ lb} \cdot 12 \text{ in}}{17.65 \text{ in}^3} = 784.6 \text{ psi}$$

$$784.6 \text{ psi} < 2246 \text{ psi} \quad \checkmark$$



## Whipple Member Check

### Shear Check

$$F'_V = \lambda \cdot K_{E-FV} \cdot \Phi_V \cdot F_V \cdot C_m \cdot C_T \cdot C_i$$

$$F'_V = .8 \cdot \frac{2.16}{.75} \cdot .75 \cdot 180 \cdot 1.0 \cdot 1.0 \cdot 1.0$$

$$F'_V = 311 \text{ psi}$$

$$F_v = \frac{3}{2} \cdot \frac{V}{A} = \frac{3}{2} \cdot \frac{.163 \text{ k} \cdot 1000 \text{ lb}}{19.25 \text{ in}^2} = 12.7 \text{ psi}$$

$$12.7 \text{ psi} < 311 \text{ psi} \quad \checkmark$$

### Tension Check

$$F'_T = \lambda \cdot K_{E-FT} \cdot \Phi_T \cdot F_T \cdot C_m \cdot C_T \cdot C_F \cdot C_i$$

$$F'_T = .8 \cdot \frac{2.16}{.80} \cdot .80 \cdot 675 \cdot 1.0 \cdot 1.0 \cdot 1.3 \cdot 1.0$$

$$F'_T = 1516 \text{ psi}$$

$$f_t = \frac{.478 \text{ k} \cdot 1000 \text{ lb}}{19.25 \text{ in}^2} = 24.8 \text{ psi}$$

$$24.8 \text{ psi} < 1516 \text{ psi} \quad \checkmark$$

### Compression Check

$$C_F = 1.1 \quad C_P = 1.0$$

$$F'_C = \lambda \cdot K_{E-FC} \cdot \Phi_C \cdot F_C \cdot C_m \cdot C_T \cdot C_F \cdot C_i \cdot C_P$$

$$F'_C = .8 \cdot \frac{2.16}{.90} \cdot .90 \cdot 1500 \cdot 1.0 \cdot 1.0 \cdot 1.1 \cdot 1.0 \cdot 1.0$$

$$F'_C = 2851 \text{ psi}$$

$$F_c = \frac{2.637 \text{ k} \cdot 1000 \text{ lb}}{19.25 \text{ in}^2} = 137 \text{ psi}$$

$$137 \text{ psi} < 2851 \text{ psi} \quad \checkmark$$

## Whipple Member Check

### Member 8

No 1 Douglas Fir  
4x6 Nom.

$$L = 11' = 132 \text{ in}$$

Actual size  $5\frac{1}{2}'' \times 5\frac{1}{2}''$  in

$$\text{Area} = 19.25 \text{ in}^2$$

$$S_{xx} = 17.65 \text{ in}^3 \quad I_{xx} = 98.53 \text{ in}^4$$

### Forces from Risa

$$\text{Axial max} = 8.461 \text{ k (t)}$$

$$\text{min} = -0.818 \text{ k (c)}$$

$$\text{Shear max} = 0.071 \text{ k}$$

$$\text{min} = -0.353 \text{ k}$$

$$\text{Moment max} = 1.178 \text{ ft}\cdot\text{k}$$

$$\text{min} = -2.372 \text{ ft}\cdot\text{k}$$

$$F_b = 1000 \text{ psi} \quad F_v = 180 \text{ psi} \quad F_T = 675 \text{ psi} \quad F_c = 1500 \text{ psi} \quad E = 1700000 \text{ psi}$$

$$C_m = 1.0 \quad C_R = 1.0 \quad C_T = 1.0 \quad C_i = 1.0$$

$$\phi_b = 0.85 \quad \phi_v = 0.75 \quad \phi_T = 0.80 \quad \phi_c = 0.90$$

$$\lambda = 0.8 \quad K_F = \frac{2.16}{\phi}$$

### Bending Check

$$C_L = 1.0 \quad C_F = 1.3$$

$$F'_b = \lambda K_{F-FB} \cdot \phi_b \cdot F_b \cdot C_m \cdot C_T \cdot C_F \cdot C_i \cdot C_L \cdot C_R$$

$$F'_b = 0.8 \cdot \frac{2.16}{0.85} \cdot 0.85 \cdot 1000 \cdot 1.0 \cdot 1.0 \cdot 1.3 \cdot 1.0 \cdot 1.0 \cdot 1.0$$

$$F'_b = 2246 \text{ psi}$$

$$f_b = \frac{M}{S_x} = \frac{2.372 \text{ ft}\cdot\text{k} \cdot 1000 \text{ lb} \cdot 12 \text{ in}}{17.65 \text{ in}^3}$$

$$f_b = 1613 \text{ psi}$$

$$1613 \text{ psi} < 2246 \text{ psi} \quad \checkmark$$



## Whipple Member Check

### Shear Check

$$F'_v = \lambda \cdot K_{E-FV} \cdot \phi_v \cdot F_v \cdot C_m \cdot C_T \cdot C_i$$

$$F'_v = .8 \cdot \frac{2.16}{.75} \cdot .75 \cdot 180 \cdot 1.0 \cdot 1.0 \cdot 1.0$$

$$F'_v = 311 \text{ psi}$$

$$f_v = \frac{3}{2} \cdot \frac{V}{A} = \frac{3}{2} \cdot \frac{.353 \text{ k} \cdot 1000 \text{ lb}}{19.25 \text{ in}^2} = 27.5 \text{ psi}$$

$$27.5 \text{ psi} < 311 \text{ psi} \quad \checkmark$$

### Tension Check

$$F'_T = \lambda \cdot K_{E-FT} \cdot \phi_T \cdot F_T \cdot C_m \cdot C_T \cdot C_F \cdot C_i$$

$$F'_T = .8 \cdot \frac{2.16}{.80} \cdot .80 \cdot 675 \cdot 1.0 \cdot 1.0 \cdot 1.3 \cdot 1.0$$

$$F'_T = 1516 \text{ psi}$$

$$f_t = \frac{8.461 \text{ k} \cdot 1000 \text{ lb}}{19.25 \text{ in}^2} = 440 \text{ psi}$$

$$440 \text{ psi} < 1516 \text{ psi} \quad \checkmark$$

Compression check is not necessary because this member is never in compression.

## Whipple Member Check

### Member 6

Nol Douglas Fir  
4x6 Nom.

$$L = 8' = 96 \text{ in}$$

$$\text{Actual size} = 3\frac{1}{2}'' \times 5\frac{1}{2}''$$

$$\text{Area} = 19.25 \text{ in}^2$$

$$S_{xx} = 17.65 \text{ in}^3 \quad I_{xx} = 48.53 \text{ in}^4$$

### Forces From Risa

$$\text{Axial} \quad \text{max} = -1.09 \text{ k (C)} \\ \text{min} = -4.464 \text{ k (C)}$$

$$\text{Shear} \quad \text{max} = 1.348 \text{ k} \\ \text{min} = -2.17 \text{ k}$$

$$\text{Moment} \quad \text{max} = 1.798 \text{ ft}\cdot\text{k} \\ \text{min} = -1.201 \text{ ft}\cdot\text{k}$$

$$F_b = 1000 \text{ psi} \quad F_v = 180 \text{ psi} \quad F_T = 675 \text{ psi} \quad F_c = 1500 \text{ psi} \quad E = 1700000 \text{ psi}$$

$$C_m = 1.0 \quad C_R = 1.0 \quad C_T = 1.0 \quad C_i = 1.0$$

$$\phi_b = .85 \quad \phi_v = .75 \quad \phi_T = .80 \quad k = .90$$

$$\lambda = .8 \quad K_F = \frac{2.16}{\phi}$$

### Bending Check

$$C_L = 1.0 \quad C_F = 1.3$$

$$F'_b = \lambda \cdot K_{F-FB} \cdot \phi_b \cdot F_b \cdot C_m \cdot C_T \cdot C_F \cdot C_i \cdot C_L \cdot C_R$$

$$F'_b = .8 \cdot \frac{2.16}{.85} \cdot .85 \cdot 1000 \cdot 1.0 \cdot 1.0 \cdot 1.3 \cdot 1.0 \cdot 1.0 \cdot 1.0$$

$$F'_b = 2246 \text{ psi}$$

$$e_b = \frac{M}{S_x} = \frac{1.798 \text{ ft}\cdot\text{k} \cdot 1000 \text{ lb} \cdot 12 \text{ in}}{17.65 \text{ in}^3}$$

$$e_b = 1222 \text{ psi}$$

$$1222 \text{ psi} < 2246 \text{ psi} \quad \checkmark$$

AMTAD

## Whipple Member Check

### Shear Check

$$F'_V = \lambda \cdot K_{F-FV} \cdot \phi_V \cdot F_V \cdot C_M \cdot C_T \cdot C_i$$

$$F'_V = .8 \cdot \frac{2.16}{.75} \cdot .75 \cdot 180 \cdot 1.0 \cdot 1.0 \cdot 1.0$$

$$F'_V = 311 \text{ psi}$$

$$f_v = \frac{3}{2} \cdot \frac{V}{A} = \frac{3}{2} \cdot \frac{.348 \text{ k} \cdot 1000 \text{ lb}}{19.25 \text{ in}^2} = 27.1 \text{ psi}$$

$$27.1 \text{ psi} < 311 \text{ psi} \quad \checkmark$$

### Compression Check

$$C_F = 1.1 \quad C_P = 1.0$$

$$F'_C = \lambda \cdot K_{F-FC} \cdot \phi_C \cdot F_C \cdot C_M \cdot C_T \cdot C_F \cdot C_i \cdot C_P$$

$$F'_C = .8 \cdot \frac{2.16}{.90} \cdot .90 \cdot 1500 \cdot 1.0 \cdot 1.0 \cdot 1.1 \cdot 1.0 \cdot 1.0$$

$$F'_C = 2851 \text{ psi}$$

$$f_c = \frac{4.464 \text{ k} \cdot 1000 \text{ lb}}{19.25 \text{ in}^2} = 231.9 \text{ psi}$$

$$231.9 \text{ psi} < 2851 \text{ psi} \quad \checkmark$$

Tension Check is not necessary because this member is never in tension.



# Flatcar Design

Flat Car

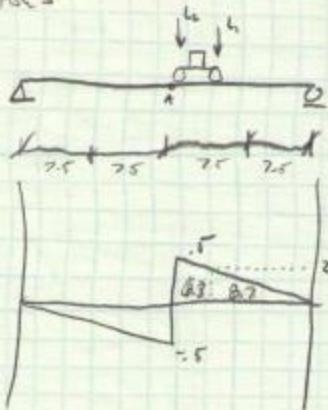
CASE 1

$$\begin{aligned}
 V_A &= (L_1)(.75) + (L_2)(z) \\
 &= (L_1)(.75) + (L_2)(-.54) \\
 &= (4,000)(.75) + (1,000)(-.54) \\
 &= 3000 - 540 \\
 &= 2460
 \end{aligned}$$

CASE 2

$$\begin{aligned}
 V_A &= (L_2)(z) + (L_1)(.75) \\
 &= (L_2)(-.04) + (L_1)(.75) \\
 &= (4,000)(-.04) + (1,000)(.75) \\
 &= -160 + 750 \\
 &= 590
 \end{aligned}$$

Case 3

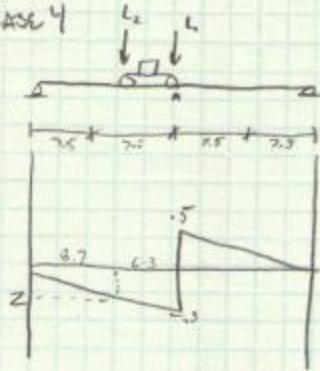


$$\begin{aligned}
 V_A &= (L_1)(.5) + (L_2)(z) \\
 &= L_1(.5) + L_2(-.29) \\
 &= 4000(.5) + 10000(-.29) \\
 &= 2000 - 2900 \\
 &= -900
 \end{aligned}$$

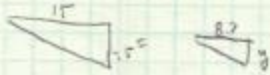


$$\frac{.5}{15} = \frac{x}{8.7} \Rightarrow x = .29$$

Case 4

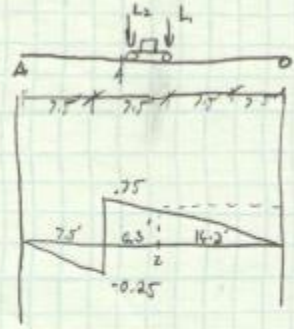


$$\begin{aligned}
 V_A &= (L_1)(.5) + (L_2)(z) \\
 &= L_1(.5) + L_2(-.29) \\
 &= 1000(.5) + 4000(-.29) \\
 &= 500 - 1160 \\
 &= -660
 \end{aligned}$$



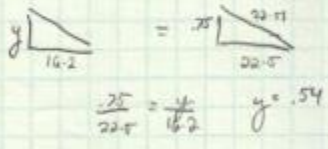
$$\frac{.5}{15} = \frac{x}{8.7} \Rightarrow x = -.29$$

Case 1 HAD Max SHEAR FORCE



SHEAR CALCULATION

$$\begin{aligned}
 V_A &= (L_1)(.75) + (L_2)(2) \\
 &= (1000)(.75) + (4000)(.54) \\
 &= 1000(.75) + (4000)(.14) \\
 &= 3000 + 540 \\
 &= 3540
 \end{aligned}$$



MOMENT CALCULATION CASE 1

$$\begin{aligned}
 \Delta M &= (-1000)\left(\frac{25}{22.5}\right)(6.3) + (4000)\left(\frac{22.11}{22.5}\right)(6.3) \\
 \Delta M &= -630 + 840 = 210 \text{ lbs/ft}
 \end{aligned}$$

Case 1

$$M = 1000(.75) + 4000(.54) = 2910 \text{ lbs/ft}$$

Case 2

$$M = 1000(.75) + 4000(.04) = 590 \text{ lbs/ft}$$

Case 3

$$M = 1000(.5) + 4000(.29) = 1660$$

Case 4

$$M = (.5)(4000) + 1000(.09) = 2290$$

Case 1 yields Maximum Moment of 2910 lbs/ft



ALLOWABLE LOADING

FLAT CAR

Max Force From Gates Loading: Case 1

$$\text{DEAD LOAD} = 472 \text{ lb/ft} \times 30' = 14,160 \text{ lb}$$

$$\text{PEDESTRIAN LIVE LOAD} = 100 \text{ lb/ft} \times 30' = 3,000 \text{ lb}$$

$$\text{JIB CRANE LOAD} = 50 \text{ lb/ft} \times 30' = 1,500 \text{ lb}$$

$$\text{VEHICLE LIVE LOAD} = 5,000 \text{ lb}$$

$$1.2D + 1.6L + 0.5J = 1.2(14,160) + 1.6(5,000) + 0.5(1,500)$$

$$= 25,742 \text{ lbs}$$

$\approx 26,000 \text{ lbs}$  ROUNDED UP

40 KSI YIELD STRENGTH, 22 KSI ALLOWABLE STRESS LIMIT ← IOWA STATE

AASHTO LIMIT:  $\text{SPAN}/800$

$$22 \text{ KSI} = 3168 \text{ psf}$$

30' LONG

9' WIDE

$$30 \times 9 = 270 \text{ ft}^2 \times 3168 \text{ psf} = 855360 \text{ POUNDS} / 30 = 28,512 \text{ POUNDS PER FOOT}$$

THEREFORE, ALLOWABLE LOAD IS 28,512 POUNDS PER FOOT.

$$26,000 / 30' = 867 \text{ POUNDS PER FOOT}$$

THE LOADING FOR THE 30' SPAN IS LESS THAN THE ALLOWABLE LOADING OF 28,512 psf (POUNDS PER LINEAR FOOT)

Floor Load

Dead Load @ 472 lb/ft ← 100% WASTE U

$$472(30) = 14,160 \text{ lbs}$$

PRESTRESSING LIM LOAD = 100 lb/ft

$$100(30) = 3,000 \text{ lbs}$$

SNOW LOAD = 50 lbs/ft

$$50(30) = 1,500 \text{ lbs}$$

$$1.2D + 1.6L + 0.5S$$

$$1.2(14,160) + 1.6(3,000) + 0.5(1,500)$$

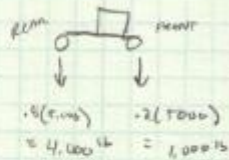
$$= 16,992 + 4,800 + 750 = 22,542 \text{ lbs}$$

$$\text{ROUNDING UP} = 23,000 \text{ lbs}$$

EACH ABUTMENT NEEDS TO HOLD 11,500 lbs, MINIMUM

WHEEL BASE OF UTILITY GARDER = 75.2" @ 6.3'  
- ACCORDING TO JOHN DEERE ON ROUTE 146

5,000 lb GARDER VEHICLE, 80% OF LOAD IS ON BACK TIRES



FLYCAR

Moment of Dead Load

$$M_{DL} = \frac{W_{DL} L^2}{8}$$

$$M_{DL} = \frac{(472)(30)^2}{8} = 53,100 \text{ ft}\cdot\text{lb}$$

Moment of Snow Load

$$M_s = \frac{W_s L^2}{8}$$

$$M_s = \frac{(50)(30)^2}{8} = 5625 \text{ ft}\cdot\text{lb}$$

Moment of Gerson = 2,910 ft·lb

$$M_{\text{Total}} = M_{DL} + M_s + M_{\text{Gerson}}$$

$$= 53,100 + 5625 + 2910$$

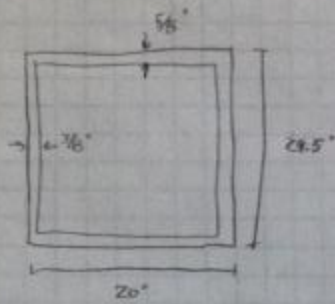
$$= 61,635 \text{ ft}\cdot\text{lb}$$

Answers



Flex. Cos.

Moment Capacity



$$C = \frac{20 \cdot 20}{2}$$

$$I_x = \sum \left( \frac{1}{12} b_i h_i^3 \right) + \sum (A_i d_i^2) \quad \text{Parallel Axis Theorem}$$

$$\sum \left( \frac{1}{12} b_i h_i^3 \right) = 2 \times \frac{1}{12} (20 \cdot 3^3) + 2 \left( \frac{3}{8} \times 29.5 \cdot 1.75^3 \right) = 16909.8$$

$$\sum (A_i d_i^2) = 2 (20 \cdot 3) \left( \frac{20 \cdot 20 - 14 \cdot 14}{2} \right)^2 = 360.94 \quad \text{DUE TO FINISH FLATS}$$

$$I_x = 17270.74 \text{ in}^4$$

$$S_x = I_x / C = \frac{17270.74}{20 \cdot 20} = 1171$$

$$\text{ALLOWABLE MOMENT} \left( \frac{M_n}{\phi} \right) = S_x \cdot 22 \text{ ksi}$$

$$\text{LFD CAPACITY} \phi M_n = 1.67 \times \left( \frac{M_n}{\phi} \right) \times (0.9)$$

$$\text{CAPACITY} = 38,720 \text{ ft-k} \rightarrow 464,640 \text{ ft-lb}$$