ENGINEERING 90 SENIOR PROJECT REPORT

DESIGN OF A PEDESTRIAN BRIDGE FOR THE QUADRANGLE RETIREMENT COMMUNITY

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Abstract

This report contains the design of a pedestrian bridge located at *The Quadrangle*, a retirement community in Haverford, Pennsylvania, to be built at the north end of a pond spanning a feeder stream. The report contains hydrologic, EIS and geotechnical information for the site as well as structural, foundation, and construction plans. We primarily used Multiframe 2D and Microsoft Excel to complete the design work. Bid documents were drawn using AutoCAD and could, if presented to a contractor, be used to construct the bridge.

At the client's request, the bridge has been designed to resemble the one painted by Claude Monet in his "*Japanese Footbridge*" and is structurally capable of carrying both pedestrians and scooters. Bid documents include designs for spans of 30 and 35 feet, with corresponding cost estimates for construction using two kinds of wood as well as a plastic-wood composite. We found wood to be the most cost effective structural system given the design parameters. Reasons for the materials selection are provided in Section 3.2. Though both spans are acceptable, the 35 foot span requires less earth work and smaller abutments. It is also less susceptible to flooding and scour problems.

The hydrological, geotechnical, material, structural, and foundation designs are discussed in separate sections. The recommended foundations consist of a masonry wing-type abutment designed against overturning and sliding failure. Comprehensive CAD drawings are located in Appendix A and design calculations are provided in the subsequent appendices.

Acknowledgements

We would like to thank our advisor, Professor Faruq Siddiqui, for his guidance and infinite patience over the length of the project. In addition to teaching us all we know about structural and geotechnical engineering, he gave us a substantial amount of time during his sabbatical.

We would also like to thank Dr. Steven Phillips for commissioning this project and providing community support at The Quadrangle. His help in obtaining site and historical information was invaluable.

Dan Honig was also a useful resource, helping us to locate the appropriate building codes and providing general advice. Don Dukert, Head of Engineering at the Quadrangle, was also helpful in providing us with reference information about the property.

Thanks are also due to the architects at Wallace, Roberts, and Todd for supplying reference materials, Jennifer Preston of Turner Construction and Cornell for her advice about Ecoboard, and Col. Steven Ressler, a faculty member at West Point U.S. Military Academy, for his advice. Thanks are also due to those people at Tague Lumber and Ecoboard who helped us obtain pricing and availability information about the different materials for the cost estimate.

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1.0 Introduction

1.1 Statement of Interest

The E90 design project is intended to be the culminating experience for engineering students at Swarthmore, where students investigate and report on a problem of their choice in an area of interest to them under the guidance of a faculty member. Both a written report and an oral presentation are required. Given our interests in civil and structural engineering, we elected to undertake the design of this pedestrian bridge as our E90 design project because it integrated material from our course preparations, provided us with a venue through which to demonstrate our competence in these areas, and required a balanced application of theoretical and practical knowledge. We chose Professor Siddiqui to act as our advisor because of his governing influence on our training. We feel that this project is a culmination of all we have learned in our studies and will provide us with a real view of our capabilities and limitations in these areas of engineering.

In addition to fulfilling our personal motivations, we feel this project will significantly improve the quality of life for residents of The Quadrangle. They will be able to enjoy the scenic nature of the site and also have a complete path all the way around the pond.

The construction of this pathway has been a goal of the community since the Quadrangle was built. The seminal concept was first put together by William J. Cohen, who has since died of pancreatic cancer. Since his death, the bridge has been an ongoing wish of the Quadrangle Residents and we feel it is important to help them realize their desire for this bridge. The community felt strongly that the bridge should resemble Cohen's initial conception of Monet's *"Japanese Footbridge",* thus we have attempted to replicate this image in our design. Dr. Steven Phillips, a Quadrangle resident and Chair of the Quadrangle Landscaping Committee, brought this project to our attention in the summer of 2004.

1.2 Project Scope

As can be seen on the site map (Figure 1), the bridge will span a small feeder stream at the northwest end of the pond. It will be 30 or 35 feet in span and will be built out of either wood or plastic-wood composite.

The scope of this project includes the design of the bridge in its entirety including materials, connections, structural members, deck, railings, and foundations, and a cost estimate in order to enable easy comparison between the multiple designs.

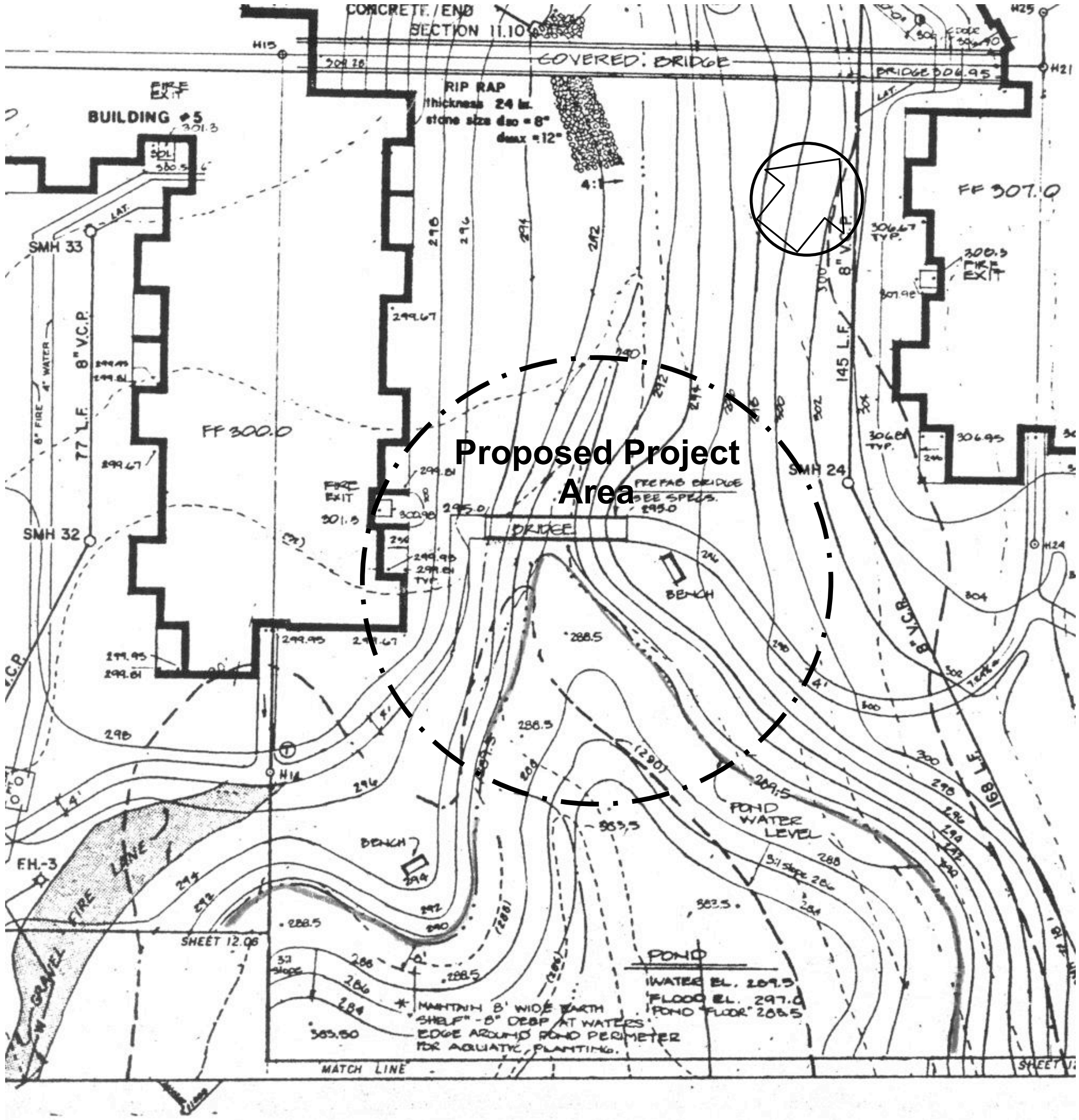

Figure 1.1: Site map of the Quadrangle

1.3 Applicable Codes and Provisions

The American Association of State Highway and Transportation Officials (AASHTO) Guide Specifications for Design of Pedestrian Bridges [4] provides the design loads and design details for pedestrian bridges. These include pedestrian live loads, vehicle live loads, wind loads, and combination loads. Additionally provisions are specified for maximum deflection and allowable vibrations. All design was completed using Load Resistance Factor Design (LRFD) methodology. The American Paper Association (APA) LRFD Manual for Engineered Wood

Construction [1] and the American Institute of Timber Construction (AITC) Timber Construction Manual Fourth Edition (1994) [2] were consulted in the design of all wood members. Additionally, the American Concrete Institute (ACI) Strength Design of Steel Reinforced Concrete (ACI 318-99) specifications were used for this project.

This design will satisfy the realistic constraints criteria stipulated as a requirement for culminating design projects, which include economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political considerations. All of these considerations have been addressed in the design of this bridge.

1.4 Group Design Project Philosophy

The complete assembly of a set of construction bid documents for this structure is a huge undertaking. It is for this reason that we have chosen to work on this project as a group. A much more complete product can be provided if we work together. This group effort is also excellent preparation for the situations professional engineers face every day. Not only were we responsible for our individual work in the project, but we were forced to communicate those parts effectively to each other, divide the work fairly and cooperate in order to be successful. We believe that the design of this bridge is of large enough scope and sufficient difficulty to engage two senior engineering students for over a full semester, while still within the realm of feasibility.

1.5 Public Opinion

In order for the bridge to be constructed, its design must be approved by multiple parties. The design will initially need to be presented to the Quadrangle Landscape Committee by Dr. Phillips, who is the chair. This committee is composed of 17 residents and the Head of Engineering at the Quadrangle, Don Dukert. The committee will then recommend action to the Quadrangle Resident's Association Steering Committee, who will bring it up at a semiannual residents meeting for affirmation by the community. If its desirability is affirmed, it will be forwarded to the Sunrise Management Company through Greg Leonard, the Quadrangle's resident manager. Because the original property owner, Marriott, sold the property rights to CNL Retirement Corporation and the management contract to Sunrise Management Company, the design will have to be approved by both organizations.

Given that neither of these companies will necessarily want to fund the bridge, Esther Cohen and her family are willing to attempt to raise the funds necessary for construction of the bridge and offer it to Sunrise on a cost share basis, where Sunrise will pay for all of the grading and paving needed.

Dr. Philips will be responsible for guiding the design through these channels, assisted by our group as the need arises. He has stated that he feels confident of the community's support of this endeavor and feels that its construction would be a further example of how the Quadrangle is an outstanding, unique retirement community with a spirit of involvement.

Due to the large number of non-industry individuals who will read this report at the Quadrangle, this report has not been written as a standard engineering report. Instead, a good amount of background information and explanation has been included. Also, an attempt has been made to avoid the use of jargon. The result is a less concise report with sections that may seem superfluous to professional engineers, but one that will hopefully give a greater understanding to those who approach this design with less previous knowledge of the issues surrounding its construction.

2.0 Site Inventory and Analysis

2.1 Geotechnical Report and Subsurface Investigations

This report is for the construction of a pedestrian bridge for the pond located on the grounds of the Quadrangle. All of the contour information used was obtained from the Quadrangle's architect: Wallace, Roberts, & Todd, LLC. There are no existing boring logs or geotechnical information about the site. These investigations should be performed by a licensed Geotechnical Engineer before the start of construction and any necessary changes made to the design. Given that there will be a large amount of fill necessary at the construction site in which most of the construction will take place; we anticipate that some changes will need to be made. However, this work should be relatively easy for a geotechnical engineer to complete and should not significantly alter the design or add to the expense of the bridge.

2.2 Hydrology

The topography of the Quadrangle is such that surface water drains south toward the pond. The drainage channel that runs through the proposed bridge site provides drainage for much of the Quadrangle land. In addition, a natural spring on the Quadrangle premises feeds the stream channel. The water continues through the channel into the pond.

It exits the pond on the opposite side though a large corrugated metal pipe which dumps the water into Darby Creek, which leads to the Delaware River. Large amounts of water have been observed running through the channel and the water level of the pond has been observed to rise as much as four feet. Accordingly, erosion and siltation in and around the drainage channel occur regularly.

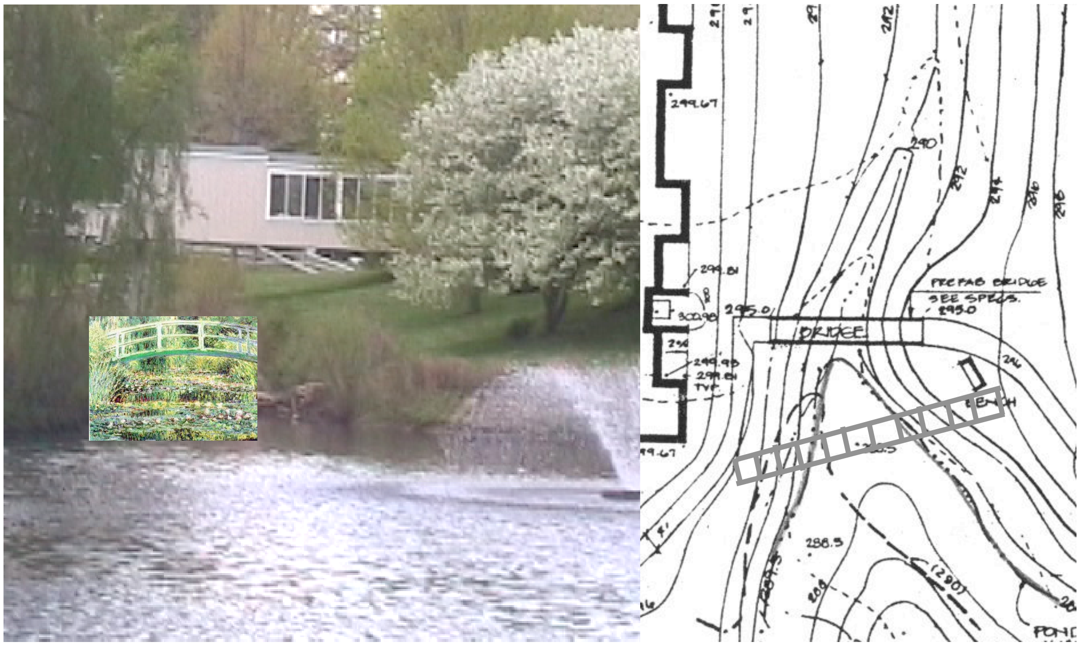

Figure 2.1: The bridge superimposed onto a site photo and plan

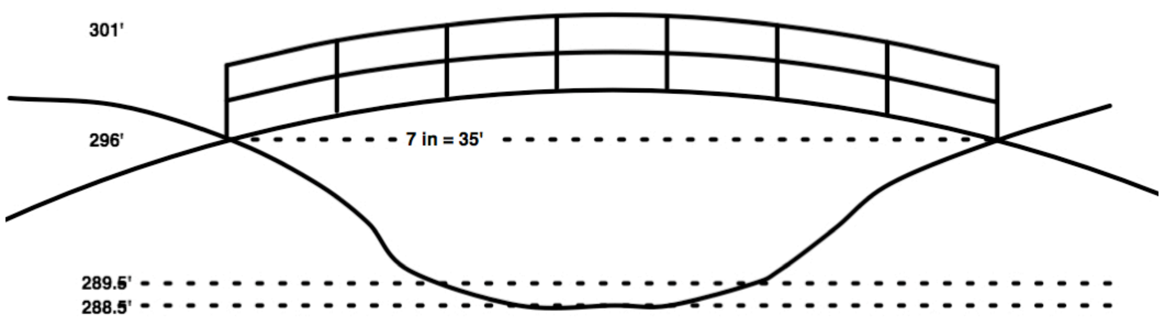

Figure 2.2: Cross-section of Bridge Site

2.3 Vegetation/ Large Tree Survey

In consultation with Dr. Philips, we examined the existing vegetation in the considered area. Of the existing vegetation, Dr. Philips has stated that only the Willow tree on the south bank must be maintained in its current location. In order to make the bridge more closely resemble Monet's more Willow trees, Wisteria and other appropriate vegetation should be added after the bridge is constructed.

2.4 General Description of Subsurface Materials

The soil surrounding the pond is mainly sandy silt that has washed down the culvert and settled as it reached the pond. There are no existing boring logs so no more is known about these materials.

2.5 Man-made Features

The presence of man-made features on our site is minimal. There is one existing electrical box that is located approximately 10 feet to the south of the Willow tree along the bank of the pond. This box controls the two fountain pumps that are in the middle of the pond. We expect that there are some electrical and water lines running from this box to the pumps, but there is no reliable information about the exact location of any such lines. Thus, care must be taken when excavating around this box, but this should not be necessary given that the location of the bridge is relatively far away from the electrical box.

There is an existing system of concrete paths that extend around the pond. These paths generally indicate the routes of minimal slope between points of interest, making them optimal for the elderly residents. This is especially important because many residents use powered chairs to get around the Quadrangle. These vehicles are limited to a maximum slope of fifteen degrees. Therefore, our bridge and the accompanying paths that connect to it were designed to integrate into the existing path system and to adhere to this grade limit.

2.6 Constructability and Access

2.6.1 *Construction Access*

Due to the proximity of the bridge site to the pond and the restricted site access, construction will require some additional planning. It is clear that, due to the proximity of existing structures and the Willow tree, we will not have use of any large construction vehicles. The back road that approaches from the east bank of the pond is the widest and should be used by all construction vehicles. From this road small off road utility vehicles will be able to travel the short distance to the construction site. Depending on the rainfall, it may be difficult for heavily loaded construction vehicles to remain stable in muddy conditions, but construction during the summer season should not be hindered by this factor.

2.6.2 *Constructability Constraints*

An approach path will have to be laid on the northern bank of the creek, extending around to the east side of the pond, where it will connect with the existing road. A similar approach path is already in place on the south bank, which also connects with the path on the far side of the pond.

A full sized concrete mixing truck will be too heavy and large to traverse any of the paths so concrete will have to be transported from the back road. Any prefabricated structural members should be small enough to fit in the flatbed of a 4x4 truck. The only possible on-site staging areas are on the southern or eastern bank area. Components should be small enough and light enough so that erection can proceed largely without the aid of significant construction machinery.

3.0 Design of Superstructure

3.1 Design Process Overview

Pedestrian bridges, though relatively simple structures, pose some complex design problems. The superstructure comprises all the components of a bridge above the supports. It generally includes the deck, primary members (also called stringers or girders), and secondary members. The primary members distribute loads longitudinally and are usually designed principally to resist flexure. The secondary members are bracing between the primary members designed to resist cross-sectional deformation of the superstructure frame and help distribute part of the vertical load between primary members [Tonais].

After first surveying the site and deciding generally what the finished product should look like, the most important step in design is to become familiar with any applicable codes. One should also become familiar with the LRFD design process, which works from the loads to design the structure. In this case, this process began with the material design and the design of the deck and railings, and then moved on to the structural members and connections. The last step in the design process was to design the footings and abutments and to perform a cost analysis.

For this bridge, the general architecture was stipulated by the Quadrangle community to be similar to the bridge in Monet's painting, thus the general shape and final appearance were pulled from his paintings (Figure 4). After the materials explorations were complete, we moved on to the LRFD design process.

The LRFD design process was carried out using Microsoft Excel® [20] and Multiframe [21]. This process begins with the determination of the design loads, initial selection of member sizes, and then becomes an iterative process to find the most efficient member sizes that can accommodate the design loads and adjustment factors.

Two such loads on the structure are the dead load from the deck and the dead load from the railing. Since it was hypothesized that deflection of the deck would be the controlling factor in design, the design process began with the deck members. From this design process it was determined that three girders would be needed as opposed to 2 girders. The dead load that the deck members would exert on the girders was also found.

The next step was to design the handrails, which was straightforward given that the arrangement had been laid out for us by Monet (Figure 4). The railings members were subject to the specifications laid out in 2003 IBC 1009, 1010, and 1607 [12]. The Muller-Breslau principle was used to determine the load application of appropriate load combinations. Once we determined the member sizes, the dead load from the railings was established. It was then added to the dead load of the deck to give the final dead loads.

Once the final design loads were known, the design of the girders was performed using Multiframe and Excel. We based the design and load analysis on the design process for constant-radius arches specified in AITC Timber Construction Manual 5.13.8. This design process was carried out for each material and a cost estimate was performed for each material and span. This concluded the design of the superstructure. Each of these steps is described in detail in the subsequent sections.

Figure 3.1: Monet's Japanese Garden Bridge (the superstructure shape)

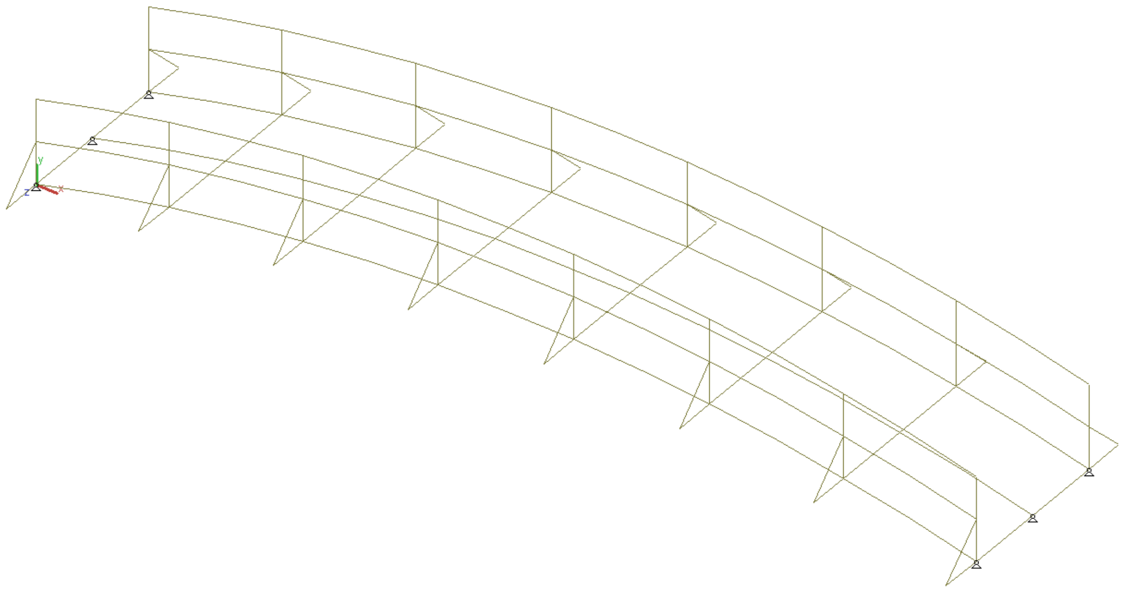

Figure 3.2: Bridge (elevation view)

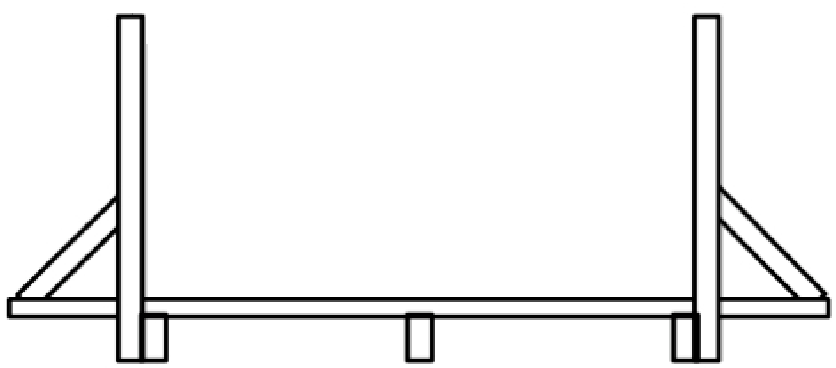

Figure 3.3: Bridge (cross-section)

3.2 Materials Design

3.2.1 *Introduction*

A complete investigation of structural, decking/railing and connection materials was conducted in preparation for design. For the structural members, the use of Glue-laminated Pine or Ecoboard was explored. For the decking/railing material the use of Ipe, Ecoboard or Cedar was investigated. For the connections, the use of aluminum angles, stainless steel screws, and stainless steel bolts was determined to be optimal, given the empirical findings of another group in the construction of their pedestrian bridge [Preston, Cornell].

3.2.2 *Structural Wood*

For the structural members, we investigated Glue-laminated Pine. This material has the advantage of being the least expensive and most readily available of all the choices, but has some drawbacks. This material would require sanding, sealing, and painting. Over time it will rot or be weakened by parasites, thus shortening the lifespan of the bridge [AITC 1974]. In addition to sealing, the use of Glue-lam members will also necessitate a membrane to prevent water penetration from the top. However, it is the most easily available material and its use would ease construction considerably compared to construction with Ecoboard.

3.2.3 *Plastic-Wood Composites*

In choosing a plastic-wood composite, the choice of the manufacturer is crucial to the design, as the material properties of plastic composites at this early stage in the materials' development depend to a marked extent on the fabricator. On the suggestion of a student group from Cornell we explored the use of Ecoboard, a plastic-wood composite made by American Ecoboard, Inc. The Cornell group experienced success with this product in the construction of their pedestrian bridge.

Ecoboard also has the capability of being shaped into arched structural members, but will be more expensive than structural wood.

Ecoboard is for the most part a confection of Medium- and Hard-Density Polyethylene (MDPE and HDPE) and is reinforced with embedded fiberglass threads. It uses nontoxic additives to reduce weight, increase strength and mechanical properties. The resulting material is strong, light, impact resistant and wood like in appearance. Ecoboard is also maintenance free with none of the drawbacks associated with wood, such as rotting and susceptibility to parasites. The typical lifespan of the material is 75 years and it is warranted for 25 years (Ecoboard website).

Downsides include higher initial cost, greater short- and long-term deflections, greater thermal expansion and localized melting from cutting and drilling [Preston, Cornell].

The installation may be slightly more difficult with this material, given that the material is so dense. All the screw holes must have pilot holes drilled for them and each screw must be lubricated. These difficulties doubled the erection time in comparison with timber, in the experience of the Cornell Group. However, Ecoboard can be cut, drilled, mitered, and sanded with conventional woodworking tools. Carbide tipped saw blades with fewest teeth are recommended. No special installation crew is required.

3.2.4 *Decking/Railing Wood*

For the decking/railing material two woods (Ipe and Cedar) were considered in addition to Ecoboard. Ipe is a South American wood also known as "ironwood", which is a heavy, hard, and strong wood that is very resistant to both rot and parasites. It does not need to be sealed or stained. It has a nice color and is practically faultless. Because it is so hard it has a much longer lifespan than other natural woods [Ipe Website]. It is available only by special order and accordingly is very expensive.

Cedar is much more widely available and less expensive. It has a shorter lifespan and requires sealing to make it resistant to rot [AITC 1994]. It is also aesthetically pleasing, but it is less resistant to rot and would require more frequent replacement.

3.2.5 *Conclusions*

Given that Ipe, Ecoboard and Glue-lam Pine would all be acceptable for construction, design calculations were completed for both materials and a cost comparison was produced (Section 5.0). We believe that having all these design options will allow the Quadrangle community and it's owners to choose the design they deem most appropriate to their needs, both budgetary and aesthetically.

3.3 Deck Design

3.3.1 *Design Considerations*

The main function of the deck is to distribute loads along the bridge transversely. The deck either rests on or is integrated with a structural system designed to distribute loads along the length of the bridge longitudinally.

The main concern in the design of the deck was to limit the amount of deflection. This is mainly so that people will not perceive the deck moving as they walk across, which makes them feel unsafe and uncomfortable. The acceptable deflection of the deck under live load for any structural member is stipulated in the AASHTO Pedestrian Bridge Code (1997) as the length of the member over 500 (_≤span/500). The deck width was dictated by the desire for two motorized scooters, which many residents utilize to move around the grounds, to pass each other on the bridge. This required a 6 ft width of deck, which means that under the maximum load, it could not deflect more than 0.144 in.

The AASHTO code specifies that the vehicle live load would be determined by the operating agency. The largest of the scooters we observed at the Quadrangle were Golden Technologies' Golden Companion II. These scooters have three wheels in total, two in the rear. The wheels are spaced two feet apart from each other on center. The weight of a scooter carrying the maximum capacity was 500 lbs. We conservatively assumed that the two wheels would bear all of the weight and that two of these fully loaded scooters would be side by side (see Figure 3.4). Under these conditions, the deflection of the deck supported by two girders, given our chosen materials and manufacturered sizes, was in excess of the specified standard.

With three girders supporting the decking, the span of the decking member becomes 3 ft, requiring a maximum deflection of 0.072 in. Under the conditions in Figures 3.4-3.5, the minimum cross section for each material was determined (Table 3.2). Obviously, it was also desirable to design the decking to be as light as possible so as to minimize the dead load on the girders.

Table 3.1: Material Properties

Material	Density (lb/cu ft)	Modulus of Elasticity (ksi)	Fb (ksi)	Fv (ksi)
Cedar	22	1110	2.54	0.22
Ecoboard	60.12	330.4	2.5	0.986
Ipe	66.6	3301	24.08	N/A
Glu-lam Pine	36	1400	4.07	0.505

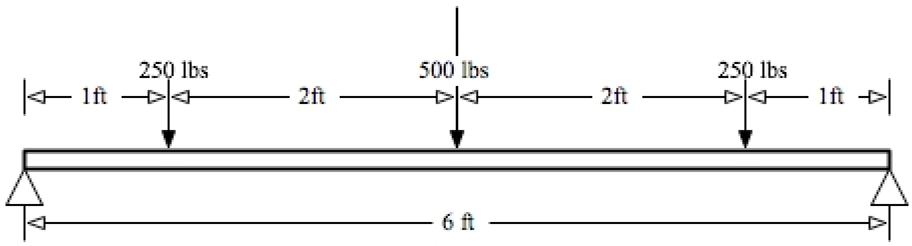

Figure 3.4: Two-girder decking with vehicle live load

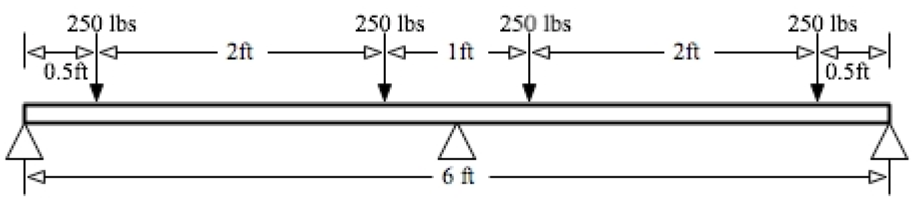

Figure 3.5: Three-girder decking with vehicle live load

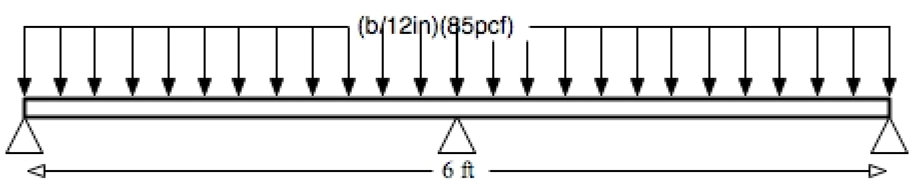

Figure 3.6: Three-girder decking with distributed live load

Table 3.2: Decking Cross-Section Dimensions

Material	Section Height	Section Width
Cedar	2 in	6 in
IPE	28 mm	145 mm
Ecoboard	3 in	6 in

3.3.2 *Multiframe Analysis*

An analysis of the decking portion of the bridge was performed. Each of the three possible decking materials was modeled using multiple different cross-sections for each. The controlling design consideration was allowable deflection. The results can be seen in Appendix B. All the materials were found to be adequate for the standard manufacturer's sizes.

3.3.3 *Conclusions*

It was determined from this analysis that the 2-girder configuration was not acceptable due to excessive deflections and thus the 3-girder configuration was decided upon for the final design. The standard sizes that Ipe comes in are in metric measurements, making it inconvenient to use in construction. Because Ecoboard has such large deflection, the section size required is very thick (3" compared to Cedar, which requires 2"). This increase in thickness is unseemly, heavy, and more expensive because it is simply more material. Given that cedar is equally as efficient as the other materials, more widely available and cheaper, and lighter in weight, this is the decking material we would recommend for use in the construction of the bridge.

3.4 Railing Design

3.4.1 *Design Considerations*

Upon the completion of the decking design, the railings were designed using the design loads and specifications in the International Building Code (IBC, 2003), which stipulates the handrail height, graspability, continuity and live loads to be resisted (Appendix G). Given that the bridge was to resemble Monet's paintings, the railings were designed as constant radius arches that matched the girder shape (Figure 3.6). It was decided that, for aesthetic purposes, the railing material should match that of the deck, and we analyzed each material for use with the railing.

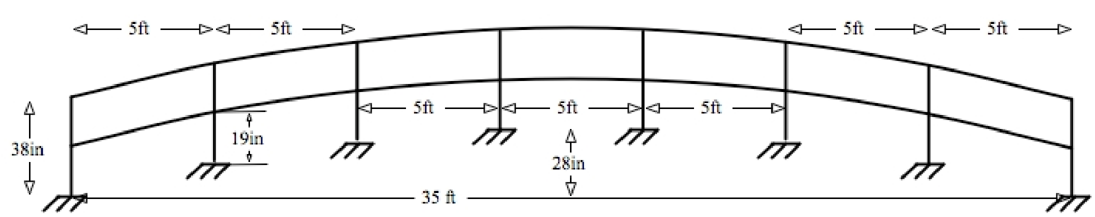

Figure 3.7: Railing

It was determined that a maximum of five feet was desired between vertical posts for aesthetic purposes. For the 30 foot span, this stipulates 7 posts per side. For the 35 foot span, this stipulates 8 posts per side. The bottom longitudinal rail was placed midway between the top rail and the deck.

3.4.2 *Multiframe Analysis*

The design loads are specified in the IBC and the desired arrangement was known, so the Multiframe analysis was simply a process of insuring that the design was acceptable using LRFD methods. The equations and adjustment factors used may be found in Appendix K. This included applying the required loads at different points along the bridge and comparing the performances of the different materials. The section properties for the railing types are listed in Table 3.3. The results of this loading can be found in Appendix C. The dead loads contributed by each of the three possible designs were then calculated.

Table 3.3: Railing Section Properties

Material	Height (nominal)	Width (nominal)	Height (actual)	Width (actual)	Moment Capacity (kip-in)	Shear (kip)
IPE	37 mm	40 mm	1.46 in	1.57 in	9.120	2.073
	42 mm	70 mm	1.65 in	2.76 in	20.56	4.119
	80 mm	80 mm	3.15 in	3.15 in	85.27	8.967
Cedar	3 in	3 in	2.5 in	2.5 in	4.498	0.5500
	4 in	4 in	3.5 in	3.5 in	12.34	1.078
	6 in	6 in	5.5 in	5.5 in	47.89	2.662
EcoBoard			4 in	4 in	18.13	6.310
			5 in	5 in	35.42	9.860
			6 in	6 in	61.20	14.19

3.4.3 *Conclusions*

It was established that each design was acceptable on the basis of its ability to resist the required loads. Given that the decking and handrail materials were to match, the overall dead weights of the three possible deck/handrail designs were computed. As Cedar was again the least expensive and lightest material possible, this was determined to be the most desirable choice; however, any of the designs would be acceptable.

3.5 Arched Girder Design

3.5.1 *Design Considerations*

The primary members distribute loads longitudinally and are usually designed principally to resist flexure. The design of wood structural members is governed by the AITC Timber Construction Manual and the AF&PA LRFD Manual for Engineered Wood Construction.

Based on these guidelines we determined our critical loading scenario to include both dead loads and live loads, which are permanent loads and temporary loads, respectively. Neither the AASHTO Pedestrian Bridge Code nor the AASHTO Standard Specifications for Highway Bridges site snow or rain loads for bridges. wind loads that needed to be accounted for. It was also determined that there would be no significant temperature deflections.

The dead load weight was determined by the design of both the decking and railings. The dead load was computed for each possible material combination. Refer to Appendix D for the full analysis and notes.

The live loads were determined to include pedestrian live load and vehicle live load, as stipulated in the AASHTO Pedestrian Bridge Code. There were many girder configurations possible, but as specified by the AITC Timber Manual, each girder was analyzed as a two hinged arch.

Blocking was included between the three girders to ensure equal distribution of the loads on each girder. This will allow the girders to deflect equally. It will be of the same material as that of the girders and will be spaced 9 feet on center.

The ramps from the abutments to the decking will need to be designed at a later date once the exact amount of earthwork required is known.

3.5.2 *Multiframe Analysis*

Each girder was treated as a constant radius arch. We used the design and load analysis specified in AITC Timber Construction Manual 5.13.8. The arch is divided up into 40 separate sections. The dead, live, and wind loads are then applied to the arch in a series of different combinations. Please refer to Appendix D for the various combinations and results.

3.5.3 *Conclusions*

It was determined that the Glue-laminated Pine arches were optimal for use in the construction of this bridge. This is mainly due to their ability to be formed into a constant radius arch of adequate length, given that this will simplify construction as it does not necessitate moment connections. EcoBoard is much denser proving for much heavier members. GluLam members are also the most readily available and the least expensive of the two options. The optimal cross section we determined had a size of 5 1/2” x 3 1/8”.

3.6 Connections Design

3.6.1 *Deck to Girders*

The decking members will be screwed directly into the girders using stainless steel square head #10 decking screws. Two screws should be used at each end of the plank. All fasteners should be placed no closer than 1” from any edge nor protrude from any board closer than 1” from any edge. Additionally, the screw heads will need to be countersunk. This will be cumbersome, but is necessary to ensure smoothness along the deck.

In the design that uses Glue-lam structural members and wood planking, a membrane will need to be placed in between the decking and the girders. The recommended membrane is a self-adhesive waterproof flashing membrane. This membrane has a self-sealing rubberized asphalt core and is reinforced by a strong cross-laminated high-density polyethylene film.

In the design that uses Ecoboard planking, pilot holes will need to be pre-drilled at the desired location of each screw due to the hardness of the material.

If installation takes place at temperatures over 45°F, all ends should be butted tightly together. In all other conditions, a space of _” should be allowed between ends.

3.6.2 *Railing Posts to Girders*

Posts for railings will be connected to the girders using aluminum angles. These should be tag bolted to the girder on the outside edge. It is imperative to refrain from notching posts during construction. Details can be found in Appendix E.

3.6.3 *Railing Components*

The railing components will be screwed together using #10 stainless steel screws.

3.6.4 *Girder Diaphragms*

Diaphragms should be screwed in horizontally between the three girders every nine feet. These will be offset from railing posts to avoid connection conflicts. This will serve to ensure equal distribution of the loads on each girder. This will allow the girders to deflect equally. This blocking can be attached to girders using stainless steel screws.

3.6.5 *Arch to Abutment*

These connections will be hinge connections. There will be a total of six, one at each end of each girder. At these connections a steel bearing plate will be bolted to the abutment and the hinge will be connected to this plate. The other side of the hinge will be bolted to the end of each girder. Details can be found in Appendix E.

4.0 Design of Substructure

4.1 Design Process Overview

The substructure consists of all elements required to support the superstructure. The basic substructure is composed of abutments, bearings, and footings. The function of a foundation is to transfer the loads from the bridge elements above ground to the soil or rock without objectionable vertical or lateral movement. Selection and design of the proper foundation is dependent upon the design structural loading conditions and surface and subsurface conditions at the site [Tonais].

4.2 Abutments

4.2.1 *Design Considerations*

Bridge abutments are structures at the two ends of a bridge used for the double purpose of transferring the loads from the bridge superstructure to the foundation bed and giving lateral support to the approach embankment. In the case of a river crossing, an abutment may also function to protect the embankment against scour of the stream.

The foundation should be located as high as feasible, since costs increase significantly with depth. The foundation elevation should also be deep enough to provide long term bearing support, to prevent undue total and differential settlement, to resist lateral forces and to avoid problems from ground movement (such as frost heave), scour and/or future deepening of a channel area.

Scour is one of the basic characteristics of streams and is defined as the removal of stream bed material by stream or tidal currents. It may naturally occur as the result of channel construction or changes in the flow pattern. Local scour may occur, in this case, due to obstructions: the local scour hole around a bridge abutment occurs because the abutment is an obstruction to the flow [Troitsky].

The need for scour protection can be minimized by locating bridges on stable tangential reaches of channels and by placing foundations on inerodible materials. However, such a solution is not always practical, economical or desirable from a usage standpoint. In addition to these, abutment scour could be reduced by rip-rap protection, a sheet pile or a spur dike.

In designing water crossing bridges an estimate of possible scour is required because scour may occur unless the stream bed is inerodible rock. The following three design factors should be considered: the flood frequency and magnitude, the flow pattern for each flood with geometry of the given design, and the resulting scour. If a scour prediction cannot be made explicitly, as is the case of our design, the foundation should be designed more conservatively to accommodate unexpected scour depth.

Bridge abutments are generally made of reinforced concrete. Stonemasonry may be used, but is ordinarily incorporated as a facing backed with concrete in the case when architectural effects and durability or surface are desired, as in this case.

The forces considered for the design of abutments are: to prevent uplift on the back side of the footing; the resultant load of the lateral earth pressure and weight of the masonry and bridge must fall inside the middle third of the base; for embankment stability the design must be of sufficient depth of the abutment below the ground surface combined with a sufficient shear strength of the soil; proper drainage of the fill immediately behind the abutment; and because of the considerable difference in loadings it is advisable to consider the wing walls as structures separated from the abutment and to provide expansion joints completely through walls and footings [Troitsky].

4.2.2 *Abutment Types*

Though we have had courses in geotechnical engineering in which we gained experience designing retaining walls, we possessed very little experience with designing abutments. Thus, concurrent with our structural design we conducted a literature search of abutments that might be acceptable for use with our bridge. Faced with actually designing our own abutments, we were forced to go into more detail but the following types were investigated.

Wing Type Abutment: In the wing-wall type the wings may be at any angle with the breast wall (angles of 30 and 45 degrees are commonly used). The wing wall abutment is used to protect the embankment against washing out under high water as well as to furnish better hydraulic conditions by providing a gradual change in the cross section of the channel. In general, such an abutment is heavy and is most suitable on firm soils. The wings are designed as retaining walls.

Straight Wing Abutment: This is a special form of wing wall abutment. Essentially, these are retaining walls modified so as to support the superstructure. They are used with embankments of moderate height and mainly for smaller bridges. Straight wing abutments are often built at stream crossings where the wings prevent the fill from blocking the stream and where they tend to restrict the scouring action of water eddying around the main support. Such abutments are usually massive and must resist large overturning moments. The tops of the wings are sloped to conform to the slope of the embankment fill.

Flanking Span Abutment: It is logical in many cases to reduce the lateral pressure on abutments and reduce costs further by use of a flanking abutment, which stands free of the fill at the edge of the water except for the small piece that serves to anchor it to the fill.

4.2.3 *Conclusions*

We designed our abutments as wing-type abutments due to the desirable aesthetic nature of these walls. Because the abutments will function much like retaining walls, they were designed as such and then modified so as to include a bridge seat and bearing pad. Since the bridge is relatively small, as is the quantity of soil behind the abutments, the abutments were designed as gravity walls. These walls use their own weight to resist failure. Thus, a gravity wall must be heavy enough and of sufficient proportions to be able to safely withstand the tendency to slide and the tendency to overturn.

The abutment will be made almost entirely from concrete, but will have dowels where the wing walls connect to the main wall and reinforcement where the bearing plate bolts into the wall. Additionally, the bearing plate bolts will be cast in place with the wall. The wall may also be faced with masonry for aesthetic purposes if the community so desires. Drainage should be provided behind the wall in the form of a gravel drain along the back of the wall and a pipe drain at the base of the wall.

The abutment will have a height of 7-ft and a base of 6-ft. The footing will be 2-ft thick and the bridge seat will be 2-ft wide and 1-ft high. These dimensions lead to a Factor of Safety against Overturning of 2.42 and a Factor of Safety against Sliding of 3.42. Both values are more than ample. The comprehensive abutment design can be found in Appendix E in addition to the design assumptions.

The exact dimensions of the abutment will not be known until a more detailed survey of the site is performed and a span length is determined, indicating the amount of fill that will be needed. The design is a simple one and a spreadsheet was created so as to facilitate any changes that need to be made. The general abutment geometry will remain as shown in Appendix E.

4.3 Bearings

Bearings are mechanical systems which transmit the vertical loads of the superstructure to the substructure. Bearings come in a variety of shapes and sizes. The applicability of certain types of bearings will vary depending on the loads and movements the bearing is required to sustain. In this case, hinges will be employed as the connection from the superstructure to the abutment. Each hinge will be attached to a bearing plate bolted to the abutment. The abutment will be reinforced with dowels at these connections to resist pulling out of the bearing plate from the abutment. The details of the bearing design for this bridge can be found in Appendix F.

4.4 Footings

As bearings transfer the superstructure loads to the substructure, so in turn do the abutment footings transfer loads from the substructure to the subsoil. In the case of the gravity wall type retaining wall, there is not a footing in the conventional sense of the word. The wall retains the earth entirely by its own weight, as opposed to a cantilever retaining wall which is a vertical wall held in place by the footing. Though there is not a footing, there is a base to the wall. In this case the base is 6 feet in width and 2 feet in height.

Thus, in this case the only real considerations in the design of the footing were to ensure that the weight of the whole wall was high enough to offset that of the soil and to ensure that the allowable bearing pressure of the soil was not exceeded. The footing does not require reinforcement, but care should be taken that the base is set deep enough to avoid exposing the footing to freezing. As can be seen in the design, this necessitates a minimum of 36" of soil above the base of the footing.

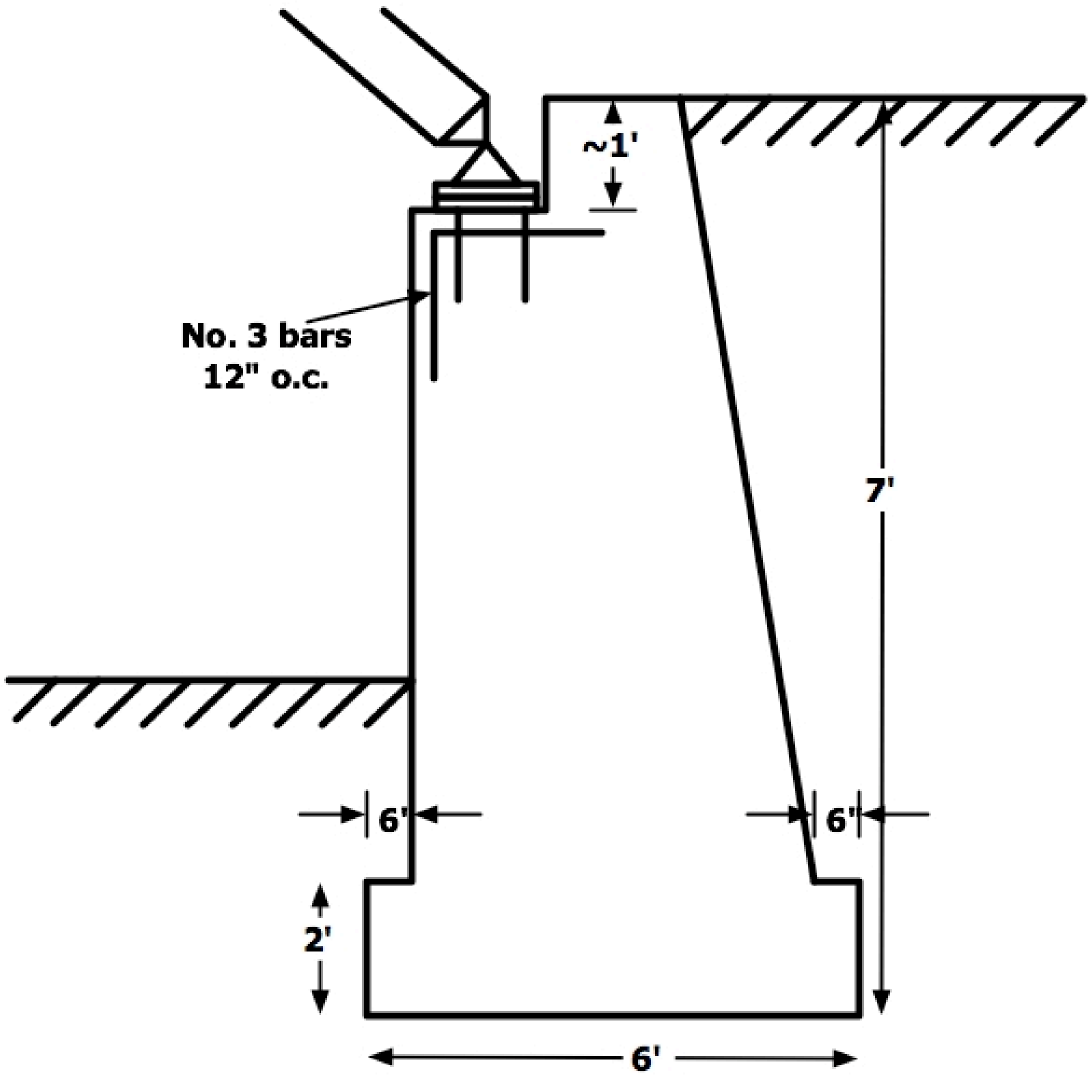

Figure 4.1: Abutment side view

5.0 Cost Estimate

5.1 Introduction and Assumptions

As of the conclusion of this project the engineers were unable to obtain pricing information of more detail than to be able to provide a relative measure of overall cost. This problem was mainly due to the unwillingness of the suppliers to provide cost estimates without reviewing the final design of the bridge, which was not completed until the final compilation of this report. Supplier contact information has been included in Appendix J so that once a final design has been chosen by the Quadrangle community, obtaining materials should be a simple matter.

5.2 Conclusions and Recommendations

From the relative pricing information available, it is the recommendation of the engineers that Cedar be used for the deck and railings of the bridge and Glue-lam Pine should be used for the structural members.

The span length of 35 feet is also recommended, given that this will supply the most stable bridge site and will require the least earthwork. The cost may be slightly greater due to the additional materials and larger abutments needed; however, this cost is justified to ensure the longevity of the bridge.

6.0 Environmental Impact Statement

The environmental impacts of our bridge were examined under the framework of the Pennsylvania Department of Transportation's Categorical Exclusion Evaluation Form. While the form is meant to be used for the evaluation of a highway project, the environmental constraints on a project are similar. There were multiple codes and provisions included in the form that were not accessible and therefore were not consulted. The form provides a opportunity for commentary on the following (those that were applicable are marked with an * and remarks are provided):

- Land acquisition
- Involvement with utilities*
  - There are electrical and water utilities that lead to the fountain in the pond. These should not be in the way of construction, but their presence should be noted.
- Roadway characteristics
- Setting*
  - rural
- Topography*
  - Rolling to mountainous
- Design vehicles
- Design speeds*
  - The scooters travel at a maximum speed of , no posted speed limit needed.
- Traffic control measures
- Estimated project costs*
  - See Section 5.0 for cost estimate.
- Aquatic resources
  - Streams, rivers and watercourses*
    - The drainage ditch and thus the steam that it feeds into may be impacted.
  - National and state wild and scenic rivers and streams
  - Navigable waterways
  - Other surface waters*
    - The artificial pond is identified as one such water body.
  - Groundwater resources
  - Wetlands
  - Coastal zone
  - Floodplains
  - Soil erosion and sediment*
    - Permanent effects due to construction activities have the potential to enflame the soil and erosion situations in the area. An erosion and sedimentation (E&S) control plan should be

drafted before construction begins and there should be coordination with the *** County Conservation District.

- Land
  - Agricultural resources
  - Vegetation*
    - Minimal impact to vegetation will occur. Clearing of shrubs and undergrowth will be required in order to install the bridge. The removal of trees on the east bank will also be necessary. The maintenance of the willow tree on the west bank has been a major construction consideration. The bridge has been sited accordingly.
  - Unique geologic resources
  - Parks and recreation facilities
  - National natural landmarks
  - Natural and wild areas
  - Hazardous or residual waste sites
  - Wildlife and habitat*
    - The only wildlife in the construction area is a large flock of Canadian Geese, who use the pond as a migratory stop over. Construction may disturb this pattern for a short time, but upon completion of construction the habitat should not be impacted.
  - Threatened and endangered plants and animals
  - Cultural resources
    - Prehistoric archeology
    - Historic archeology
    - Historic structure
    - Historic transportation corridor
  - Section 4(f) resource
  - Air quality and noise
  - Socioeconomic areas
    - Regional and community growth
    - Public facilities and services
    - Community cohesion
    - Environmental justice
    - Displacement of people, businesses or farms
    - Maintenance and operating costs of the project and related facilities*
      - The maintenance of the bridge will be paid for by the management company responsible for the land, Marriott. It is also possible that the ** family may be willing to pay for some of these costs. These costs will vary depending on the initial design choosen.
    - Public controversy on environmental grounds
    - Aesthetics and other values*

            - This structure will enhance the scenic nature of the pond and will bring to fruition the community's wish for the bridge.
- Temporary impacts
    - Temporary impacts to resources
        - Air quality
        - Noise levels*
            - Noise levels during construction may be an issue, especially given the proximity of the construction site to the residence buildings. Since this is unavoidable, heavy machinery hours of operation will be limited and the construction period should not be prolonged.
        - Water quality*
            - The water quality of the pond may be negatively impacted due to the large amounts of earthwork that will be required; however, this earthwork may result in better water quality in the long term.
        - Soil erosion and sedimentation*
            - Soil erosion and sedimentation may be affected by construction given the relatively large amounts of earthwork required. As noted earlier, a erosion and sedimentation control plan should be made prior to beginning construction.
        - Wetlands
        - Agricultural resources
- Consistency determinations
    - DEP Costal Zone Management Plan (NA)
    - DEP/NPS Wild and Scenic River Management Plan (NA)
    - FEMA Flood Map Modification (NA)

7.0 References

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[17] *Ipe*. (no date). Retrieved 24 Feb 2005 from DLH-Nordisk South American Timber Specifications Website:http://www.dlhnordisk.com/timbers/technical_ descriptions/southamerica.htm

[18] *Specifications*. (no date). Retrieved 24 Feb 2005 from American Ecoboard Inc. Website: http://www.recycledplastic.com/specs.html

Software:

[19]AutoCAD LT 2003
[20] Microsoft Office Excel 2003
[21] Microsoft Office Word 2003
[22] Multiframe3D 8.63
[23] OmniGraffle 3.1.2 (v70)

Appendices

A. AutoCAD Drawings

B. Multiframe Analysis of Deck

C. Multiframe Analysis of Handrails

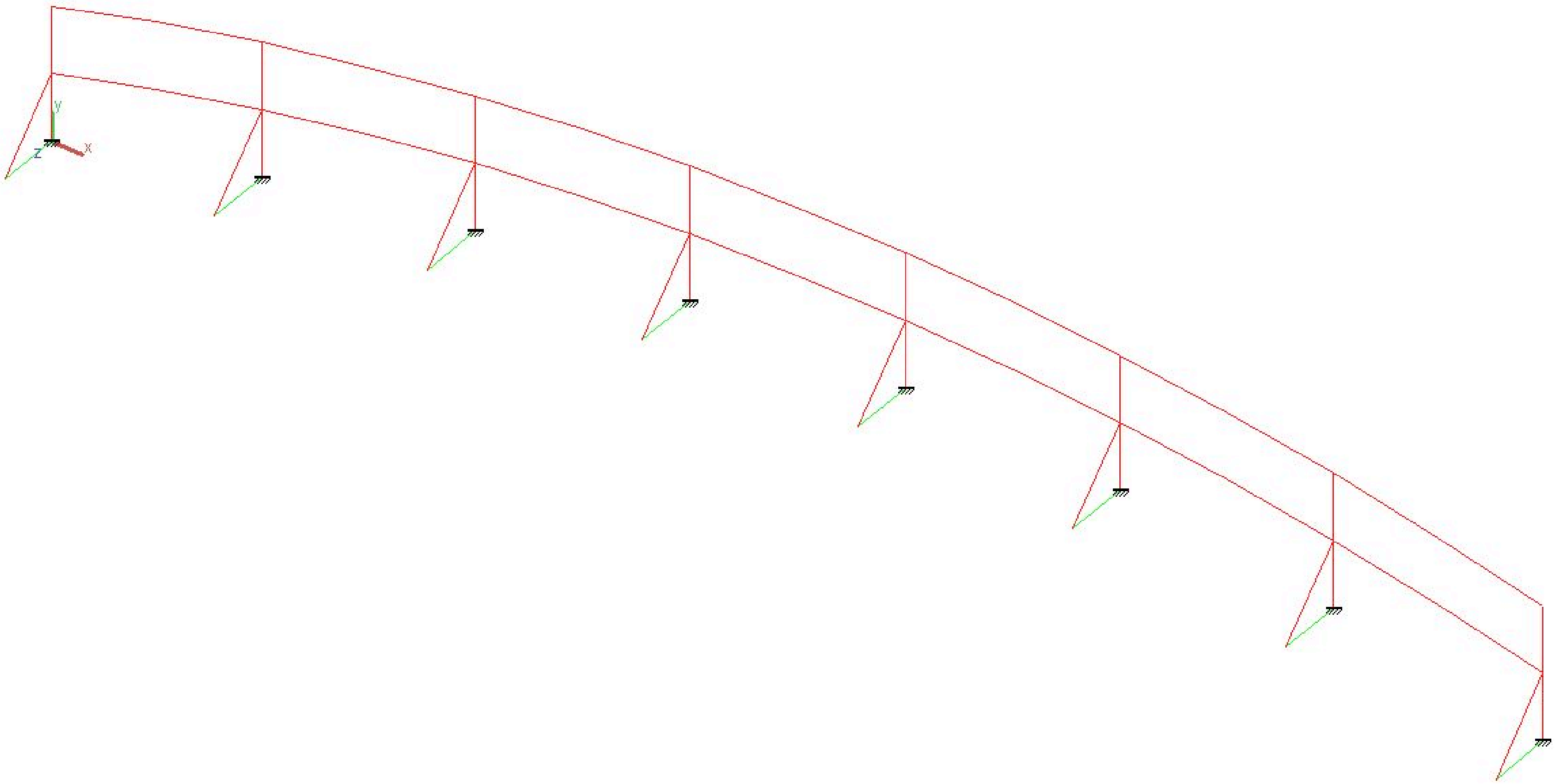

Figure 0.1: Multiframe Railing Frame

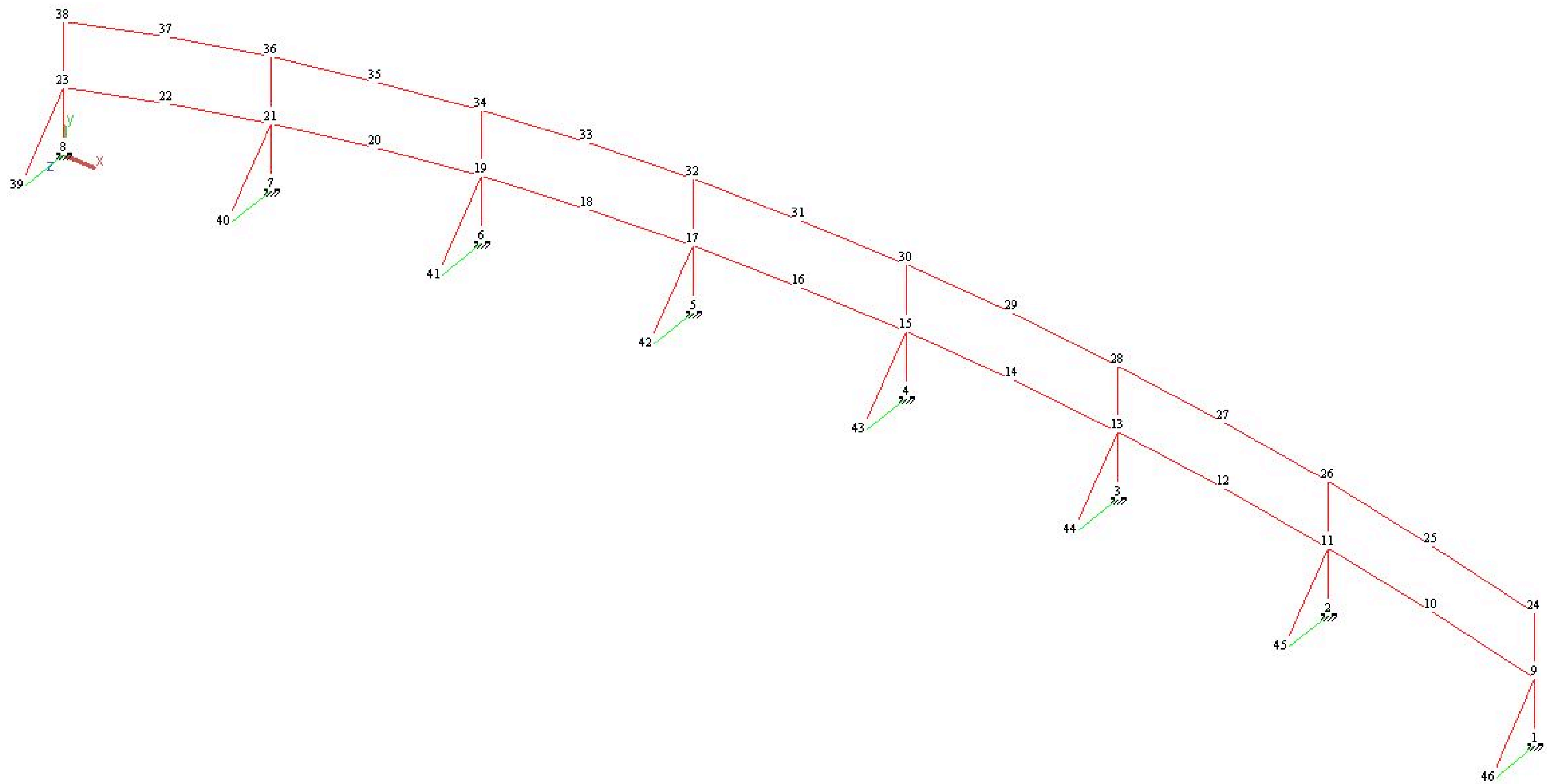

Figure 0.2: Multiframe Railing with labeled Joints

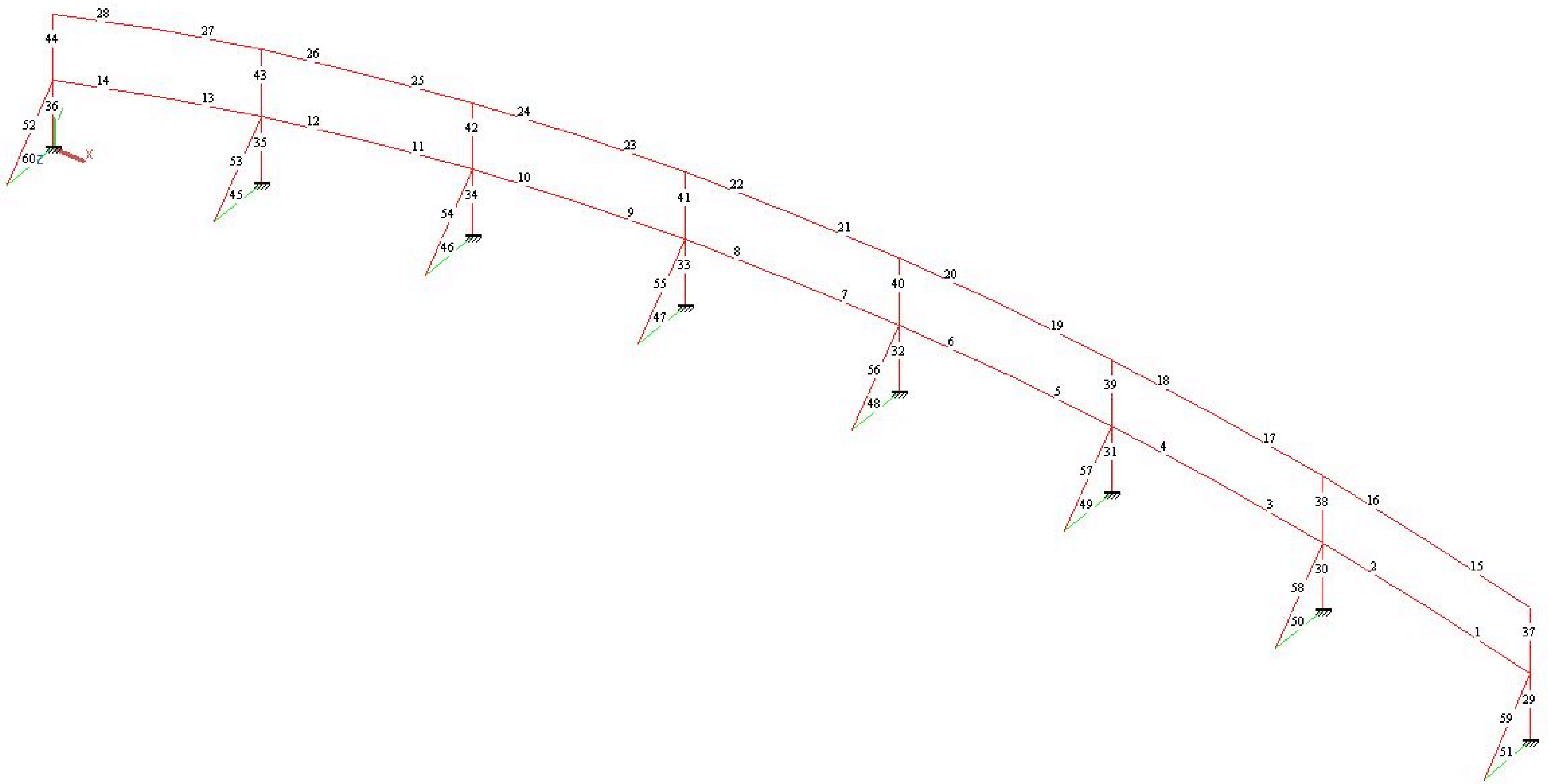

Figure 0.3: Multiframe Railing with labeled members

D. Multiframe Analysis of Arch

E. Abutments and Footings Design

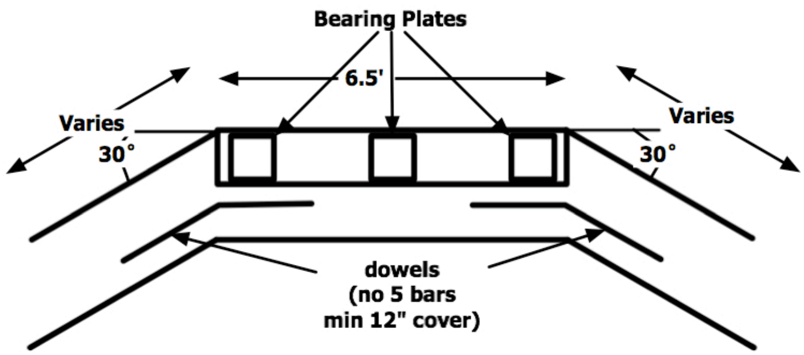

Figure 0.4: Abutment plan view

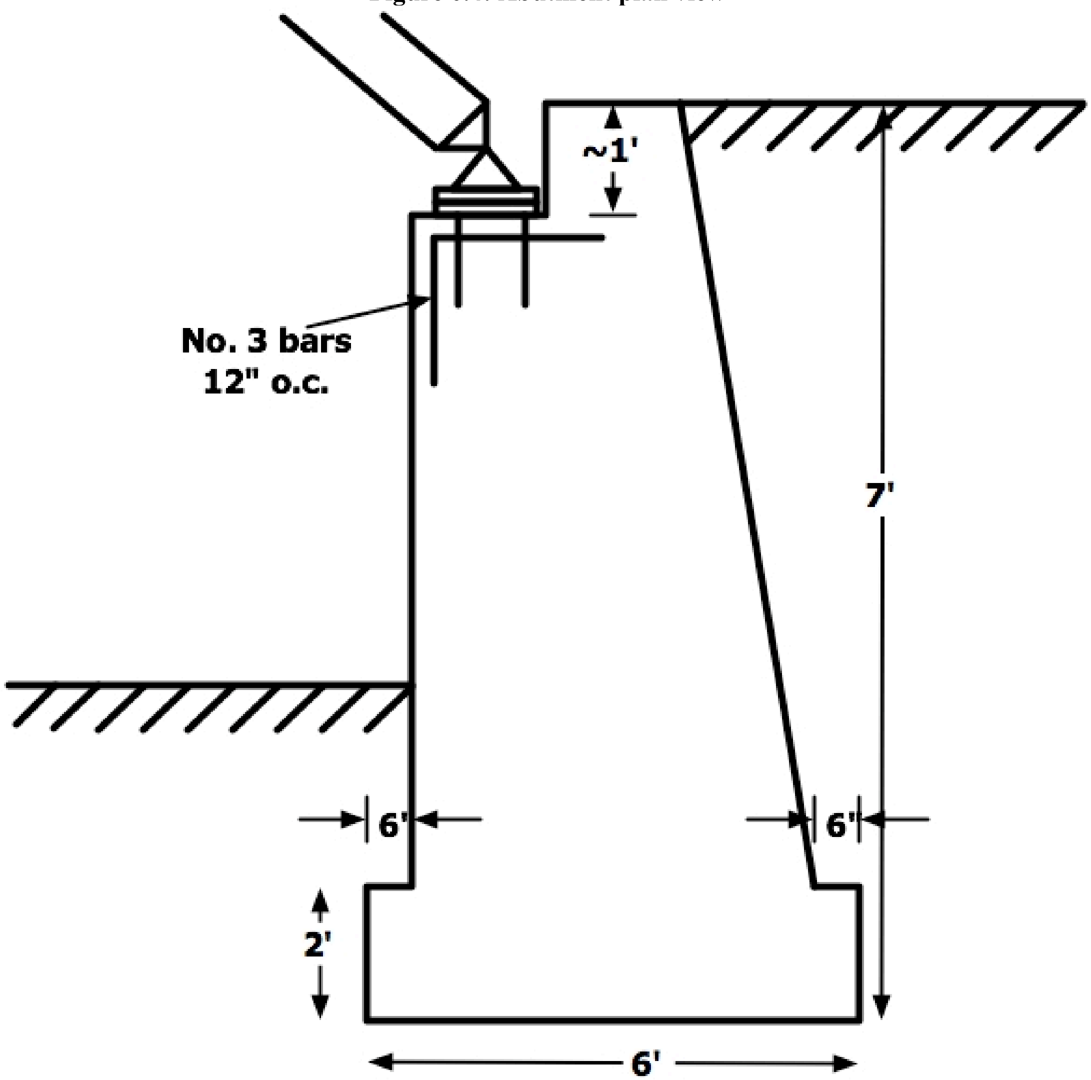

Figure 0.5: Abutment side view

F. Connections Design

Connection Summary:

- Deck to Girders
  - #10 Stainless Steel Screws
  - Placed through the center of the girders
  - Two are placed equidistant from each other and the edge of the decking plank. The minimum distance between the screws is 1”.
- Railing posts to Girders
  - Bolted in with two _” diameter bolts.
  - Pre-drilled bolt holes.
  - Holes go through the center of the Railing posts through the girders
  - 1/8” washers.
- Railing Components & Girder Bracing
  - Bolted in with 1/4” Aluminum plates.
  - Plates are 2” wide and 4” long.
- Arch to Abutment
  - Steel hinged connection, Figure F.1.

G. IBC Specifications

Handrail Code
Taken From 2003 International Building Code

1009.11.1 Height. Handrail height, measured above stair tread nosings, or finish surface of ramp slope, shall be uniform, not less than 34 inches (864 mm) and not more than 38 inches (965 mm).

1009.11.3 Handrail graspability. Handrails with a circular cross section shall have an outside diameter of at least 1.25 inches (32 mm) and not greater than 2 inches (51 mm) or shall provide equivalent graspability. If the handrail is not circular, it shall have a perimeter dimension of at least 4 inches (102 mm) and not greater than 6.25 inches (160 mm) with a maximum cross-section dimension of 2.25 inches (57 mm). Edges shall have a minimum radius of 0.01 inch (0.25 mm).

1009.11.4 Continuity. Handrail gripping surface shall be continuous without interruption by newel posts or other obstructions.

1607.7.1 Handrails and guards. Handrail assemblies and guards shall be designed to resist a load of 50 plf (0.73 KN/m) applied in any direction at the top and to transfer this load through the supports to the structure.

1607.7.1.1 Concentrated load. Handrail assemblies and guards shall be able to resist a single concentrated load of 200 pounds (0.89 kN) applied in any direction at any point along the top, and have attachment devices and supporting structure to transfer this loading to appropriate structural elements of the building. This load need not be assumed to act concurrently with the loads specified in the preceding paragraph.

H. AASHTO Pedestrian Bridge Specifications

Pedestrian Bridge Code
Taken From AASHTO Guide Specifications for Design of Pedestrian Bridges
1997

1.2 Design Loads

1.2.1 Live Loads

1.2.1.1 Pedestrian Live Loads: Main supporting members, including girders, trusses, and arches, shall be designed for a pedestrian live load of 85 pounds per square foot (psf) of bridge walkway area. The pedestrian live load shall be applied to those reas of the walkway so as to produce maximum stress in the member being designed. There is a separate equation for bridge walkways with decks exceeding 400 square feet.

1.2.1.2 Vehicle Load: Pedestriab/bicycle bridges should be designed for an occasional single maintenance vehicle load provided vehicular axxess is no physically prevented. A specified vehicle configuration determined by the Operating Agency may be used for this design vehicle.

1.2.2 Wind loads: A wind load of the following intensity shall be applied horizontally at right angles to the longitudinal axis of the structure. The wind load shall be applied to the projected vertical area of all superstructures elements, including exposes truss members on the leeward truss. For girders and beams, the load is 50 pounds per square foot.

1.2.3 Combination Loads: The load combinations. i.e., allowable stress percentages for service load design and load factors for load factor design as specified in Table 3.22.1A of the *Standard Specifications for Highway Bridges*, shall be used while modifying both the longitudinal force , LF, and the wind on live load, WL, to zero.

1.3 Design Details

1.3.1 Deflection: Members should be designed so that the deflection due to the service pedestrian live load does not exceed 1/500 of the length of the span. It is 1/300 for the length of cantilever arms.

I. Time Log and Critical Path Method

J. Materials & Supplier Information

Table 0.1: Detailed Material Properties

	h (mm)	w (mm)	h (in)	b (in)	Area (sq in)	Spec Grav	Density (pcf)	E (ksi)	Fb (ksi)	Fv (ksi)	Mom (kipin)	Shear (kip)	Ix	Iy	sx	sy
IPE	19	90	0.748	3.54	2.65	1.04	66.6	3301	24.08	2.26	5.411	2.396	0.1236	2.773	0.3304	1.565
	19	145	0.748	5.71	4.27	1.04	66.6	3301	24.08	2.26	8.717	3.860	0.1991	11.60	0.5324	4.063
	21	120	0.827	4.72	3.91	1.04	66.6	3301	24.08	2.26	8.813	3.531	0.2225	7.265	0.5382	3.076
	21	145	0.827	5.71	4.72	1.04	66.6	3301	24.08	2.26	10.65	4.267	0.2688	12.82	0.6504	4.491
	25	145	0.984	5.71	5.62	1.04	66.6	3301	24.08	2.26	15.09	5.079	0.4536	15.26	0.9217	5.346
	28	145	1.10	5.71	6.29	1.04	66.6	3301	24.08	2.26	18.93	5.689	0.6373	17.09	1.156	5.987
	35	145	1.38	5.71	7.87	1.04	66.6	3301	24.08	2.26	29.58	7.111	1.245	21.36	1.807	7.484
	45	145	1.77	5.71	10.11	1.04	66.6	3301	24.08	2.26	48.90	9.143	2.645	27.47	2.986	9.623
Handrail	37	40	1.46	1.57	2.29	1.04	66.6	3301	24.08	2.26	9.120	2.074	0.4056	0.4741	0.5569	0.6021
	42	70	1.65	2.76	4.56	1.04	66.6	3302	24.08	2.26	20.56	4.120	1.038	2.884	1.256	2.093
Post	80	80	3.15	3.15	9.92	1.04	66.6	3301	24.08	2.26	85.27	8.968	8.201	8.201	5.207	5.207
	100	100	3.94	3.94	15.50	1.04	66.6	3302	24.08	2.26	166.5	14.012	20.02	20.02	10.17	10.17
	145	145	5.71	5.71	32.59	1.04	66.6	3303	24.08	2.26	507.7	29.460	88.50	88.50	31.01	31.01
Cedar	nominal size		0.75	3.5	2.63	0.35	22	1110	2.54	0.22	0.5667	0.2310	0.1230	2.680	0.3281	1.531
	1	6	0.75	5.5	4.13	0.35	22	1110	2.54	0.22	0.8906	0.3630	0.1934	10.40	0.5156	3.781
	2	4	1.5	3.5	5.25	0.35	22	1110	2.54	0.22	5.290	0.4620	0.9840	5.359	3.063	1.313
	2	6	1.5	5.5	8.25	0.35	22	1110	2.54	0.22	13.06	0.7260	1.547	20.80	7.563	2.063
Post	3	3	2.5	2.5	6.25	0.35	22	1110	2.54	0.22	4.498	0.5500	3.255	3.255	2.604	2.604
	4	4	3.5	3.5	12.25	0.35	22	1110	2.54	0.22	12.34	1.078	12.51	12.51	7.146	7.146
	6	6	5.5	5.5	30.25	0.35	22	1110	2.54	0.22	47.89	2.662	76.26	76.26	27.73	27.73
EcoBoard			2	6	12.00	0.965	60.12	330.4	2.50	0.986	6.800	4.733	4.000	36.00	4.000	12.00
			2	8	16.00	0.965	60.12	330.4	2.50	0.986	9.067	6.310	5.333	85.33	5.333	21.33
			3	8	24.00	0.965	60.12	330.4	2.50	0.986	20.40	9.466	18.00	128.0	12.00	32.00
Handrail			2	2	4.00	0.965	60.12	330.4	2.50	0.986	2.267	1.578	1.333	1.333	1.333	1.333
			2	4	8.00	0.965	60.12	330.4	2.50	0.986	4.533	3.155	2.667	10.67	2.667	5.333
Posts			4	4	16.00	0.965	60.12	330.4	2.50	0.986	18.13	6.310	21.33	21.33	10.67	10.67
			5	5	25.00	0.965	60.12	330.4	2.50	0.986	35.42	9.860	52.08	52.08	20.83	20.83
			6	6	36.00	0.965	60.12	330.4	2.50	0.986	61.20	14.20	108.0	108.0	36.00	36.00
GluLam	Lam	1 3/8	5 4/8	3 1/8	17.19		36	1400	4.07	0.505	24.94	3.472	43.33	13.99	15.76	8.95

Tague Lumber (for both Cedar & Ipe)

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Phone: 610-566-1200
Fax:(610) 565-2107
media@taguelumber.com

American Ecoboard Inc. (for Ecoboard)

200 Finn Court
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K. Load and Resistance Factor Calculations